Supercritical Carbon Dioxide Primary Power Large-Scale Pilot Plant

Final Scientific/Technical Report

Award Number: DE-FE-0031585

Submitted By:
Echogen Power Systems (DE), Inc.
365 Water Street
Akron, Ohio 44308

Principal Investigator:
Dr. Timothy J. Held
Chief Technology Officer
theld@echogen.com
234-542-8029 (office)

Prepared By:
Jason D. Miller
Engineering Manager
jmiller@echogen.com
234-542-8037 (office)

Jason A. Mallinak
Senior Systems Engineer
jmallinak@echogen.com
234-542-8036 (office)

The University of Missouri
Columbia, MO

Electric Power Research Institute
Palo Alto, CA

Louis Perry and Associates
(a CDM Smith Company)
Wadsworth, OH

Riley Power, Inc.
(a Babcock Power, Inc. Company)
Marlborough, MA

Table of Contents

Terminology 3
Executive Summary 7
1. Technical Status 11
    1.A. Design Basis 11
    1.B. Technology Development Status 113
    1.C. Choice of Scale 119
    1.D. Phase III Cost Estimate and Schedule 124
    1.E. Updated Techno-economic Analysis 126
2. Team Status 162
    2.A. Host Site Selection 162
    2.B. Team Status 177
    2.C. Cost Share Status 178
3. Technology Commercialization Plan 179
    3.B. United States 181
    3.C. International 183
    3.D. Technological Advantages 185
    3.E. Competition and Techno-economic Cost Targets 187
    3.F. Technology Gap 190
References 197
Appendices 201
    I. Fuel Analysis
    II. Design Report (Dispersion Modeling)
    III. Design Drawings (Balance of Plant)
    IV. Design Report (Process Hazard Analysis)
    V. Design Report (Performance Test Plan)
    VI. Phase III Budget (EPC)
    VII. Phase III Schedule
    VIII. Detailed Overall Commercial Plant Cost Estimates
    IX. Construction Permit
    X. NEPA Environmental Questionnaire

Terminology

AACE	Association for the Advancement of Cost Engineering
AEP	American Electric Power
APH	Air preheater
API	American Petroleum Institute
AQCS	Air quality control systems
ASME	American Society of Mechanical Engineers
ATWACC	After tax weighted average cost of capital
AUSC	Advanced ultra-supercritical
BEC	Bare erected cost
BFB	Bubbling fluidized bed
BH	Baghouse
B&M	Burns & McDonnell
BNI	Barber-Nichols, Inc.
BOP	Balance of plant
BPVC	Boiler and Pressure Vessel Code
BV	Ball valve
CCS	Carbon capture and storage
CDMS	CDM Smith
CDS	Circulating dry scrubber
CEMS	Continuous emissions monitoring system
CF	Capacity factor
CHP	Combined heat and power
CHX	Cooling heat exchanger
COE	Cost of electricity
CRF	Capital recovery factors
CS	Carbon steel
CS FMU	Co-simulation functional mock-up unit
CT	Combustion turbine
C_v	Flow coefficient
CVD	Callendar-Van Dusen
CX	Categorical exclusion
DCS	Distributed control system
DE	Drive end
DOE	Department of Energy
DoE	Design of experiments
EH	Electrohydraulic
EIV	Environmental information volume
EOR	Enhanced oil recovery
EPC	Engineering, procurement, and construction
EPRI	Electric Power Research Institute

EPS	Echogen Power Systems
ERV	Electronic relief valve
EQ	Environmental questionnaire
FCR	Fixed charge rates
FD	Forced draft
FEED	Front End Engineering Design
FOAK	First-of-a-kind
GHG	Greenhouse gas
HART	Highway addressable remote transducer
HHV	Higher heating value
HMI	Human-machine interface
HPVC	High pressure fluid service
HTC	High-temperature compressor
HTC-DT	High-temperature compressor drive turbine
HTR	High-temperature recuperator
H_2O	Water
I&C	Instrumentation & controls
ID	Induced draft
IDLH	Immediately dangerous to life or health
IGMP	Internet group management protocol
IHX	Intermediate heat exchanger
J-POWER	Electric Power Development Co., Ltd.
LCOE	Levelized cost of electricity
LTC	Low-temperature compressor
LTC-DT	Low-temperature compressor drive turbine
LSP	Large scale pilot
LTR	Low-temperature recuperator
MAWP	Maximum allowable working pressure
MDNR	Missouri Department of Natural Resources
MISO	Midcontinent Independent System Operator, Inc.
MU	University of Missouri
MW_e	Megawatts (electric)
MWh	Megawatt hours
MW_{th}	Megawatts (thermal)
NA	Nickel alloy
NDE	Non-drive end
NEPA	National Environmental Policy Act
NETL	National Energy Technology Laboratory
NFS	Normal fluid service
NG	Natural gas
NH_3	Ammonia
NIOSH	National Institute for Occupational Safety and Health

NOAK	Nth-of-a-kind
NO_x	Nitrogen oxides
NRV	Non-return valve
N_s	Specific speed
N_{ss}	Suction specific speed
O&M	Operation and maintenance
PCCC	Post-combustion carbon capture
PCHE	Printed circuit heat exchanger
PCV	Pressure control valve
PDP	Pump discharge pressure
PDR	Preliminary design review
PFD	Process flow diagram
PHA	Process hazard analysis
PHX	Primary heat exchanger
PHX-1	Primary heat exchanger (main)
PHX-2	Primary heat exchanger (economizer)
P&ID	Piping & instrumentation diagram
PJFF	Pulse jet fabric filter
PMG	Permanent magnet generator
PRB	Powder River Basin
PSFM	Power systems financial model
PSV	Pressure safety valve
PT	Power turbine
PTC	Performance test code
PTP	Performance test plan
QoS	Quality of service
RCBC	Recompression Brayton Cycle
RCBC-E	Recompression Brayton Cycle (economized)
R&D	Research & development
RPI	Riley Power, Inc.
sCO_2	Supercritical carbon dioxide
SCPC	Supercritical pulverized coal
SCR	Selective catalytic reduction
SEL	Schweitzer
SIL	Safety integrity level
SIS	Safety instrumented systems
Southern	Southern Company
STEL	Short term exposure limits
TASC	Total as-spent cost
T_{cw}	Cooling water temperature
TEA	Techno-economic analysis
TEWAC	Totally enclosed water-to-air cooled

TIT	Turbine inlet temperature
TOC	Total overnight cost
TP	Transfer pump
TPC	Total plant cost
Tri-State	Tri-State Generation
TSH	Thermodynamic suppression head
TSV	Turbine stop valve
TWA-TLV	Time-weighted average threshold limit value
UA	Heat transfer conductance
UPS	Uninterruptible power supply
VFD	Variable frequency drive
VRE	Variable renewable energy
WP	Water pump
9C	Nine-chrome alloy

Executive Summary

The project team of Echogen Power Systems (EPS); Riley Power, Inc. (RPI); Louis Perry and Associates, a CDM Smith Company (CDM Smith); the University of Missouri (MU); and the Electric Power Research Institute (EPRI) conducted a detailed Front End Engineering Design (FEED) study of the installation of a fossil fuel Large-Scale Pilot (LSP) plant. The team's LSP design couples an advanced supercritical carbon dioxide (sCO_2) power cycle with a stoker coal combustion and primary heater system at the University of Missouri's Combined Heat and Power (CHP) Plant. Major systems and equipment were progressed through preliminary design to determine interface, cost, and schedule requirements. Designs of the primary heater system, including Air Quality Control Systems (AQCS); the sCO_2 power cycle, including the turbomachinery; and the balance of plant (BOP) systems were advanced through the production of preliminary design packages.

EPS has been an industry leader in sCO_2 power cycle development and commercialization, having previously designed and tested the EPS100—the world's first commercially available sCO_2 power cycle. For the LSP project, EPS was responsible for the design of the sCO_2 power cycle. Having previously optimized cycle architectures of coal-sCO_2 systems for a DOE study led by EPRI (DE-FE0025959), EPS selected the Recompression Brayton Cycle (RCBC) architecture as the basis for the pilot project due to the RCBC's superior thermodynamic efficiency compared to steam-Rankine cycles. EPS subcontracted the design of the power cycle turbomachinery to Barber-Nichols, Inc. (BNI), a specialty turbomachinery designer which also designed the EPS100 turbomachinery. BNI completed the conceptual

design of the high-temperature compressor (HTC) in Phase I and the low-temperature compressor (LTC) and power turbine (PT) in Phase II.

RPI, which has designed steam boilers for over one hundred years, leveraged its boiler expertise to design a coal-fired heater—the primary heater of the sCO_2 working fluid. RPI's fired heater design accounts for spatial and operational requirements of the host site while also considering capital costs (tube materials) and operating costs (heater efficiency). Additionally, RPI has designed preliminary AQCS for the pilot plant to ensure that the plant will satisfy all applicable emissions regulations. The AQCS scope includes Selective Catalytic Reduction (SCR), a Circulating Dry Scrubber (CDS), and a Pulse Jet Fabric Filter (PJFF, or baghouse). RPI scope also includes the relevant fans, combustion equipment (including stoker grate, coal distributors, and natural gas burners capable of full heat input), and flues and ducts.

CDM Smith is a multi-disciplined architectural, engineering, and construction firm, specializing in the industrial and power markets with a long history of Engineering, Procurement, and Construction (EPC) of industrial and test facilities. CDM Smith has previously provided EPC services to EPS and has significant experience with sCO_2 systems and equipment design and fabrication (including detailed skid design and installation of the EPS100). CDM Smith used the design packages from EPS and RPI to design BOP systems and to prepare detailed layout and construction packages. Several prospective construction contractors used these packages to provide quotes for the construction of the pilot plant.

The MU CHP plant is an established plant with a track record of success, winning the 2017 System of the Year award from the International District Energy Association. In

preparation for leading pilot operations in Phase III, MU provided input related to both the technical design and the operation and maintenance (O&M) costs of the pilot plant. MU also provided the project team with design documents and operating data for the existing BOP equipment that will be used by the pilot plant. This equipment includes electrical systems, lime and ammonia transport systems, coal and ash handling systems, the cooling tower and circulated water system, and the flue gas stack. MU also obtained the construction permit from the Air Pollution Control Program of the Missouri Department of Natural Resources (MDNR). Burns & McDonnell (B&M) provided consulting services to the project team in preparation for the permit application, advising the team of applicable rules and regulations for the pilot's environmental permits.

EPRI's multi-disciplined team led Phase II efforts in several areas: fulfilling the obligations of the National Environmental Policy Act (NEPA), completing the Techno-Economic Analysis (TEA), drafting the Performance Test Plan (PTP), managing the Process Hazard Analysis (PHA), and serving as the liaison between the project team and industry partners.

- For the NEPA process, the Department of Energy (DOE) advised that the project qualified for a Categorical Exclusion (CX). The team completed an Environmental Questionnaire (EQ) to fulfill the CX requirements.
- The TEA established an Association for the Advancement of Cost Engineering (AACE) Class IV (+50/-30%) cost estimate for a small utility-scale (120 MW_e) coal-sCO_2 plant. The TEA results indicated that the levelized cost of electricity (LCOE) of the coal-sCO_2 plant would be similar to that of a similarly sized steam-Rankine coal plant, with

potential for further improvement with envisioned research and development (R&D).

- The PTP outlined test plans and procedures based on FEED technical packages including piping and instrumentation diagrams (P&IDs) and the 3D plant model.
- EPRI subcontracted ioMosaic to facilitate the PHA. Technical input was provided by EPS (power cycle equipment design), RPI (primary heater and AQCS equipment design), MU (O&M), and CDM Smith (BOP). EPRI contributed general expertise during the PHA process.
- EPRI brought Phase II cost share from four industry partners: American Electric Power (AEP), Southern Company (Southern), Tri-State Generation (Tri-State), and the Electric Power Development Co., Ltd. (J-POWER). EPRI and EPS provided regular updates to these industry partners throughout Phase II.

1. Technical Status

1.A. Design Basis

1.A.i. Power Cycle Architecture

The Recompression Brayton Cycle (RCBC) is advantageous for optimizing thermal efficiency in indirectly heated sCO_2 primary power applications [1]. Recuperative preheating creates a narrow temperature range for heat addition. A recompressor introduces a partial recuperator bypass, minimizing exergy destruction in the recuperators and optimizing internal heat recovery. The combination of high average hot-side temperature and highly effective recuperation results in cycles with high thermodynamic efficiencies relative to steam.

Standard RCBC architecture (configured with turbine-driven compressors) is shown in Figure 1. The main compressor, or low-temperature compressor (LTC), compresses relatively dense fluid after the final heat rejection step in the cycle. The recompressor, or high-temperature compressor (HTC), compresses a lower-density fluid that bypasses heat rejection. Drive turbines (LTC-DT and HTC-DT) power the LTC and HTC, respectively. Net and auxiliary electrical power are supplied by a synchronous generator driven by the power turbine (PT). Heat addition from the thermal resource occurs in a single primary heat exchanger (PHX). Heat rejection to the cooling fluid occurs in the cooling heat exchanger (CHX). Ambient-range cooling fluid temperatures limit the pressure ratio of the working fluid, such that the CO_2 leaves the turbines at relatively high temperature. Two internal heat exchangers recuperate this energy to preheat the CO_2 entering the PHX. The high-temperature recuperator (HTR) preheats the full

high-pressure flow. The low-temperature recuperator (LTR) preheats a portion of the high-pressure flow, minimizing the exergetic destruction associated with recuperation by closely matching the temperature glide between the hot and cold CO_2 streams.

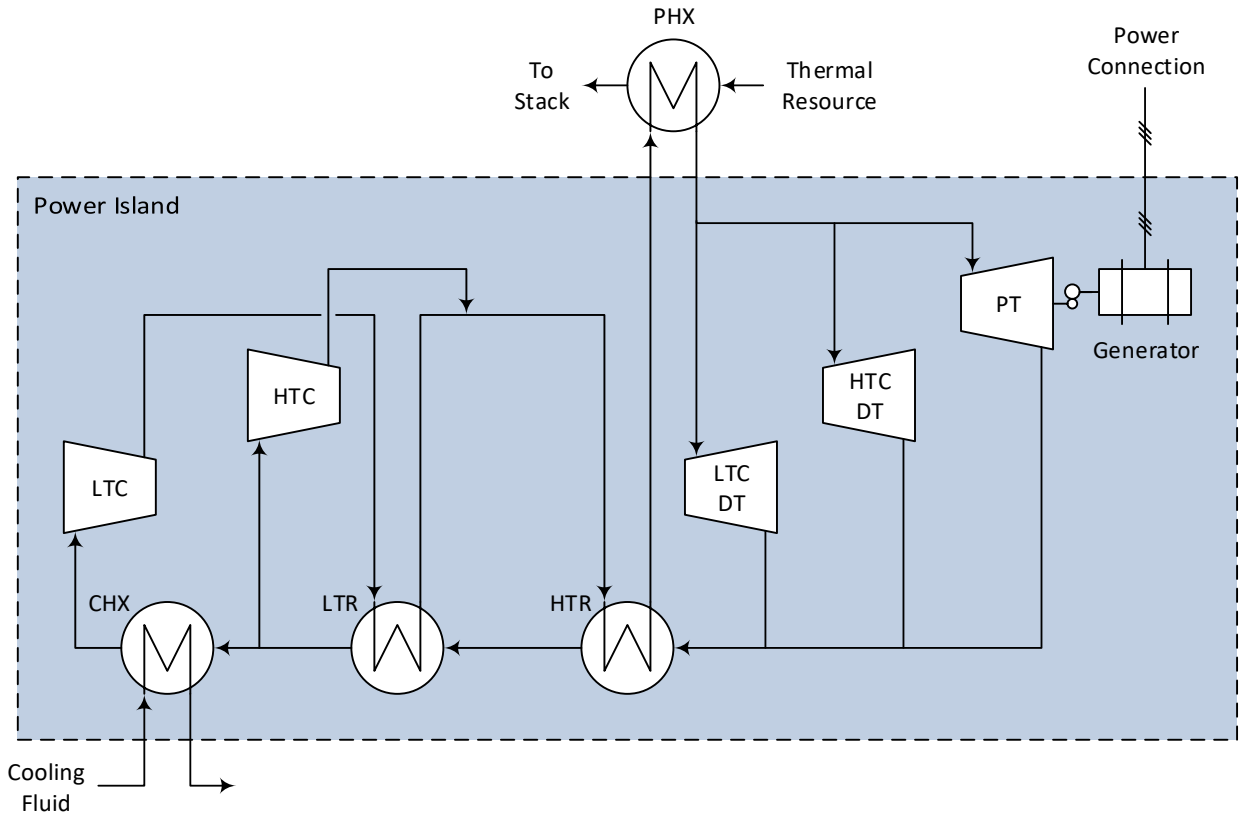


Figure 1: RCBC configured with turbine-driven compressors

For this project, the thermal resource is a combustion byproduct (flue gas) from a coal-fired heater. While ideal for optimizing power cycle efficiency, standard RCBC architecture can restrict the efficiency of the fired heater and reduce the overall plant efficiency. Recuperative pre-heating of the CO_2 produces a high PHX inlet CO_2 temperature, limiting the enthalpy extraction from sensible thermal resources. Adding a combustion air preheater (not shown) has the potential to reduce the waste heat in the exhaust gas to the stack. In Phase I design, the air

preheater size was constrained by combustion air temperature limits, resulting in a preliminary fired heater efficiency of only 76%.

To increase net plant efficiency, an economized RCBC architecture (RCBC-E, Figure 2) is considered. The RCBC-E uses an sCO_2 economizer to increase the fired heater efficiency. In the flue gas stream, the sCO_2 economizer (PHX-2) is in series with the main PHX (PHX-1), reducing the heat that is exhausted through the stack. In the CO_2 stream, PHX-2 is in parallel with the HTR, so that a portion of the total CO_2 flow bypasses high-temperature recuperation for low-temperature heat addition.

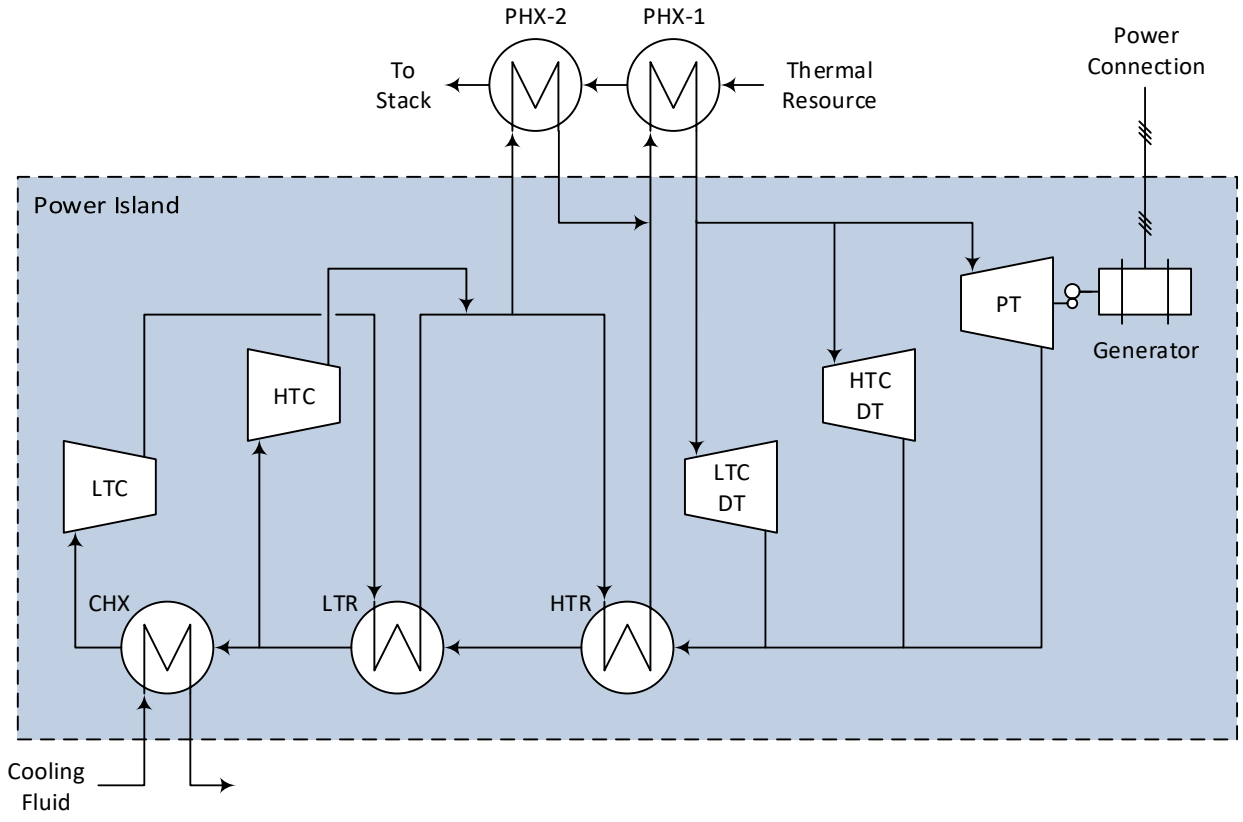


Figure 2: RCBC-E with an sCO_2 economizer (PHX-2)

Depending on its duty, PHX-2 may penalize the power cycle efficiency. As the PHX-2 duty increases, the bypass flow requirement increases. The corresponding reduction of HTR high-pressure flow raises the HTR high-pressure outlet temperature. If the bypass flow is sufficiently high, the HTR duty is constrained by the heat capacity rate of the high-pressure CO_2, penalizing the power cycle efficiency. For low bypass flow, the HTR duty is unconstrained by the high-pressure CO_2, and the RCBC-E can achieve the same power cycle efficiency as the RCBC. (Note that a larger RCBC-E HTR is required to meet the same duty as the RCBC HTR.) In Phase II design, the addition of PHX-2 created a potential increase of 10% points relative to the Phase I fired heater efficiency. Since the PHX-2 duty requires low bypass flow (approximately 10% of the total flow), the RCBC-E architecture can potentially be used without penalizing the power cycle efficiency.

Considering the overall plant efficiency benefit, the RCBC-E architecture was chosen for the pilot plant. The plant process flow diagram (PFD), shown in Figure 3, displays the proposed plant configuration. The power island matches the RCBC-E cycle described previously in Figure 2. For heat rejection, a clean-water cooling loop with an intermediate heat exchanger (IHX) is used to transfer heat to an existing plant water loop and cooling tower. Water in both the intermediate and plant loops is circulated by pumps (WP1 and WP2, respectively). The heat addition system includes coal combustion (with natural gas co-firing) in a stoker-fired heater. Combustion air is supplied from a forced draft (FD) fan through an air preheater (APH). Air Quality Control Systems (AQCS) include selective catalytic reduction (SCR) for NO_x reduction, a circulating dry scrubber (CDS) for SO_2 reduction, and a baghouse (BH) for particulate

management. The unit is balanced draft, with an induced draft (ID) fan discharging flue gas to an existing stack. The CO_2 economizer is split into sections downstream (PHX-2A) and upstream (PHX-2B) of the SCR to optimize the gas temperature for effective NO_x reduction.

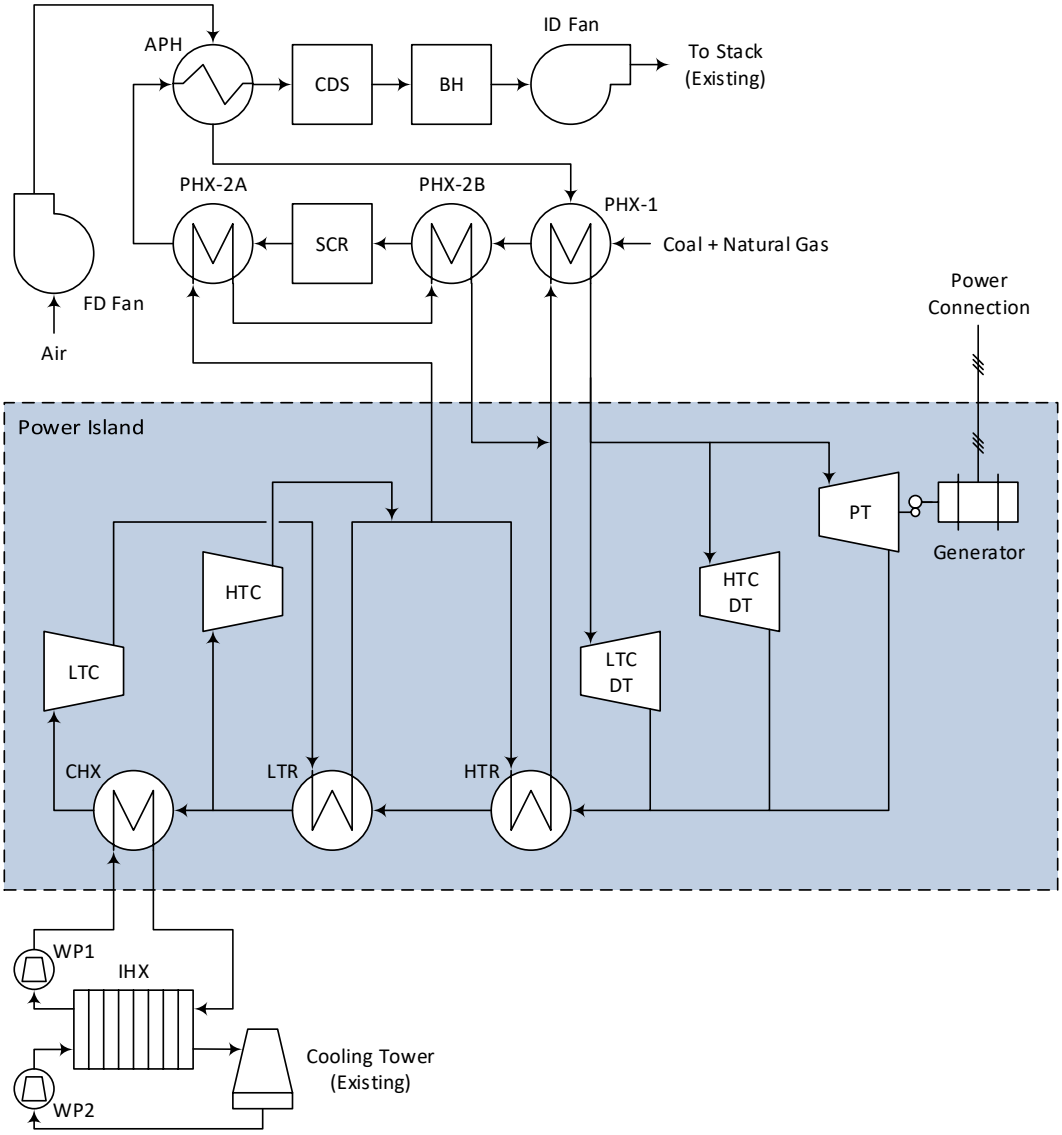


Figure 3: FEED study process flow diagram

1.A.ii. Site-Specific Design Conditions

As indicated in Figure 3, the existing cooling water system at the MU CHP will be used for the pilot plant. Plant staff provided two years of historical data for the cooling tower water supply temperature (summarized in Table 1). The pilot plant design point is based on the mean temperature (26.0°C). The 99% operating range was used to define typical performance, and the 100% operating range was used to set requirements for equipment performance limits.

Table 1: Cooling tower water supply temperature design data

Interval	Temperature (°C)
Mean	26.0
Range (99% of operation)	21.7 to 28.9
Range (100% of operation)	17.8 to 32.2

Cooling tower performance data over a three-year period were averaged to estimate the related parasitic loads associated with cooling (Table 2).

Table 2: Cooling tower parasitic load design data

Parameter	Value
Cooling tower parasitic loads, kWe/MWth	17.6

The plant will burn subbituminous (Illinois #6) coal provided by Knight Hawk Coal, LLC. The ultimate and proximate analyses are in Appendix I. Natural gas will be co-fired at a nominal heat input of 10% of the total heat input. Design fuel parameters are shown in Table 3.

Table 3: Fuel design data

Parameter	Coal	Natural Gas
Higher Heating Value, Btu/lbm (kJ/kg)	11,338 (26,372)	22,666 (52,721)
Heat input (nominal), %	90	10
Heat input (capacity), %	100	100

1.A.iii. Primary Cycle Design Parameters

Three primary design parameters determined at the beginning of cycle design are nominal power output, pump discharge pressure (PDP), and turbine inlet temperature (TIT). The proposed pilot plant is 10 MW_e (nominal). The choice of 10 MW_e as an appropriate large pilot scale for the system is discussed in detail in 1.C. Power cycle gross efficiency is plotted as a function of PDP and TIT in Figure 4, where

- Other parameters are defined as described in 1.A.ii and 1.A.iv.
- Power cycle gross efficiency is defined as the power output at the generator terminals divided by the heat input to the power cycle.
- The efficiency datum is defined at a PDP of 20 MPa and a TIT of 500°C.

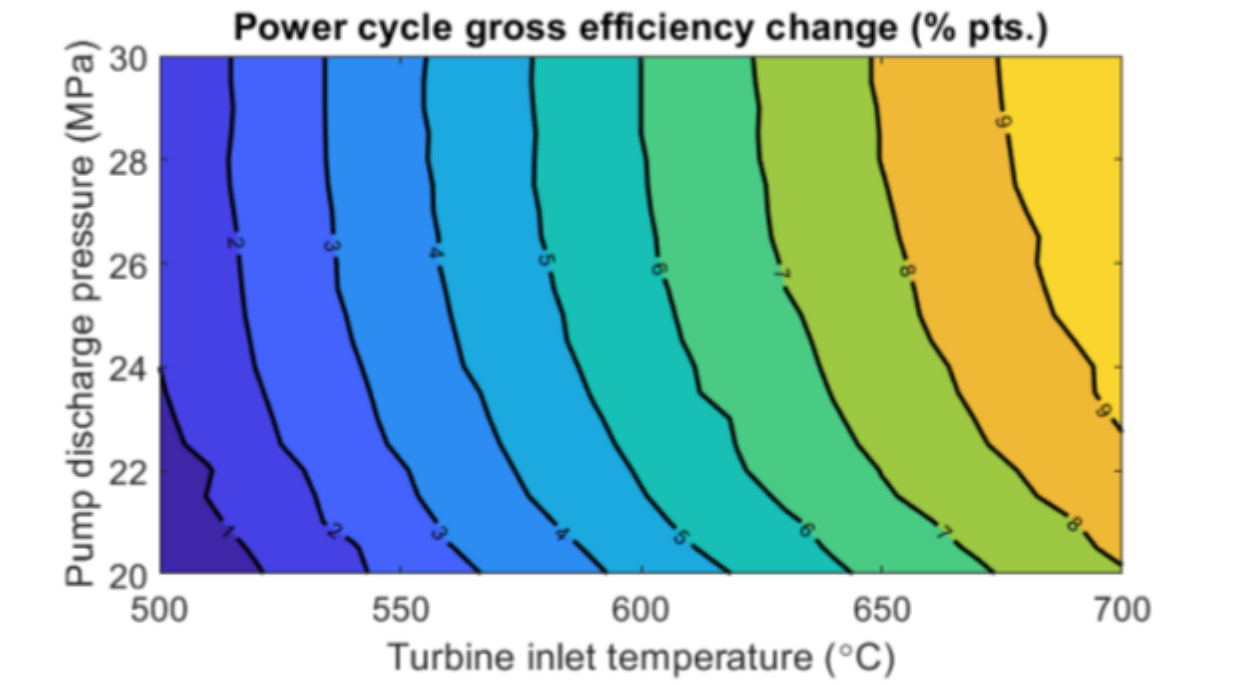


Figure 4: Potential power cycle gross efficiency change from a baseline at 20 MPa PDP and 500°C TIT

Most potential efficiency gains via increased PDP are realized by raising the PDP from 20 MPa to 25 MPa. The PDP was set at 25 MPa. A 10% margin was applied for piping design pressure (27.5 MPa).

A TIT of at least 600°C is desirable in order to demonstrate the sCO_2 RCBC technology under similar turbine inlet conditions as steam ultra-supercritical cycles (the state-of-the-art steam-Rankine cycle technology) [1]. While potential efficiency gains via increased TIT are significant for further temperature increases, it is critical to account for other performance and capital costs related to material selection, most notably in relation to PHX design. Reduced allowable stress for applicable austenitic stainless-steel materials at high temperatures raise PHX tube wall thickness requirements. Thicker PHX tube walls increase not only the direct material cost but also the PHX pressure drop, which can negate the potential efficiency benefit of a higher TIT, especially for CO_2 fluid temperatures exceeding 600°C. Similarly, the allowable stress for Inconel 625 (EPS's preferred material for turbine inlet piping) declines significantly above 621°C (1150°F), in which range schedule pipe would no longer be a viable option. The operating temperature was set at 600°C MPa, and a 10°C margin was applied for design temperature (610°C).

Table 4: Primary cycle design parameters

Parameter	Value
Net Plant Power (MWe)	10
Pump Discharge Pressure (MPa)	25
Turbine Inlet Temperature (°C)	600

1.A.iv. Major Equipment Design Parameters

1.A.iv.a. Turbomachinery

Turbine efficiencies were estimated based on each turbine's shaft power (Figure 5), and compressor efficiencies were estimated based on each compressor's CO_2 flow rate (Figure 6).

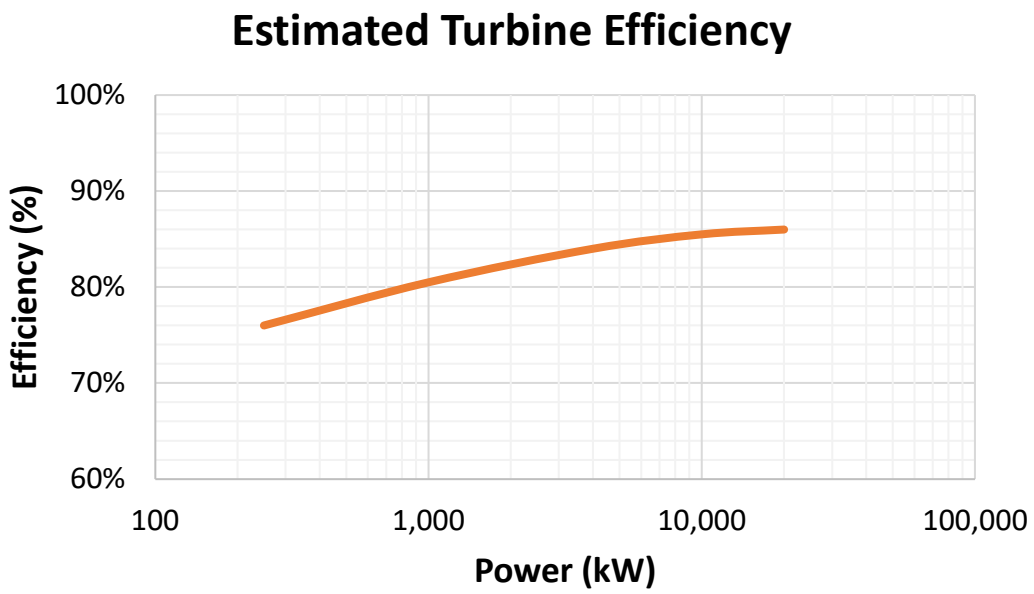


Figure 5: Curve for estimating turbine efficiencies

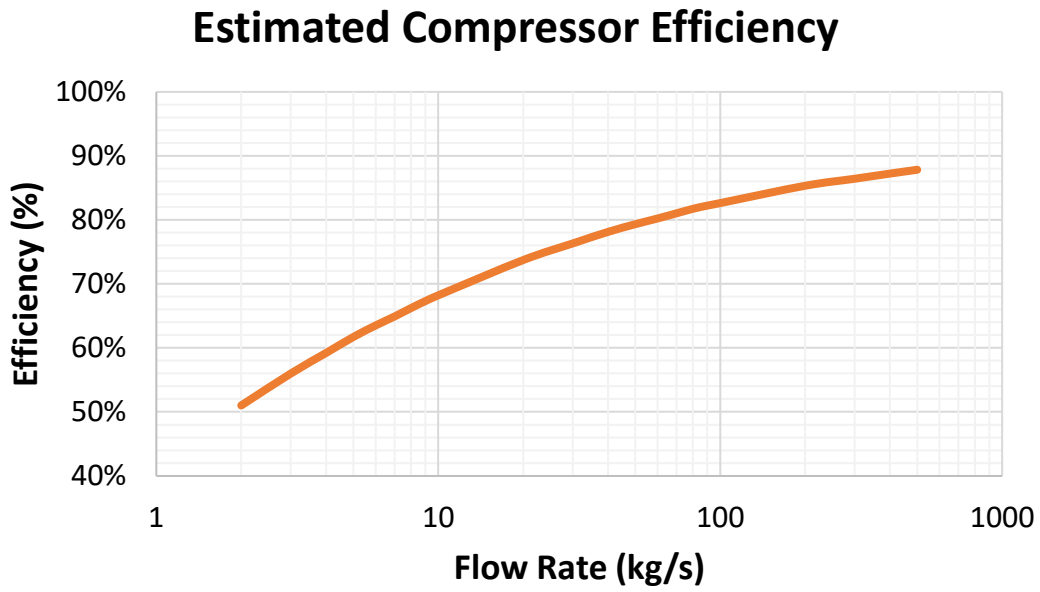


Figure 6: Curve for estimating compressor efficiencies

Turbocompressor shaft power losses account for the difference between turbine power and compressor power. Full-speed, full-load windage losses were estimated based on EPS100 test experience. Additionally, 4 kg/s of LTC flow was budgeted to supply flow to the LTC and HTC bearings. The suction side of the LTC operates near the saturation line. To ensure appropriate suction margin, the design point was set at 0.69 MPa (100 psi) isenthalpic suction margin. (The EPS100 operated stably in a similar range during testing.)

Table 5: Turbomachinery design parameters (FEED)

Component	Turbine Eff. (%)	Compressor Eff. (%)	Windage (kW)	Aux. Flow (kg/s)	Suction Margin (MPa)
PT	Figure 5	Figure 6	12	Oil bearing	n/a
LTC	Figure 5	Figure 6	59	2.0	0.69
HTC	Figure 5	Figure 6	59	2.0	n/a

1.A.iv.b. Heat Exchangers

EPS's design approach to the sCO_2 power cycle is mindful of the significant cost-adders within the sCO_2 loop. In particular, heat exchanger costs are highly sensitive to thermal "size" (UA), effectiveness, and pressure drop. EPS has developed proprietary techniques for heat exchanger cost prediction subject to these variables. Given the asymptotic relationship between incremental cost and cycle efficiency near an architecture's theoretical peak performance and the complex interplay between heat exchanger design variables (particularly in architectures with parallel flow paths and multiple recuperators), a key factor in selecting a design point is evaluating heat exchanger cost versus cycle efficiency.

RCBC efficiency depends on highly effective recuperators with low pressure drop. To achieve the required effectiveness (typically 95-98%), EPS uses printed circuit heat exchangers (PCHEs). As shown in Figure 7, the estimated PCHE marginal costs begin to increase above 97%—with dramatic marginal cost increases above 98% effectiveness. For this reason, EPS typically examines performance-versus-cost trades for HTR and LTR effectiveness of up to 98% when selecting a design point. The water-cooled CHX will also be PCHE technology, and the same maximum effectiveness is applied, although the optimal cycle efficiency does not always require such an elevated CHX effectiveness.

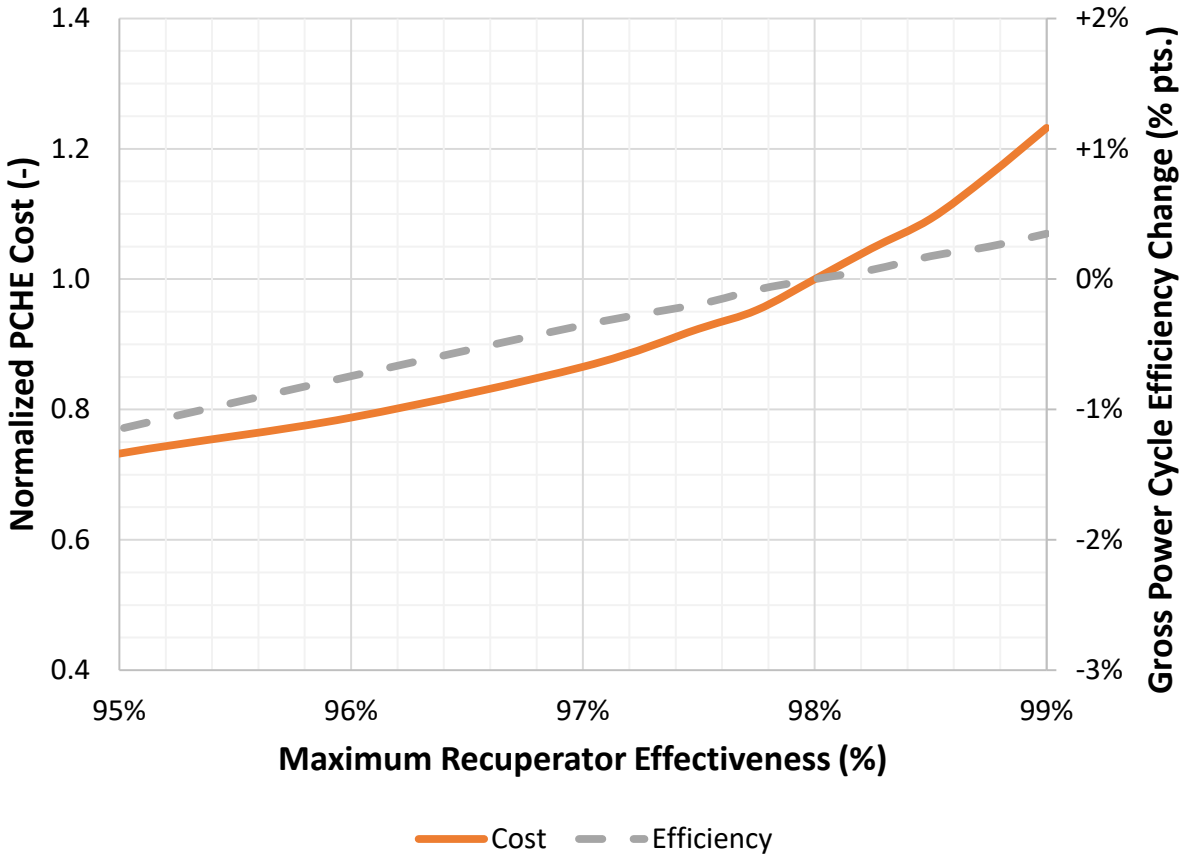


Figure 7: PCHE cost and efficiency trends as functions of recuperator effectiveness (baseline at 98% effectiveness)

The RCBC efficiency is sensitive to CO_2 pressure drop due to the cycle's low pressure ratio. EPS uses 1 bar as a practical minimum pressure drop for each PCHE flow. Raising pressure drop and reducing effectiveness both trade performance (cycle efficiency) for cost savings. EPS cost models were used to predict cost-versus-performance trades for three recuperator design combinations: a baseline design (1 bar pressure drop each for HTR and LTR), a design allowing higher HTR pressure drop (2 bar) with baseline LTR pressure drop (1 bar), and a design allowing higher LTR pressure drop (2 bar) with baseline HTR pressure drop (1 bar). For each design, cost-optimized cases were generated across an efficiency range. Results indicate that, for a given

efficiency, it is more cost-effective to sacrifice heat exchanger effectiveness than pressure drop (Figure 8).

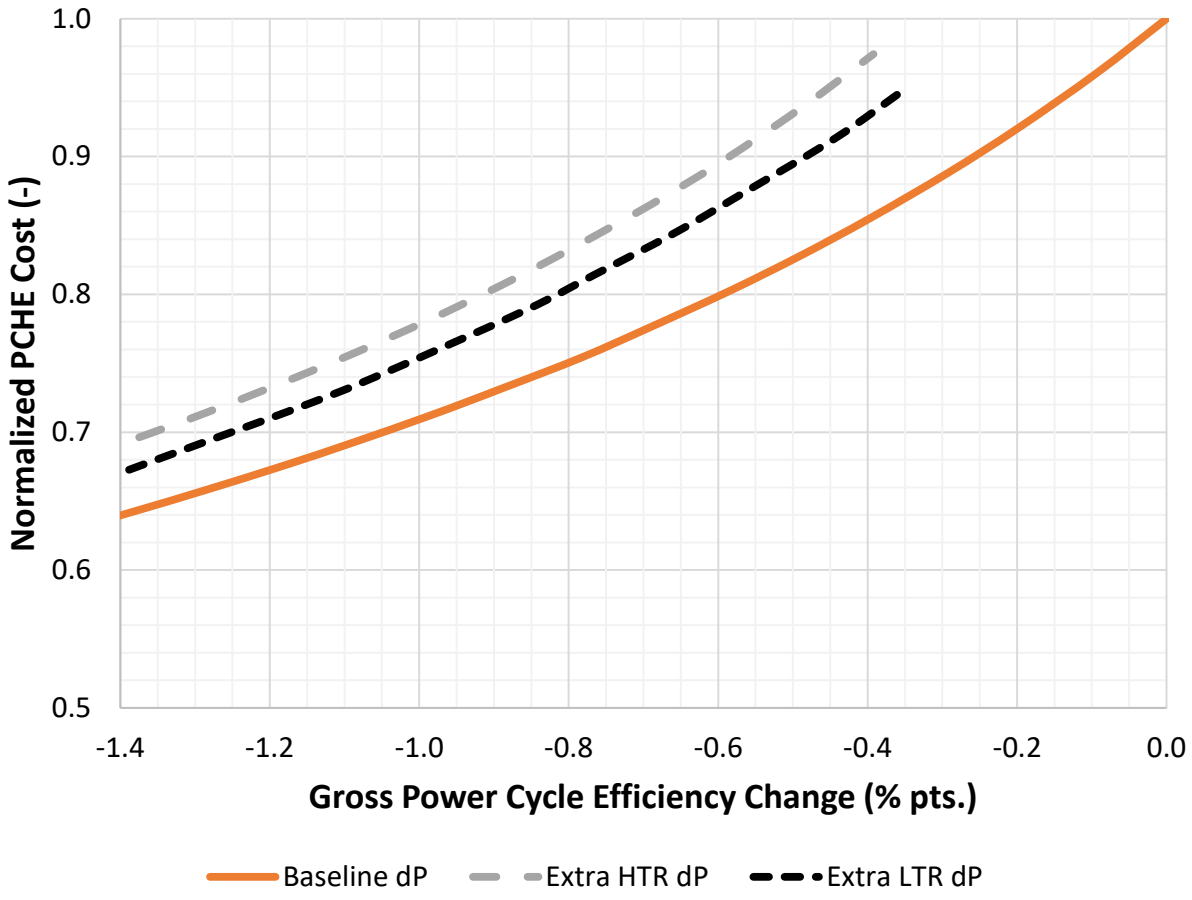


Figure 8: Comparison of expected PCHE cost versus performance trades with different pressure drop assumptions (baseline pressure drop: 1 bar each for HTR and LTR; extra pressure drop: an increase to 2 bar total for the named heat exchanger)

Table 6: PCHE design parameters (FEED)

Parameter	HTR	LTR	CHX
Effectiveness, %	≤ 98.0	≤ 98.0	≤ 98.0
Low-pressure ΔP, MPa	0.1	0.1	0.1
High-pressure ΔP, MPa	0.1	0.1	0.1

A trade study was performed to optimize the sizing of the plate-and-frame IHX. For a given plant efficiency, a smaller (less effective) IHX requires larger (more effective) recuperators. As shown in Table 7, estimates from EPS cost models indicate that the marginal recuperator costs are greater than the marginal IHX costs. Due to concerns about the tight temperature difference (1.1°C) and extensive spatial requirements for the 90% effectiveness option, the IHX effectiveness was set to 80%. EPS uses 1 bar as the standard design pressure drop for each IHX flow.

Table 7: IHX trade study results

Parameter	Component	Option 1	Option 2	Option 3
Efficiency, %	Power cycle	Baseline	Baseline	Baseline
Effectiveness, %	IHX	70.0	80.0	90.0
	HTR	98.0	97.9	97.4
	LTR	98.0	97.7	97.3
Cost ($1000)	IHX	Baseline	+45	+138
	HTR	Baseline	-69	-225
	LTR	Baseline	-624	-853
	IHX + HTR + LTR	Baseline	-648	-939

Table 8: IHX design parameters (FEED)

Parameter	Value
Effectiveness, %	80.0
Low-pressure ΔP, MPa	0.1
High-pressure ΔP, MPa	0.1

1.A.iv.c. Losses and Auxiliary Loads

EPS estimated piping lengths and loss coefficients based on the conceptual (Phase I) plant layout, completed preliminary pipe sizing, and (using the Swamee-Jain equation for the

Darcy-Weisbach friction factor) estimated piping pressure drop of 0.175 MPa (high-pressure piping) and 0.250 MPa (low-pressure piping).

Table 9: Fluid losses (FEED)

Parameter	Value
High-pressure piping losses (MPa)	0.175
Low-pressure piping losses (MPa)	0.250

Gearbox and generator efficiencies were assumed to be 98.0% and 97.0%, respectively.

Table 10: Energy conversion losses (FEED)

Parameter	Value
Gearbox efficiency, %	98.0
Generator efficiency, %	97.0

Each water pump load was calculated based on a flow rate optimized for system efficiency, with assumed pump efficiency of 88.3%. (Higher water flow rates reduce the approach temperature for cooling at the expense of pump power.) RPI estimated fan and fired heater loads. EPS estimated power cycle loads based on EPS100 design experience.

Table 11: Parasitic loads (FEED)

Parasitic Load	Value (kW)
Intermediate Water Loop Pump	145
Plant Water Loop Pump	140
Cooling Tower Fan	271
Forced Draft Fan	51
Induced Draft Fan	145
Overfire Air Fan	13
CO2 System Auxiliaries	130
Heater System Auxiliaries	10

Table 12: Parasitic loads assumed as ratios of plant heat input (FEED)

Parasitic Load	Value (% of heat input)
Environmental System Auxiliaries	0.33
Transformer Losses	0.37

1.A.v. Design Basis (FEED)

Cost-versus-efficiency trade studies early in the development process can identify cost-effective means of achieving the reported cycle efficiency without including superfluous equipment offering only marginal performance gains. Within the power cycle equipment scope, PCHEs typically have the strongest impact on cost and cycle efficiency. (At the end of Phase I, PCHEs were estimated to comprise 20% of total power cycle cost.) However, the significant equipment and construction costs related to the heat source in an RCBC plant reduce the relative cost contribution of the power cycle equipment. (At the end of Phase I, power cycle equipment costs were estimated to comprise 23% of total project cost.) Preliminary optimizations of normalized cost versus net plant efficiency (Figure 9) demonstrate the cost-versus efficiency trades for PCHEs, the full power cycle, and the full plant. Other than PCHEs, all costs are fixed based on the Phase I cost estimate.

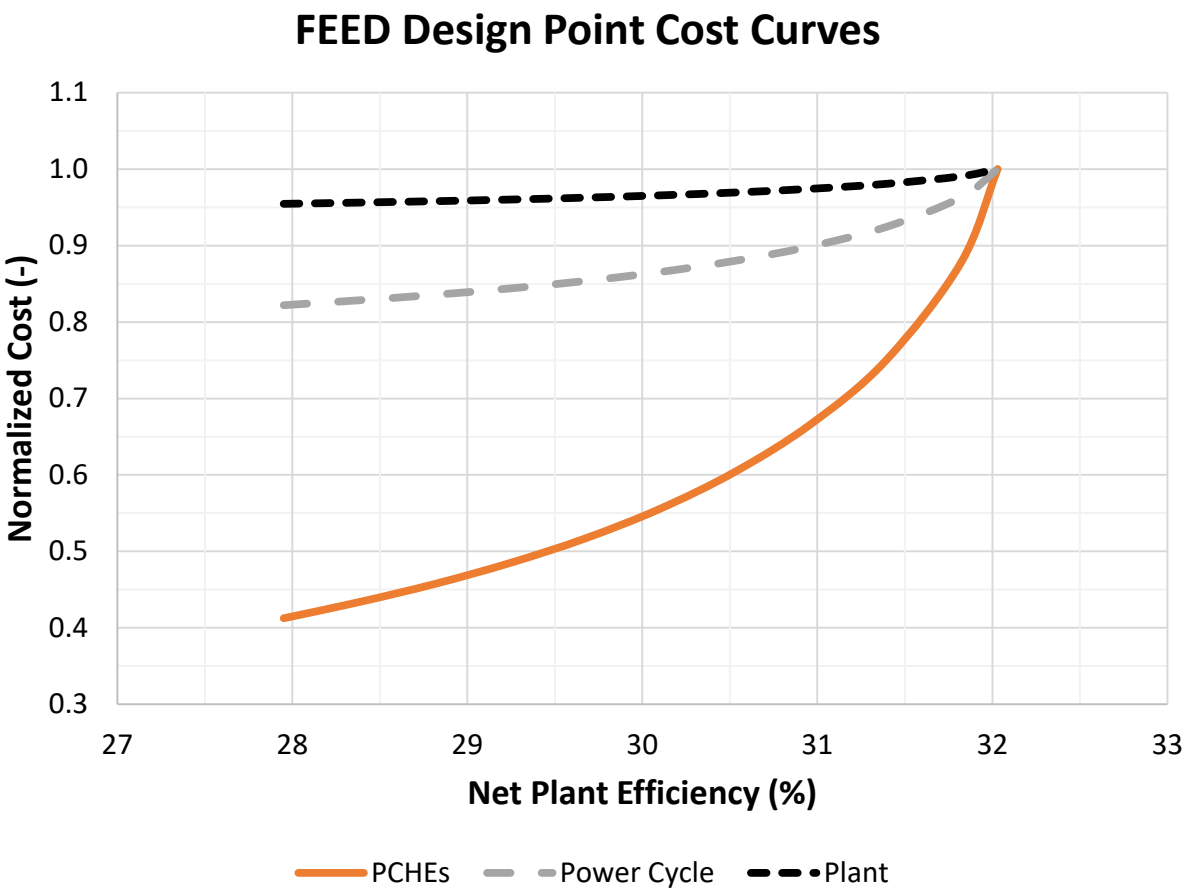


Figure 9: Normalized cost curves as a function of design point net plant efficiency

Varying the PCHE sizing in the 94-98% effectiveness range would not significantly shift the boundary conditions of other critical equipment. Most significantly—in view of the complex design temperature calculations and resulting tube wall thickness requirements in the PHX—system optimization shows little variation in CO_2 flow (less than 4%) and temperature (less than 1%) entering PHX-1 (Figure 10).

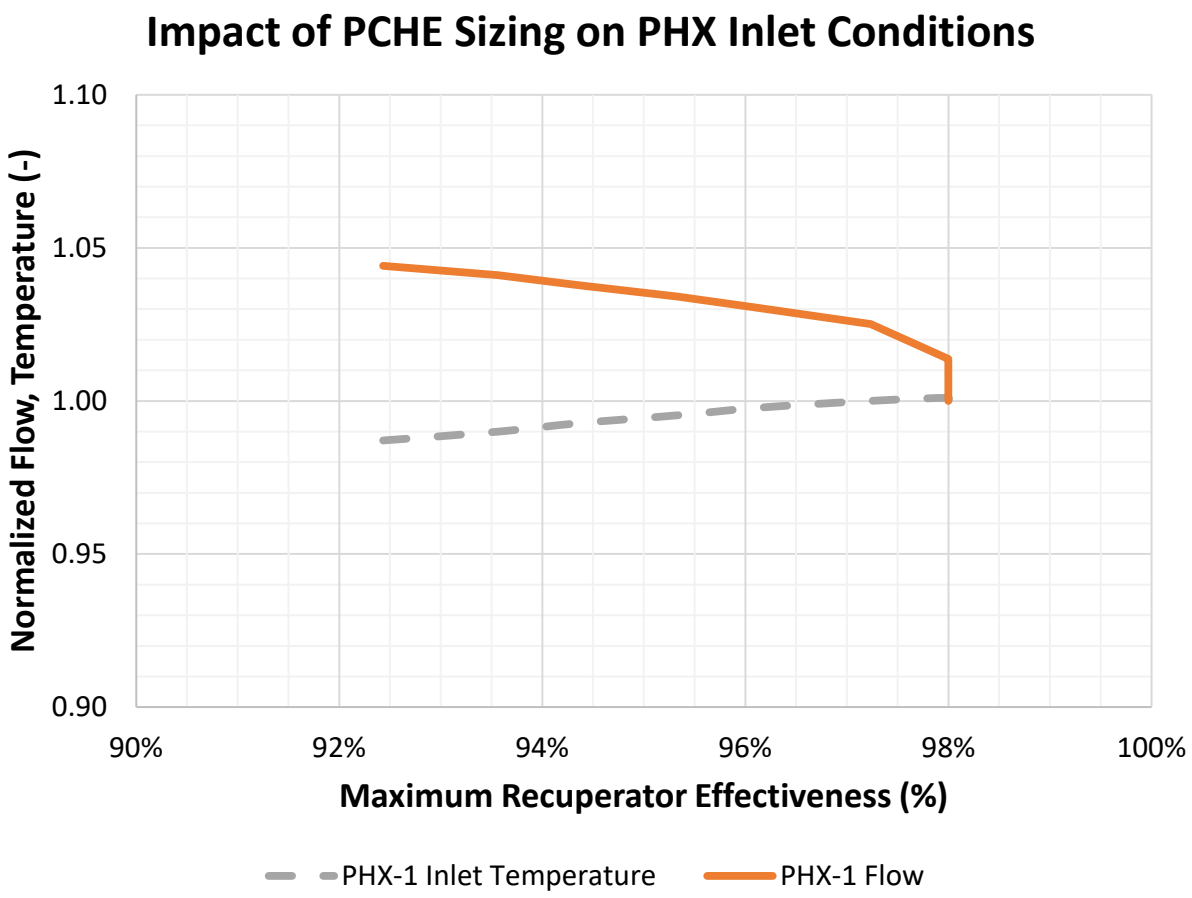


Figure 10: Selection of the FEED design point from the cost curve

Initial system sizing was based on ~98% effective recuperators, with the potential to reduce recuperator size and associated costs at the end of the FEED study (if necessary). Changing from larger to smaller PCHEs would be conservative for PHX cooling flow supply (the direction of increasing flow and decreasing inlet temperature, Figure 10), further supporting this approach.

In Figure 11, a process flow diagram identifies power cycle state points corresponding to the design point process conditions (Table 13). Following are additional design point

summaries: Table 14 lists design data for the turbomachinery and heat exchangers, Table 15 lists system power loads, and Table 16 lists system efficiencies.

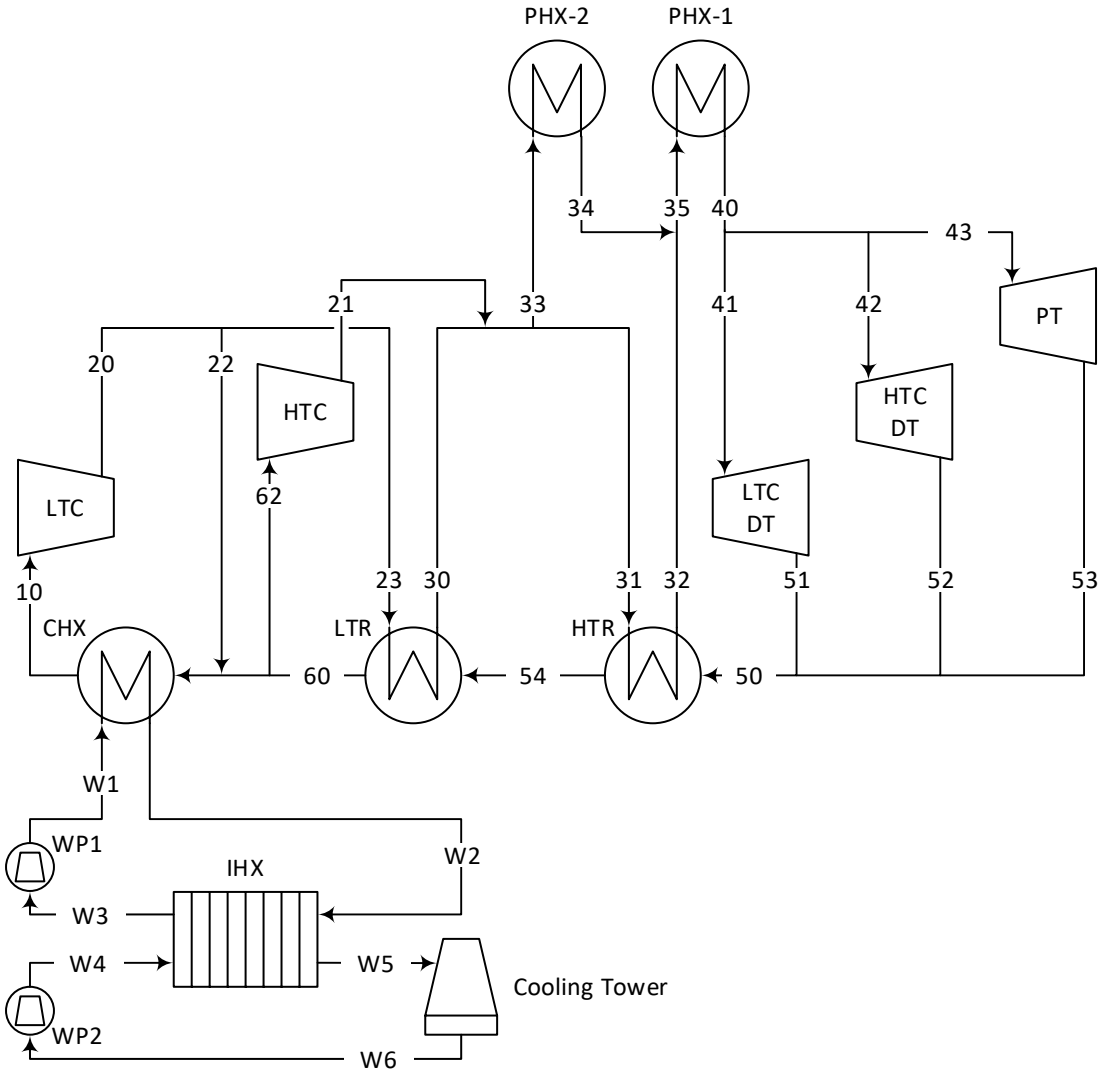


Figure 11: Power cycle process flow diagram with state points identified

Table 13: Design point process conditions at each state point (FEED)

State	Description	Temp. (°C)	Pressure (MPa)	Flow (kg/s)	Enthalpy (kJ/kg)
10	CHX Outlet - LTC Inlet	29.3	7.66	87.13	284.1
20	LTC Outlet	58.6	25.00	87.13	312.0
21	HTC Outlet	174.8	24.80	47.62	545.1
22	Bearings & Seals	58.6	25.00	4.00	312.0
23	LTR High Pressure Inlet	58.6	24.97	83.13	312.0
30	LTR High Pressure Outlet	181.4	24.80	83.13	555.5
31	HTR High Pressure Inlet	178.8	24.73	118.89	551.7
32	HTR High Pressure Outlet	462.2	24.53	118.89	922.5
33	PHX2 Inlet	178.9	24.75	11.86	551.7
34	PHX2 Outlet	470.0	24.45	11.86	932.3
35	PHX1 Inlet	462.8	24.45	130.75	923.4
40	PHX1 Outlet	600.0	23.45	130.75	1095.5
41	LTC Turbine Inlet	600.0	23.35	18.83	1095.5
42	HTC Turbine Inlet	600.0	23.35	28.08	1095.5
43	Power Turbine Inlet	600.0	23.35	83.85	1095.5
50	HTR Low Pressure Inlet	478.7	8.11	130.75	959.5
51	LTC Turbine Outlet	482.2	8.21	18.83	963.4
52	HTC Turbine Outlet	480.9	8.21	28.08	961.9
53	Power Turbine Outlet	477.4	8.21	83.85	957.8
54	HTR Low Pressure Outlet	184.8	8.01	130.75	622.3
60	LTR Low Pressure Outlet	64.1	7.86	130.75	467.5
61	CHX Inlet	59.6	7.79	87.13	460.4
62	HTC Inlet	63.6	7.79	47.62	467.5
W1	WP1 Outlet - CHX Inlet	28.3	0.40	425.80	119.1
W2	CHX Outlet - IHX Inlet	37.0	0.30	425.80	155.1
W3	IHX Outlet - WP1 Inlet	28.3	0.10	425.80	118.5
W4	WP2 Outlet - IHX Inlet	26.1	0.39	425.81	109.7
W5	IHX Outlet - Cooling Tower Inlet	34.8	0.19	425.81	145.9
W6	Cooling Tower Outlet - WP2 Inlet	26.0	0.10	425.81	109.1

Table 14: Design data for turbomachinery (shaft power and efficiency for each component) and heat exchangers (duty and effectiveness for each component) (FEED)

Component	Duty (kW)	–	(kW/°C)	Efficiency / Effectiveness	–	
LTC - Shaft Power (T – C)	2,488	–	2,429	81.9%	–	82.0%
HTC - Shaft Power (T – C)	3,752	–	3,693	82.8%	–	79.0%
PT - Shaft Power	11,541			85.4%		
IHX - Heat Transferred – UA	15,500	–	7,119	80.0%		
CHX - Heat Transferred – UA	15,355	–	5,845	97.3%		
HTR - Heat Transferred – UA	44,083	–	2,808	98.0%		
LTR - Heat Transferred – UA	20,239	–	4,312	98.0%		
PHX1 - Heat Transferred – UA	22,513	–				
PHX2 - Heat Transferred – UA	4,514	–	66	84.7%		

Table 15: Design power loads (FEED)

System Parasitics	Loss (kW_e)	Power (kW_e)
Power Turbine Shaft Power		11,541
Gearbox Losses	-231	
Generator Losses	-339	
Generator Power		10,971
Intermediate Water Loop Pump	-145	
Cooling Tower Pump	-140	
Cooling Tower Fan	-271	
Forced Draft Fan	-51	
Induced Draft Fan	-145	
Overfire Air Fan	-13	
CO2 System Auxiliaries	-130	
Heater System Auxiliaries	-10	
Environmental System Auxiliaries	-25	
Transformer Losses	-41	
System Net Power		10,000

Table 16: Design system efficiencies (FEED)

System	Energy In (kW)	Energy Out (kW)	Efficiency
Fired Heater	31,427	27,027	86.0%
Power Cycle (gross)	27,027	10,971	40.6%
Power Cycle (net)	27,027	10,000	37.0%
Overall Plant	31,427	10,000	31.8%

Based on preliminary estimates from RPI, the estimated thermal efficiency of the fired heater was 86.0%. The gross power cycle thermal efficiency was 40.6%, with a net efficiency (debiting parasitic loads) of 37.0%. The overall plant efficiency was 31.8% based on the higher heating value (HHV) of the fuel input to the fired heater.

1.A.vi. Major Equipment Design (FEED)

The Phase II design process started with the establishment of the FEED design point (1.A.v). The FEED design values were supplied to project partners and vendors for preliminary design of all engineered systems and equipment.

1.A.vi.a. sCO_2 Power Cycle

1.A.vi.a.1. Turbomachinery

Turbines (PT, LTC-DT, and HTC-DT, introduced in 1.A.i) extract thermal energy from the pressurized sCO_2 flow and convert it to mechanical shaft power, driving either a synchronous generator or compressors (LTC and HTC, also introduced in 1.A.i). BNI completed conceptual designs of all turbomachinery. The PT and LTC conceptual designs are summarized below (1.A.vi.a.1.1 and 1.A.i.a.1.1, respectively), with the full design reports in Appendices 0 and I. The

HTC conceptual design was completed in Phase I. Turbomachinery design parameters were updated according to BNI's conceptual designs (Table 17). Note that the PT bearing design changed from oil bearings (see Table 5 on page 20) to CO_2 bearings (as described in 1.A.vi.a.1.1).

Table 17: Turbomachinery design parameters (Final)

Component	Turbine Eff. (%)	Compressor Eff. (%)	Windage (kW)	Aux. Flow (kg/s)	Suction Margin (MPa)
PT	84.1	n/a	24	4.9	n/a
LTC	83.5	84.1	56	4.0	0.69
HTC	83.3	80.2	37	3.5	n/a

1.A.vi.a.1.1. Power Turbine

The PT extracts thermal energy from a pressurized flow of sCO_2 and converts it to mechanical shaft power. EPS and BNI previously partnered to complete the conceptual design of a 700°C TIT turbine under DOE contract DE-NE0008470, Conceptual Design for sCO_2 Power Test Facility.

The project elected to pursue an axial turbine design in order to improve the scalability for commercial-scale plants. BNI conducted a parametric trade study for stage count, degree of reaction, and speed to downselect a core aerodynamic configuration. The goal of the optimization was to trade complexity (stage count and airfoil design) with performance to arrive at a multi-stage axial design that demonstrates reasonable pilot-plant efficiency at reasonable cost. The Design of Experiments (DoE) included 63 total configurations analyzed in the following solution space:

- Speed: 9.4 to 30.0 KRPM

- Pressure reaction: 10% to 50%
- Stage count: 2 to 4

The initial target of 85.4% efficiency was only achievable with high reaction and high stage count designs. Given the large cost of each turbine stage and the high thrust associated with higher-reaction designs, the DoE was refined to maximize efficiency at 10% reaction and 3 stages while pushing blade geometry to a challenging but obtainable limit (in terms of hub-to-tip ratio). The resulting selections for design aerodynamic geometry are:

- Speed: 20.0 KRPM
- Pressure reaction: 10%
- Stage count: 3

PT design challenges related to sCO_2's high power density, high pressure, and high temperature include:

- Effective sealing to mitigate process fluid loss
- Appropriate bearing systems and rotor design to produce robust rotor dynamics that can handle the sources of destabilizing forces in the machine and avoid operating near a critical speed (bending mode)
- Thrust mitigation for both start up (shaft piston area) and operation
- Thermal management of bearing systems

Sealing – For conceptual aerodynamic design, BNI kept conservative clearances for defining the flow that goes around the stator and rotors. As the design matures, it will be feasible to refine possible minimum clearances as well as identify alternate rotor sealing

technology (labyrinth, stepped labyrinth, honeycomb). Baseline performance is based on 0.015" radial clearance to the nozzles and 0.020" radial clearance to the blades as a safely achievable clearance at the conceptual level of maturity. Table 18 below shows the predicted increase in turbine isentropic efficiency as clearance is reduced. (Zero clearance, while not feasible, brackets the problem to demonstrate the total efficiency penalty of leakage.) Case 2 shows an upper end of what could be achievable with a combination of tighter clearances and advanced seals. There is a potential for a two-percentage point increase in turbine efficiency from optimizing the seals. This will be fully investigated in the next design phase.

Table 18: Rotor and stator clearance impact on turbine isentropic efficiency

Case	Clearance, inches		Efficiency, %
	Nozzles	Blades	Total-to-Static
1	0.000	0.000	4.1
2	0.005	0.010	1.9
3	0.015	0.020	Baseline
4	0.025	0.030	-1.4

Bearing Systems – Bearing technology selection was a key trade in the conceptual development of the power turbine. The choice was between tilt-pad oil lubricated bearings or hydrostatic sCO_2 bearings. The key considerations were performance, applicability to full scale, operability, and load capacity. The difference in how the two bearing technologies operate is notable. Tilt-pad bearings generate bearing lift by hydrodynamic effects of the lubricated oil and depend on the velocity of the journal and viscosity of the lubricant to generate lift. Hydrostatic bearings use a supplied pressure and a self-regulating hydraulic circuit to generate a reactive force proportional to displacement and the supplied pressure ratio. The bearing selection comparison focused on the thrust bearing as the primary technical challenge of the

bearing system. Compared to a higher stage count machine (made for 3600 RPM operation), the 3-stage power turbine is a relatively high-speed machine (20,000 RPM).

Thrust bearings are limited by a given unit load (effective pressure that the projected area of the bearing can support). For hydrodynamic oil lubricated bearings, that steady load is on the order of 400 psi. For hydrostatic sCO_2 thrust bearings, a load approximately 50% of the Δp supplied can be supported. However, because the machine is relatively high speed, thrust bearing power loss must be considered carefully. Thrust bearing power loss scales with speed to the 2nd power, diameter to the 5th power, and area to the 2nd power. Thus, high load capacity and minimization of thrust is necessary for keeping thrust bearing power loss in control.

Table 19: Thrust bearing performance comparison (not including auxiliaries and parasitic losses associated with radial bearings)

Bearing fluid	Oil	CO_2
Bearing type	Hydrodynamic	Hydrostatic
Thrust disk, in.	7.0	5.5
Unit load capacity, psi	400	800
Max. thrust load, lb	12,000	16,000
Windage power loss, kW	68	12
Flow supply, gpm or kg/s	32 gpm	2.0 kg/s
Pump power, kW	1	80
Total system therm. loss, %	0.6	0.4

The higher thrust capacity from zero speed and increased thermodynamic performance of the system make the hydrostatic sCO_2 bearings an attractive selection for the power turbine. As a new conceptual machine, predicted machine thrust inherently carries a large amount of uncertainty. Both designs have room for performance optimization as understanding of on- and off-design thrust requirements evolve. For the oil-lubricated bearing, optimization would consider thrust bearing size and the effect on windage power and load capacity. For the

hydrostatic bearing, optimization would consider the implementation of a control valve to reduce the feed pressure and thus the flow supply (primary source of loss) in-situ without a change to hardware.

The bearing selection drives operability challenges for this design. There are potential challenges with both start-up and emergency shut-down thrust loads. Both can be addressed with secondary flow. However, at the design level there is a significant impact from bearing selection that cannot be easily mitigated with secondary flow circuits. Though this machine has three stages, resulting in a reduction of speed relative to the EPS100 power turbine designs, it still presents notable rotor dynamic challenges with regards to shaft length and critical frequencies. The extremely high power density of sCO_2 turbomachinery creates challenges managing destabilizing forces. Though both bearing solutions offer a high level of damping, if there is a design solution that completely avoids critical modes, it can be considered more robust and lower risk.

No arrangement of oil-lubricated bearings could be found that met the needs of the design and avoided the first bending mode (critical speed) of the machine (Figure 12). The more compact shaft length of the hydrostatic sCO_2 bearings allowed for a machine design that fully operates below the first bending mode—a significant increase in design robustness that is valuable in a prototype pilot plant demonstration machine.

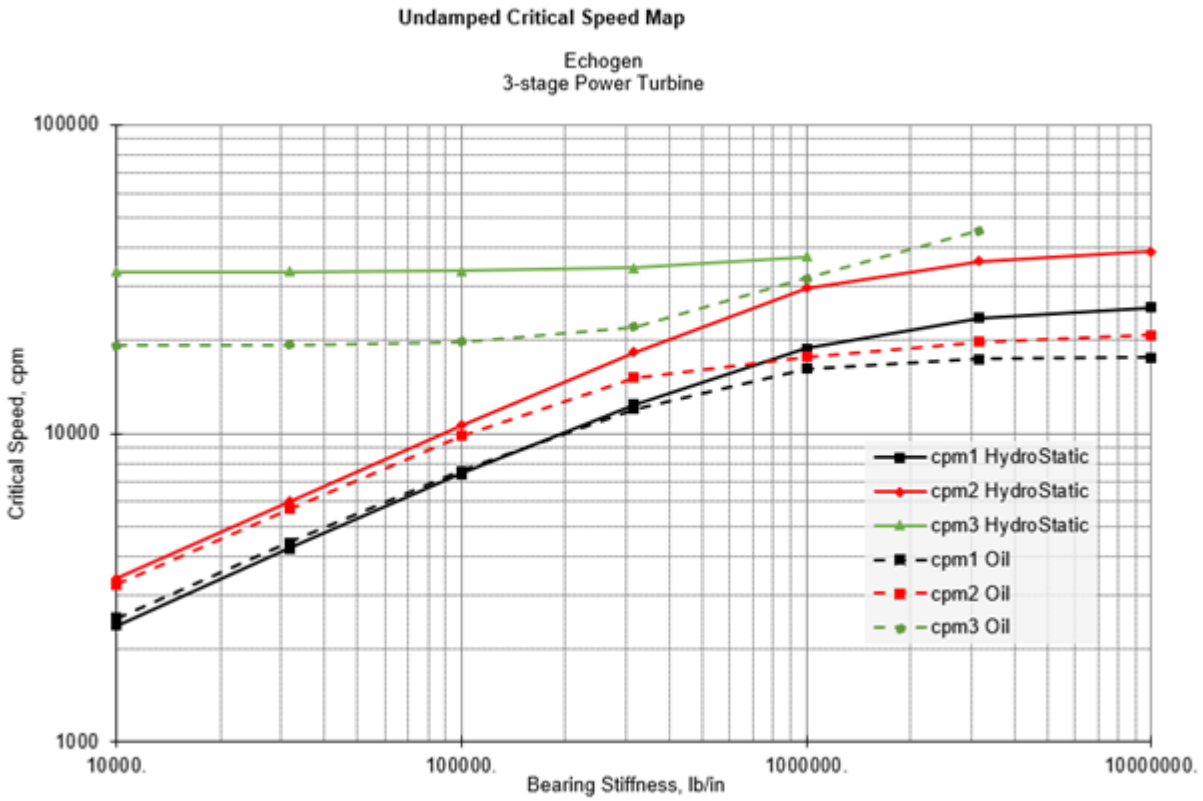


Figure 12: Undamped critical speed comparison between conceptual oil-lubricated and sCO_2 hydrostatic bearing configuration. (Note that the free-free bending frequency of the oil lubricated layout is near the 20,000 RPM design speed due to longer shaft requirement.)

Due to the power density and rotor dynamic strategy for this machine, the large shaft diameter results in a large seal area for the shaft. For process loss and cost considerations, it is desirable to have only one dry gas seal on the rotating assembly. The dry gas seal size is 4" and with a startup pressurization of 8.2 MPa, the resulting static thrust load is approximately 15,000 lb. For an oil lubricated thrust bearing, this is a unit load of 390 psi at startup and would require a high-pressure oil pump and some hydrostatic features on the bearing for startup. For the sCO_2 hydrostatic thrust bearing, the unit load for the thrust bearing from startup is 630 psi, which is well within the capacity for lifting off the bearing from the available hydrostatic bearing pressure feeds.

The hydrostatic bearings showed competitive system performance, increased rotor dynamic robustness, and reduced process gas loss, as well as competitive conceptual performance at 120 MW design space. A hydrostatic thrust bearing also has an inherent ability to measure thrust and offers some in-situ turn down of bearing flow, making the selection of hydrostatic sCO_2 bearings for this machine a good choice.

The principal challenge that remains for the bearings pertains to loss of pressure during emergency shut down. Coming out of conceptual design, the notional emergency shut down scenario includes venting the high-pressure bearing cavity and using the main system pressure to maintain bearing feed while the machine coasts down.

Thrust Mitigation – The machine thrust balance is a function of three main components. Thrust developed by the aerodynamic forces on the rotor blades, thrust from the piston area of the dry gas seal, and any difference in pressure on either side of the rotor drum (Figure 13). The drive end (DE) of the machine (and thus dry gas seal location) was designed such that the piston area thrust and the resulting aerodynamic thrust work in opposing directions. For a conceptual design, 50% margin on thrust bearing capacity gives adequate margin on the uncertainty for thrust at this stage of design. By back pressuring the DE bearing cavity with a control valve on the DE sump drain, the thrust can be reduced by approximately 2000 lb, and 50% thrust capacity margin is demonstrated at this stage of design. As the thrust prediction models mature through detailed design, utilization of that control valve can be reevaluated.

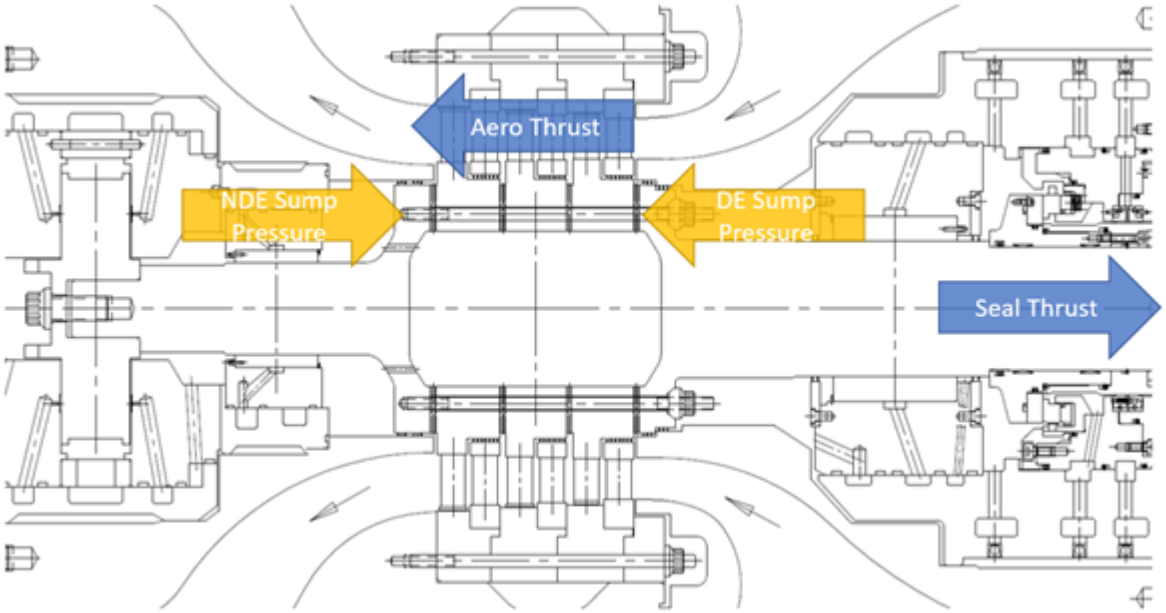


Figure 13: PT thrust balance

Thermal Management of Bearing Systems – sCO_2 can generate high convection coefficients for effective heat transfer. For the PT conceptual design, steps were taken to mitigate the flow of heat into the bearing and seal systems. Those heat flows produce modest bearing flow temperature rises (5 to 10°C). Further isolation is warranted to ensure the hydrostatic bearings operate at a thermodynamic state of low compressibility. Detail work will include a gas passage heat shield on the inner diameter of both gas passages to further reduce heat flow into the bearing systems.

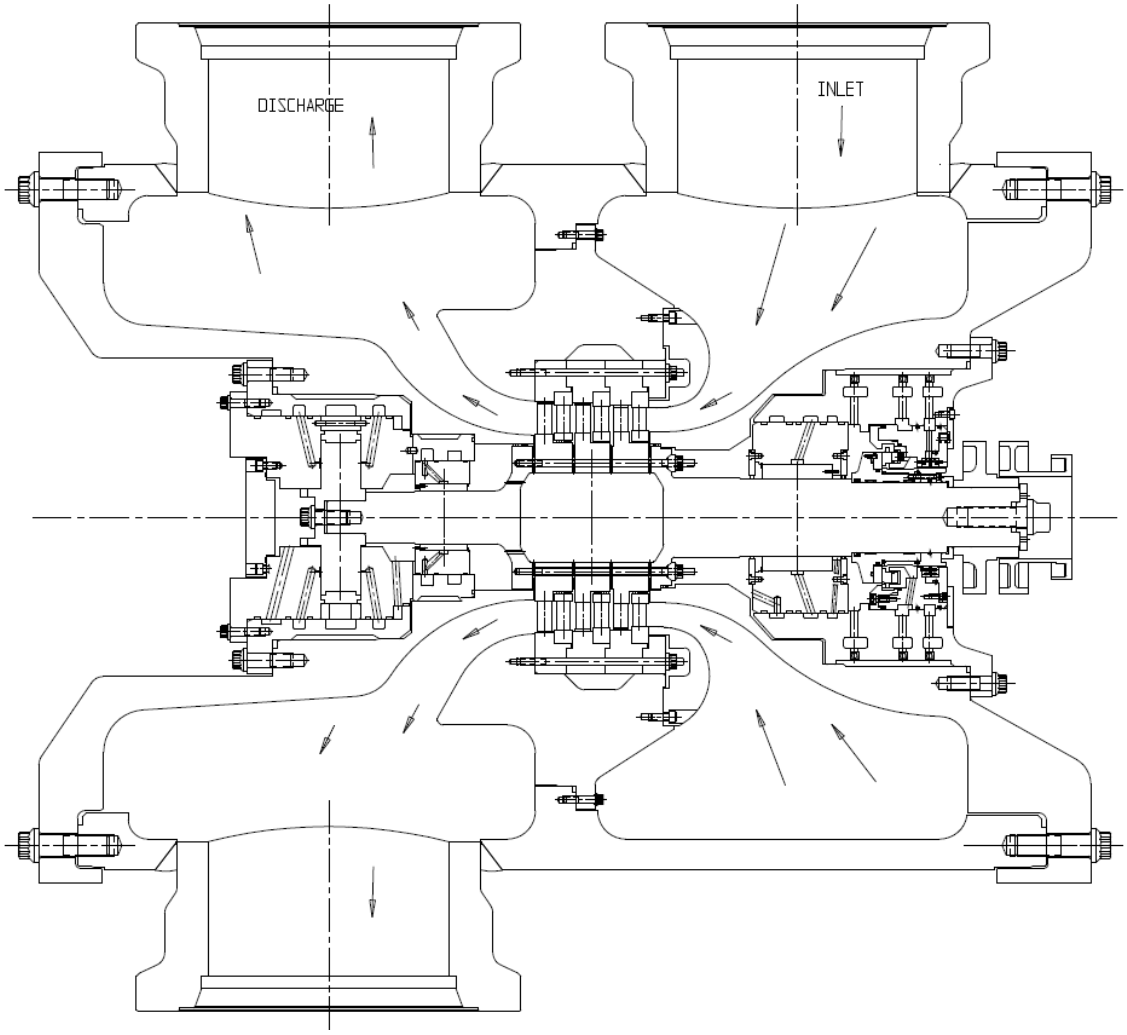


Figure 14: Power turbine conceptual layout

1.A.vi.a.1.2. Low Temperature Compressor and Drive Turbine

The LTC will receive high-density (liquid-like) CO_2 from the CHX in either low-temperature supercritical or liquid state and compress it to the high-side system pressure. The compressor will be driven by the expansion turbine. BNI successfully designed and fabricated a low temperature compressor of similar scale and requirements for the EPS100. (The LSP LTC-DT has a higher TIT requirement.) The compressor uses CO_2 hydrostatic bearings to support the rotor and is hermetically sealed, offering a leak-free solution.

The bearing system was chosen to be interchangeable with the Phase I HTC design work by BNI. Conceptual design results suggest that, with some minor design decisions on the HTC and LTC, the central housing component could be common between the two turbo compressors.

LTC design challenges include:

- Suction margin
- Mechanical robustness
- Variable density ratio
- High-efficiency operation
- High thrust and radial loads

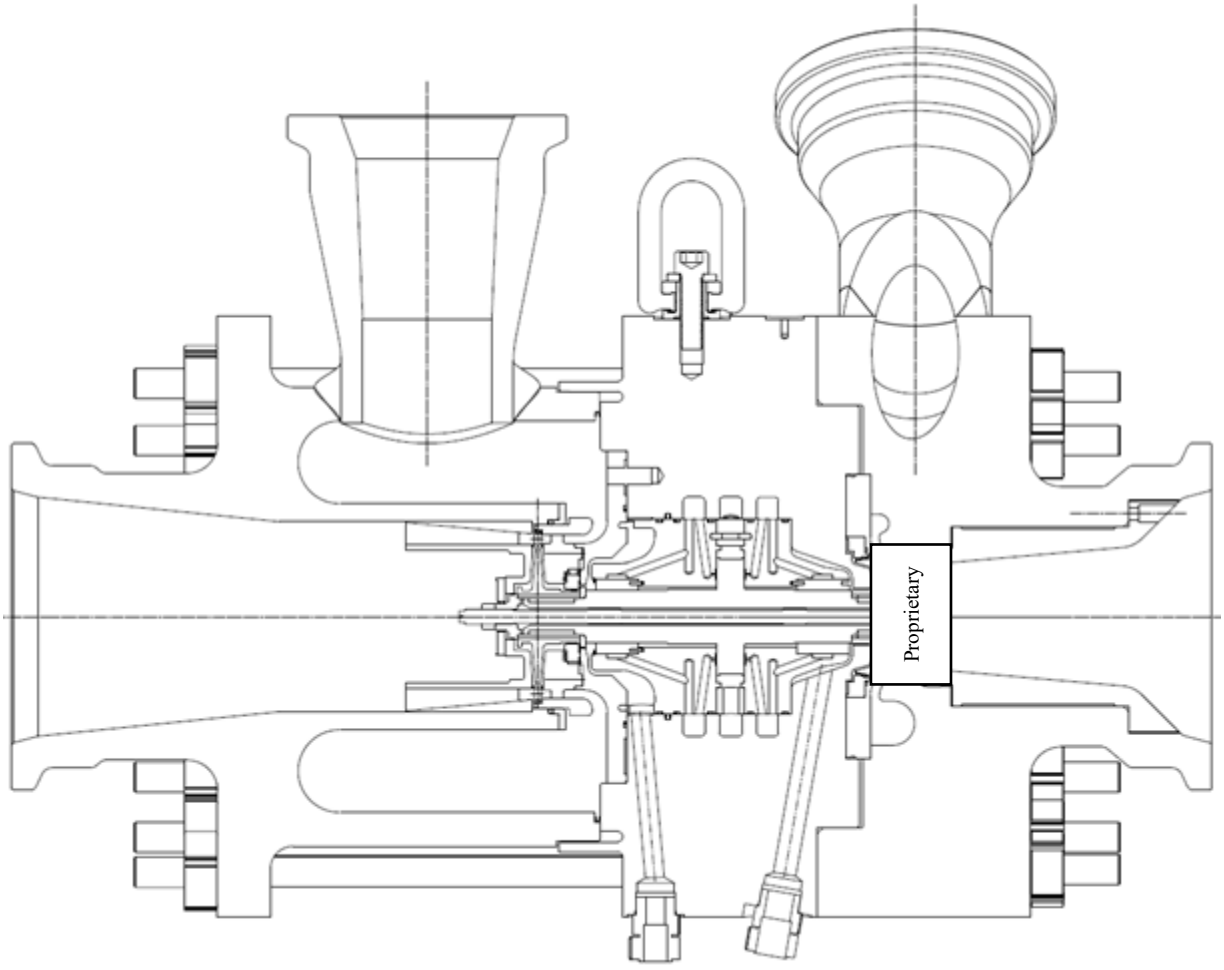


Figure 15: Low-temperature compressor and turbine drive conceptual layout

1.A.vi.a.1.3. High Temperature Compressor and Drive Turbine

The HTC takes low-pressure, gas-phase CO_2 and compresses it up to the high-side system pressure. In Phase I, EPS commissioned BNI to complete a conceptual design of the HTC. The full report was included with the Phase I Topical Report.

An aerodynamic trade study was conducted to identify the most appropriate turbomachine topology. The resulting design concept consisted of a shrouded centrifugal compressor driven by a single-stage axial turbine with a nominal shaft speed of 43 KRPM

(Figure 16). The HTC uses CO_2 hydrostatic bearings. There is no shaft seal present, and the compressor is hermetically sealed to atmosphere.

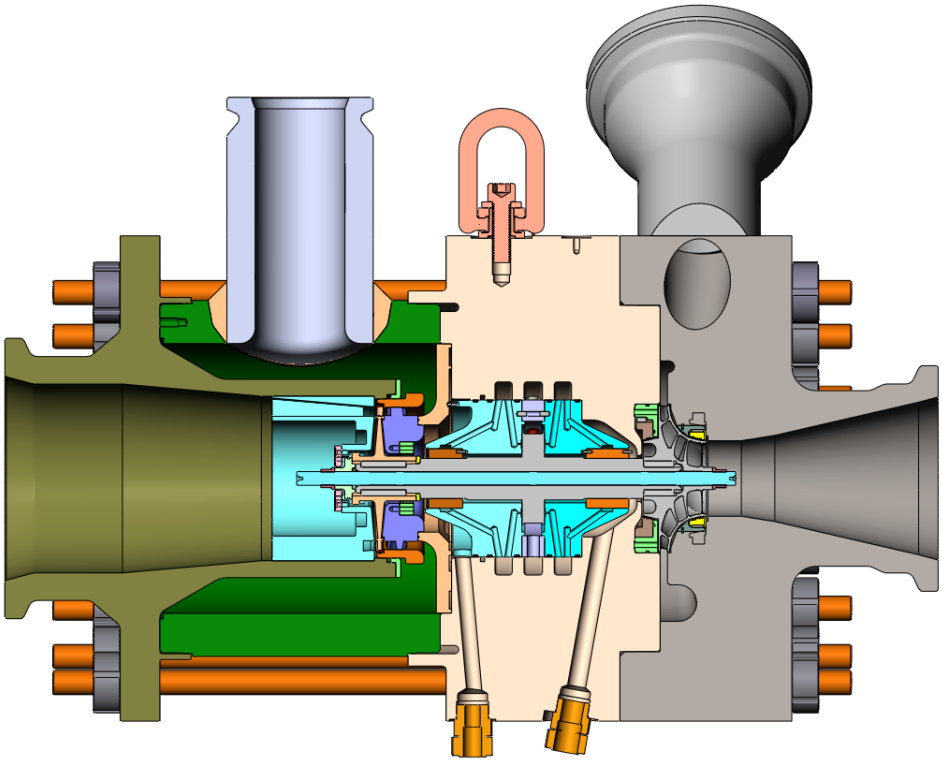


Figure 16: High-temperature compressor and turbine drive conceptual layout

1.A.vi.a.2. Heat Exchangers

1.A.vi.a.2.1. Printed Circuit Heat Exchangers (HTR, LTR, CHX)

Recuperators (HTR and LTR, introduced in 1.A.i) recycle heat within the power cycle, transferring heat between CO_2 flows at various points in the process and greatly increasing cycle efficiency. The CO_2 cooler (CHX, also introduced in 1.A.i) rejects heat from the power cycle, transferring heat from CO_2 to cooling water. As discussed in 1.A.iv.b, PCHE designs are advantageous for achieving the required heat exchanger effectiveness (~98%). PCHEs take advantage of very small channels to create high heat transfer area in a relatively small volume.

EPS solicited budgetary or firm quotes from two suppliers. Both suppliers responded with a quote and an acceptable technical offering. EPS has successfully deployed this technology from lab scale to commercial scale (Figure 17) with multiple suppliers. The recuperators on EPS's three largest prototype units were supplied by one of these suppliers and all have performed well. The second vendor has supplied recuperators for laboratory installations that have also performed well.



Figure 17: EPS100 PCHEs

The provided quotes met the performance requirements (Table 13). From these quotes, physical size characteristics (Table 20) were determined for the FEED study.

Table 20: PCHE sizing based on FEED design basis

Parameter	HTR	LTR	CHX
Dry mass, mt	31.8	47.2	15.6
Length, m	4.5	4.4	1.7
Width, m	0.7	0.7	0.6
Height, m	1.5	2.4	2.9

1.A.vi.a.2.2. Plate-and-Frame Heat Exchanger (IHX)

The intermediate plate-and-frame heat exchanger (IHX, introduced in 1.A.i) transfers heat from a closed-loop flow of treated water (accepting heat from the sCO_2 power cycle) to an open-loop flow of plant water (rejecting heat to the cooling tower). The intermediate water loop is required to prevent fouling in the CHX's small PCHE channels.

EPS solicited firm quotes from two suppliers. Both suppliers responded with a quote and an acceptable technical offering. The provided quotes met the performance requirements (Table 13). From these quotes, physical size characteristics (Table 21) were determined for the FEED study.

Table 21: IHX sizing based on FEED design basis

Parameter	IHX
Dry mass, mt	11.8
Length, m	4.0
Width, m	1.0
Height, m	3.1

1.A.vi.a.3. Power Train

1.A.vi.a.3.1. Gearbox

The 20,000 RPM shaft speed of the PT is reduced to 1800 RPM synchronous generator speed via a compound epicyclic gearbox. (Parallel shaft gearboxes were not an option for this application due to site spatial constraints.)

EPS solicited quotes from three suppliers, each of which responded with a firm quote and an acceptable technical offering. The specification required a 98.0% efficiency. The preferred vendor quoted a 99.2% efficiency.

1.A.vi.a.3.2. Generator

The generator is a totally enclosed water-to-air cooled (TEWAC) unit designed to operate at 4-pole synchronous speed (1800 RPM). Electrical output is 13.8 kV at 60 Hz. The nameplate rating of 11,500 kW is at a power factor of 0.8 and reflects standard 25°C generator capability when limited to 80°C (class B) rise above 25°C ambient (cooling air) temperature.

EPS solicited quotes from two suppliers. Both suppliers responded with a firm quote and an acceptable technical offering. The specification required a 97.0% efficiency. The preferred vendor quoted a 97.4% efficiency.

1.A.vi.a.4. Inventory Control System

The CO_2 inventory control system consists of a storage system and a pump to transfer CO_2 between the storage system and the main power cycle loop. The storage system includes an insulated storage tank, a refrigeration system, and a vaporizer (Figure 18).

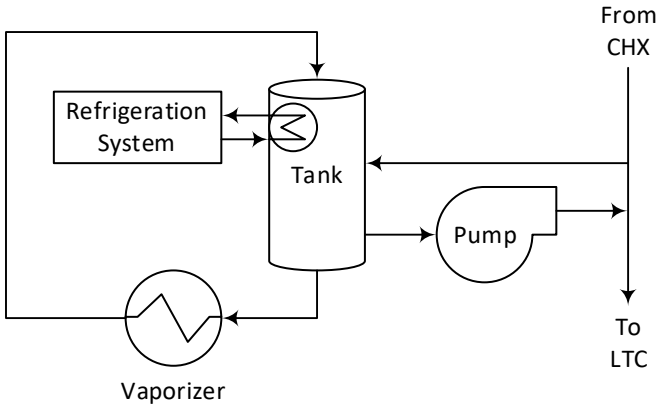


Figure 18: Inventory control system

1.A.vi.a.4.1. Storage System (Tank, Condenser, Vaporizer)

An insulated storage tank holds excess CO_2 for storage at a pressure below that of the power cycle circulation loop. Whereas the power cycle normal operating pressure is 7 to 25 MPa, the tank is rated for a maximum allowable working pressure (MAWP) of 2.51 MPa (350 psig), with standby pressure of 1.51 to 1.58 MPa (205 to 215 psig). The CO_2 is stored at saturation temperature (-28.2 to -26.9°C during standby, -11.8°C at MAWP).

The refrigeration system condenses CO_2 in the storage tank. The refrigeration system is a closed-loop system that uses forced air cooling of the refrigerant to reduce the pressure in the storage tank. Due to the low storage temperature, the ambient surroundings gradually warm the stored CO_2. The refrigeration system operates to prevent undesired pressure rise in the tank. The refrigeration system also operates when CO_2 from the power cycle loop is returned to storage. Although the CO_2 in the power cycle loop is cooled by the CHX before returning to storage, the CHX cooling temperature (limited by the 26°C nominal cooling tower water supply temperature) is significantly warmer than the storage temperature. The

refrigeration system size is set by the time allotted for the return of full system inventory to storage (eight hours for the pilot project).

Like the refrigeration system, the vaporizer also maintains the tank storage pressure in the proper range. When storage CO_2 inventory is reduced by mass transfer to the power cycle loop, vaporizing a small amount of liquid CO_2 and returning it to the tank maintains the tank pressure.

EPS solicited a quote from an approved supplier, which responded with a firm quote and an acceptable technical offering.

1.A.vi.a.4.2. Transfer Pump

The CO_2 transfer pump (TP) is used to transfer working fluid from the storage tank to the power cycle. The performance requirements were determined using cycle startup modeling.

EPS solicited quotes from multiple suppliers and received three firm quotes with acceptable technical and commercial offerings. The preferred vendor offers a reciprocating (plunger style) positive displacement pump.

1.A.vi.a.5. Valves

1.A.vi.a.5.1. Turbine Stop Valve

The turbine stop valve (TSV) is designed to stop flow to the power turbine to prevent power train overspeed events. The closing time requirement was 0.3 seconds based on energy

modeling (fluid and power train inertia) for a loss-of-load event, with a maximum speed of 120% of rated operating speed.

EPS solicited and received a firm quote from a supplier that has demonstrated the ability to achieve similar closing time requirements for past sCO_2 projects. The design consists of a Y-Pattern globe stop valve and a gas/hydraulic valve actuator (Figure 19).

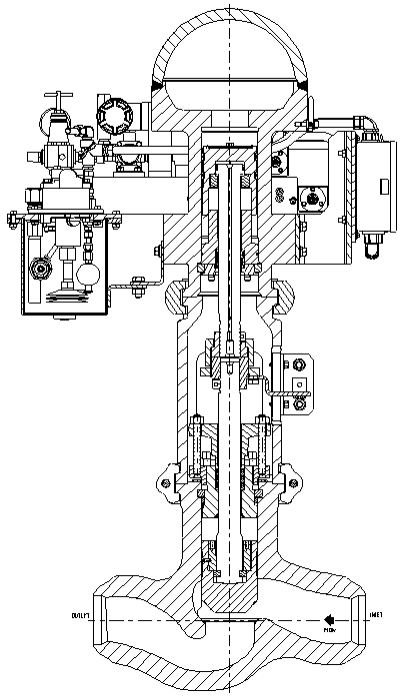


Figure 19: TSV assembly

The TSV is designed to operate normally with flow over the valve seat. During valve closure, flow through the valve assists closing. The valve actuator uses compressed nitrogen as the stored energy source that closes the valve. An integral hydraulic system retracts the actuator (opening the TSV) and simultaneously compresses the nitrogen.

The main piston design incorporates an internal dashpot. The dashpot is provided to control the valve closing speed. During closing, the main piston is accelerated downward in the main cylinder. Part way through the closing stroke, the main piston engages the lower closure to form the dashpot. As the main piston continues to move downward, the resistance to flow out of the dashpot chamber steadily increases. Without the dashpot, the velocity of the impact of the valve main disk onto the valve body seat could result in damage to the seat. The internal dashpot limits the closing speed to an acceptable level.

All of the hydraulic system components are located in manifolds attached to the actuator main cylinder. The manifolds are referred to as the “pump side” and the “non-pump side” manifolds. The hydraulic pump forces high pressure hydraulic fluid into the main cylinder through the pump side manifold. The high-pressure fluid forces the main piston to move upward, retracting the actuator and compressing the nitrogen.

The actuator operates in the “fail closed” configuration. Actuator operation is controlled by hydraulic solenoid valves located on both hydraulic manifolds. All of the solenoid valves must be energized before the actuator can be retracted. If electrical power is lost to the solenoid valves, the actuator will close the TSV (fail closed).

Each hydraulic manifold includes three hydraulic solenoid valves and a pilot pressure-operated dump valve. Two of the solenoid valves (main dump solenoids) control operation of the main dump valve and the third provides a slow close capability for the actuator. When both hydraulic solenoid valves are de-energized, pilot pressure on the main dump valve is relieved,

allowing the main dump valve to open and allow hydraulic fluid to flow from the main cylinder to the hydraulic fluid reservoir through the main dump valve.

Both main dump solenoids on each manifold must be de-energized to allow the main dump valve to open and allow the TSV to close. This prevents inadvertent closure if one solenoid valve should be inadvertently de-energized, for example, due to a failure of the solenoid coil winding.

The third hydraulic solenoid valve provides a slow closing function. When this solenoid valve is energized, hydraulic fluid flow from the main cylinder flows directly to the hydraulic fluid tank through this solenoid valve. (Note that de-energizing both main dump solenoid valves on one manifold will cause the actuator to close the TSV. However, closing time will be greater than 0.3 seconds.)

The actuator design includes pressure transmitters that allow the nitrogen and hydraulic system pressures to be monitored continuously during plant operation. Isolation valves are provided on the actuator manifolds to allow maintenance on the attached peripheral equipment during plant operation without having to close the TSV. The actuator main cylinder uses non-chromium based hard surfacing and environmentally friendly hydraulic fluid.

A second vendor supplied a budgetary offering for a combined control and stop valve solution. The design was technically sound but commercially not competitive.

1.A.vi.a.5.2. Control Valves

Modulating control valves are used to manage control variables and transition the system from one operating state to another. The sizing, pressure and temperature

requirements were determined based on the results of detailed steady-state cycle modeling and optimization and on the control strategy during startup and shutdown. Control valves are summarized in Table 22 (below).

Table 22: Modulating control valves summary. Location (Loc.) relative to the referenced component is either inlet (I) or outlet (O). Line size (LS) is in inches or vendor advised (VA). Actuator (Act.) is either pneumatic (P) or electrohydraulic (EH).

Description						Des. Press. (MPa)	Des. Temp. (°C)
Tag	Function	Component	Loc.	LS	Act.		
PCV-0433	Throttle	PT	I	12	P	27.5	610
PCV-0041	Throttle	LTC-DT	I	6	P	27.5	610
PCV-0042	Throttle	HTC-DT	I	8	P	27.5	610
PCV-3300	Throttle	Inv. return	I	4	P	10.0	300
PCV-0060	Throttle	LTC brgs.	O	2	P	27.5	200
PCV-0022	Throttle	HTC brgs.	O	2	P	27.5	200
PCV-0530	Bypass	PT	I	VA	P	27.5	610
PCV-3200	Bypass	TP	O	2	P	10.0	300
PCV-0024	Bypass	SP	O	2	P	27.5	200
PCV-0020	Bypass	LTC	O	4	EH	27.5	200
PCV-0021	Bypass	HTC	O	4	EH	27.5	200
PCV-0033	Flow Bias	PHX-2	I	4	P	27.5	200

The PT throttle valve (PCV-0433) is expected to be fully open during normal operation and is used during turbine synchronization, which takes place at partial flow and pressure. It is sized large enough to produce minimal pressure drop (approximately 0.14 MPa) during normal operation.

The LTC-DT and HTC-DT throttle valves (PCV-0041 and PCV-0042, respectively) are expected to be at or near the full-open position during normal operation. Full-load throttling would only be employed to trim power to one of the compressors for the purpose of optimizing system efficiency. Each DT throttle valve is used during the startup of its respective turbocompressor as well as for turbocompressor throttling during low-load operation.

The inventory return throttle valve (PCV-3300) is used to control the rate of mass flow returning from the power cycle loop to the storage system. During normal operation, it is fully closed.

The LTC and HTC bearing throttle valves (PCV-0060 and PCV-0022, respectively) provide backpressure for each turbomachine's bearings, controlling the rate of auxiliary bearing flow.

The PT bypass valve (PCV-0530) is used to provide the fine flow control required for turbine synchronization. Flow passes through the bypass during startup until the turbine is synchronized. Synchronization occurs at partial flow, reduced pressure, and reduced temperature compared to normal operation. The PT bypass is sized for full PT flow since it would also open in the event of a TSV closure. The PT bypass valve is required to be rated for 610°C because of its position near the turbine inlet.

The TP bypass (PCV-3200) is used to recirculate flow from the TP back to the storage tank, controlling the rate of flow addition to the power cycle loop.

The SP bypass is expected to be fully closed during normal operation (at which point the SP will not be operating). The SP bypass valve (PCV-0024) is used during startup to keep the SP operating above its minimum continuous stable flow.

The LTC and HTC bypass valves (PCV-0020 and PCV-0021, respectively) are expected to be fully closed under normal operation. They open during startup and shutdown to keep the LTC and HTC at or near their design flow. These valves are equipped with electrohydraulic actuators to provide the rapid response times and fine-tuned flow control required for smooth

turbocompressor operation. The sizing case is emergency shutdown, where each valve may be required to quickly bypass full compressor flow at full pressure.

The PHX-2 flow bias valve (PCV-0033) controls the flow split between the PHX-2 path and the HTR path. It is located on the smaller line (the PHX-2 flow path). During normal operation, it will be in a partially open position, with the ability to further bias the flow rate toward either flow path.

EPS solicited quotes from multiple suppliers and received two firm quotes with acceptable technical and commercial offerings. The turbine throttle and bypass valves (PCV-0433, PCV-0041, PCV-0042, and PCV-0530) required detailed collaboration between EPS and the vendors to identify acceptable solutions for the demanding specifications. The design conditions (27.5 MPa and 610°C) required Class 4500 valves bodies, and the elevated CO_2 temperature precluded the consideration of typical nine-chrome materials (such as F91) due to long-term corrosion concerns [2, 3]. Instead, stainless steel valve bodies have been selected. The specification also targeted a high valve flow coefficient (C_v) for each throttle valve to minimize the full-open pressure drop and corresponding cycle efficiency penalty. EPS relaxed the targeted pressure drop for the PT throttle valve (PCV-0433) from 0.08 MPa (12 psi) to 0.14 MPa (20 psi), since the original specification would have required a larger valve body size.

1.A.vi.a.5.3. Isolation Valves

On/off isolation valves are also used to transition the system from one operating state to another. Two isolation valves are located around the SP (BV-0011 at suction, BV-0012 at discharge) to close the SP flow path during normal operation. Each DT is also equipped with a

small isolation valve (BV-0051 and BV-0052) to bleed a small amount of flow during startup to warm up the area piping. Additional isolation valves are used to isolate inventory control and turbine auxiliary systems.

EPS solicited quotes from multiple suppliers and received two firm quotes with acceptable technical and commercial offerings.

1.A.vi.a.5.4. Check Valves

Check valves prevent backflow of CO_2. During startup, check valves in the LTC discharge line (NRV-0231) and bearing supply line (NRV-0228) prevent backflow into the LTC prior to its operation. Similarly, a check valve in the HTC discharge line (NRV-0211) prevents backflow into the HTC prior to its operation. A check valve in the SP discharge line (NRV-0240) prevents backflow into the SP when the LTC is in operation. Check valves are depicted in Figure 20 (below).

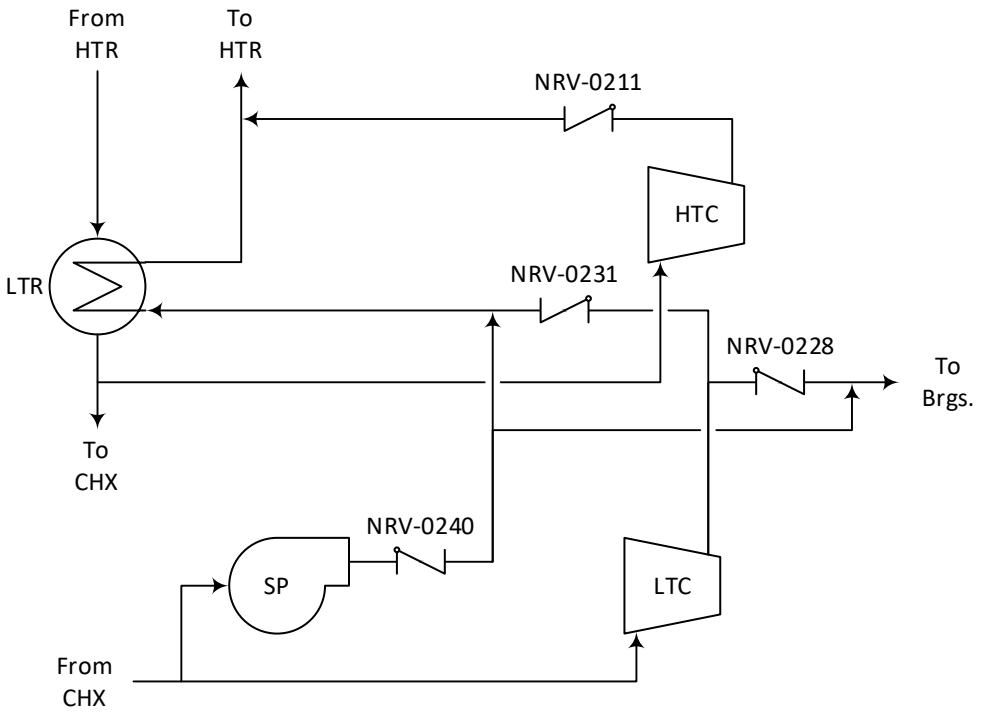


Figure 20: Check valves protecting backflow into the LTC (NRV-0231 and NRV-0228), HTC (NRV-0211), and SP (NRV-0240)

EPS solicited quotes from multiple suppliers and received four firm quotes with acceptable technical and commercial offerings.

1.A.vi.a.5.5. Pressure Relief Valves

Overpressure protection is provided by five mechanical and two electronic relief valves. The mechanical (spring release) relief valves are also referred to as pressure safety valves (PSVs). The electronic (pneumatically controlled) ball valves are also referred to as electronic relief valves (ERVs).

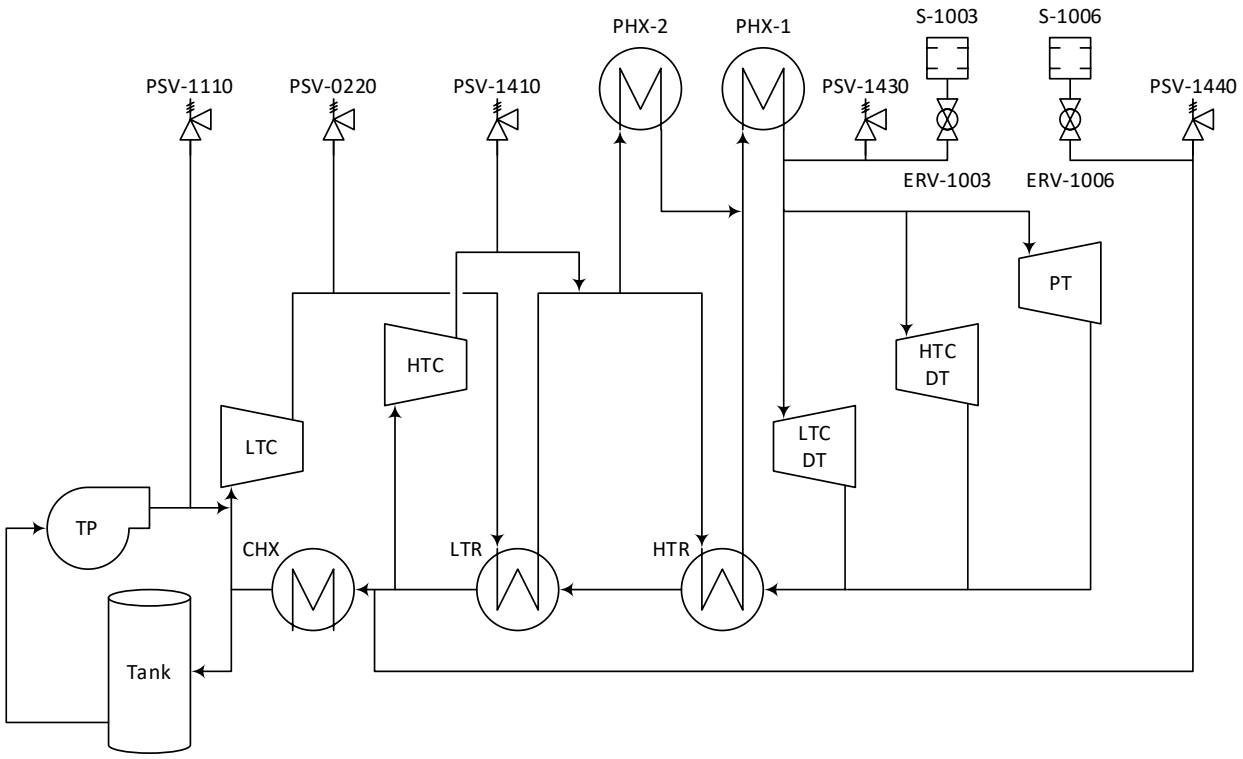


Figure 21: Overpressure protection system, including five PSVs and two ERVs equipped with silencers

The PSVs are designed to meet the requirements of applicable codes and standards, including

- ASME Boiler and Pressure Vessel Code (BPVC) Section VIII (Rules for Construction of Pressure Vessels)
- API 520 (Sizing, Selection, and Installation of Pressure-relieving Devices in Refineries)
- API 521 (Pressure-relieving and Depressuring Systems)

ASME BPVC Section VIII defined overpressure limits and supplier testing requirements. API 521 served as a guideline for selecting applicable relieving cases and determining relieving rates. API 520 B.3.1 provided valve sizing equations (based on isentropic nozzle relations) that were used to size valve orifices.

Four of the PSVs are designed for the API 521 “closed outlets” case: PSV-0220 (at the LTC outlet), PSV-1410 (at the HTC outlet), PSV-1430 (at the PHX outlet), and PSV-1110 (at the TP outlet). (Note that the SP is not capable of exceeding the pipe design pressure.) PSV-1430 is sized for the PT design flow, which could be blocked in the event of a TSV closure and a PT bypass failure to open. The set pressure is 10% above the normal operating pressure. The other three PSVs (PSV-0220, PSV-1410, PSV-1110) are sized for the full design flow of the respective pump or compressor, each with a set pressure matching the local piping design pressure (minimum 10% above the normal operating pressure).

The final PSV is designed for the API 521 “cooling failure” case. In a loss-of-cooling event, the expected density increase across the CHX will not occur. PSV-1440 (at the CHX inlet) is sized to maintain a consistent volume flow leaving the CHX, despite the lower density. The set pressure matches the local piping design pressure (minimum 10% above the normal operating pressure).

Overpressure events resulting in PSV activation are short duration due to the rapid release of CO_2 from the operating loop. Re-seat pressure is expected to be 3-7% below set pressure, depending on the valve, with corresponding lift durations on the order of fifteen seconds or less. The MU CHP does not require silencers for these short-duration vent scenarios.

When liquid CO_2 or dense sCO_2 (with enthalpy close to critical enthalpy) is depressurized below a pressure of approximately five atmospheres (0.5 MPa), the phase changes to solid. As shown in Figure 22, the relief valves at the discharge of the TP (PSV-1110) and LTC (PSV-0220) fall under this condition. To prevent the possibility of solid CO_2 deposition plugging the vent

stacks, the safety system is designed with standoffs (pipes at operating pressure) connecting the main operating loop to PSVs located outdoors at the desired vent elevation.

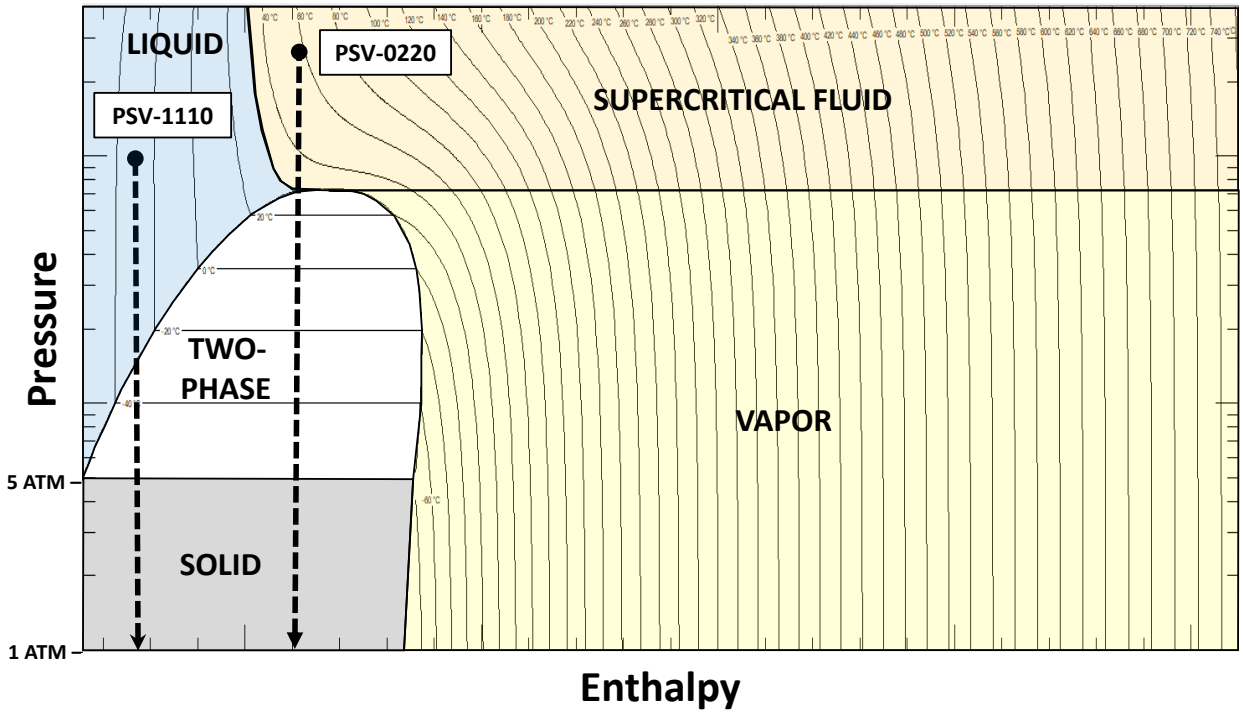


Figure 22: Pressure-enthalpy phase diagram for CO_2, highlighting PSVs which discharge solid-state CO_2 at atmospheric pressure

Standoff pipes are not required for the remaining PSVs (PSV-1410, PSV-1430, PSV-1440), for which CO_2 will be in the vapor state when expanded to atmospheric pressure. However, as shown in Table 23, the required diameter of low-pressure vent pipes (downstream of the PSVs) is significantly greater than the required diameter of high-pressure standoff pipes (upstream of the PSVs), since required area scales with specific volume. Standoffs were used for all PSVs to reduce costs associated with large pipe diameters and simplify the pipe routing and support.

Table 23: Specification comparison for relief piping options: vents (downstream of PSVs) and standoffs (upstream of PSVs). Materials selections are carbon steel (CS), nine-chrome (9C) and nickel alloy (NA).

Description	PSV-1410		PSV-1430		PSV-1440	
	Vent	Standoff	Vent	Standoff	Vent	Standoff
Size	20"	6"	34"	8"	24"	6"
Schedule	10	160	40	160	10	80
Material	CS	CS	9C	NA	CS	CS

To assist in system pressure control, the operating loop is equipped with two ERVs. The ERVs allow for preemptive pressure relief via the control logic. During upset conditions, the brief opening of an ERV provides for a controlled vent of CO_2 prior to activating a PSV (uncontrolled venting).

The ERV on the high-pressure side of the operating loop (ERV-1003) is downstream of the PHX, co-located with PSV-1430. ERV-1003 provides PHX over-temperature protection by automatically opening during emergency shutdown events such as loss of power or loss of cooling. During an emergency shutdown, the LTC and HTC will spool down, eliminating the motive force circulating CO_2 to the PHX. Opening a vent on the PHX discharge line provides continued cooling flow to the PHX while the heat input decays. This scenario was evaluated with detailed transient modeling. (See 1.A.viii.b for a study summary.)

The ERV on the low-pressure side of the operating loop (ERV-1006) is upstream of the CHX, co-located with PSV-1440. The set point for ERV-1006 is 0.69 MPa (100 psi) below the set point of PSV-1440. ERV-1006 is also used to vent low-pressure CO_2 during initial system startup.

At a pressure of one atmosphere (0.1 MPa), CO_2 vapor density is greater than 1.2 kg/m^3 for temperatures below 175°C. (The isenthalpic temperature at operating pressure may be as

high as 240°C.) Thus, some vapor CO_2 vent conditions may not be buoyant in ambient air. The locations of the atmospheric discharge must be determined accordingly. Long-duration vent scenarios were identified and studied using detailed dispersion modeling. (See 1.A.viii.c for a study summary and Appendix II for the full report.) The MU CHP requires silencers for these longer-duration vent scenarios. (See 1.A.vi.a.8.2 for silencer information.)

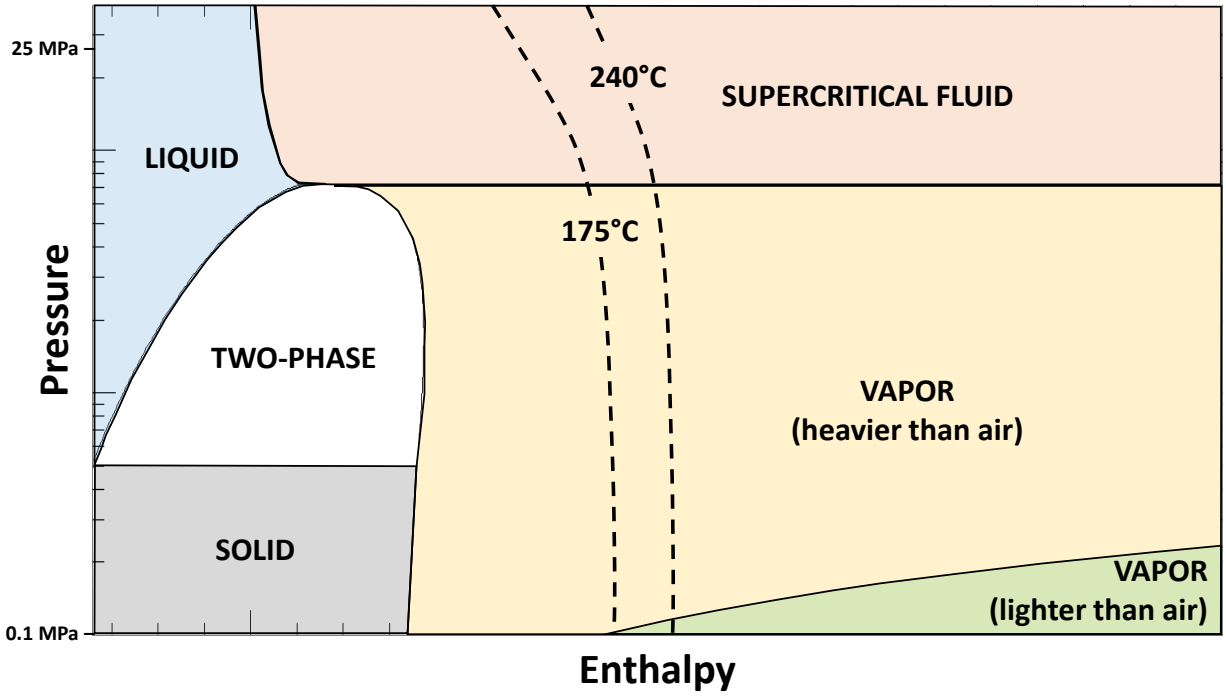


Figure 23: Pressure-enthalpy phase diagram for CO_2, highlighting the density line (1.2 kg/m^3) of ambient air

EPS solicited quotes from multiple suppliers and received two firm quotes with acceptable technical and commercial offerings. However, only one of the two vendors was able to quote the highest temperature valve (PSV-1430).

1.A.vi.a.6. Piping

1.A.vi.a.6.1. Piping

EPS developed specifications for the power cycle piping (Table 24).

Table 24: Piping specification. Piping is marked for high pressure fluid service (HPFS) or normal fluid service (NFS).

Specification	Material	Design Temp.	Design Pressure	Service
9CHP	A335 P91	-20°F (-29°C) 932°F (500°C)	≤ 3975 psig (274 barg)	CO_2 (HPFS)
CSHP	A106 Gr. B	-20°F (-29°C) 392°F (200°C)	≤ 3975 psig (274 barg)	CO_2 (NFS)
CSLP	A106 Gr. B	-20°F (-29°C) 572°F (300°C)	≤ 1436 psig (99 barg)	CO_2 (NFS)
NAHP	B444 Gr. 1 N06625 Annealed	-20°F (-29°C) 1130°F (610°C)	≤ 3975 psig (274 barg)	CO_2 (HPFS)
SSHP	A312 TP316	-20°F (-29°C) 392°F (200°C)	≤ 3975 psig (274 barg)	CO_2 (NFS)
SSLP	A312 TP316	-20°F (-29°C) 1130°F (610°C)	≤ 1436 psig (99 barg)	CO_2 (NFS)
CSPW	A106 Gr. B / A53 Gr. B	0°F (-18°C) 150°F (65°C)	≤ 195 psig (13.4 barg)	Plant Water (NFS)
SSTW	A312 TP304L	-20°F (-29°C) 200°F (93.3°C)	≤ 195 psig (13.4 barg)	Treated Water (NFS)
SSLO	A312 TP304L	-20°F (-29°C) 200°F (93.3°C)	≤ 195 psig (13.4 barg)	Lube Oil (NFS)
SSIA	A312 TP304L	-20°F (-29°C) 200°F (93.3°C)	≤ 195 psig (13.4 barg)	Instrument Air (NFS)

The piping specification was supplied to CDM Smith for use in the BOP bid packages.

1.A.vi.a.6.2. Flanges

Grayloc compact flanges or Grayloc compact hubs are specified for all CO_2 piping connections. Grayloc supplied a firm quote for the specified connections and has supplied equipment to EPS for numerous past projects.

1.A.vi.a.6.3. Piping Insulation

Each pipe was insulated according to one of three categorizations. A “Hot Conservation” specification was applied to high-pressure CO_2 piping. (High pressure heat loss penalizes cycle efficiency.) An “Anti-Sweat” specification was applied to low-pressure CO_2 piping and water piping. (Low pressure heat loss does not penalize cycle efficiency.) A “Personnel Protection” specification was applied to all lube oil piping.

The piping insulation specification was supplied to CDM Smith for use in the BOP bid packages.

1.A.vi.a.7. Skid Assembly

A skid containing the LTC, HTC, SP, and associated valves and piping (Figure 24) will be fabricated and delivered to the construction site. EPS worked with the fabricator of the EPS100 skids to obtain a firm quote for the skid fabrication and assembly.

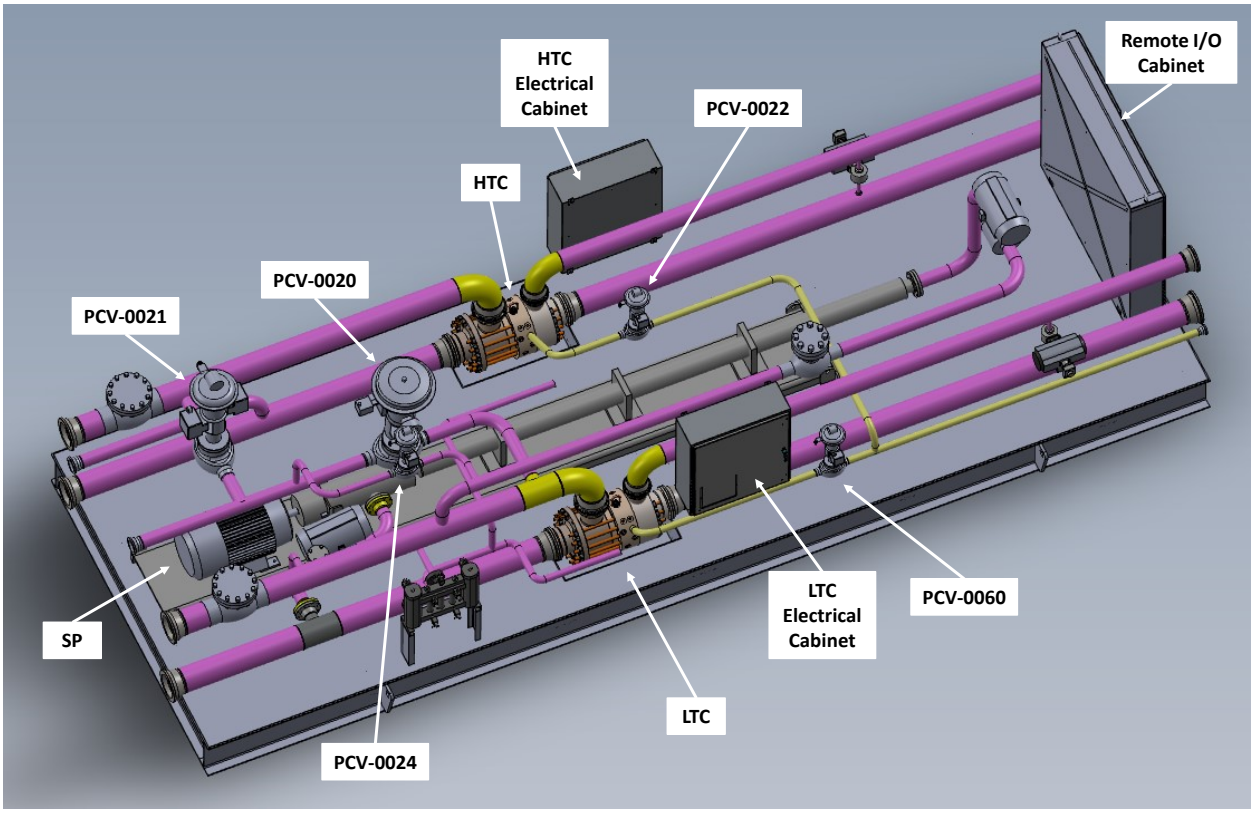


Figure 24: Process skid equipment (including LTC, HTC, SP, and associated valves and piping)

1.A.vi.a.8. Sound Protection

1.A.vi.a.8.1. Sound Enclosures

Sound enclosures are provided for the process skid and the power train to limit the sound level to 85 dB(A) at 3 ft. Each enclosure is ventilated with an induced draft fan discharging to the outdoors. EPS solicited and received a firm quote for the sound enclosures from one supplier.

1.A.vi.a.8.2. Vent Silencers

The MU CHP requires silencers for long-duration vents. A silencer was specified for each ERV to limit the sound level to 90 dB(A) at 3 ft. EPS solicited quotes from multiple suppliers and received two firm quotes with acceptable technical and commercial offerings.

1.A.vi.a.9. Auxiliary Flow Supply and Conditioning

1.A.vi.a.9.1. Lube Oil System

The gearbox and the generator are each oil-lubricated. EPS solicited quotes from multiple suppliers and received three firm quotes with acceptable technical and commercial offerings.

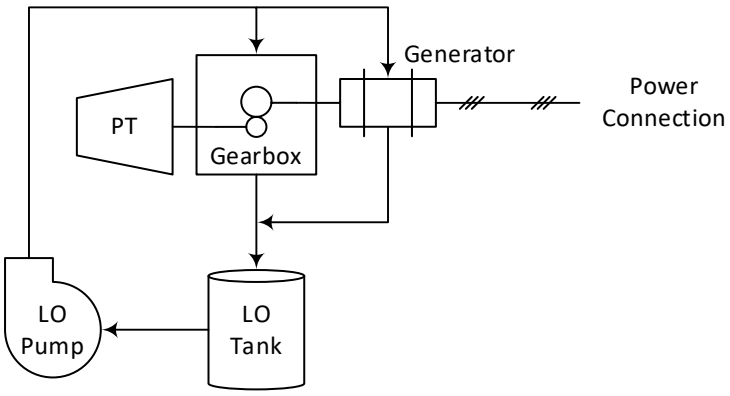


Figure 25: Power train lube oil supply

1.A.vi.a.9.2. Filters

The main operating loop includes two CO_2 filters. The main process filter has a requirement of 250 µm and is located between the CHX and the LTC. The second filter is located in the supply line for the turbocompressor bearing flow. Its filtration requirement is 10 µm (nominal) and 25 µm (absolute). It was decided to make both filters duplex with double-

block-and-bleed valving so that they could be replaced (if necessary) between normal maintenance shutdowns. EPS solicited quotes from multiple suppliers and received two firm quotes with acceptable technical and commercial offerings.

1.A.vi.a.9.3. Seal Gas Conditioning

The seal gas conditioning system regulates the pressure and temperature of CO_2 supplied to the PT seals. The seal gas conditioning unit supplies 150-250 g/s of filtered, conditioned CO_2 as dry gas seal flow (flow B in Figure 26). This corresponds to a pressure differential of 10-20 psid (0.07-0.14 MPa) between cavities D and E. The unit also supplies 1-2 g/s of filtered, conditioned CO_2 as buffer flow (flow C). This corresponds to a pressure differential of 3-7 psid (0.02-0.05 MPa) between cavities G and F. The temperature of flows B and C is 80-100°C. The filtration requirement is 1 µm (nominal) and 3 µm (absolute). Approximately 0.8 g/s of CO_2 is lost to the atmosphere, while approximately 4.5 g/s is recovered (flow H), recompressed, and returned to the inventory.

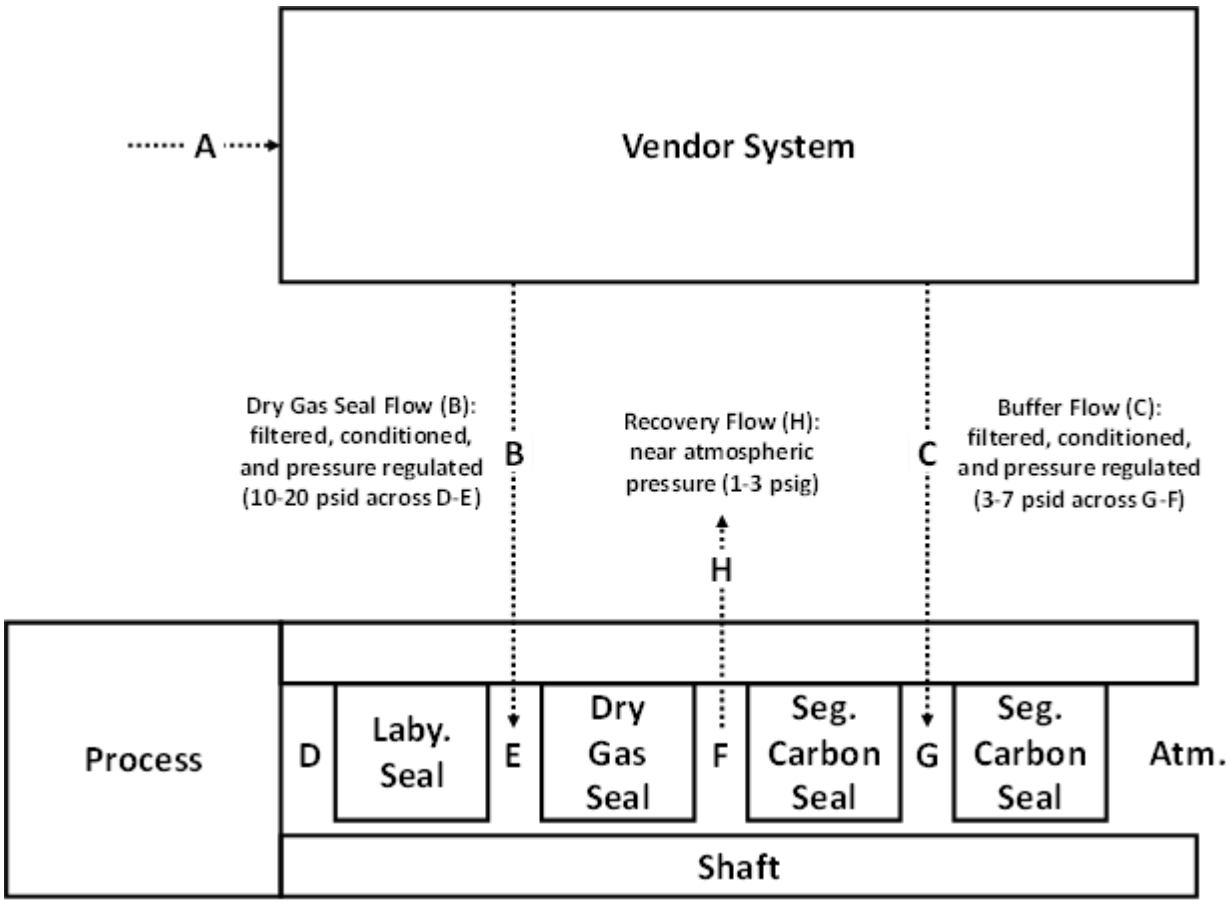


Figure 26: Dry gas seal arrangement. The seal conditioning system (vendor system) receives its supply (flow A) from the LTC discharge. A seal gas return line (flow H) discharges to a seal gas recovery compressor.

1.A.vi.a.10. Startup Systems

1.A.vi.a.10.1. Start Pump

The SP is a horizontal surface-style multistage centrifugal pump. It is long and narrow due to the number of pump stages (approximately twenty anticipated). The SP is used to circulate CO_2 to the fired heater during initial heat addition. Additionally, the SP supplies the minimum flow to the LTC-DT required to start up the LTC and to supply the LTC bearing flow. The SP is powered down after the LTC achieves stable operation.

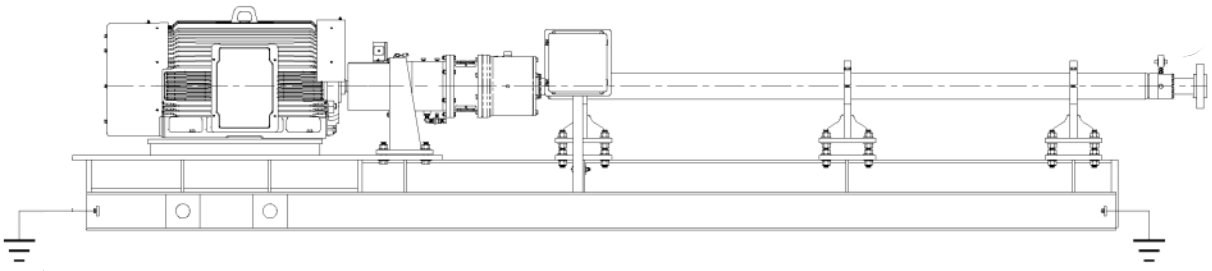


Figure 27: A horizontal surface pump (technology selected for the SP)

Startup procedures were evaluated with detailed transient modeling. (See 1.A.viii.b for a study summary.)

1.A.vi.a.11. Control System

The control system monitors, controls, and provides safety protection for the pilot plant. It manages the startup, shutdown, and steady state operation and performs emergency protection in the event of an unforeseen failure. By leveraging the various products offered by the control system vendor, the control system will also be one of the layers of protection for over speed, over pressure, and PHX flow supply as well as generator control, synchronization, and protection.

The control system performs all data acquisition, historical data collection, control functions, and protection logic for the pilot plant, including the turbomachinery and generator. It is based on the Allen-Bradley family of products—implemented in a distributed I/O architecture—and leverages the integration between their various product lines. The system is designed with redundancy to provide the highest level of system reliability. At the core of the control system are two Control Logix processors configured as a redundant pair. The control

system network utilizes Ethernet TCP/IP with embedded switch support. Condition monitoring for the turbo machinery also utilizes Ethernet connections.

The control system interfaces to field devices using two different I/O product lines: Flex 5000 I/O and Dynamix I/O. Flex 5000 I/O connects to analog field transmitters and actuators using 4-20 mA loops (powered from the control cabinet). Discrete devices use 24 Vdc sourced from the control system cabinet. Dynamix I/O is used for high-speed turbomachinery monitoring and uses API-approved signal conditioning, typically 24 Vdc or -24 Vdc sourced from the control system cabinet. Each I/O location will include 30% implemented spares to accommodate future expansion.

Field transmitters and actuators utilize the Highway Addressable Remote Transducer (HART) protocol where possible to reduce calibration, maintenance and troubleshooting at the plant site. The Flex 5000 analog input cards are HART compatible, therefore transmitters can be re-ranged from within the control room rather than an instrument technician being dispatched to the actual transmitter location.

Automatic generator control, synchronization and protection is performed by a combination of Rockwell Automation products, Schweitzer (SEL) 700G Generator Protection Relay and a Basler 205D Excitation Unit. These devices interface to the generator's Permanent Magnet Generator (PMG) and exciter and is an integral part of the control system and control network. Utilizing these products will allow for voltage, frequency, power factor, and exciter control directly from the control system program without the need to interface through specialized standalone controllers.

Although the control system for the pilot plant can operate in a standalone configuration, it is designed to integrate with the customer's Distributed Control System (DCS) using a wide range of protocols and media. Interfaces include Allen-Bradley ECIP, DAS, Device Net, OPC Master / Slave, Modbus RTU / ASCII, and Ethernet TCP/IP.

The Human-Machine Interface (HMI) uses a combination of Wonderware and Rockwell Automation's Factory Talk to allow the operator to interact, monitor and perform diagnostics on the pilot plant system from the control room or at the field level. Data shared at this information network level is via Ethernet TCP/IP and RSLinx Enterprise between the HMIs and the Control Logix processors. Programming and configuration of the Control Logix processors is performed using RSLogix 5000. The processors receive and send their data to field sensors, transmitters and actuators via the control system network which is Ethernet-based with a 10 ms update time. The control system network shall meet the ODVA specification and support the Quality of Service (QoS) and Internet Group Management Protocol (IGMP) protocols. Critical subsystems such as the MCC, condition monitoring of the turbomachinery, and generator monitoring and synchronization all communicate to the controllers via the control system network. Some of the subsystems, the MCC, Power Electronics and condition monitoring (Dynamix I/O) communicate internally between their various sub-components using either Ethernet or DeviceNet.

Historical data collection and extensive remote monitoring and control will be provided for data logging and troubleshooting. Historical data collection is facilitated by Wonderware with an interface to Rockwell Automation's PLC Processors which allows for direct access to

control system tags. Provisions for remote monitoring and control extending beyond the rudimentary level is being provided using a network secure hardware and software solution that currently meets NERC and ISA 99 / IEC 62443 requirements for control system network protection.

In order to meet current trends in Safety Instrumented Systems (SIS) and increase the Safety Integrity Level (SIL) of the control system, an emphasis has been placed on redundancy and diagnostic monitoring of the components and subsystems of the control system. Processors, HMI servers, power supplies, communication networks and their components, and critical control instrumentation are all redundant and monitored. Other factors that increase the system availability and reliability such as control system cabinet environmental control and cabinet temperature are monitored. Control system cabinets will all be secured with a locked NEMA 4X cabinet. A double conversion Uninterruptable Power Supply (UPS) with a 15-minute battery backup will supply power to all control system cabinets and instrumentation power.

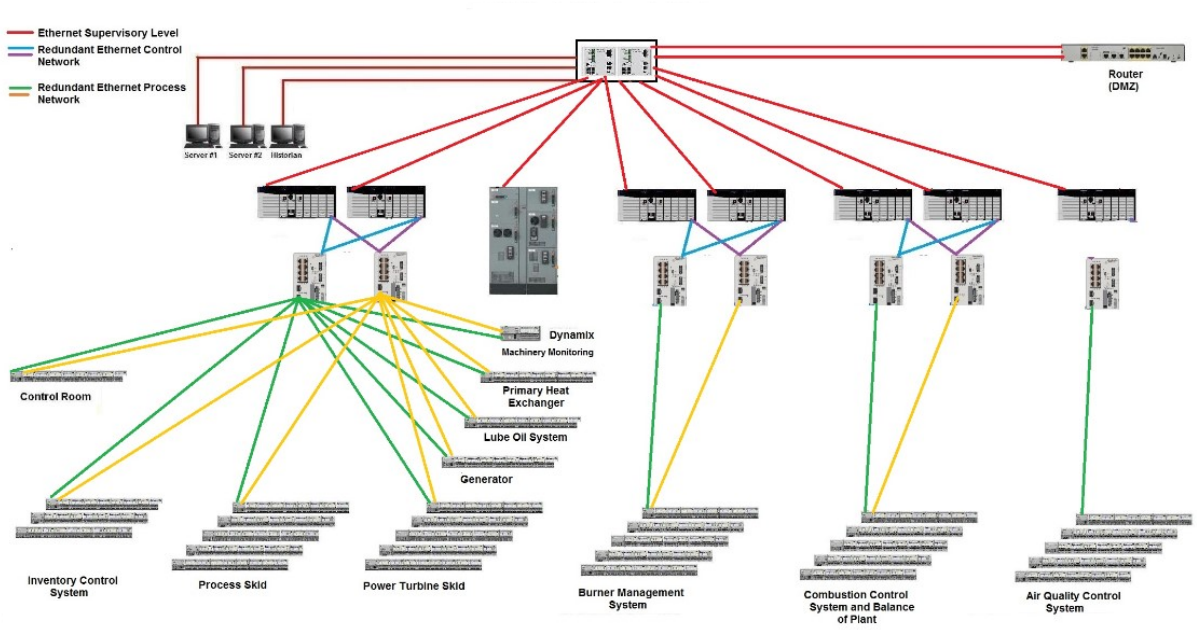


Figure 28: Pilot plant control system architecture

1.A.vi.a.12. Instrumentation

1.A.vi.a.12.1. Requirements

Instrumentation provides conversion of physical properties (pressure, temperature, flow, vibration, etc.) to electrical signals that are measured and recorded in a data acquisition and control system.

ASTM Performance Test Codes (PTC) are followed for instrumentation selection and installation guidelines, including:

- PTC 19.1 (Test Uncertainty)
- PTC 19.2 (Pressure Measurement Instruments and Apparatus)
- PTC 19.3 (Temperature Measurement Instruments and Apparatus)
- PTC 19.5 (Flow Measurement)

- PTC 19.22 (Data Acquisition Systems)

For measurements of pressure, temperature, and flow, three classifications of instrumentation are considered: Class A, Class B, and Class C. Instrumentation classification is noted in the instrumentation database.

Class A instrumentation is used for evaluation of component and system performance. The accuracy required is calculated on the basis of a performance uncertainty analysis, with consideration of the state of the art in instrumentation accuracy availability. For temperature measurements, this classification requires individual calibration of the sensor and transmitter to NIST-traceable standards. Standard pressure transmitter accuracy from the preferred supplier is sufficient to meet the required performance accuracy. The flow meters for this classification are orifice plate flow meters.

Class B instruments are used to monitor and control the power cycle and auxiliary equipment (note that Class A instruments can also be used in this service) but are not used to evaluate component or system performance. Standard supplier accuracy is adequate for this service.

Class C instruments are used to monitor and control non-critical auxiliary systems, such as auxiliary cooling systems, load bank temperatures, etc.

EPS received a quotation from their preferred instrumentation supplier of per-unit pricing for each type of sensor.

1.A.vi.a.12.2. Temperature

Class A measurements up to 600°C are conducted with IEC 751 Class A quality RTDs, with custom Callendar-Van Dusen (CVD) constants determined based on a 5-point temperature calibration with matched sensor/transmitter sets (e.g., Rosemount Series 78 RTD matched to a 3144 transmitter with the V3 option).

Class B measurements are conducted with the same RTDs as Class A measurements, but without the added cost of custom CVD constants.

Class C measurements are conducted with IEC 751 Class B RTDs.

1.A.vi.a.12.3. Pressure

Class A and Class B both use high-accuracy industrial strain gage pressure integrated sensor/transmitters from Rosemount (3051 Series and 2051 Series, respectively). The standard accuracy for these transmitters is ±0.04% and ±0.05% of span, respectively, with NIST-traceable calibration certificate provided.

1.A.vi.a.12.4. Flow

Class A and B flow transmitters for this project are orifice plate flow meters, calibrated with an accuracy of ±1.0%.

Class C flow transmitters are for approximate measurement of flows such as lubrication oil, in which precise measurement is not required. Acceptable flow meter types include turbine, paddlewheel, and similar devices. Accuracy is typically in the ±2-5% range.

1.A.vi.a.12.5. Vibration

Vibration measurements are conducted with piezoelectric transducers typically supplied with the rotating equipment. Integrated signal conditioning/amplifier modules are used to translate the raw signal to an overall RMS value. In addition, a dedicated high speed data acquisition system will be used to collect and store the raw signals.

1.A.vi.a.12.6. Displacement

Shaft displacement measurements are conducted with eddy current or similar transducers typically supplied with the rotating equipment. Integrated signal conditioning/amplifier modules are used to translate the raw signal to an overall RMS value. In addition, a dedicated high speed data acquisition system will be used to collect and store the raw signals.

1.A.vi.a.12.7. Speed

Shaft speed measurements are conducted with eddy current, magnetic pickup or similar transducers typically supplied with the rotating equipment. Integrated signal conditioning/amplifier modules are used to translate the raw signal to a shaft speed value. In addition, a dedicated high speed data acquisition system will be used to collect and store the raw signals.

1.A.vi.a.12.8. Electrical Power

Generator electrical power will be measured by a utility grade electrical power revenue meter (Ametek JEMSTAR or equivalent), with a rated accuracy of at least 0.07%. Generator

efficiency will be measured continuously by IEEE 115-2009 Method 1 (Segregated Losses, Section 4.6), with losses evaluated by the Heat Transfer method (Section 4.5). Note that this method requires a TEWAC or similar generator, which is consistent with that proposed for this program.

1.A.vi.b. sCO_2 Heating and Air Quality Control Systems Design

The sCO_2 power cycle will be demonstrated using an sCO_2 heating system developed by RPI for the pilot project. A stoker-fired combustor generates the hot flue gas, furnace and convective sections transfer heat to the sCO_2 working fluid, and a tubular air heater transfers heat to under-grate air and overfire air. The design was developed for fuel flexibility, firing coal during the demonstration project and allowing for fuel flexibility in future operation with biomass or natural gas. The AQCS include in-furnace combustion NO_x control using overfire air and an external SCR. SO_2 is controlled using a CDS that includes a PJFF for particulate control. A schematic of the heater system and control equipment is shown in Figure 29. The heater system components are described in 1.A.vi.b.1 through 1.A.vi.b.3. Descriptions of the NO_x control, SO_2 scrubber and particulate removal equipment are included in 1.A.vi.b.4 and 1.A.vi.b.5. Auxiliary equipment, including fans, sootblowers, lime and reagent systems are summarized in 1.A.vi.b.6.

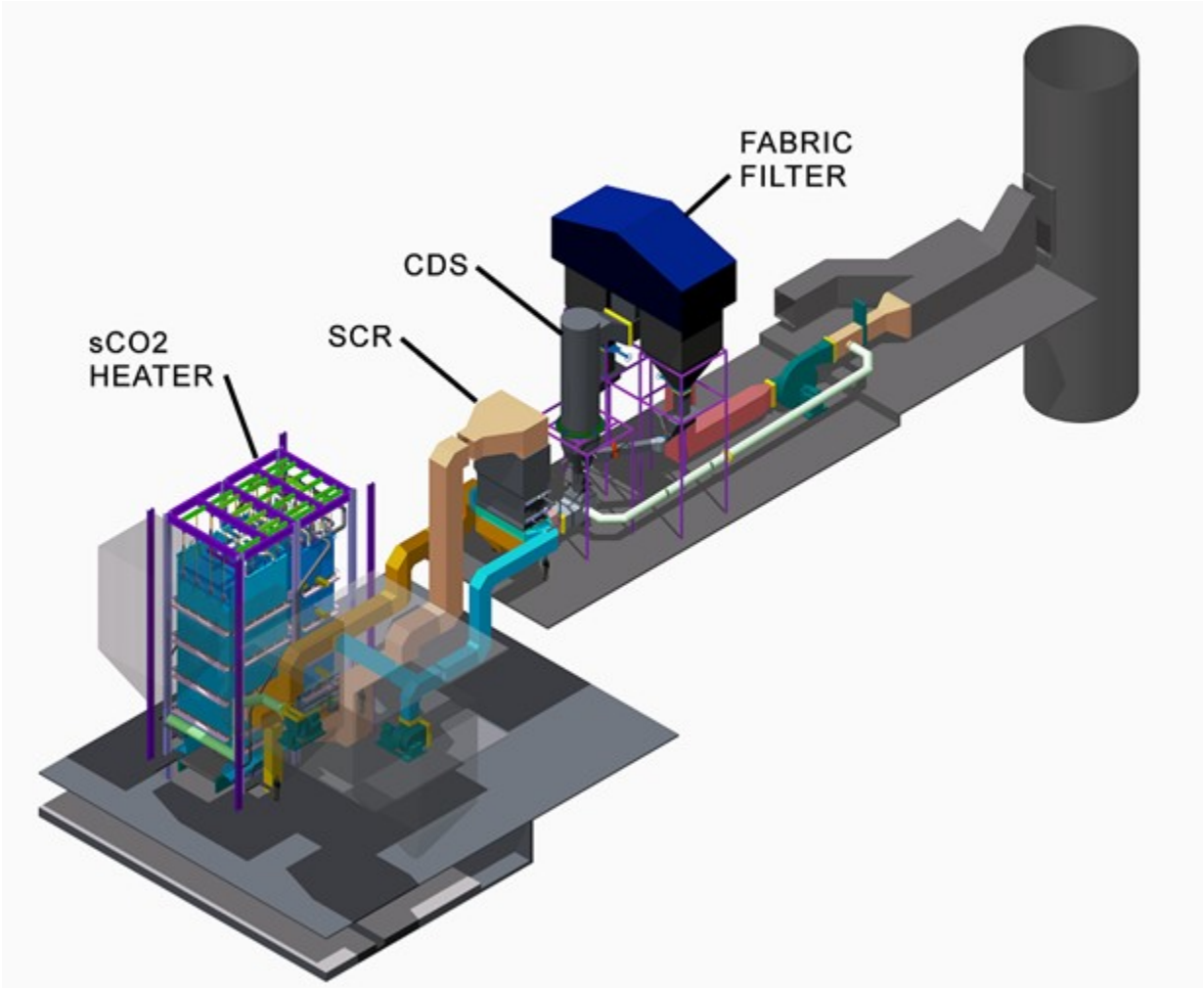


Figure 29: Arrangement of the sCO_2 fired heater system and AQCS equipment

1.A.vi.b.1. Fuel Systems

1.A.vi.b.1.1. Stoker Fired Combustor

The demonstration plant design was developed using a stoker firing system to align with the operating experience of the MU CHP staff. The stoker is a traveling grate design that is cooled by combustion air flow through the grate. An over-fire air system assists with complete burnout and CO reduction. This stoker system is designed to be capable of burning both coal and biomass, providing fuel flexibility for long-term operation of the unit.

1.A.vi.b.1.2. Natural Gas Burners

Wall-mounted natural gas burners provide a secondary firing system. The burners are sized to allow for 100% natural gas operation. The burners will also be used in co-firing applications, providing a rapid-response heat input control and allowing the unit to maintain the target fluid outlet temperature.

1.A.vi.b.1.3. Combustion Air Systems

Both firing systems share combustion air equipment, and the unit will be able to co-fire any combination of fuels. Combustion air is provided by a single FD fan. Ambient air is taken through the air preheater, after which a set of dampers will control the flow and pressure to the windbox for the natural gas burners, the grate for undergrate air, and the overfire air fan inlet. The overfire air fan will take the heated air, boost the pressure, and provide this flow to the overfire air headers for injection into the furnace.

1.A.vi.b.2. Primary Heat Exchanger

The CO_2 heater design considers overall efficiency, metal temperatures, existing space requirements for installation, mechanical interaction of equipment, and fabrication of the elements and tubing.

1.A.vi.b.2.1. Heater Efficiency

One of the driving factors of sCO_2 technology development is improving the overall efficiency of future plants. Efficiency of the CO_2 heater plays a large role in overall plant efficiency and is determined by several factors. The main goal of efficiency optimization is

reducing heat losses, where the largest loss is the energy in the flue gas at the heater exit. Other losses include radiant heat loss to the environment, moisture loss from hydrogen combustion, and ash loss. Reducing the flue gas exit temperature is the most effective means of increasing unit efficiency.

Gas exit temperatures are primarily limited by the cold fluid temperatures available. The relationship between the fluid temperature and the gas temperature is called an approach temperature. In RPI's design experience, typical heat transfer surfaces have an approach temperature of approximately 55°C. For a counterflow element, this approach temperature is the difference between the coldest fluid at the fluid inlet and the coldest flue gas at the gas outlet. Attempting to reduce this further provides diminishing returns, as the amount of material required for additional heat transfer increases non-linearly with the heat recovered.

This 55°C approach temperature indicates that having the coldest fluid at the outlet of the heater's flue gas path results in the highest overall heater efficiency. In a traditional steam system, this is accomplished by adding an economizer element at the heater flue gas exit. The CO_2 system designed for this pilot has a similar economizer fluid flow. This flow is selected to achieve a flue gas outlet temperature comparable to a traditional steam unit and to achieve a similar efficiency in the heater. For this application, the flue gas temperature is reduced from 525°C at the primary circuit outlet down to approximately 250°C at the economizer outlet. This economizer accounts for approximately 17% of the total duty added to the CO_2.

Additional efficiency can be gained by adding an air preheater to the unit. This system recovers waste heat into the combustion air, reducing fuel firing rate. For a coal-fired stoker

system, this air preheat temperature is limited by the ash softening temperature of the fuel. For this unit, the maximum combustion air temperature is 120°C, based on the provided design fuel analysis. With a combustion air mass flow based on 30% excess air, this system further reduces the flue gas temperature to approximately 175°C.

Considering the above constraints, the unit achieves a CO_2 heater efficiency of 84.3%, with a heat input of approximately 32 MW_{th}.

1.A.vi.b.2.2. Heater Design and Surface Layout

As a pilot-scale plant, one of the goals of the design is to develop a configuration that may scale up to achieve greater duties in future applications. This unit has been designed with a similar overall layout to a traditional utility-scale steam boiler. A rectangular furnace composed of tube and membrane walls sits above the stoker, and a tube- and membrane-walled convective pass provides space for serpentine tube elements in the convective zone. This design can scale to achieve a wide variety of fluid flows and overall heater duties, while keeping the general design principles intact.

To achieve maximum efficiency, the coldest fluids are used at the flue gas outlet. Fluid flows through the convective elements counter to the flue gas before being mixed through pipes and headers and sent to the furnace. The fluid flows up through the furnace walls and down the convective walls before achieving final temperature and leaving the system.

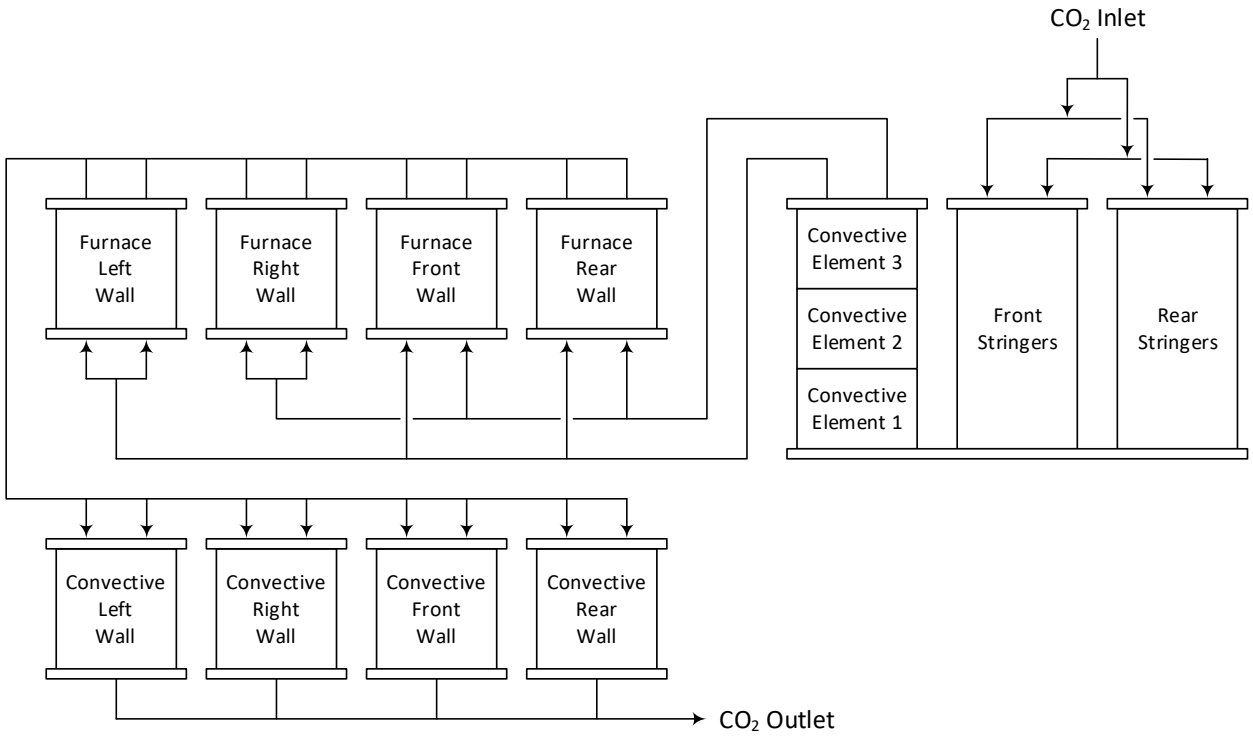


Figure 30: CO_2 flow path through PHX-1

The economizer surface (PHX-2) is split, with a hot economizer inside the convective pass of the heater, and a cold economizer external to the main heater unit. This allows for flue gas temperature control entering the SCR, where the catalysts can be operated at ideal conditions. Temperature control is achieved by individual fluid bypasses on each of the economizer modules. To minimize the number of tubes required and the space consumed, both economizer elements are finned-tube surfaces.

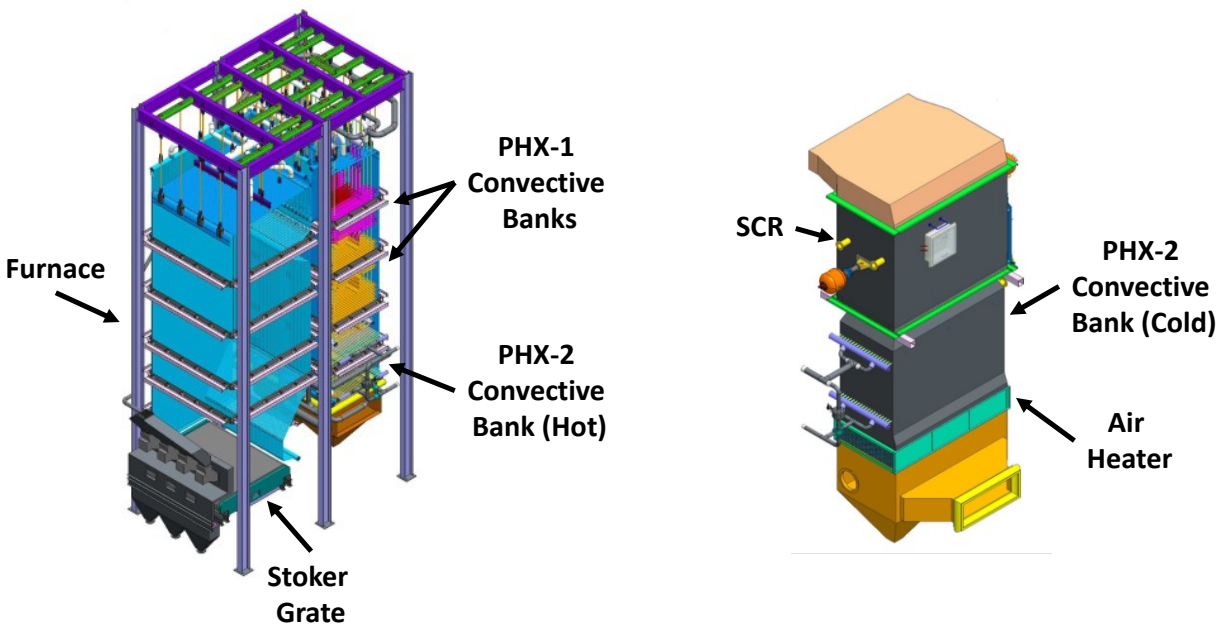


Figure 31: CO_2 surface arrangement

Final CO_2 temperature control is achieved via heat input control similar to a process fired heater and atypical to a traditional fired steam generator. CO_2 attemperation is not effective since it lacks the latent heat available with water/steam attemperation. The volume of CO_2 required to provide a sufficient temperature control range means a substantial portion of the CO_2 flow would bypass the heater for attemperation. Firing 10% natural gas will provide sufficient heat input control with reasonable response time to maintain CO_2 outlet temperatures within the acceptable range.

1.A.vi.b.2.3. Tube Materials

Fluid temperatures and furnace fluxes result in a peak mid-wall metal temperature of approximately 665°C. Considering the high design pressure of this unit, this requires advanced

materials for the furnace tubing. The unit is designed with Super304 furnace tubes, providing adequate margin for fluid temperature and radiant flux variation within the walls.

The convective walls and coils are also designed with Super304 materials, allowing for minimal material changes and ensuring that mechanical properties such as thermal expansion are similar throughout the unit.

Due to the lower fluid temperatures, the economizer elements are composed of carbon steel in the cold economizer, and SA213-T22 in the hot economizer.

1.A.vi.b.3. Air Preheater

The CO_2 heater will be equipped with a tubular air preheater. This system will be designed to achieve a maximum combustion air temperature of 120°C for 100% coal firing. For off-design loads, the air temperature can be controlled by an air bypass around the air preheater.

1.A.vi.b.4. NOx Control System

1.A.vi.b.4.1. Process Description

NO_x is a gaseous mixture of nitric oxides that consists of approximately 95% nitric oxide (NO) and 5% nitrogen dioxide (NO_2). The SCR process converts the NO_x contained in the flue gas into nitrogen (N_2) and water (H_2O) with the use of ammonia (NH_3) as the reduction agent.

To achieve sufficient reaction rate at temperatures available at the sCO_2 heater outlet (between approximately 280°C and 425°C) specially formulated catalysts are required. Before the flue gas enters the SCR catalyst, ammonia is added and mixed in such a way that a near-

homogeneous distribution of ammonia and NO_x in the flue gas is achieved. In addition, the fly ash concentration, gas temperature, and gas velocity are also made uniform within the required ranges at the catalyst face for high removal efficiency and long catalyst life. The flue gas then flows through the catalyst, in which the NO_x is reduced using the ammonia.

1.A.vi.b.4.2. System Configuration

The SCR reactor design for the sCO_2 large scale pilot plant currently includes a single-layer catalyst reactor design to meet the performance and arrangement requirements without utilizing a spare layer. Provisions are also made in the catalyst design for removable test samples of catalyst material that can be used to monitor and predict catalyst activity during the catalyst life. This arrangement was selected to minimize maintenance and initial capital costs, fit within the arrangement constraints, and meet the emissions requirements.

If a second layer is determined to be beneficial for catalyst management (e.g., replacing one layer at a time for extended catalyst life) or for reducing ammonia slip to lower levels, the reactor height can be increased. The projected fired heater CO emission will be within permit limits without further treatment. However, if required due to higher fired heater emissions, the reactor can also be designed to accommodate CO catalyst or combined CO/NO_x catalyst.

The ductwork and the exterior of the reactor is carbon steel. The ammonia injection location and the SCR reactor are located upstream of the cold economizer and downstream of the hot economizer. After ammonia injection and before the SCR reactor, mixers are installed to ensure uniform temperature, velocity, NO_x, and ammonia distribution in the flue gas entering the catalyst.

Once the flue gas is homogeneously distributed over the reactor cross-sectional area and passes through the catalyst face, the flue gas exits the reactor and passes through the cold economizer and the air heater, and then onto the CDS system.

The SCR reactor is fitted with removable door sections which are used to load and unload catalyst from the reactor. These door sections are bolted in place to prevent leakage of flue gas or infiltration of air into the reactor.

Instrumentation is installed throughout the SCR system. The temperature measurement connections at the SCR inlet and outlet are used to monitor the temperature of the catalyst and reactor steel structure during start-up and operation. The catalyst ash sweeper cleaning system on the reactor provides the required cleaning of the catalyst during normal operation. Inlet and outlet flue gas pressure transmitters are provided across the SCR reactor to continually measure and record SCR pressure loss. NO_x measurement instruments are installed at the stack to monitor emissions and control the ammonia injected into the reactor.

1.A.vi.b.4.3. SCR Catalyst

The catalyst's ability to promote the conversion of NO_x into elemental nitrogen and water vapor deactivates over time and depends on flue gas composition. As the catalyst deactivates, the catalyst will have to be replaced.

The base design for the sCO_2 pilot plant includes only a single layer of catalyst. Preliminary evaluation from catalyst suppliers indicates that the necessary NO_x reduction can be achieved with a single layer of catalyst by allowing somewhat higher ammonia slip than the 2 ppm that would typically be specified for a utility boiler at full load.

A utility boiler typically sees a significant reduction in temperature at the SCR over its load range, and as temperature decreases, NO_x removal efficiency decreases and slip increases. In the sCO_2 plant, a split economizer design will be used to maintain the temperature at the SCR at a relatively constant, high temperature over the full load range, reducing the potential for slip as load falls, as well as reducing the potential for ammonia salt formation. The cold economizer downstream of the SCR utilizes finned tubes, but metal temperatures in the economizer are high enough to avoid fouling due to ammonium salts or acid. In the air preheater, bare tubes (as opposed to finned tubes or closely spaced plates in a typical utility regenerative air heater) are used to minimize fouling. These features will allow higher slip levels without operational impacts.

1.A.vi.b.4.4. Ash Sweeper System

Ash sweepers are used to clean the particulate buildup on the catalyst surface in the SCR reactor. Ash sweepers use a nozzle to direct a blast of compressed air horizontally over the catalyst screen. The resultant surge of air dislodges particles and allows the flue gas flow to take them out of the system. The SCR is equipped with two ash sweepers.

Each ash sweeper is equipped with an in-line solenoid operated valve that controls the air supply to each sweeper. A pressure transmitter is installed in the common air header to the SCR reactor. To isolate an individual ash sweeper from the SCR reactor, an isolation thermal safety shield is installed between the ash sweeper and the SCR reactor.

1.A.vi.b.4.5. Aqueous Ammonia System

The ammonia system is a direct injection system. The aqueous ammonia (19% by weight) system consists of the following subsystems: ammonia truck unloading, ammonia storage, ammonia pumps, ammonia injection, atomizing air, and protection air systems. The ammonia pump, ammonia and air flow meters and piping, and injection lance for the sCO_2 system will be provided. Other supporting systems are already present at the MU CHP. These include the ammonia tank, truck unloading, and compressed air supply systems.

1.A.vi.b.5. SO_2 and Particulate Control Systems

1.A.vi.b.5.1. Process Description

A CDS removes the acid gas constituents of flue gas, primarily SO_2, but also SO_3, HCl, and HF by reacting the acid gases with hydrated lime, $Ca(OH)_2$. The CDS system also removes a high percentage of mercury in the flue gas.

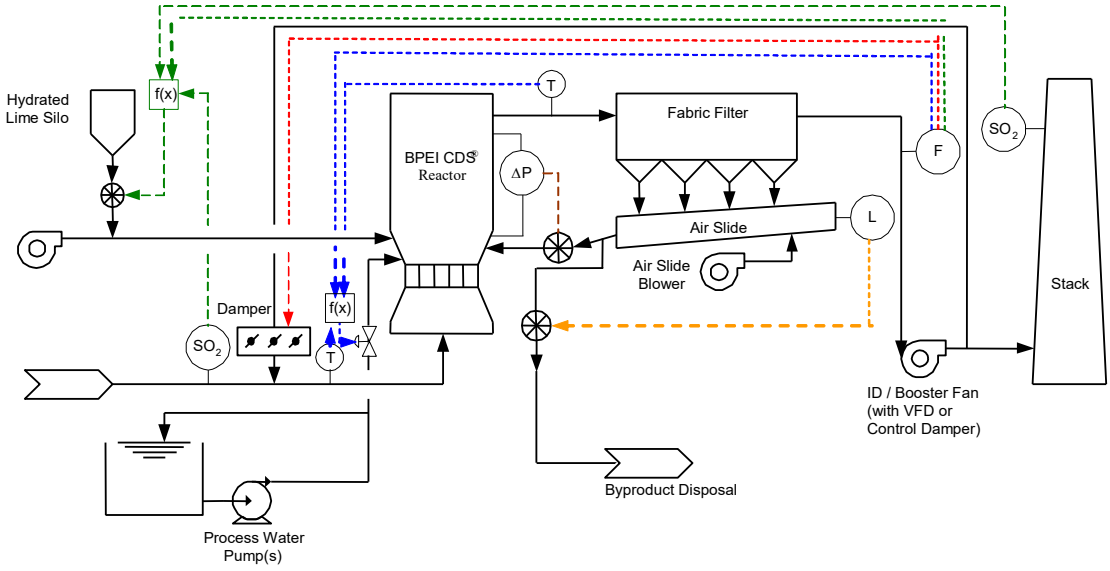


Figure 32: Overview of typical circulating dry scrubber and fabric filter system

The system includes a CDS reactor where hydrated lime and water are injected. The injected water brings the flue gas closer to the saturation temperature, where SO_2 absorption is most effective. The solid CDS byproduct—which is a mixture of fly ash, unreacted lime, and $CaSO_3$, $CaSO_4$, $CaCO_3$, $CaCl_2$, and CaF_2—exits the reactor and is removed from the flue gas with a fabric filter. The byproduct removed by the fabric filter is cycled back to the reactor at a high rate through air slides. The byproduct circulation flow establishes a fluidized bed in the CDS reactor. The fluidized bed provides a high contact time for the byproduct with the flue gas to minimize unreacted lime in the system.

The fabric filter removes the byproduct to meet the particulate emission requirement as the flue gas exits the stack. The clean flue gas from the CDS system is directed to the stack through the ID fan. The CDS system pressure is negative due to the ID fan. The system includes a duct from the positive discharge of the ID fan to the negative pressure inlet of the CDS. When the sCO_2 heater operates at low load, a damper in the duct opens to recirculate enough flue gas to maintain a minimum flue gas velocity required for the fluidized bed in the CDS reactor.

1.A.vi.b.5.2. System Configuration

The CDS system includes a reactor followed by a PJFF system which is downstream of the SCR, the cold economizer, and the air heater. Untreated flue gas reaches the CDS reactor and undergoes the scrubbing process as described in 1.A.vi.b.5.1. Clean, treated flue gas continues to an ID fan and discharges to the stack. A duct from the discharge of the ID fan provides flue gas recirculation to the inlet duct upstream of the CDS reactor at low loads. The

inlet ducts are designed to minimize the velocity distribution into the reactor to keep the fly ash suspended and to minimize pressure drop.

The CDS reactor includes a venturi upstream of hydrated lime and water injection which is critical to the process. The flue gas enters the bottom of the reactor and the venturi increases the velocity of the flue gas, which entrains the injected hydrated lime and water in the flue gas and promotes mixing and absorption of the acid gases. The CDS reactor and venturi are sized for optimum velocities that keep the byproduct circulating throughout the unit load range at minimum pressure drop.

The hydrated lime used in the CDS reactor is unloaded from trucks on site and stored in a hydrated lime silo. A blower is used to transport the lime to the CDS reactor, where it enters the reactor downstream of the venturi. The hydrated lime is metered by rotary feeders which control the flow of hydrated lime based on the SO_2 removal set point and the stack SO_2 concentration. There is existing hydrated lime system equipment at the MU CHP. The existing equipment will be modified based on the suitability of integration with the new CDS system.

A water flow control skid controls the water to the CDS reactor where it is injected downstream of the venturi through a water injection lance. The water is controlled with a pneumatically modulated valve, based on the CDS outlet temperature setpoint and measured temperature.

The PJFF includes four compartments of bags. One compartment can be taken out of service for maintenance while scrubbing. Bag cleaning air is provided by air compressors that also provide instrument and service air to the CDS.

A large flow of byproduct collected by the fabric filter circulates back to the reactor by air slides located below the fabric filter hoppers. Two air slides are sized for the byproduct circulation rate needed to establish a fluidized bed pressure drop at startup in the reactor and maintain it at full load. Each air slide consists of a closed-top chute that includes an air plenum along the bottom. Air slide aeration blowers provide air to the plenum, and the air fluidizes the solids through a thick fabric material, permitting the solids to flow by gravity to the reactor. Excess byproduct is discharged to the disposal system. Each of the byproduct removal rotary feeders on the air slides are sized to remove the full flow byproduct from one reactor to allow the CDS to continue to operate for any interruption with one of the byproduct removal and disposal trains. The freeboard of the air slides also provides several hours of continued operating time in the unlikely event that both downstream byproduct disposal systems are interrupted.

There is one reactor bottom hopper. During shutdown or under upset conditions, byproduct may fall out of suspension and into the hopper. The reactor bottom hopper includes a rotary valve and ash intake valve.

The byproduct from both the surge bins and the CDS hopper (when required) is discharged to the existing vacuum ash system and is transferred to a common ash/byproduct silo.

Surge bins are typically provided under each air slide. However, these may be eliminated in favor of direct discharge from the air slides through a metering rotary valve to the existing ash system. As noted above, the air slide hoppers provide several hours of capacity to

accumulate byproduct during interruptions of the ash transport system. Normal byproduct discharge is intermittent and can be coordinated with cycling of the ash system among the various ash discharge points in the heating plant.

1.A.vi.b.5.3. Hydrated Lime Injection

Hydrated lime for a CDS is delivered directly to a hydrated lime silo via truck. Based on CDS chemistry demand, a variable-speed rotary feeder controls the flow of hydrated lime from the hydrated lime silo as it is pneumatically injected by air blowers into the CDS reactor. The hydrated lime control loop controls the SO_2 flue gas concentration at the outlet of the CDS.

1.A.vi.b.5.4. Water Injection

The injection of water and subsequent cooling of the flue gas set the optimum operating conditions for the reaction of the acid gas pollutants with the basic hydrated lime particles. The temperature of the flue gas is reduced, and the flue gas humidity is increased in the reactor. Additionally, the water rewets the byproduct when it circulates back to the reactor.

1.A.vi.b.5.5. Pulse Jet Fabric Filter

As part of the CDS system, the fabric filter removes the circulating byproduct from the flue gas before it exits the stack. The particulate forms a layer on the outside of the filter bags that both aids in filtration and enhances SO_2 and Hg removal. A constant fabric filter pressure drop maintains removal of the circulating byproduct. The pressure drop across the fabric filter is maintained by cleaning the bags with compressed air. A pulse of compressed air cleans the bags row by row in a sequence until the pressure drop returns to the set point. The compressed

air pulse knocks the cake of byproduct off of the filter bags. The byproduct falls to a hopper below each compartment. The hoppers include startup heaters and vibrators to enhance byproduct flow from the hoppers to the air slides below.

1.A.vi.b.5.6. Byproduct Circulation

A large flow of byproduct collected by the fabric filter circulates back to the reactor by air slides located below two rows of fabric filter hoppers. Each air slide consists of a sloped wall and closed-top chute that includes an air plenum along the bottom. Air slide aeration blowers provide air to the plenum, and the air fluidizes the solids through a thick fabric material permitting the solids to flow by gravity to the reactor.

1.A.vi.b.5.7. Byproduct Removal

The byproduct generated from the CDS is removed from the air slides by a removal control loop that keeps the air slide levels at a set point. Each air slide includes a byproduct removal train that includes a variable-speed rotary feeder to remove the solids and a surge bin for downstream interruptions. The freeboard in the air slides also provides capacity for downstream interruptions. Each byproduct removal train is sized to remove a full flow of byproduct if the other train is out of service. Byproduct is also removed from the hoppers at the bottom of the CDS reactor in the event of an upset or off-design condition.

1.A.vi.b.5.8. Flue Gas Recirculation

To maintain a fluidized bed in the CDS reactors at low loads, a portion of the flue gas stream downstream of the ID fans recirculates to the inlet duct of the CDS reactor through the

flue gas recirculation duct. A modulating damper at the entrance to the CDS inlet duct modulates the flue gas recirculation rate according to a control loop that keeps the fabric filter outlet flue gas flow above a minimum set point throughout a range of low sCO_2 heater loads. The modulating damper provides smooth control of the CDS throughout a large range of loads.

1.A.vi.b.6. Auxiliary Equipment

1.A.vi.b.6.1. Induced Draft Fan

The unit will be provided with an induced draft fan capable of meeting the required flue gas flow, while providing adequate draft to maintain negative furnace pressure. This fan will be controlled by inlet vanes, though RPI will pursue Variable Frequency Drive (VFD) pricing during detailed design if appropriate for turndown cases.

1.A.vi.b.6.2. Forced Draft Fan

Included in the project is a new forced draft fan. This fan will take air from the building and provide flow to the air preheat systems prior to combustion in the furnace. This fan will be controlled by inlet vanes, with an option for VFD control if appropriate for turndown loads.

1.A.vi.b.6.3. Overfire Air Fan

To improve stoker combustion characteristics, an overfire air system is included. This system requires air pressure greater than the FD fan can provide. This overfire air fan will take hot air from the under-grate air duct and raise the pressure before it is introduced to the furnace to increase momentum and penetration in the furnace.

1.A.vi.b.6.4. Aqueous Ammonia Storage and Injection Systems

The ammonia storage will be optimized to utilize as much of the existing plant ammonia storage system as possible.

A dual fluid nozzle is used to mechanically atomize the aqueous ammonia directly into the flue gas stream. This technology avoids the use of an ammonia vaporizer, which is very expensive to operate. The droplets thus produced turn to vapor in the flue gas stream by absorbing heat from the flue gas. The dual fluid nozzle technology is capable of producing droplets in the range of 40 microns, which is much smaller than can be achieved with conventional spray nozzles. Atomizing air is separately controlled using a closed loop feed-forward system and is generally set at a fixed flow rate.

1.A.vi.b.6.5. Stack CEMS and Process Analyzers

The control of reagent flow to SCR and CDS systems requires continuous emission monitors for NO_x and SO_2 in order to accurately inject reagents at stoichiometric requirements. The Continuous Emissions Monitoring System (CEMS) can be used for control and additional process analyzers are required at the inlet to the SCR and
CDS systems.

1.A.vi.b.6.6. Air Compressors

Air compressors supply the cleaning air for the baghouse and atomization air for the ammonia injection system. The compressed air is directed to desiccant air dryers to ensure dry compressed air is used for cleaning and atomization. The compressed air supply is part of the existing MU CHP equipment.

1.A.vi.b.6.7. Ash Handling Equipment

Ash is removed from the heater at the combustion grate and backpass hoppers. CDS byproduct is removed from the reactor bottom and from the air slides. From these locations, ash will be sent to the existing ash handling system and equipment.

The CDS byproduct—which is a mixture of particulate, unreacted lime, $CaSO_3$, $CaSO_4$, $CaCO_3$, $CaCl_2$, CaF_2, and inert material—exits the reactor and is removed from the flue gas with the baghouse. The byproduct removed by the baghouse is cycled back to the reactor at a high rate through air slides. The byproduct circulation flow establishes a fluidized bed in the CDS reactor.

The byproduct inventory in the CDS is maintained by intermittently removing the byproduct from the solids recycle stream with the byproduct removal system. The byproduct is then transported to a byproduct disposal system.

1.A.vi.c. Balance of Plant Design

RPI created a detailed 3D layout of the fired heater and AQCS equipment (Figure 29 on page 78) and provided a set of fired heater and AQCS arrangement drawings. CDM Smith used this input from RPI and the available drawings of the MU CHP plant and created a 3D plant equipment arrangement (Figure 33). Appendix III includes the design drawings package:

- Civil drawings (including laydown/site plan and traffic control plan)
- Structural drawings (including plan, elevation, and detail drawings)
- Architectural drawings (including plan, elevation, and detail drawings)
- Mechanical drawings (equipment arrangement drawings and airflow diagram)

- Piping drawings (3D views at various levels)
- Electrical drawings (including single line diagrams, panel schedules, plan drawings, and PLC drawings)

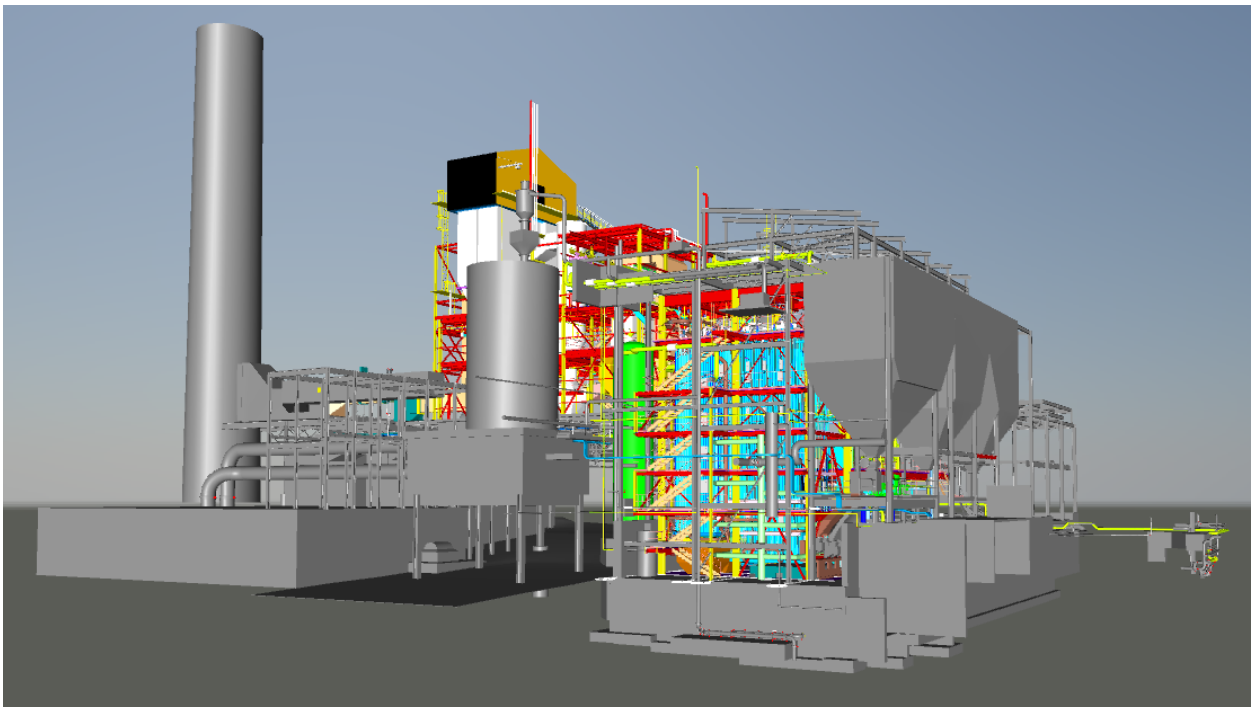


Figure 33: 3D general arrangement of the pilot plant

To support a Class 3 EPC cost estimate, CDM Smith prepared the following discipline bid packages:

- BOP
- Civil and foundations
- Electrical
- EPDM roofing
- Mechanical
- Metal siding

- Specialty demolition
- Structural steel

Potential construction contractors provided bids to CDM Smith, forming the basis for the EPC cost estimate.

1.A.vi.d. Losses and Auxiliary Loads

EPS completed working fluid pressure drop calculations based on the BOP piping layout and in-line devices (valves, filters, and flow elements). In the main flow paths, flow losses totaled 0.592 MPa (high-pressure piping) and 0.336 MPa (low-pressure piping). The largest contributors to the high-pressure piping losses were the PT control and stop valves (0.268 MPa).

Table 25: Fluid losses

Parameter	Piping	Devices	Total
High-pressure piping losses (MPa)	0.289	0.303	0.592
Low-pressure piping losses (MPa)	0.266	0.070	0.336

Gearbox and generator efficiencies from preferred vendor bids were 99.2% and 97.4%, respectively.

Table 26: Energy conversion losses

Parameter	Value
Gearbox efficiency, %	99.2
Generator efficiency, %	97.4

Parasitic loads were updated based on FEED design calculations. Fired heater fans and environmental system auxiliaries represented the largest increases from initial FEED estimates.

Table 27: Parasitic loads

Parasitic Load	Value (kW)
Intermediate Water Loop Pump	145
Plant Water Loop Pump	97
Cooling Tower Fan	277
Forced Draft Fan	58
Induced Draft Fan	240
Overfire Air Fan	26
CO2 System Auxiliaries	130
Heater System Auxiliaries	10
Environmental System Auxiliaries	105
Transformer Losses	40

1.A.vii. Construction Preparedness

1.A.vii.a. EPC Execution Plan

EPS is the program prime contractor, and the team members will contract with EPS. All sCO_2 power cycle equipment will be procured by EPS. RPI will be responsible for all fired heater and AQCS equipment procurement through a single subcontract with Echogen. CDM Smith will own the demolition and construction schedule, shown in Appendix VII. Coordinating with MU, CDM Smith will manage all on site work and contractors and required plant shutdowns. A division of responsibility matrix is shown below in Table 28.

A constructability review was completed with the MU and the Columbia Fire Department and laydown and construction areas were identified. Detailed demolition and construction schedules are to be developed during the initial detailed design phase during Phase III.

Table 28: Division of responsibility matrix

Category	Item	EPS	MU	EPRI	CDMS	RPI
Project	Phase III Detailed Design and Construction Schedule	S	S	S	P	S
Primary Heater	Fabrication/Procurement					P
	Foundation Support Structure		S		P	S
	Fans and Ductwork		S		S	P
	Installation		S		P	S
	Control System (Instruments, Hardware and Logic)					P
	Control Integration		S		P	S
AQCS	Procurement/Fabrication					P
	Installation		S		P	
	CEMS (Continuous Emission Monitoring)		S		P	
sCO2 Power Cycle	Fabrication/Procurement	P				
	Installation	S	S		P	
	Fresh Water Loop	S	S		P	
	Instrument Air	S	S		P	
	Controls System (Instruments, Hardware and Logic)	P	S			
	Control Integration	S	S		P	
Engineering and Construction	Demolition - Boilers 7,8,9		S		P	
	Structural		S		P	
	Equipment Setting		S		P	
	Piping	S	S		P	S
	Electrical	S	S		P	S
	Controls and Instrumentation (Integration and Balance of Plant Instruments, Hardware and Logic)	S	S		P	
	Communications (Phone/Internet)		P			
	Construction Schedule	S	S		P	
	Engineering/Procurement	P			S	S

1.A.viii. Operations Preparedness

1.A.viii.a. Process Hazard Analysis

The PHA assessed potential hazards associated with the pilot design, its associated equipment, and the process around it. Focus was on the equipment, instrumentation, human actions, and external factors that might impact the process around the pilot plant. Systems that were reviewed included the fired heater, sCO_2 power island (sCO_2 turbine, recuperators, compressors, condenser, etc.), environmental controls, and CO_2 storage.

The PHA was done using information produced during the project, including piping and instrumentation diagrams, and through interaction with the project team. ioMosaic, which has prior experience with reviewing EPS's sCO_2 technology, was chosen to lead the effort.

The scope of the PHA included an initial review of design materials provided, multiple days of teleconferences to review the process and equipment designs with the project team, initial feedback from these teleconference meetings, and then issuance of the PHA study results. A decision was made to do teleconferences in lieu of a site visit given travel restrictions due to COVID-19.

The PHA was performed in a structured, systematic way following a HAZOP methodology. ioMosaic used the teleconferences to gather information to perform a qualitative risk ranking of identified scenarios to determine their criticality and the need for changes to the design or updates to safety procedures. Consequence and frequency ranges were applied using a risk ranking to prioritize the results of the PHA study and identify recommendations designed to reduce or eliminate hazards.

The PHA focus was on several "nodes" (areas or components of the cycle) related to the project. The selected nodes are shown in Table 29.

Table 29: PHA Nodes

Node	Description
KO	Kickoff Meeting
1	sCO_2 Loop High-Temperature and Low-Temperature Compressors and
2	sCO_2 Power Turbine/Generator and Auxiliaries
3	sCO_2 Fired Heater
4	CO_2 Storage
5	Circulating Dry Scrubber, Fabric Filter, and Selective Catalytic Reduction

All of the team members participated in the PHA meetings with representatives from EPS, RPI, MU, CDM Smith, and EPRI attending every session. ioMosaic used that information to prepare the report.

The most significant risks identified for the project included indoor and outdoor loss of CO_2 containment and expensive equipment damage.

For loss of CO_2 containment (indoor), key risk mitigation recommendations included:

- Transient analysis of upset conditions
- Valve modifications (change fail positions, add check valves)
- Controls modifications (add interlocks)
- Alternative fluids for equipment hydrotesting
- Safety systems (CO_2 detectors, respirators)

For loss of CO_2 containment (outdoor), key risk mitigation recommendations included:

- Dispersion modeling of CO_2 vent scenarios
- Design modifications as recommended per modeling results (raise discharge elevation, add dispersion fan)
- Crash barriers near CO_2 storage system

For equipment damage, key risk mitigation recommendations included

- Detailed analysis of upset conditions
- Valve modifications (change fail positions, add check valves)

Transient and dispersion modeling were performed during the Phase II work to begin risk mitigation per the PHA recommendations. Other recommended design modifications

(valves, controls, hydrotest plans) will be evaluated during detailed design. The full report is included in Appendix IV.

1.A.viii.b. Transient Modeling

To better understand the system responses and determine the adequacy of the current system equipment specifications for system startup and emergency shutdown, EPS performed a transient system modeling study of the proposed sCO_2 power cycle. This study included the construction of full power cycle system models using the GT-SUITE 1D system simulation software package.

Due to the early stage of the analysis, data provided from vendors for vital system components such as the turbomachines and heat exchangers were limited to a small sample of performance data points. The fired heater was modeled as a Co-Simulation Functional Mock-up Unit (CS FMU) by RPI. The CS FMU allows for a greater level of fidelity due to increased model detail but still uses correlation factors to model the extremely complex heat transfer within the fired heater.

Given the limited fidelity at this design stage, results are primarily used to show the general validity of the component sizing and procedures, not to precisely determine final component settings. The 1D system models used in this study could easily be updated with more complete data sets in the future to produce more accurate results that could be used to determine system control settings, strategy, and final component specifications.

The full power cycle system model was constructed and then simplified into two models that specifically matched the power cycle components and controls needed for the startup and

emergency shutdown cases. These 1D transient system models allowed for the analysis of details such as

- Startup: Start pump inlet quality and pump sizing
- Startup: CO_2 inventory requirement
- Emergency shutdown: peak fired heater metal temperature

1.A.viii.b.1. Startup: Start Pump Inlet Quality and Pump Sizing

For the startup procedure transient model analysis, three cases were run with cooling water temperature (T_{cw}) at the slave side of the condenser being 18°C, 26°C, 32°C to represent the range of possible cooling water temperatures from the MU cooling tower (Table 1 on page 16). It was important to use these different cooling water temperatures because the startup procedure is controlled based on pressure targets at the SP inlet. These pressure targets are tied to the saturation pressure of CO_2 at the temperature of the condenser cooling water.

Results from the startup model analysis showed that brief periods—250s and 110s—of a two-phase fluid at the SP inlet exist in the 18°C and 26°C T_{cw} cases, and no two-phase condition was seen in the 32°C T_{cw} case. This was caused by a large spike of SP mass flow rate at the initial activation of the pump due to the lack of flow resistance to pumping. Solutions for this include adding a control valve close to the SP to allow instantaneous flow resistance or increasing the TP flow from the nominal design speed to the max speed at the moment the SP activates. With these solutions and the low duration of the two-phase inlet condition, it was determined that the current transfer and SP specifications could execute the planned startup procedure.

1.A.viii.b.2. Startup: CO_2 Inventory Requirement

The peak amount of CO_2 mass needed to achieve startup was found to be 22,100 kg in the T_{cw} = 32°C case. The lower T_{cw} cases of 18°C and 26°C required a peak CO_2 mass of 19,000 kg and 19,800 kg. These results show an approximate reduction in peak CO_2 mass needed to achieve start-up of 44% versus flooding the system with liquid CO_2 and confirm the adequacy of the selected storage tank size.

1.A.viii.b.3. Emergency Shutdown: Peak Fired Heater Metal Temperature

The emergency shut down case was performed by initializing the power cycle at design point conditions and then triggering a power failure event. The model then utilized a control logic setup to initiate the EPS emergency shutdown procedure of venting the system CO_2 via an ERV positioned after the fired heater to force CO_2 flow through the fired heater, keeping the metal cool until the coal burned out. Four different ERV inner diameter sizes—4”, 6”, 8”, and 10”—were modeled using the baseline piping design, and a 6” ERV was modeled with a direct routing from the inventory tank to the fired heater inlet.

Peak metal temperatures from the conventional routing cases were 880°C, 841°C, 836°C, and 832°C in order of increasing ERV size. All ERV sizes failed to keep the peak metal temperature below the target of 816°C per RPI design guidelines. The peak metal temperature for the 6” direct routing case was 802°C. These results conclude that either the direct routing venting method or a different method, such as active quenching of the fuel source, would be needed to control temperatures in the fired heater during an emergency shut down.

1.A.viii.c. Atmospheric Dispersion

The plant will include a purge venting system for startup, as well as several safety relief valves for venting CO_2 during potential upset conditions (1.A.vi.a.5.5). CDM Smith was contracted to perform dispersion modeling analysis of the various purge and safety venting scenarios. Because vented pure CO_2 can result in the release of either dense (heavier than ambient air) or buoyant (lighter than air) plumes under different discharge temperatures, CDM Smith identified several screening-level models that were used to provide an initial assessment of whether the discharge was dense or buoyant and estimate potential concentrations of CO_2 at locations that could be occupied by people within the impact zone of the releases.

A number of CO_2 concentration thresholds were identified. Concentrations above these thresholds for the identified exposure durations associated with each threshold could be potentially harmful to human health. The thresholds identified by the National Institute for Occupational Safety and Health (NIOSH) include those identified as Immediately Dangerous to Life or Health (IDLH), the 15-minute Short Term Exposure Limit (STEL), and the recommended 8-hour time-weighted average threshold limit value (TWA-TLV). In addition to occupational exposure, research into the effects of exposures for a typical workday in an office environment at approximately 1,000 to 1,400 ppm indicate a decrease in cognitive skills. These levels are relevant due to the CHP plant's location on the MU campus with several nearby high-rise buildings.

CDM Smith recommended that the modeling analysis identify potentially occupied areas where concentrations could exceed the following levels for the noted exposure durations:

- 40,000 ppmv CO_2 – Concentrations above this level at any location and averaging period
- 30,000 ppmv CO_2 – Concentrations above this level for any off-site location for any period, and concentrations above this level on-site for more the 15 minutes
- 5,000 ppmv CO_2 – Concentrations above this level for any off-site location for more than 15 minutes and concentrations above this level on-site for more than 1 hour
- 1,000 ppmv CO_2 – Concentrations above this level for any off-site location for 1 hour or more

For the CO_2 purge that occurs during startup, the peak CO_2 concentrations for the one-hour averaging period due to purge venting does exceed the suggested off-site 1-hour threshold identified above. Several options for reducing those impacts were analyzed, including raising the stack from 115 ft to 140 ft or 167 ft above ground, increasing the venting duration to reduce the mass flow rate, and adding a vent fan to increase the exit velocity and exit temperatures. The most effective means to reduce the off-site concentrations was to increase the vent discharge elevation to 167 ft and add a 1,250 CFM vent fan downstream of the valve.

The full dispersion report is included in Appendix II.

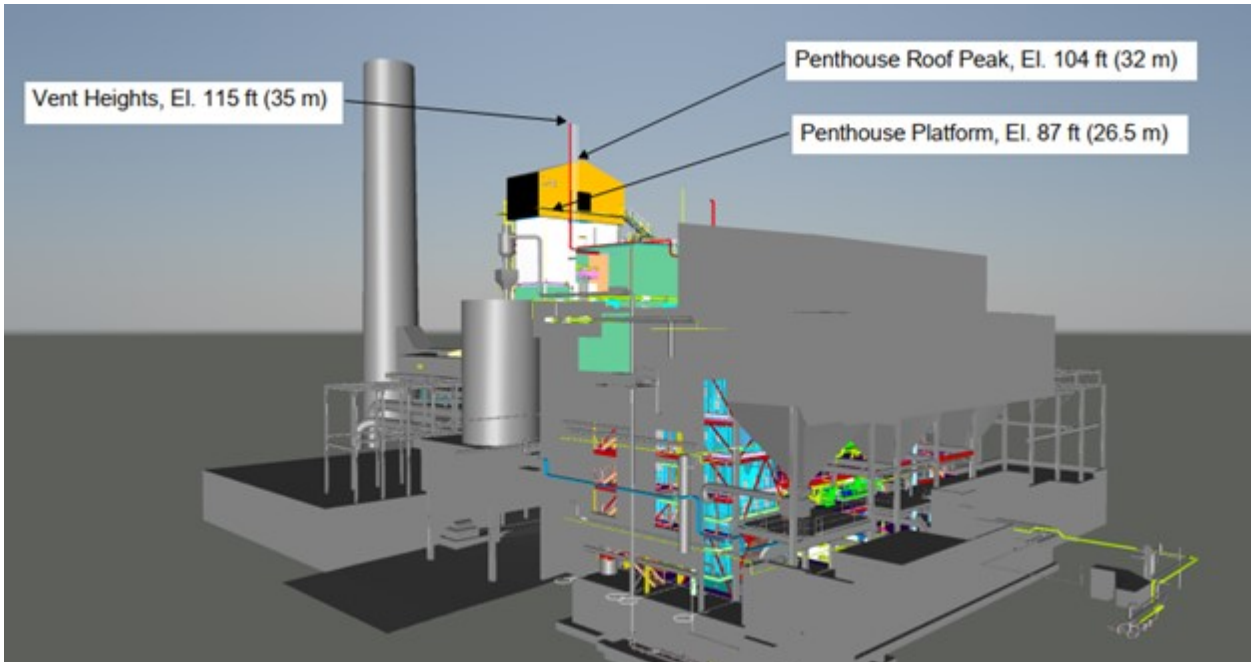


Figure 34: Vent locations

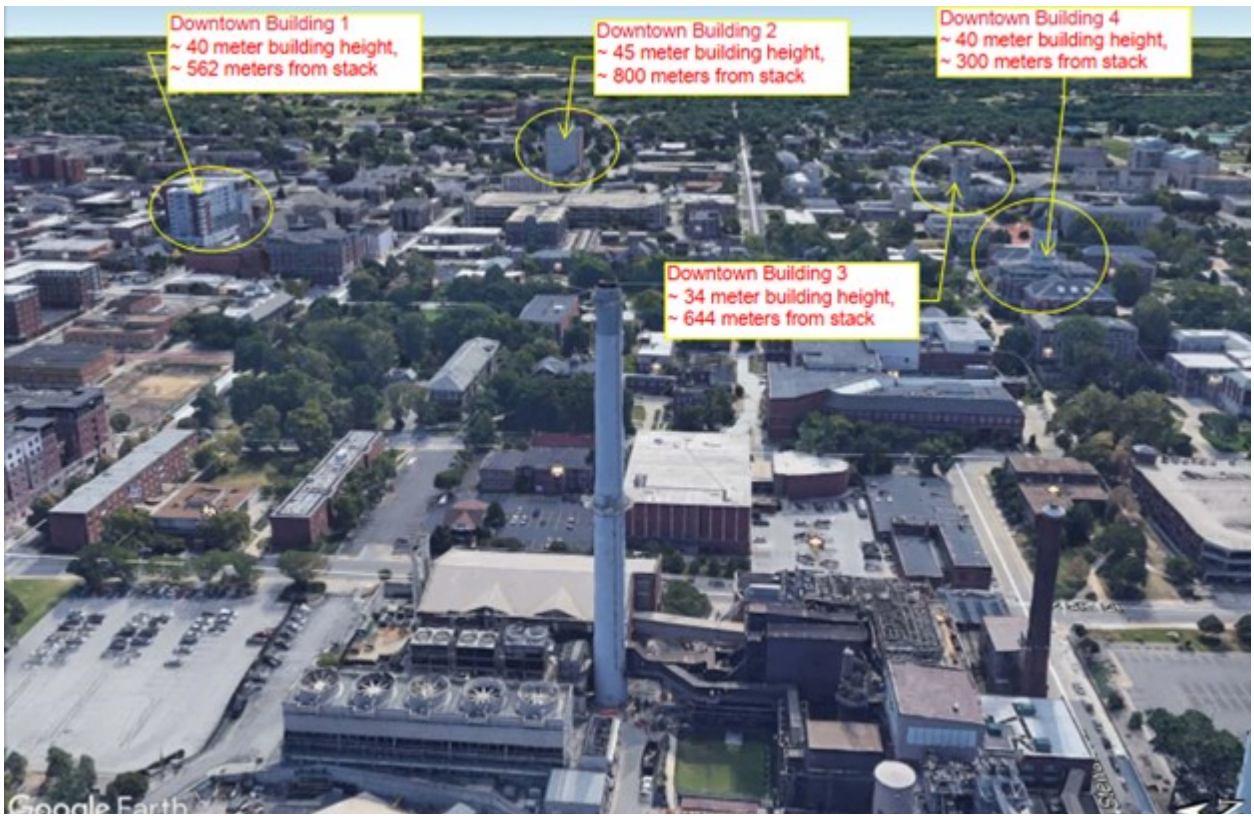


Figure 35: Nearby building heights and distances from the plant stack

1.A.viii.d. Performance Test Plan

EPRI developed a PTP based on the FEED P&IDs. The performance test plan is consistent with American Society of Mechanical Engineers (ASME) Performance Test Code (PTC) 46. The plan details the primary objective of conducting a performance test to verify the equipment installed meets the designed operating characteristics. This is of critical importance to verify the performance of the system as installed or to identify corrective actions that may be needed. For this system, the primary performance indicator identified is the overall net plant efficiency.

Each of the parameters needed to calculate the net plant efficiency need to be either directly measured or derived from other measurable process conditions. Several secondary objectives have also been defined to validate the performance of parts of the system. A key point for thermal generation systems is the efficiency of the fired heater to deliver thermal energy to the working fluid and the power cycle system efficiency to convert that thermal energy to gross power. To calculate the net plant efficiency, the incoming and outgoing energy flows across the defined system boundary must be specified and quantified. The draft plan lays out the procedure for performing this calculation and the measurements required. The draft test plan also lays out a schedule for testing and the overall testing procedure.

The full PTP is included in Appendix V.

1.A.ix. Design Basis (Final)

The FEED design basis (1.A.v) was set for a 10 MWe net plant output. The numbers assumed for the design basis were refined by the results of the FEED engineering effort (1.A.vi). These results of the FEED produced a final basis for detailed engineering design.

Since it would be impractical to re-size the fired heater to maintain an exact 10 MW_e net power plant, the fired heater heat input was considered fixed at 32 MW_{th}. After updating the various efficiencies and losses (and maintain similar PCHE effectiveness), the updated net power output is 9.68 MW_e. The reduction is primarily due to increases in electrical parasitic loads and CO_2 auxiliary flow requirements.

Table 30 lists the design point process conditions corresponding to Figure 11 (page 29).

Table 30: Final design point process conditions at each state point.

State	Description	Temp. (°C)	Pressure (MPa)	Flow (kg/s)	Enthalpy (kJ/kg)
10	CHX Outlet - LTC Inlet	29.1	7.61	96.58	283.9
20	LTC Outlet	58.2	25.00	96.58	311.2
21	HTC Outlet	173.6	24.90	48.04	542.9
22	Bearings & Seals	58.2	24.99	12.40	311.2
23	LTR High Pressure Inlet	58.2	24.96	84.18	311.2
30	LTR High Pressure Outlet	178.9	24.86	84.18	551.4
31	HTR High Pressure Inlet	176.5	24.64	120.26	548.3
32	HTR High Pressure Outlet	464.5	24.54	120.26	925.4
33	PHX2 Inlet	176.6	24.69	11.95	548.3
34	PHX2 Outlet	470.0	24.53	11.95	932.2
35	PHX1 Inlet	464.9	24.41	132.18	926.0
40	PHX1 Outlet	600.2	23.31	132.18	1095.8
41	LTC Turbine Inlet	600.0	23.11	20.14	1095.7
42	HTC Turbine Inlet	600.0	23.13	27.78	1095.7
43	Power Turbine Inlet	600.0	22.92	84.30	1095.8
50	HTR Low Pressure Inlet	481.4	8.13	132.21	962.6
51	LTC Turbine Outlet	481.1	8.21	20.14	962.1
52	HTC Turbine Outlet	481.5	8.23	27.78	962.6
53	Power Turbine Outlet	481.6	8.25	84.30	962.7
54	HTR Low Pressure Outlet	182.5	8.03	132.21	619.6
60	LTR Low Pressure Outlet	63.8	7.88	132.21	466.8
61	CHX Inlet	53.1	7.82	96.58	446.8
62	HTC Inlet	63.3	7.81	48.04	466.8
W1	WP1 Outlet - CHX Inlet	28.4	0.40	425.80	119.4
W2	CHX Outlet - IHX Inlet	37.2	0.30	425.80	156.2
W3	IHX Outlet - WP1 Inlet	28.3	0.10	425.80	118.7
W4	WP2 Outlet - IHX Inlet	26.1	0.39	425.80	109.7
W5	IHX Outlet - Cooling Tower Inlet	35.0	0.19	425.80	146.8
W6	Cooling Tower Outlet - WP2 Inlet	26.0	0.10	425.80	109.1

Following are additional design point summaries: Table 31 lists design data for the turbomachinery (size and efficiency for each component) and heat exchangers (duty and effectiveness for each component), Table 32 lists system power loads, and Table 33 lists system efficiencies.

Table 31: Final design data for turbomachinery (shaft power and efficiency for each component) and heat exchangers (duty and effectiveness for each component)

Component	Duty (kW)	–	(kW/°C)	Efficiency / Effectiveness	–	
LTC - Shaft Power (T – C)	2,689	–	2,633	83.5%	–	84.1%
HTC - Shaft Power (T – C)	3,695	–	3,658	83.3%	–	80.2%
PT - Shaft Power	11,190			84.1%		
IHX - Heat Transferred – UA	15,867	–	7,119	80.0%		
CHX - Heat Transferred – UA	15,722	–	7,009	97.1%		
HTR - Heat Transferred – UA	45,352	–	2,822	98.0%		
LTR - Heat Transferred – UA	20,210	–	4,349	97.8%		
PHX1 - Heat Transferred – UA	22,441	–				
PHX2 - Heat Transferred – UA	4,589	–	62	83.0%		

Table 32: Final design power loads

Load	Loss (kW_e)	Power (kW_e)
Power Turbine Shaft Power		11,190
Gearbox Losses	-90	
Generator Losses	-289	
Generator Power		10,812
Intermediate Water Loop Pump	-145	
Cooling Tower Pump	-97	
Cooling Tower Fan	-277	
Forced Draft Fan	-58	
Induced Draft Fan	-240	
Overfire Air Fan	-26	
CO2 System Auxiliaries	-130	
Heater System Auxiliaries	-10	
Environmental System Auxiliaries	-105	
Transformer Losses	-40	
System Net Power		9,683

Table 33: Final design system efficiencies

System	Energy In (kW)	Energy Out (kW)	Efficiency
Fired Heater	32,063	27,029	84.3%
Power Cycle (gross)	27,029	10,812	40.0%
Power Cycle (net)	27,029	9,683	35.8%
Overall Plant	32,063	9,683	30.2%

Based on the final design from RPI (1.A.vi.b.2.1), the estimated thermal efficiency of the fired heater was 84.3%. The gross power cycle thermal efficiency was 40.0%, with a net efficiency (debiting parasitic loads) of 35.8%. The overall plant efficiency was 30.2% based on higher heating value (HHV) of the fuel input to the fired heater.

1.B. Technology Development Status

1.B.i. sCO_2 Power Cycles

sCO_2 power cycles were proposed as early as the 1960s [4, 5], and studied extensively for the past decade due to their potential for delivering transformational improvements in thermodynamic efficiency. The compact nature of sCO_2 turbomachinery offers capital cost and footprint advantages, and the low maintenance of a water-free power cycle can significantly reduce O&M costs over traditional steam-Rankine systems.

Initial development work was conducted in laboratory-scale systems at Sandia National Laboratory, Bechtel Marine Propulsion Corporation, and others [6, 7]. EPS was formed in 2007 to achieve commercial development and operation of sCO_2 power cycles, initially for gas turbine combined cycle and similar industrial waste heat recovery applications [8]. EPS's

development process resulted in the design, fabrication, and test of the first commercially available sCO_2 power cycle, the 7.3 MW_e EPS100 [9].

The EPS100 underwent extensive system testing at Siemens' (then Dresser-Rand's) test facility in Olean, New York. Key results of the test program have been published previously [9] and are summarized here. The principal turbomachinery components, the PT and turbine-driven LTC, met or exceeded their design target values over the range of conditions tested. sCO_2 power cycles utilize significant internal heat transfer (recuperation) to achieve their superior thermodynamic efficiency. The heat exchangers used for this duty are called recuperators—the high pressure that these devices are required to withstand, combined with the high heat transfer conductance (UA) that is needed for high cycle efficiency, limits the heat exchanger technology choice to a variant of a diffusion-bonded design, frequently referred to as PCHEs. The EPS100 uses as part of its design two recuperators, which represent two of the largest PCHEs ever constructed and tested for sCO_2 power cycle service. The performance of these heat exchangers during the test program met or exceeded the predicted values, and no performance degradation was measurable during the extent of the test program. The EPS100 also employs a fully automated operation and control system, including all sensors and actuators that are required for autonomous operation. Thus, the EPS100 has proven many of the technologies that are required for the proposed pilot scale unit.

1.B.ii. Integration of sCO_2 Power Cycles with Coal Combustion

The specific cycle to be used for the sCO_2-coal system (the RCBC, introduced previously in 1.A.i) has been developed and optimized by EPS under DOE funding (DE-FE0025959) in a

collaborative project led by EPRI, and including Babcock & Wilcox, General Electric/Alstom, Siemens, and Doosan Heavy Industries [10]. As part of the system analysis, a 90 MW_e sCO_2 power plant conceptual design, using air-fired pulverized coal combustion, was created and compared to a baseline conventional steam-Rankine power cycle with a turbine inlet temperature of 593°C. While the steam baseline uses wet cooling (cooling towers) for cycle heat rejection, the sCO_2 cases assumed direct air-cooling due to increasing water scarcity and restrictions at many plant sites.

The key result of these study cases is that the overall plant fuel higher heating value (HHV) to net electrical power efficiency is significantly improved when using sCO_2 power cycle technology. The baseline steam-Rankine cycle efficiency is 33% HHV, while the sCO_2 power cycle-equipped system efficiency ranges from 36% to 41% HHV at a turbine inlet temperature from 593°C to 730°C. Preliminary plant cost estimates show that the sCO_2 power cycle will likely achieve these power increases with no increase in plant equipment or construction costs. Lessons learned from this project—including a revised coal-fired primary heater design, less emphasis on pressure drop and more on cost, and focus on a lower operating temperature to avoid the need for costly materials—will be employed in this project.

The selection of cycle architecture, turbomachinery sizing, and primary heater (fired heater) design has been guided by the combined expertise of EPS and its partners, including the operational experience gained by EPS during the EPS100 development.

1.B.iii. Key Component Technology Readiness

The pilot plant consists of numerous components, many of which are essentially derivatives of commercially available technologies, such as instrumentation, piping, valves, etc. The "Key Components" are those that are unique to the coal-fired sCO_2 power cycle application. These include turbomachinery, internal heat exchangers (recuperators), and the primary heater.

EPS has successfully designed, built, and tested two of the largest operational sCO_2 turbines in the world during its EPS100 development program, the 10 MW_e power turbine and 3 MW LTC drive turbine. EPS and BNI were sponsored by DOE-funded programs to conduct additional turbine development. As part of the DE-NE0008470 study, BNI performed the conceptual design and preliminary cost study of the sCO_2 turbine for a 10 MW_e net output power cycle at 700°C turbine inlet temperature (Figure 36).

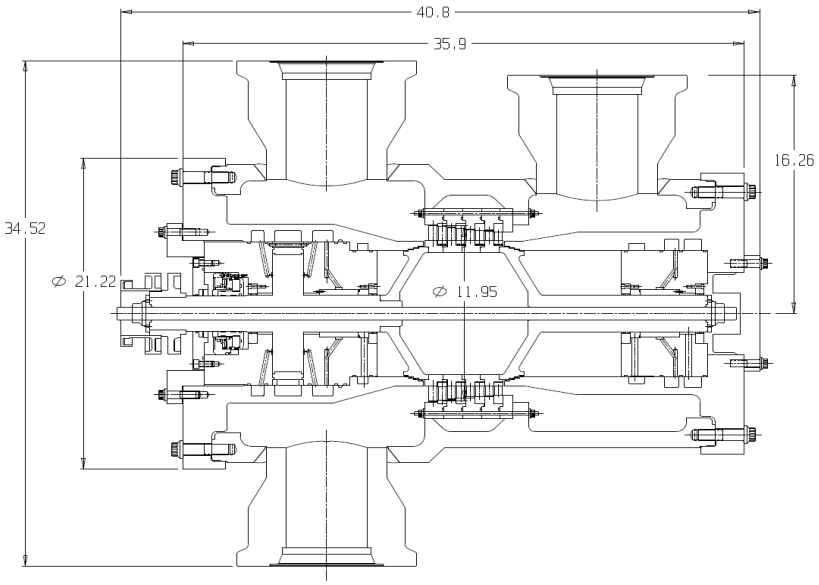


Figure 36: sCO_2 turbine design for 10 MW_e sCO_2 power cycle applications

The RCBC cycle requires two turbine-driven compressors, one at a low-temperature inlet (the LTC), and the other at a higher inlet temperature (the HTC). This program utilizes two separate turbine-driven units for improved operability and startup behavior. The LTC designed for the commercial EPS100 power cycle (Figure 37) forms the basis for both units, substantially de-risking these key components.

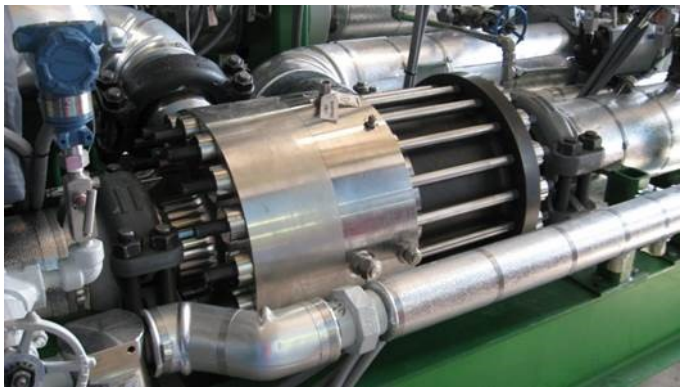


Figure 37: EPS100 Turbocompressor

The recuperators for the program are projected to be PCHE designs, comparable to those used in the EPS100. The physical scale will likely be larger than the EPS100 designs but is well within existing manufacturing capabilities.

RPI leveraged its experience as a steam boiler vendor to complete the preliminary design of a 10 MW_e sCO_2 coal-fired combustion system and primary heat exchanger. Like a steam boiler arrangement, the sCO_2 primary heater heats the sCO_2 in a radiant furnace and a downstream convective tube bank and the fired heater enclosure is composed of sCO_2-cooled membrane tube panels.

1.B.iv. Material Compatibility

Numerous studies have been performed on static interactions of high temperature and pressure sCO_2 with stainless steel and nickel-based alloys [11, 12, 13]. These studies, generally performed at static or very low-velocity conditions, have shown that—provided the proper material is selected for the proper local temperature—very little unusual corrosion or other interactions are observed. The highest-temperature components are found in the primary heat exchanger. For this project, a high-temperature austenitic alloy, Super304, has been selected for the tubes in the furnace wall and for the additional tubes in the primary heat exchanger.

1.B.v. Cycle Operability and Control

EPS has thousands of hours of practical operating and control system development experience through the EPS100 and related commercial sCO_2 power cycle programs. The parallel compressors of the RCBC cycle offer additional operational challenges, where pressure ratio interactions between the machines can lead to surge events during transient operation. EPS has significant experience in the development of dynamic models for closed-loop sCO_2 power cycles and a large operational database to verify the performance of component sub-models and overall system model behavior [14]. EPS recently received DOE funding to investigate transient modeling and operation of a combined cycle power plant under DE-FE0031621 (Integrated Optimization and Control of a Hybrid Gas Turbine/sCO_2 Power System). This modeling and control expertise will significantly reduce the technical risk associated with RCBC operation.

1.B.vi. Remaining Technical Gaps

While sCO_2 technology has advanced significantly in the last decade, no long-duration operational experience has been acquired thus far. Therefore, questions regarding long-term durability of the materials and system characteristics are thus far unanswered. The Phase III program would provide a wealth of operational experience that will facilitate further commercial development of sCO_2 power cycle technology. In addition, operation at fluid temperatures up to 600°C will provide valuable material compatibility data in a more practical environment. Finally, operation and control of a pilot-scale system will provide critical data and insights into the complex interactions between a practical sCO_2 system and a coal-fired heat source.

1.C. Choice of Scale

The project team has selected a 10 MW_e scale to be representative of a commercial-scale coal-fired power plant with an sCO_2 power cycle. The preceding DOE-sponsored studies provide perspective on the configuration of this type of power plant, including power cycle, heat source and auxiliary system design features. For the purposes of this analysis, a scale progression from the current project to 100 MW_e (and ultimately to > 500 MW_e) is envisioned. The key scale-up factors that were considered are the following:

- Power cycle architecture
- Turbomachinery architecture and design features
- Heat exchanger design

- Electrical
- Operation, instrumentation, and control

1.C.i. Power Cycle Architecture

Utility-scale sCO_2 power cycles can take several different configurations depending on the utilization of post-primary heat exchanger enthalpy. Waste heat recovery systems typically assume no further utilization of the heat source enthalpy, and thus place a higher emphasis on maximizing single-pass enthalpy extraction. A primary power cycle application, such as the present coal-fired system, can recover residual enthalpy through means such as inlet air preheating. For this type of application, power cycle thermodynamic efficiency is more important. These two approaches result in different cycle "architectures," a term that refers to the arrangement of internal and external heat exchangers and turbomachinery. The RCBC cycle (introduced in 1.A.i) is an example of the latter approach, which would apply both to the present study as well as to a utility-scale sCO_2 power cycle. Therefore, the 10 MWe pilot is well-suited toward demonstrating the utility-scale design.

1.C.ii. Turbomachinery Architecture and Design Features

The selection of turbine and compressor configuration is to some extent (though not entirely) driven by the cycle architecture. The RCBC cycle, along with several derivatives, uses two separate compressors and at least one turbine. In addition, several critical design choices must still be made regarding both the arrangement and configuration of the turbomachinery.

1.C.ii.a. Compressor Drive

At least three types of compressor drives can be used with an sCO_2 power cycle—direct motor drive, constant-speed turbine drive, or variable-speed turbine. Motor driven compressors allow for independent control of the two compressor speeds and therefore significant operational and control flexibility. However, the cost, mechanical and electrical losses required to transmit turbine aero power through a generator, variable-speed drive, motor, and potentially one or two gearboxes are significant. Additionally, at utility scale (> 100 MW_e), motor drives become challenging to source. A constant-speed turbine drive offers a more efficient, lower-cost configuration, but at the cost of off-design compressor performance due to the fixed speed constraint. EPS has pioneered the use of direct variable-speed turbine drives for their compressors. This configuration offers an excellent balance between operability and control as well as between cost and efficiency. In addition, the variable-speed drive approach is very scalable, as the optimal aerodynamic speeds of the turbine and compressors trend similarly with scale. For this reason, EPS has selected the latter approach for its cycle architecture.

1.C.ii.b. Radial vs. Axial Turbines

At small scales, radial inflow turbines offer simplicity and higher efficiency relative to their axial counterparts. However, at very large scales, multi-stage axial turbines offer better performance at speeds that allow direct matching of optimal shaft speed with the driven load (a synchronous generator at 3600 RPM, for instance). It is for this reason that we have chosen a multistage axial turbine for the power-generating turbine.

1.C.iii. Heat Exchanger Design

1.C.iii.a. Recuperators

The recuperators used in sCO_2 power cycles are typically of the PCHE type. These heat exchangers are directly scalable up to a maximum single core mass of approximately 70 metric tons, which corresponds to a conductance (UA) of approximately 5000 kW/K. Scaling to 100 MW_e or larger requires the recuperators to be constructed as multiple PCHE blocks manifolded together, which does not constitute a technical risk.

1.C.iii.b. Heat Rejection

Like the recuperators, the technology selected for the heat rejection heat exchangers is highly scalable. For this project, space limitations and the readily available cooling tower water make water-cooled heat rejection the preferred approach. While EPS believes that the long-term approach will likely be predominantly air-cooled systems, water cooling is the more traditional approach for utility-scale power plants. Therefore, the selected approach here is representative of a significant fraction of coal-fired, utility-scale applications.

1.C.iii.c. Primary Heat Exchanger Design

RPI has broad experience providing optimized pressure parts and new boiler systems for both utility and industrial applications. Leveraging this broad-scale experience base, RPI designed the primary heat exchanger (fired heater) with scalability in mind. The large-scale pilot primary heat exchanger is top-supported, is designed with membrane tube wall enclosures, and uses flow arrangements that are conducive to utility-scale designs. As is the case with steam

boilers, material and cost optimization would be custom for each project. At utility scale, the combustion technology would change from stoker to suspension firing, resulting in improved heater efficiency through improved carbon burnout as well as the use of lower excess air and higher-temperature combustion air (two factors that would contribute to a larger air preheater). Previous DOE-funded work (DE-FE0025959) found that the high-temperature air heaters required for utility-scale, RCBC-based sCO_2 power cycles were well within commercial experience.

1.C.iv. Electrical

Utility-scale electrical power generation uses synchronous generators that operate at the line frequency (60 Hz in the United States). At 10 MW_e, the predominantly available generator type is an air-cooled, 4-pole synchronous machine operating at 1800 RPM. Optimal sCO_2 turbine speeds at this scale are considerably higher, requiring use of a speed-matching gearbox. Utility-scale generators are frequently hydrogen-cooled, 2-pole machines that operate at 3600 RPM. With appropriate design, direct drive with an sCO_2 turbine becomes feasible. In all cases, the scalability and technical risks of the driven equipment (generators and gearboxes) are very low, since commercial devices are available.

1.C.v. Operation, Instrumentation and Control

By implementing scalable system and turbomachinery architectures, EPS's solution allows use of commercial instrumentation and control (I&C) systems that are directly relevant to a utility-scale system. EPS's approach is to use market-accepted industrial I&C hardware and

software tools to develop the pilot-scale control systems, significantly reducing subsequent scale-up risks, development time, and long-term support requirements. At the selected 10 MW_e scale, system fluid, thermal and mechanical time scales are comparable to those expected for a 100-500 MW_e system design.

1.D. Phase III Cost Estimate and Schedule

Table 34 summarizes the Phase III budget (detailed design, construction, and operation). Further details for the BOP and construction costs are included in Appendix VI. The preliminary Phase III project schedule is included in Appendix VII. It outlines an 18-month detailing phase with an overlapping a 25-month fabrication and construction phase (totaling approximately 2.5 years). Phase III ends with a 24-month operation and commission phase for a total Phase III length of approximately 4.5 years.

Table 34: Phase III budget for detailed design, construction, and operation

	Category	Description	Cost ($MM)	
POWER CYCLE (EPS)	Power train	Power turbine, gearbox, generator, couplings, and guar	$ 3.5	$ 27.6
	Power train auxiliaries	Lube oil system, seal gas conditioning system	$ 0.8	
	Compressors (incl. turbine drives)	High temp. compressor, low temp. compressor, start pu	$ 2.3	
	Heat exchangers	High temp. recuperator, low temp. recuperator, conder	$ 9.4	
	Inventory control system	CO2 storage tank, refrigeration system, vaporizer, trans	$ 0.5	
	Valves & vents	Stop, control, check, isolation, and relief valves; silence	$ 1.8	
	Instruments and Controls	Control system, transmitters	$ 0.8	
	Skids and enclosures		$ 0.8	
	Vendor NRE		$ 2.7	
	Freight		$ 1.0	
	Spares		$ 2.0	
	Commissioning		$ 0.4	
	Final engineering & PM		$ 1.8	
FIRED HEATER & AQCS (RPI)	Fired Heater	Pressure parts, air heater, dry ash system, sootblowers,	$ 13.9	$ 25.1
	Fuel System	Coal feeders, mills, and pipe; gas burners and skids	$ 2.2	
	Selective Catalytic Reactor	Casing, catalyst, ammonia system	$ 1.4	
	Circulating Dry Scrubber	Scrubber vessel, lime system, water system, air system	$ 1.7	
	Pulse Jet Fabric Filter		$ 1.6	
	Instruments and Controls		$ 1.7	
	Fans	FD fan, ID fan, OFA fan	$ 0.7	
	Ductwork	Combustion air, flue gas	$ 1.9	
BALANCE OF PLANT & CONSTRUCTION (CDM SMITH)	Existing conditions	Asbestos abatement, mechanical demolition, electrical	$ 6.6	$ 63.1
	Concrete	Civil roadways, concrete & foundations, masonry	$ 3.4	
	Metals	Metal wall panels, structural steel fabrication	$ 1.4	
	Fired heater equipment	Equipment and structural steel erection (including fans	$ 12.1	
	AQCS equipment	Equipment and structural steel erection (including CEM	$ 6.3	
	Power cycle equipment and piping	Equipment, structural steel erection and CO2 piping	$ 6.7	
	Special construction	CEMS, stack testing, 3rd party inspections	$ 0.5	
	HVAC	Makeup air, ductwork and exhaust systems	$ 0.6	
	Integrated automation	Network equipment, CO2 monitoring & alarms	$ 0.3	
	Electrical	Equipment, power, control, network & grounding wirin	$ 6.2	
	Utilities	Balance of Plant Piping	$ 2.0	
	Permits and insurance		$ 0.5	
	Standard general conditions		$ 1.6	
	Final engineering		$ 1.6	
	CM and construction engineering		$ 5.8	
	PM and contingency		$ 7.5	
PLANT OPER. & MANAGEMENT (MU)	System leases (100% in kind)	Lease rates for shared use of existing systems	$ 3.9	$ 12.0
	Staff costs (100% in kind)	Project support from management, engineering, opera	$ 2.9	
	Operational costs (~50% in kind)	Fuel, ash disposal, consumables, cooling water, mainte	$ 5.3	
PROGRAM SUPPORT (EPRI)	Performance test plan and testing		$ 0.5	$ 0.9
	Technoeconomic analysis		$ 0.1	
	HAZOP		$ 0.2	
	Industry participation		$ 0.1	
TOTAL				$ 128.7

1.E. Updated Techno-economic Analysis

1.E.i. Plant Design

1.E.i.a. sCO_2 Power Cycle

The commercial-scale plant uses the same cycle architecture as the pilot plant (Figure 2, page 13). The choice of scale is 120 MW_e (net), the type of scale that is expected to be an advantageous entry point in the market, as outlined in 3.D.i. A key difference from the pilot plant is that the commercial plant is air cooled, aligning with the technology development goal of minimized water consumption.

Turbomachinery efficiencies were estimated on the same principles as the pilot plant (1.A.iv.a). HTR and LTR effectiveness limits were set at 98% (1.A.iv.b). Total PHX pressure drop was increased to 2.0 MPa, and 24 kg/s (about 2% of total loop flow) was allocated for CO_2 auxiliary flow. Auxiliary loads were estimated similarly to previous studies (DE-FE0025959) and the overall auxiliary load estimate was confirmed to be consistent with total auxiliary estimates from RPI.

1.E.i.b. Primary Heater

The design of the commercial scale heater is similar to the pilot plant in overall layout and flow paths. Fluid enters the convection bundles, is partially heated, and then passes through the radiant portions of the heater to achieve final temperature. To manage the size of the commercial-scale furnace, radiant platens are included to maximize heat transfer surface area. Combustion systems for this unit are designed with pulverized coal as the primary fuel,

with a small amount of natural gas (5% of heat input) fired to provide for temperature control. A dry bottom ash system has been included under the furnace. See Figures 38 and 39 for an overview of the heater arrangement.

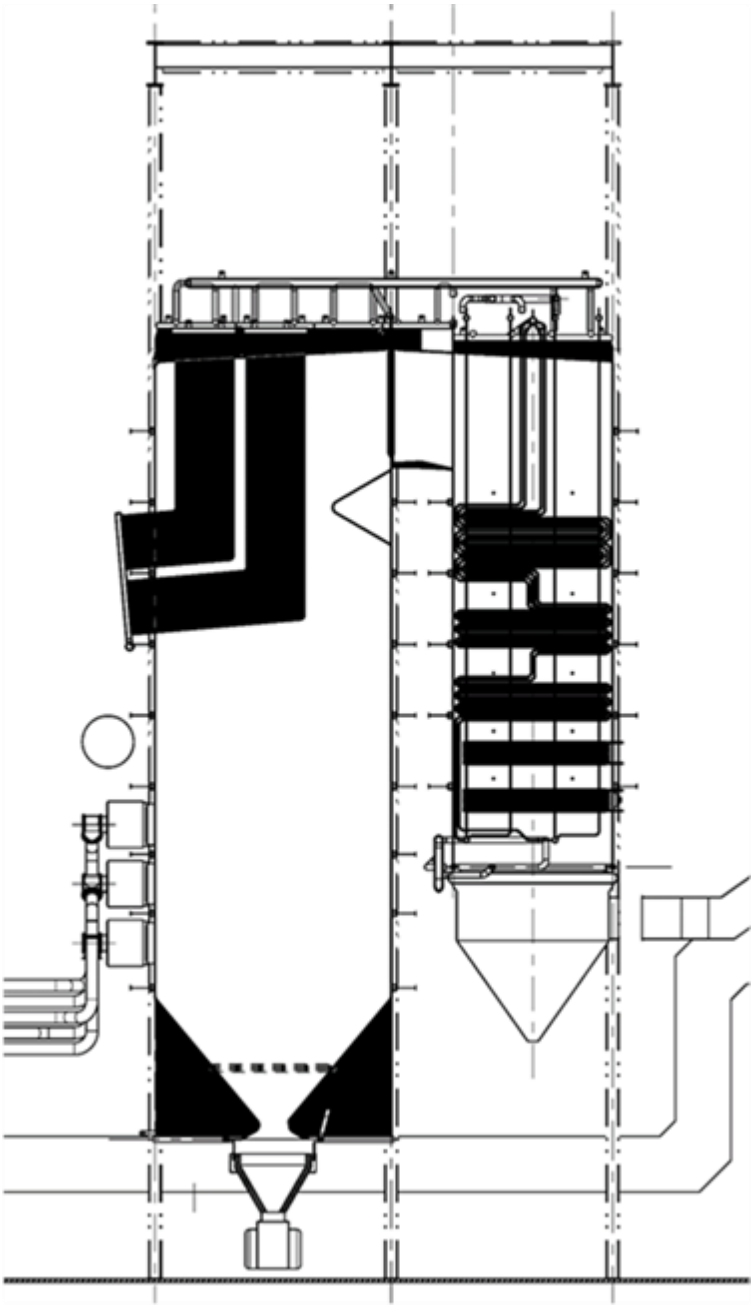


Figure 38: Commercial scale up – heater layout (right hand side view)

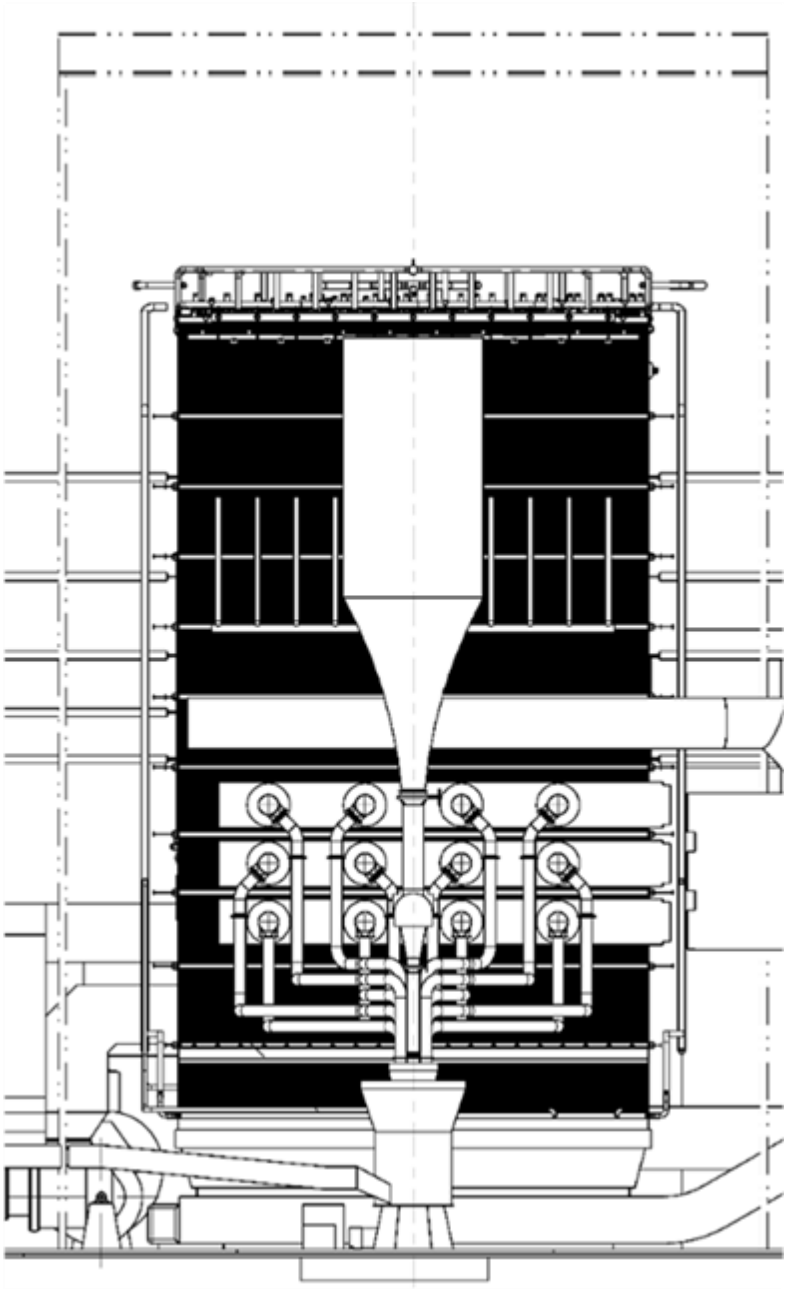


Figure 39: Commercial scale up – heater layout (front view)

AQCS equipment selection is consistent with the pilot plant, including SCR, CDS, and PJFF. Air preheat replaces much of the economizer surface as pulverized coal will allow for

higher air temperatures. See Figure 40 for a conceptual arrangement of RPI's full scope, from coal mills to flue gas discharge.

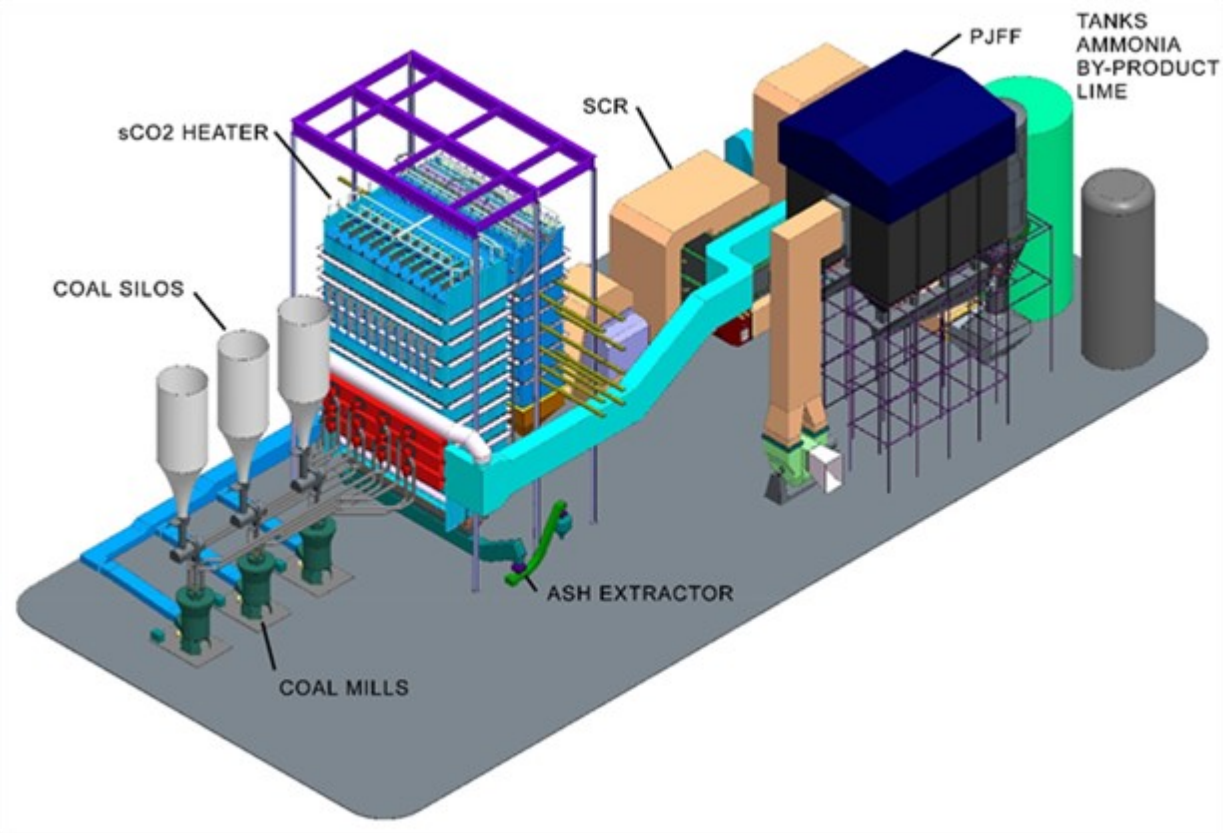


Figure 40: Commercial scale up – plant layout concept

1.E.ii. Performance Design Basis

In Figure 41, a process flow diagram identifies power cycle state points corresponding to the design point process conditions (Table 35). Following are additional design point summaries: Table 36 lists design data for the turbomachinery and heat exchangers, Table 37 lists system power loads, and Table 38 lists system efficiencies.

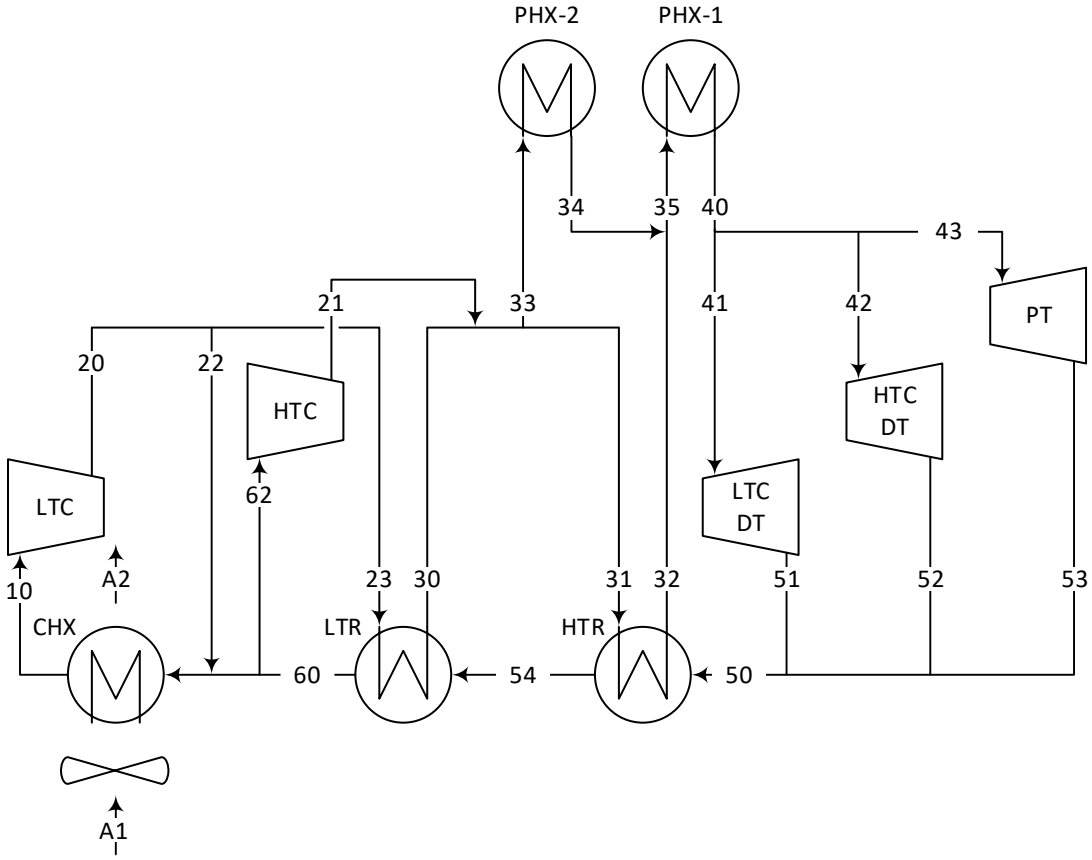


Figure 41: Power cycle process flow diagram with state points identified (air cooled).

Table 35: Design point process conditions at each state point (commercial scale)

State	Description	Temp. (°C)	Pressure (MPa)	Flow (kg/s)	Enthalpy (kJ/kg)
10	CHX Outlet - LTC Inlet	21.3	6.46	702.23	257.0
20	LTC Outlet	45.6	26.00	702.23	283.5
21	HTC Outlet	181.5	25.68	461.47	553.0
22	Bearings & Seals	45.6	26.00	24.00	283.5
23	LTR High Pressure Inlet	45.6	25.97	678.23	283.5
30	LTR High Pressure Outlet	186.4	25.68	678.23	560.5
31	HTR High Pressure Inlet	184.3	25.61	1087.89	557.5
32	HTR High Pressure Outlet	418.8	25.41	1087.89	867.5
33	PHX2 Inlet	184.3	25.63	51.81	557.5
34	PHX2 Outlet	470.0	25.33	51.81	931.5
35	PHX1 Inlet	421.0	25.33	1139.70	870.4
40	PHX1 Outlet	600.0	23.63	1139.70	1095.4
41	LTC Turbine Inlet	600.0	23.53	117.55	1095.4
42	HTC Turbine Inlet	600.0	23.53	239.87	1095.4
43	Power Turbine Inlet	600.0	23.53	782.29	1095.4
50	HTR Low Pressure Inlet	452.3	6.96	1139.70	929.8
51	LTC Turbine Outlet	458.8	7.06	117.55	937.2
52	HTC Turbine Outlet	455.9	7.06	239.87	933.8
53	Power Turbine Outlet	450.4	7.06	782.29	927.4
54	HTR Low Pressure Outlet	191.0	6.86	1139.70	633.8
60	LTR Low Pressure Outlet	56.2	6.71	1139.70	469.0
61	CHX Inlet	51.8	6.64	702.23	462.6
62	HTC Inlet	55.6	6.64	461.47	469.0
A1	Air Inlet	15.0	0.00	12635.96	2529.3
A2	Air Outlet	26.4	0.00	12635.96	2550.5

Table 36: Design data for turbomachinery (shaft power and efficiency for each component) and heat exchangers (duty and effectiveness for each component) (commercial scale)

Component	Duty (kW) – (kW/°C)	Efficiency / Effectiveness
LTC - Shaft Power (T – C)	18,600 – 18,600	86.5% – 88.9%
HTC - Shaft Power (T – C)	38,763 – 38,763	88.3% – 87.4%
PT - Shaft Power	131,479	91.8%
CHX - Heat Transferred – UA	144,383 – 21,033	90.7%
HTR - Heat Transferred – UA	337,296 – 15,649	97.5%
LTR - Heat Transferred – UA	187,867 – 23,276	97.6%
PHX1 - Heat Transferred – UA	256,482 –	
PHX2 - Heat Transferred – UA	19,380 – 156	84.5%

Table 37: Design power loads (commercial scale)

Load	Loss (kW_e)	Power (kW_e)
Power Turbine Shaft Power		131,479
Gearbox & Generator Losses	-1,677	
Generator Power		129,802
Air-cooled Condenser Fan	-3,466	
Primary Air Fan	-1,266	
Forced Draft Fan	-966	
Induced Draft Fan	-2,052	
Pulverizer Seal Air Fan	-121	
Pulverizers	-566	
Atomizer	-262	
Turbine Auxiliaries	-158	
Transformer Losses	-444	
Miscellaneous Balance of Plant	-500	
System Net Power		120,000

Table 38: Design system efficiencies (commercial scale)

System	Energy In (kW)	Energy Out (kW)	Efficiency
Fired Heater	328,407	275,862	84.0%
Power Cycle (gross)	275,862	129,802	47.1%
Power Cycle (net)	275,862	120,000	43.5%
Overall Plant	328,407	120,000	36.5%

Based on preliminary estimates from RPI, the estimated thermal efficiency of the fired heater was 84.0%. The gross power cycle thermal efficiency is 47.1%, with a net efficiency (debiting parasitic loads) of 43.5%. The overall plant efficiency is 36.5% based on the higher heating value (HHV) of the fuel input to the fired heater.

1.E.iii. Cost Design Basis

This section describes the basis for estimating capital and O&M costs for the commercial-scale design.

1.E.iii.a. Site-Related Conditions

The assumed site location for this project is a generic plant site in Midwestern U.S. The site is typical of Midwestern power generation facilities and has access to rail or highway transportation. The site is assumed to be clear and level with no special problems; however, 30-m (98.4-ft) pile foundations are required. The site is in Seismic Zone 0 at an elevation of 180 m (590.6 ft) above mean sea level.

For all cases, a raw water supply is available within 10 km (6.2 miles) of the site. Ash disposal is assumed to be off-site. The design is based on indoor construction.

1.E.iii.b. Site Ambient Conditions

Annual average ambient air conditions for material balances, thermal efficiencies, and equipment sizing are in Table 39.

Table 39: Annual average ambient conditions

Description	Value
Dry-bulb temperature [1]	15°C (59°F)
Atmospheric pressure [1]	0.99 bar (14.4 psia)
Minimum dry-bulb temperature	
1% coldest month	-6.7°C (20°F)
99% cold day	-18.9°C (-2°F)
Record cold day, record low design limit	-35°C (-31°F)
Maximum dry-bulb temperature	
0.4% hot day	32°C (89°F)
1% hot day	30°C (86°F)
2% hot day	28°C (83°F)
Relative humidity [1]	60%

[1] Reference air conditions for plant performance evaluation.

1.E.iv. Technical Data

Common technical data include:

- The nominal net power production of the plant is 120 MW_e.
- The design fuels are Montana Rosebud sub-bituminous coal and Illinois #6 Bituminous coal with the characteristics and analyses presented in Table 40.
- The backup and startup fuel is natural gas (NG). The characteristics of the NG are presented in Table 41.
- The main electric power product of the plant is produced at the following conditions:
    - Voltage: 345 kV
    - Frequency: 60 Hz
- Coal is delivered to the site by rail.

- The coal storage pile is sized for 45 days of storage.
- Onsite emergency ash storage is sized for 90 days. Final disposal is off site.
- Other balances-of-plant criteria are shown in Table 42.

Table 40: Design coal analyses

	Sub-Bituminous Montana Rosebud		**Bituminous Illinois #6**	
Proximate Analysis, wt %				
	As Received	Dry	As Received	Dry
Moisture	25.77	0.00	11.12	0.00
Ash	8.19	11.04	9.70	10.91
Volatile Matter	30.34	40.87	34.99	39.37
Fixed Carbon	35.70	48.09	44.19	49.72
Total	100.00	100.00	100.00	100.00
HHV, kJ/kg (Btu/lb)	19,920 (8,564)	26,787 (11,516)	27,113 (11,666)	30,506 (13,126)
LHV, kJ/kg (Btu/lb)	19,195 (8,252)	25,810 (11,096)	26,151 (11,252)	29,544 (12,712)
Ultimate Analysis, wt %				
	As Received	Dry	As Received	Dry
Moisture	25.77	0.00	11.12	0.00
Carbon	50.07	67.45	63.75	71.72
Hydrogen	3.38	4.56	4.50	5.06
Nitrogen	0.71	0.96	1.25	1.41
Chlorine	0.01	0.01	0.29	0.33
Sulfur	0.73	0.98	2.51	2.82
Ash	8.19	10.91	9.70	10.91
Oxygen	11.14	15.01	6.88	7.75
Total	100.00	100.00	100.00	100.00

Table 41: Natural gas composition

Components		Volume Percentage
Methane	CH_4	93.9
Ethane	C_2H_6	3.2
Propane	C_3H_8	0.7
n-Butane	C_4H_{10}	0.4
Carbon Dioxide	CO_2	1.0
Nitrogen	N_2	0.8
Sulfur	S	0.0004
Total		*100.0*
Units	**LHV**	**HHV**
kJ/m^3	34.99	38.75
Btu/scf	939.2	1040.2

Table 42: Balance-of-plant criteria

Cooling System	
Cooling System	Forced Air Cooling
Plant Distribution Voltage	
Motors below 745 W (1 hp)	110/220 volts
Motors 186 kW (250 hp) and below	480 volts
Motors above 186 kW (250 hp)	4160 volts
Motors above 3.7 MW (5000 hp)	13,800 volts
Steam and Gas Turbine Generators	24,000 volts
Grid Interconnection Voltage	345 kV

1.E.v. Costing Methodology

1.E.v.a. Capital Cost Estimating Basis

Capital costs are reported in June 2019 dollars (base-year dollars) to put them on a consistent and up-to-date basis. Construction costs at the reference site were based on union labor. (National Energy Technology Laboratory economic studies typically assume non-union labor rates. Union labor rates were chosen to better match up with conditions in 2019 and based on other studies performed by EPRI.)

For cost-estimating purposes, the plants are generally assumed to be in a “mature” state of development, meaning that no extra equipment or costs are included to account for unit malfunction or extra equipment outages. Also, costs associated with extra facilities needed for demonstration of first commercial plants are not normally reflected in the cost estimates.

As illustrated in Figure 42, this study reports capital cost at four levels: Bare Erected Cost (BEC), Total Plant Cost (TPC), Total Overnight Cost (TOC), and Total As-spent Capital (TASC). BEC, TPC, and TOC are “overnight” costs and are expressed in “base-year” dollars. The base year is the first year of capital expenditure, which for this study is 2019. TASC is expressed in mixed-year, current-year dollars over the entire capital expenditure period, which is assumed to last five years for coal plants (2019 to 2023).

BEC comprises the cost of delivered process equipment, on-site facilities, and infrastructure that support the plant (e.g., shops, offices, labs, roads), and the direct and indirect labor required for its construction and/or installation. The cost of EPC services and contingencies are not included in BEC. BEC is an overnight cost expressed in base-year dollars.

TPC comprises the BEC plus the cost of services provided by the EPC contractor and project and process contingencies. EPC services include detailed design, contractor permitting (i.e., permits that individual contractors must obtain to perform their scopes of work, as opposed to project permitting, which is not included), and project/construction management costs. TPC is an overnight cost expressed in base-year dollars.

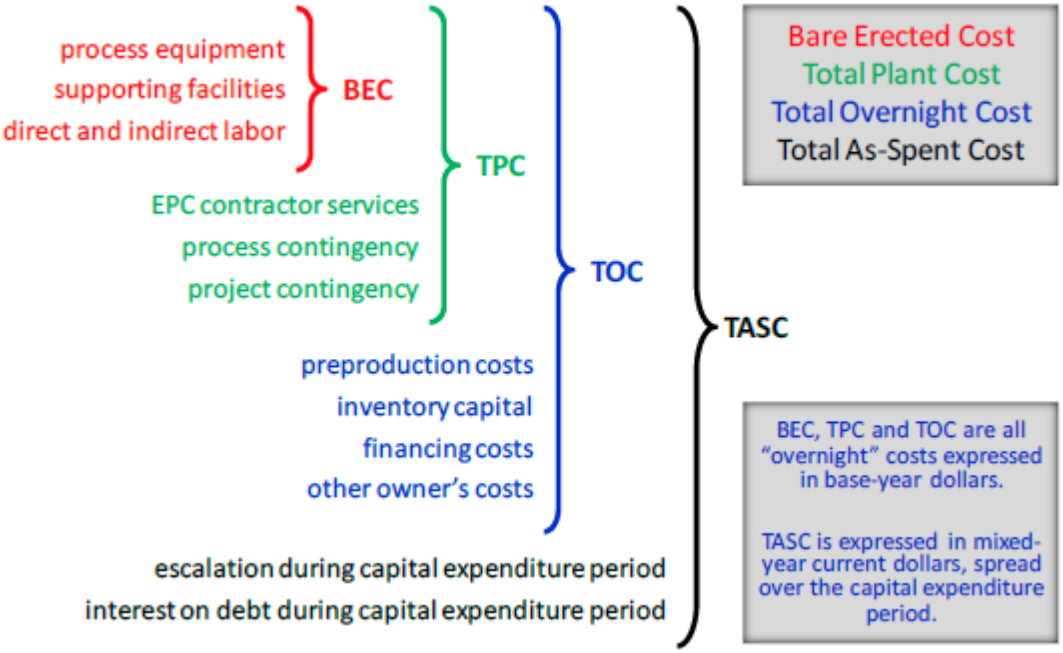


Figure 42: Capital cost levels and their elements

TOC comprises the TPC plus owner's costs. TOC is an "overnight" cost, expressed in base-year dollars, and as such does not include escalation during construction or interest during construction. TOC is an overnight cost expressed in base-year dollars. TOC is calculated using a simple multiplier on TPC. The multiplier used for this study was 1.23.

TASC is the sum of all capital expenditures as they are incurred during the capital expenditure period including their escalation. TASC also includes interest during construction. Accordingly, TASC is expressed in mixed, current-year dollars over the capital expenditure period. TASC is also calculated using a simple multiplier, this time on TOC. The multiplier of 1.154 used for this study was taken from DOE / National Energy Technology Laboratory (NETL) guidelines for five-year construction projects [15].

1.E.v.b. Cost Estimate Classification

Recommended Practice 18R-97 of the AACE describes a Cost Estimate Classification System as applied in EPC for the process industries. The capital cost estimates for the commercial scale plants in this study shall be classified as an AACE Class 4 Conceptual/Screening Study. Typical accuracy ranges for AACE Class 4 estimates are -15% to -30% on the low side, and +20% to +50% on the high side. Table 43 describes the characteristics of an AACE Class 4 Cost Estimate [16].

Table 43: AACE Class 4 estimate description

CLASS 4 ESTIMATE	
Description: Class 4 estimates are generally prepared based on limited information and subsequently have fairly wide accuracy ranges. They are typically used for project screening, determination of feasibility, concept evaluation, and preliminary budget approval. Typically, engineering is from 1% to 15% complete, and would comprise at a minimum the following: plant capacity, block schematics, indicated layout, process flow diagrams (PFDs) for main process systems, and preliminary engineered process and utility equipment lists. **Maturity Level of Project Definition Deliverables:** Key deliverable and target status: Process flow diagrams (PFDs) issued for design. 1% to 15% of full project definition. **End Usage:** Class 4 estimates are prepared for a number of purposes, such as but not limited to, detailed strategic planning, business development, project screening at more developed stages, alternative scheme analysis, confirmation of economic and/or technical feasibility, and preliminary budget approval or approval to proceed to next stage.	**Estimating Methodology:** Class 4 estimates generally use factored estimating methods such as equipment factors, Lang factors, Hand factors, Chilton factors, Peters-Timmerhaus factors, Guthrie factors, the Miller method, gross unit costs/ratios, and other parametric and modeling techniques. **Expected Accuracy Range:** Typical accuracy ranges for Class 4 estimates are -15% to -30% on the low side, and +20% to +50% on the high side, depending on the technological complexity of the project, appropriate reference information, and other risks (after inclusion of an appropriate contingency determination). Ranges could exceed those shown if there are unusual risks. **Alternate Estimate Names, Terms, Expressions, Synonyms:** Screening, top-down, feasibility (pre-feasibility for metals processes), authorization, factored, pre-design, pre-study.

1.E.v.c. System Code of Accounts

The costs are grouped according to a process/system-oriented code of accounts. Consistent with other DOE/NETL economic studies, 14 accounts are used as shown in Table 43.

Table 44: Accounts for the capital costs

1 COAL & SORBENT HANDLING
1.1 Coal Receive & Unload
1.2 Coal Stackout & Reclaim
1.3 Coal Conveyors
1.4 Other Coal Handling
2 COAL & SORBENT PREP & FEED
2.1 Fuel System: Coal Feeders, Coal Mills, Coal Pipe, Burners, Natural Gas Skids
2.2 Fired Heater Fuel System Foundations
3 FEEDWATER & MISC. BOP SYSTEMS
(not used)
4 PC BOILER & ACCESSORIES
4.1 Furnace and Radiant Platens, Convective and Economizer Elements, Air Preheaters, Dry Ash System, Soot blowers, Heater Intimate Steel.
4.2 Fans – Forced Draft, Primary Air, and Booster Fan
4.3 Major Component Rigging
4.4 Fired Heater & Accessories Foundations and Support Steel
4.5 Fired Heater Ducting: Combustion Air, Flue Gas
5 FLUE GAS CLEANUP
5.1 Circulating Dry Scrubber: Scrubber Vessel, Lime System, Water System, Air System, Air Slide – Product Recirculation
5.2 Selective Catalytic Reduction (SCR)
5.3 Bag House & Accessories
5.4 Installation, foundations, stack, and support steel
5B CO_2 REMOVAL & COMPRESSION
(not used)
6 COMBUSTION TURBINE/ACCESSORIES
(not used)
7 HRSG
(not used)

8B sCO2 POWER CYCLE
8B.1 Compressor (High and Low Temperature)
8B.2 Internal Recuperation (HTR and LTR)
8B.3 CO2 Air-Cooled Condenser
8B.4 CO2 Power Turbine (Includes 130 MW generator and turbine throttle valve)
8B.5 System Piping and Valves
8B.6 CO2 System Foundations, Storage Tanks, and Utility Rack
9 COOLING WATER SYSTEM
(not used)
10 ASH/SPENT SORBENT HANDLING SYS
10.6 Ash Storage Silos
10.7 Ash Transport & Feed Equipment
10.9 Ash/Spent Sorbent Foundations and Steel
11 ACCESSORY ELECTRIC PLANT
11.1 Generator Equipment
11.3 Switchgear & Motor Control
11.5 Wire & Cable
11.8 Main Power Transformers
11.9 Electrical Foundations
12 INSTRUMENTATION & CONTROL
12.1 Fired Heater Control Equipment
12.2 Combustion Turbine Control
12.3 sCO2 Power Cycle Control
12.4 Signal Processing Equipment
12.6 Distributed Control System Equipment
12.8 Other I & C Equipment
13 IMPROVEMENTS TO SITE
13.1 Site Preparation
13.2 Site Improvements
13.3 Site Facilities
14 BUILDINGS & STRUCTURES
14.1 Boiler Building
14.2 Turbine Building (Gas Turbine)
14.3 Administration Building
14.4 Circulation Water Pumphouse
14.5 Water Treatment Buildings
14.7 Warehouse
14.8 Other Buildings & Structures (sCO2 Cycle)

Note that there is some variation in Account 8 to account for the differences between a steam and sCO_2 power cycle. This type of code-of-account structure has the advantage of grouping all reasonably allocable components of a system or process, so they are included in the specific system account. In addition, costs for each code of account are further broken down into major equipment cost, material cost, and labor cost. Labor cost includes both direct and indirect costs.

1.E.v.d. Plant Maturity

Cost estimates in this report reflect the cost of the next commercial offering for plants that include technologies that are not yet fully mature and/or which have not yet been deployed in a commercial context. These cost estimates for next commercial offerings include the unique cost premiums typically associated with first-of-a-kind (FOAK) plants that must demonstrate emerging technologies and resolve the cost and performance challenges associated with initial deployments. Note that these FOAK cost estimates do utilize currently available cost bases for emerging technologies. Process contingencies applied to the appropriate subsystem levels were derived from the AACE guidelines shown in Table 45.

Cost estimates were also developed for Nth-of-a-kind (NOAK) plants utilizing both coal feedstocks. These NOAK estimates assume no process contingencies are required. In addition, learning rates and reduced engineering costs were assumed for key components such as the fired heater and sCO_2 power cycle recuperators.

Cost estimates for all the plants and components, regardless of technology maturity, are based on design assumptions that affect costs, including the use of a favorable site with no

unusual characteristics. The primary value of this report lies not in the absolute accuracy of cost estimates for the individual cases, but in the fact that all cases were evaluated using a common methodology with an internally consistent set of technical and economic assumptions. This consistency of approach allows meaningful comparisons of relative costs among the cases evaluated.

1.E.v.e. Contracting Strategy

The estimates are based on an EPC approach utilizing multiple subcontracts. This approach provides the owner with greater control of the project, while minimizing, if not eliminating, most of the risk premiums typically included in an EPC contract price.

In a traditional lump sum EPC contract, the contractor assumes all risk for performance, schedule, and cost. However, as a result of current market conditions, EPC contractors appear more reluctant to assume that overall level of risk. Rather, the current trend appears to be a modified EPC approach, where much of the risk remains with the owner. Where contractors are willing to accept the risk in EPC type lump-sum arrangements, it is reflected in the project cost. In today's market, contractor premiums for accepting these risks, particularly performance risk, can be substantial and increase the overall project costs dramatically.

This approach is anticipated to be the most cost-effective approach for the owner. While the owner retains the risks, the risks become reduced with time, as there is better scope definition at the time of contract award(s).

1.E.v.f. Battery Limits for Capital Cost Estimate

The estimates represent a complete power plant facility on a generic site. The plant boundary limit is defined as the total plant facility within the "fence line" including coal receiving and water supply system but terminating at the high-voltage side of the main power transformers. Coal transportation cost is not included in the reported capital or O&M costs (storage and coal handling maintenance are, however).

1.E.v.g. Labor Rates

The all-in union construction craft labor rate for the Midwestern U.S. site is assumed to be $81.28/hour.

The estimates are based on a competitive bidding environment with adequate skilled craft labor available locally. Labor is based on a 50-hour work week (five x 10-hour days).

1.E.v.h. Exclusions

The capital cost estimate includes all anticipated costs for equipment and materials, installation labor, professional services (engineering and construction management), and contingency. The following items are excluded from the capital costs:

- All taxes except for payroll and property
- Site-specific considerations – including, but not limited to, seismic zone, accessibility, local regulatory requirements, excessive rock, piles, laydown space, etc.
- Labor incentives
- Additional premiums associated with an EPC contracting approach

1.E.v.i. Contingency

Process and project contingencies are included in estimates to account for unknown costs that are omitted or unforeseen due to a lack of complete project definition and engineering. Contingencies are added because experience has shown that such costs are likely, and expected, to be incurred even though they cannot be explicitly determined at the time the estimate is prepared. Capital cost contingencies do not cover uncertainties or risks associated with:

- Changes in labor availability or productivity
- Changes in regulatory requirements
- Delays in equipment deliveries
- Performance of the plant after startup (e.g., availability and efficiency)
- Scope changes
- Unexpected cost escalation

1.E.v.i.1. Process Contingency

Process contingency is intended to compensate for uncertainty in costs caused by performance uncertainties associated with the development status of a technology. Process contingency is applied to each component based on its current technology status.

As shown in Table 45, AACE International Recommended Practice 16R-90 provides guidelines for estimating process contingencies.

Table 45: AACE guidelines for process contingency

Technology Status	Process Contingency (% of Associated Process Capital)
New Concept with Limited Data	40+
Concept with Bench-Scale Data	30–70
Small Pilot Plant Data	20–35
Full-sized Modules Have Been Operated	5–20
Process Is Used Commercially	0–10

1.E.v.i.2. Project Contingency

The project contingency is a capital cost contingency factor covering the cost of additional equipment or other costs that would result from a more detailed design of a definitive project at an actual site. AACE 16R-90 states that project contingency for a "feasibility" estimate (AACE Class 4) should be 15 to 20% of the sum of BEC, EPC fees, and process contingency.

1.E.v.j. Owner's Costs

Owner's costs include:

- Initial cost for catalyst and chemicals
- Inventory capital (fuel storage, consumables, etc.)
- Land
- Prepaid royalties or license fees
- Preproduction (or startup) costs

Royalty charges or license fees may apply to some portions of generating units incorporating new technologies. If known, royalty charges must be included in the capital requirement.

Preproduction costs cover operator training, equipment checkout, major changes in unit equipment, extra maintenance, and inefficient use of fuel and other materials during startup. For this project's purposes, pre-production costs were estimated as follows:

- One month fixed operating costs (O&M labor, administrative and support labor, and maintenance materials). In some cases, this could be as high as two years of fixed operating costs due to new staff being hired two years before commissioning.
- One to three months of variable operating costs (consumables) at full capacity, excluding fuel. (These variable operating costs include chemicals, water, and other consumables plus waste disposal charges.)
- 25% of full-capacity fuel cost for one month. This charge covers inefficient operation that occurs during the startup period.
- 2% of TPC. This charge covers expected changes and modifications to equipment that will be needed to bring the unit up to full capacity.
- Value of inventories of fuels, consumables, and by-products was capitalized
- An allowance for spare parts of 0.5% of the TPC
- The initial cost of any catalyst or chemicals contained in the process equipment (but not in storage, which is covered in inventory capital)
- A nominal cost of $7413/hectare ($3000/acre) for land.

Tables 46 and 47 summarize the procedure for estimating owner's costs. The methodology is defined by the U.S. DOE / NETL guidelines and mostly follows the guidelines from Sections 12.4.7 to 12.4.12 of AACE International Recommended Practice No. 16R-90 [17].

Table 46: Estimation method for owner's costs (part 1)

Owner's Cost	Estimate Basis
Prepaid Royalties	Any technology royalties are assumed to be included in the associated equipment cost, and thus are not included as an owner's cost.
Preproduction (Start-Up) Costs	•6 months operating labor •1-month maintenance materials at full capacity •1-month non-fuel consumables at full capacity •1-month waste disposal •25% of one month's fuel cost at full capacity •2% of TPC. Compared to AACE 16R-90, this includes additional costs for operating labor (6 months vs. 1 month) to cover the cost of training the plant operators, including their participation in startup, and involving them occasionally during the design and construction. AACE 16R-90[1] and EPRI's Technical Assessment Guide (TAG)[2] differ on the amount of fuel cost to include; this estimate follows EPRI.
Working Capital	Although inventory capital is accounted for, no additional costs are included for working capital.
Inventory Capital	•0.5% of TPC for spare parts •60-day supply (at full capacity) of fuel. Not applicable for NG. •60-day supply (at full capacity) of non-fuel consumables (e.g., chemicals and catalysts) that are stored on site. Does not include catalysts and adsorbents that are batch replacements such as water-gas shift, carbonyl sulfide, and selective catalytic reduction catalysts and activated carbon. AACE 16R-90 does not include an inventory cost for fuel, but EPRI's TAG does.
Land	•$3000/acre (300 acres for coal; 100 acres for NG) •Note: This land cost is based on a site in a rural location.
Financing Cost	•2.7% of TPC This financing cost (not included by AACE 16R-90) covers the cost of securing financing, including fees and closing costs but not including interest during construction (or Allowance for Funds Used During Construction). The "rule of thumb" estimate (2.7% of TPC) is based on a communication with Black & Veatch.

[1] "Conducting Technical and Economic Evaluations – as Applied for the Process and Utility Industries TCM Framework: 3.2 – Asset Planning, 3.3 – Investment Decision Making," AACE International Recommended Practice No. 16R-90, 1991.

[2] "Technical Assessment Guide (TAG®) – Power Generation and Storage Technology Options," EPRI, Palo Alto, CA, 2009. 1017465.

Table 47: Estimation method for owner's costs (part 2)

Owner's Cost	Estimate Basis
Other Owner's Costs	•15% of TPC This additional lumped cost is not included by AACE 16R-90 or EPRI's TAG. The "rule of thumb" estimate (15% of TPC) is based on a communication with Black & Veatch. The lumped cost includes: •Preliminary feasibility studies, including a front-end engineering design study •Economic development (costs for incentivizing local collaboration and support) •Construction and/or improvement of roads and/or railroad spurs outside of site boundary •Legal fees •Permitting costs •Owner's engineering (staff paid by owner to give third-party advice and to help the owner oversee/evaluate the work of the EPC contractor and other contractors) •Owner's contingency (sometimes called "management reserve" — these are funds to cover costs relating to delayed startup, fluctuations in equipment costs, and unplanned labor incentives in excess of a five-day/ten-hour-per-day work week. Owner's contingency is not a part of project contingency) This lumped cost does not include: •EPC risk premiums (costs estimates are based on an EPC Management approach utilizing multiple subcontracts, in which the owner assumes project risks for performance, schedule, and cost) •Transmission interconnection: the cost of interconnecting with power transmission infrastructure beyond the plant busbar •Taxes on capital costs: all capital costs are assumed to be exempt from state and local taxes •Unusual site improvements: normal costs associated with improvements to the plant site are included in the BEC, assuming that the site is level and requires no environmental remediation. Unusual costs associated with the following design parameters are excluded: flood plain considerations, existing soil/site conditions, water discharges and reuse, rainfall/snowfall criteria, seismic design, buildings/enclosures, fire protection, local code height requirements, and noise regulations.

1.E.v.k. O&M Costs

O&M costs are to be estimated for a year of normal operation and presented in the base-year dollars. O&M costs for a generating unit are generally allocated as fixed and variable O&M costs.

Fixed O&M costs are essentially independent of actual capacity factor, number of hours of operation, or amount of kilowatts produced, and are expressed in $/kW-year. Fixed O&M costs are composed of the following components:

- Operating labor
- Total maintenance costs (may also have a variable component)
- Overhead charges

Taxes and insurance are considered as fixed O&M costs and are estimated as 2% of the total plant cost.

Variable O&M costs and consumables are directly proportional to the number of kilowatts produced. They are generally in mills/kW-hour.

The estimation of these cost components is discussed below.

1.E.v.k.1. Operating Labor

Operating labor is based on the number of personnel required to operate the plant per shift. The total operating cost is based on the labor rate, supervision, and overhead.

1.E.v.k.2. Total Maintenance Costs

Annual maintenance costs for new technologies were estimated as a percentage of the TPC of the facilities. The percentage varies widely, depending on the nature of the processing conditions and the type of design. The ranges shown in Table 48 are representative. The percentage approach described here is recommended for use when vendor-specific O&M data are not available. For this project, the resulting overall maintenance percentage was 1.5% of TPC/year.

Table 48: Maintenance as a percentage of total plant cost

Type of Processing Conditions	Maintenance % of TPC/Year [1]
Corrosive and Abrasive Slurries	5–10+
Severe (solids, high-pressure, and temperature)	3–6+
Clean (liquids and gases only)	1.5–4
General Facilities and Steam Electrical Systems	1–3

[1] Minimum capital cost plants will generally experience maintenance costs at the high end of the range.

Estimates are separately expressed as maintenance labor and maintenance materials. A maintenance labor-to-materials ratio of 40:60 was used for this project.

The percentage approach described above is recommended for use when vendor-specific O&M data are not available.

1.E.v.k.3. Overhead Charges

The only overhead charge to be included in power plant studies is a charge for administrative and support labor, which is taken as 25% of the O&M labor.

1.E.v.k.4. Consumables

Consumables are the principal components of variable O&M costs. These include water, catalysts, chemicals, solid waste disposal, and other materials that are consumed in proportion to energy output. Costs for consumable items are shown in Table 49.

Table 49: Cost data for consumable items

Consumables and Variable Cost Items	Unit Cost
H_2O and Chemicals	
Raw Water, $/1000 liters	0.45
Ammonia (aqueous 29.4% weight), $/tonne	194
Sorbent (Delivered)	
Lime, $/tonne	155
Dry Disposal	
Bottom and Fly Ash, $/tonne	15

1.E.v.l. Financial Structure Selection

The financial structure for this study was based on a 5-year capital expenditure period, as specified in the DOE/NETL guidelines. The financial structure for is shown in Table 50.

Table 50: Nominal and real rates financial structure for investor-owned utility

Type of Security	% of Total	Current-Dollar Cost	Weighted Average Cost of Capital	After-Tax Weighted Average Cost of Capital
Nominal				
Debt	55%	5%	2.75%	2.04%
Equity	45%	10%	4.50%	4.50%
Total			7.25%	6.54%
Real (based on 2.01% average real Gross Domestic Product deflator, 1990–2018 [1])				
Debt	55%	2.94%	1.61%	1.20%
Equity	45%	7.84%	3.53%	3.53%
Total			5.14%	4.73%

[1] "Real Gross Domestic Product [GDPC1]," U.S. Bureau of Economic Analysis, Federal Reserve Bank of St Louis. https://fred.stlouisfed.org/series/GDPC1/.

1.E.v.m. Global Economic Assumptions

Table 51 summarizes the global economic assumptions specified in the DOE/NETL guidelines and used for evaluating the economic performances of the cases in this study.

Table 51: Global economic assumptions

Parameter	Value
Taxes	
Income Tax Rates	21% federal, 6% state (effective tax rate of 25.74%)
Capital Depreciation	20 years, 150% declining balance
Investment Tax Credit	0%
Tax Holiday	0 years
Contracting and Financing Terms	
Contracting Strategy	EPC Management (owner assumes project risks for performance, schedule, and cost)
Type of Debt Financing	Non-recourse (collateral that secures debt is limited to the real assets of the project)
Repayment Term of Debt	Equal to operational period in formula method
Grace Period on Debt Repayment	0 years
Debt Reserve Fund	None
Analysis Time Periods	
Capital Expenditure Period	NG plants: 3 years; Coal plants: 5 years
Operational Period	30 years
Economic Analysis Period	33 or 35 years (capital expenditure period plus operational period)
Treatment of Capital Costs	
Capital Cost Escalation During Capital Expenditure Period	0% real (3% nominal)
Distribution of Total Overnight Capital over the Capital Expenditure (before escalation)	3-year period: 10%, 60%, 30% 5-year period: 10%, 30%, 25%, 20%, 15%
Working Capital	Zero for all parameters
% of Total Overnight Capital Depreciated	100% (actual amounts are likely lower and do not influence results significantly)
Escalation of Operating Costs and Revenues	
Escalation of COE (revenue), O&M Costs	0% real (3% nominal) [1]
Fuel Costs	See “Quality Guidelines for Energy Systems Studies Fuel Prices for Selected Feedstocks” in NETL studies

[1] “The Handy-Whitman Index of Public Utility Construction Costs, 1912 to January 1 2018,” Whitman, Requardt & Associates, LLP, 2018.

1.E.v.n. Cost of Electricity

The first-year COE (or power cost) is the revenue received by the generator per net MWh during the first year of operation assuming that the COE escalates at a nominal annual rate equal to the general inflation rate (i.e., remains constant in real terms over the operational period of the plant). The levelized cost of electricity (LCOE) is the revenue received by the generator per net MWh during the first year of operation assuming that the first year of operation COE escalates at a nominal annual rate of 0% (i.e., remains constant in nominal terms over the operation period of the plant). NETL's Power Systems Financial Model (PSFM) provides a reference for COE calculations. The model accepts all the economic assumptions outlined in Table 50 and Table 51, along with specific information on the capital cost and fixed/variable O&M costs.

The approach used to calculate the first-year power costs is described below.

1.E.v.n.1. Estimating COE Using Formulas

The following simplified equation is used to estimate COE as a function of TASC, fixed O&M, variable O&M, fuel costs, capacity factor, and net output. The equation requires the application of fixed charge rates (FCR), which are based on the capital recovery factors (CRF). These FCRs and CRFs are valid only for scenarios that adhere to the global economic assumptions listed in Table 51 and utilize the stated finance structure listed in Table 50 and the stated capital expenditure period. The formulas for calculating FCR and CRF values based on other assumptions are shown below in the equations below. The formulas for calculating the FCR values include an adjustment to the CRF value to account for depreciation.:

$$COE = [\,(FCR)(TASC) + OC_{FIX} + (CF)OC_{VAR}\,] / (CF)\,(MWh)$$

where:

- COE = revenue received by the generator ($/MWh) during the power plant's first year of operation (expressed in 2019 dollars), if the COE escalates at a nominal annual rate equal to the general inflation rate; i.e., that it remains constant in real terms over the operational period of the power plant
- FCR = fixed charge rate based on CRF values that matches the finance structure and capital expenditure period. The interest rate used in the formula must by necessity be the After-Tax Weighted Average Cost of Capital (ATWACC)
- $TASC$ = total as spent capital expressed in on-line year cost in 2019 dollars
- OC_{FIX} = the sum of all fixed annual operating costs in 2019 dollars
- OC_{VAR} = the sum of all variable annual operating costs, including fuel at 100% capacity factor, in 2019 dollars
- CF = plant capacity factor, assumed to be constant over the operational period
- MWh = annual net megawatt-hours of power generated at 100% capacity factor.

Based on the economic factors specified by the DOE, the FCR for a five-year capital expenditure period is 0.0707.

1.E.vi. Overall Plant Performance

The overall plant performance for both the sub-bituminous and bituminous design coals is summarized in Table 52 below. The first column for each design coal shows the overall performance of the FOAK commercial plant, while the second column shows the projected

improvement in net power output and heat rate for the NOAK commercial plants. In all cases, natural gas is used for final temperature control in the fired heater. The quantity of natural gas required is assumed to be 5% by energy.

Table 52: Overall plant performance summary

	Sub-Bituminous (Montana Rosebud)		Bituminous (Illinois #6)	
	FOAK	**NOAK**	**FOAK**	**NOAK**
Net Power, MWe	118	120	118	120
Net Efficiency, % (HHV)	35.8	36.5	36.9	37.6
Net Heat Rate, Btu/kWh	9,542	9,351	9,255	9,077

1.E.vii. Capital and Operating Cost Estimates

This section provides details on how the specific costs were estimated for FOAK and NOAK commercial plant designs. These descriptions are then followed by the presentation of the capital and O&M costs for each case along with the LCOE.

1.E.vii.a. Cost Estimate Methodology for the Commercial Plants

An AACE Class 4 (Feasibility Study) cost estimate was developed based on guidelines from the NETL QGESS cost estimation methodology [15]. Equipment costs for the fired heater and air quality control system were provided by RPI. Installation costs for those equipment items were provided by CDM Smith. The sCO_2 power cycle equipment and installation costs were provided by EPS, with a significant portion of the equipment cost based on vendor quotes. The BOP costs were capacity factored from EPS's Coal FIRST plant with a 700°C sCO_2 power cycle (without CO_2 capture) (DE-FE0025959). The reference plant for this Coal FIRST BOP

capacity factoring was the sub-bituminous coal-fired NETL Baseline Case S12A. Scaling exponents were based on the NETL QGESS cost scaling methodology [18].

For the bituminous coal-fired plant, capital costs were factored from the sub-bituminous coal-fired plant. For the same fired heat duty, the fired heater efficiency for the bituminous coal case is 2.1 percentage points higher than for the sub-bituminous coal-fired plant. Flue gas flows are reduced by about 6%. Capital costs for the fired heater were scaled based on the lower flue gas flow rate. Coal and ash handling costs were factored by the ratio of the coal and ash flow rates, respectively. Flue gas desulfurization capital costs and limestone rates were factored based on the increased sulfur content of the bituminous coal. Scaling exponents were again based on the NETL QGESS methodology.

1.E.vii.b. First-of-a-Kind (FOAK) Cost Estimate Assumptions

The FOAK power turbine efficiency was assumed to be 2% points lower than for an Nth-of-a-kind (NOAK) plant, resulting in a net plant output of 118 MW and a net plant efficiency of 35.8% (HHV) for the sub-bituminous coal-fired plant, and 36.9% for the bituminous coal-fired plant. A 15% process contingency was included for the FOAK fired heater. Engineering costs for the sCO_2 turbomachinery (compressors and power turbine) were increased to 20%.

1.E.vii.c. NOAK Cost Estimate Assumptions

The NOAK power turbine efficiency is assumed to be 2% points higher, resulting in a net plant output of 120 MW, and net plant efficiencies of 36.5% and 37.6 % (HHV) respectively for the sub-bituminous and bituminous coal-fired plants. The 15% process contingency for the fired heater was eliminated. Other NOAK fired heater savings included an assumed learning rate of

0.95 (N = 20) applied to equipment and installation labor, and reduced engineering cost. Engineering costs for the sCO_2 turbomachinery (compressors and power turbine) were reduced to 9.3%. The NOAK recuperator equipment costs were reduced by 27% by assuming a learning rate of 0.93, with N = 20.

1.E.vii.d. Detailed Overall Plant Cost Estimate Results

The detailed capital cost estimates for the four commercial plants are shown in Appendix VIII.

1.E.vii.e. O&M Cost

Maintenance costs for feasibility studies are typically based on a percent of TPC for each plant area. The overall maintenance cost for the power plants in this study is assumed to be 1.5% of TPC/year. This is lower than for a conventional steam Rankine cycle power plant due to the reduced maintenance requirements of the sCO_2 power cycle. The maintenance cost is assumed to be 40% labor and 60% materials. Operating labor is based on six operating jobs per shift. Administrative and support labor is included at 25% of operating plus maintenance labor. Variable O&M includes maintenance materials plus major consumables cost. Fuel costs are based on the NETL QGESS fuel pricing report [19]. Delivered costs to the mid-western plant site for both the sub-bituminous and bituminous coals is $2.23/MMBtu, while the cost of natural gas is assumed to be $4.40/MMBtu.

The operating and maintenance costs for each case is summarized below in Table 53. Note that the variable O&M is higher for the bituminous coal cases due to more reagent needed for the flue gas desulfurization system.

Table 53: Non-fuel O&M costs for all cases

	Sub-Bituminous		Bituminous	
	FOAK	**NOAK**	**FOAK**	**NOAK**
Total Operating Jobs per Shift	6	6	6	6
Fixed O&M Costs				
Administrative & Support Labor	1,128	896	1,103	884
Operating Labor Costs	1,281	1,281	1,281	1,281
Maintenance Labor Costs	3,230	2,303	3,131	2,256
Property Taxes and Insurance	10,766	7,676	10,438	7,521
Total Fixed O&M Costs, $1000/yr	**16,404**	**12,156**	**15,954**	**11,943**
Variable O&M Costs				
Maintenance Material Cost	4,845	3,454	4,697	3,385
Consumables				
Ash Disposal	799	799	675	675
Chemicals	-	-	-	-
Water	-	-	-	-
Other Consumables	2,394	2,394	5,318	5,318
Total Variable O&M Costs, $1000/yr	**8,038**	**6,648**	**10,690**	**9,377**

1.E.vii.f. Levelized Cost of Electricity

The levelized cost of electricity is based on the methodology in the 2019 NETL QGESS cost estimation guidelines as explained earlier in this section. The assumed plant capacity factor is 85%. An overall summary of plant performance, capital cost, and levelized cost of electricity is shown in Table 54 for all cases. As shown in the table, the LCOEs for the NOAK plants are reduced by 23% for the sub-bituminous case and 22% for the bituminous case.

Table 54: Overall plant performance, TPC, TOC, TASC, and LCOE for all cases

	Sub-Bituminous		Bituminous	
	FOAK	**NOAK**	**FOAK**	**NOAK**
Summary				
Net Plant Output, MW	118	120	118	120
Efficiency, %	35.8	36.5	36.9	37.6
Coal Cost, $/MMBtu	2.23	2.23	2.23	2.23
Total Plant Cost, Total Overnight Cost, and Total As Spent Capital Cost				
TPC, $/kW	4,577	3,198	4,438	3,134
TOC, $/kW	5,538	3,870	5,370	3,792
TASC, $/kW	6,391	4,466	6,197	4,376
Levelized Cost of Electricity				
Capital, $/MWh	60.7	42.4	58.8	41.6
Fixed OM, $/MWh	18.7	13.6	18.2	13.4
Variable OM, $/MWh	7.8	6.3	10.4	8.9
Fuel Cost, $/MWh	22.3	21.9	21.7	21.2
LCOE, $/MWh	**109.5**	**84.2**	**109.1**	**85.1**

1.E.vii.g. Comparisons to Other Power Generation Technologies

LCOE cost comparisons were made for the following solid fuel-fired power generation systems:

- Conventional, large-scale supercritical pulverized coal (SCPC) plants based on NETL Cases S12A (Powder River Basin 550 MW) and B12A (Bituminous coal 650 MW)
- Small, 120 PRB and Ill #6 coal-fired subcritical pulverized coal plant scaled from the NETL Baseline reports with an overall 0.65 scale exponent
- A 100 MW biomass-fired boiler based on cost and performance from the EPRI Technical Assessment Guide

Figure 43 shows a comparison of the LCOEs from the above solid fuel fired power generation technologies to the LCOEs from the sCO_2 sub-bituminous and bituminous coal-fired plants.

The first observation is that the larger scale, supercritical coal plants from the NETL Baseline studies benefit from economies of scale that result in lower capital costs, and therefore lower LCOEs.

However, at comparable plant sizes, pulverized coal plants have net plant efficiencies that are 2 to 2.5 percentage points lower than the efficiencies from the coal-fired sCO_2 power plants. In addition, the NOAK sCO_2 power plants have a potentially lower specific capital cost by 10 to 15% compared to conventional steam Rankine cycle power plants.

The capital cost for biomass-fired steam power plants is slightly higher than for similarly sized coal-fired power plants. Biomass can be fired in the sCO_2 power plant with little increase in capital cost. The LCOE for the biomass power plant shown in Figure 43 assumes the same fuel cost as the coal-fired plants on a per MMBtu basis. The actual per MMBtu cost for biomass fuel is highly variable and can easily be twice the price of delivered coal. This creates a distinct advantage for the sCO_2 power plant since its efficiency is nearly 10 percentage points higher than a biomass-fired Rankine cycle power plant.

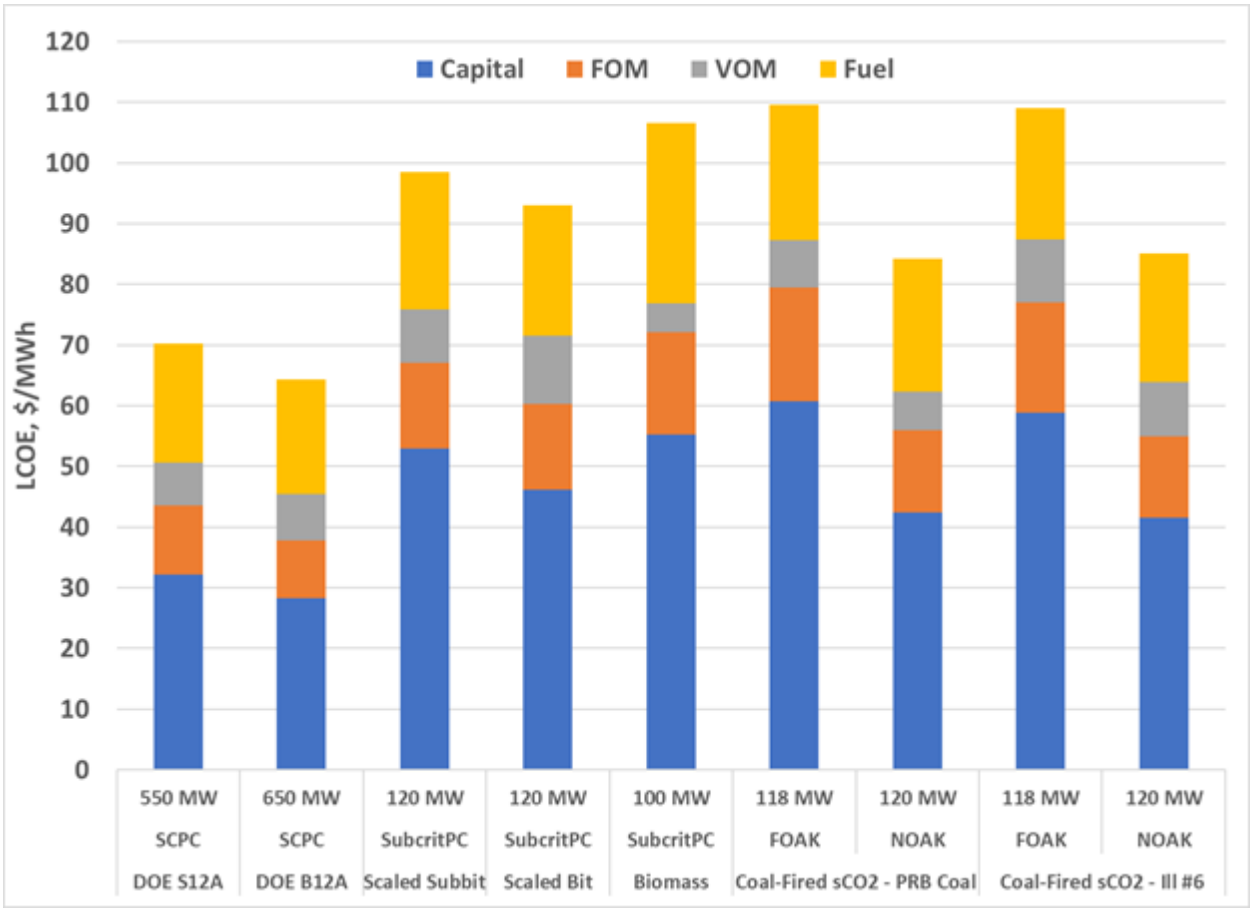


Figure 43: LCOE comparisons with other power generation technologies

2. Team Status

2.A. Host Site Selection

2.A.i. Description, Commitment, and Availability

The MU CHP plant is a cogeneration plant which supplies the needs of the campus located in Columbia, MO. The MU site, shown in Figure 44, uses power generators fueled by wood mill residue (biomass), gas, and coal. The plant also incorporates some wind and solar generation. The plant is in the middle of the campus and is used as an educational opportunity for the University. The University power plant supports 15 million square feet of facilities, including a hospital, via combined-heat-and-power and district cooling. Sustainability initiatives include biomass, solar, and wind, and the MU CHP Plant maintains of goal of carbon neutrality by 2050.

The plant has a long-term commitment to service the needs of the campus. Consequently, it is anticipated that this site will remain in operation, providing power and steam to the campus buildings, at least through the term of the pilot plant operation.

This site has the infrastructure to support pilot operations. Three of the existing boilers and their associated baghouse would need to be removed from the plant, to provide sufficient space for the new pilot equipment. Several sources of in-kind cost share by the University have been identified and were included in the final program budget.



Figure 44: Photo of University of Missouri CHP plant

2.A.i.a. Proposed Site, Physical Infrastructure and Schedule

The University of Missouri Combined Heat and Power Plant, shown in an aerial view in Figure 45, is part of campus operations and is the only source of thermal energy for the campus. Currently, the plant supplies steam to the campus at 60 psig, with a typical supply rate of 300,000 lb/hr and a maximum possible production of 1,100,000 lb/hr. On-site electricity production generally peaks at 46 MW_e and is supplied at 13,800 volts, with a maximum supply capacity of 66 MW_e. The plant buys a portion of its electricity from the Midcontinent Independent System Operator, Inc. (MISO) grid, which provides economic choice and increases

overall reliability. Operators are empowered to buy from MISO, as needed. While real-time market power sales are supported, operators do not actively sell power on a regular basis. Generally, the plant buys 15-20% of its power needs from the MISO grid annually. The power grid is considered as the backup for the plant. Critical electricity users on campus (e.g., the University hospital and telecommunications infrastructure) are provided with local diesel generators that can meet up to 80% of the local demand.

The equipment currently operated and maintained by the MU CHP plant includes: two gas turbines, four turbine generators, four stoker coal boilers installed during 1956-1972 (some with natural gas-fired retrofit), one biomass bubbling fluidized bed (BFB) installed in 2013, one package boiler installed in 1995, one wind turbine, and various electric and steam chillers. There is never a need to run all equipment to meet peak demands. On a typical day, with around 40-50 MW_e generation, the University will buy around 5 MW_e while operating the BFB and using the natural gas combustion turbine as backup, with auxiliary firing. Biomass has been the preferred fuel, due to sustainability and local sourceability. A portion of grid power purchased by the University is from wind energy in Iowa. The campus wind turbine is only 20 kW and is mostly used for demonstration projects and education. A relatively small amount of solar photo-voltaic and solar thermal assets is available on the University campus as well.

In addition to steam and electricity, chilled water (26,130 tons) is also produced to satisfy the campus air conditioning needs, via steam-driven chillers. Potable water is supplied by five deep wells, with a maximum capacity of up to 7.3 million gal/day. In recent years, the steam demand has been flat, primarily due to improved energy efficiency of the campus

buildings. Additionally, water consumption has been reduced by 50%, which leaves adequate capacity for future expansion.

The existing CHP plant is located on a plot of approximately eight acres. There is minimal vacant land on the site. Consequently, some of the existing boilers, which are at end of life (identified as Units 7, 8, and 9), would need to be demolished and removed to make sufficient space for the new pilot equipment. Each of the existing boiler buildings is approximately 50' wide x 50' long x 80' tall. The scale of the proposed pilot equipment is comparable to the footprint of the existing boilers, although AQCS equipment will be located on an existing outdoor platform. Another outdoor location—an existing stack foundation—has been identified as a potential site to install a CO_2 storage tank for the pilot.

Other planned University projects, such as replacement of a gas turbine or chiller expansion, could conflict with the construction schedule for the proposed pilot plant. However, the University has indicated that competing construction could be suspended to support the pilot construction schedule.

Existing infrastructure at the site that is planned for use by the pilot includes coal handling equipment, power distribution facilities, transformers, switchgear, water supply, water treatment, compressed air, auxiliary steam, cooling towers, and the stack. Utility services, including water, natural gas (up to 285 psi), and electricity (40 MW grid tie) are all already available on the University site. There is on-site storage of up to 2,600 tons of coal in two silos, but no coal pile. All coal handling equipment is relatively new and was installed with the biomass boiler in 2013.

Construction height limitations correspond to the 80’ maximum existing building height. The site is not located within the Federal Emergency Management Agency-mapped 100-year floodplain, and there are no known cultural, historic, archaeological, or architectural resources on the grounds.

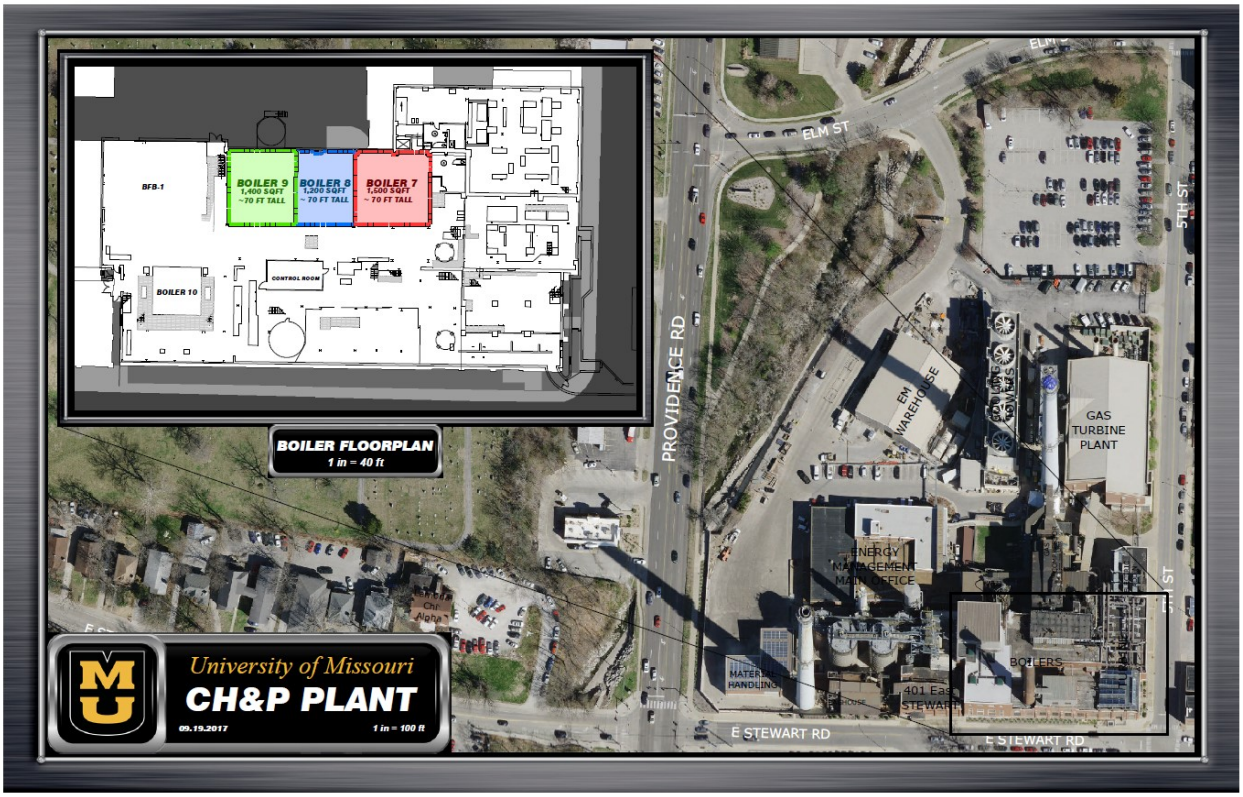


Figure 45: Satellite image of existing University of Missouri site

2.A.i.b. Host Organization Resources

Based upon discussions with the University plant management, the site would be able to support the pilot project with operating staff, environmental consulting services, project construction management, and potentially students to support data analysis.

Staffing from the University is available to support commissioning and operation of the pilot plant. The CHP plant operates continuously with on-site staffing. Additionally, some existing equipment and building structures (as defined above) would be available for use by the pilot.

2.A.i.c. Host Financials, Cost-Share by Host, State and Other Stakeholders, and Project Economics

Some of the existing infrastructure at the University site can be reused under the proposed pilot project. The existing University infrastructure was not funded by federal sources, so the existing infrastructure may be used as in-kind cost share. In-kind cost share contributions by MU could include operating labor, demolition costs, building use, switchgear, and other existing equipment that could be reused under the pilot project.

The University site has the existing infrastructure to support the sale of electricity generated by this pilot project. However, since the University is a net consumer of power and the pilot's cost to generate is expected to be greater than that of the typical CHP asset, it is not expected to be economically advantageous for the pilot project to sell power to the grid at this site.

The University has expressed interest in continuing to operate the pilot plant at the conclusion of Phase III, since this would potentially provide a pathway to improved efficiency and energy flexibility as well as ongoing research and development projects. Knight Hawk coal, shipped from Illinois (freshly mined, sized, and washed stoker-grade bituminous coal) is being used at the site under a long-term contract. It is presently the sole coal source.

2.A.ii. Selection Criteria

EPS led a Phase II project in a three-phase DOE program tailored to support the design, construction, and operation of an indirect-fired sCO_2 power cycle 10-MW_e scale coal-fired pilot plant. The pilot will be located at a selected host site, one that has the best fit for the project based on designated criteria that defines the quality of the fit.

The search for host sites began in 2017. Potential sites were required to have certain high-level characteristics or “must haves” to be considered, including the desire to be a host site and potential for cost share.

The team identified interested sites and talked with representative organizations from each about the feasibility of building the 10 MW_e pilot plant at their locations. Based on these initial reviews, a set of candidate host sites was selected for a more detailed assessment. The list of the candidate host sites that were considered, along with a high-level description of each, including its location, is given in Table 55.

Table 55: Potential host sites

Organization	Description
National Carbon Capture Center (NCCC)	The NCCC, located in Alabama, has hosted multiple CO_2 capture technologies through the DOE over its 9-year history. The site is next to Southern Company's Gaston coal-fired power plant and the NCCC team has expertise and experience in working on such research projects and an interest in housing the pilot at their removed gasification facility.
Painesville Municipal Electric Plant	The Painesville Municipal Electric Plant, located in the city of Painesville, OH, is one of the oldest continuously operating public power plant facilities in Ohio and one the few remaining coal-fired ones. The site has the requisite space and infrastructure to support pilot operations and is interested in continuing to fire coal.
University of Missouri Combined Heat and Power Plant	The University of Missouri Combined Heat and Power Plant is a cogeneration plant with a diverse set of existing power generators, which supplies the needs of the University located in Columbia, MO. The site has need for additional power and the university is interested in partaking in the research on the pilot technology.
Wellington Development	The Wellington Development site is located near the city of Carmichaels, Greene County, PA. While there currently is no operating power plant on the site, the developers intend to construct a horticultural project, which will be a large consumer of electricity and steam that the proposed pilot might be able to supply.

The next step was to develop a scoring matrix designed to capture key characteristics from each site in a quantifiable way so that comparisons could be made on a relative basis. A primary candidate and a backup could then be selected based on the results. The scoring matrix was divided into four major categories for which the team collected information from each site organization:

- Business and financing
- Environmental and permitting
- Operations
- Physical attributes.

A weighting system was developed for every item in the scoring matrix since some have a greater impact on the suitability of a particular host site. The weighting, labeled as

"Importance" for each item, was given based on the team's assessment of its relative importance. A relative score of "High," "Medium," or "Low" was given for each item with high scores given a 9, medium a 3, and low scores a 1.

Each host site was then evaluated collectively by the team for each item getting a score from 5 (best) to 0 (worst). This score was then multiplied by the weighted importance to get a numerical value for the site for the item. (For example, if the item has an importance of "High" and the site scores a 5, its score for this item is then 45.) The values for every item were then summed up to give the final score for the host site, which was then non-dimensionalized as a percentage. In this way, each host site was given a quantitative score between 0 and 100% relative to each of the other potential sites. The list of items selected to assess the host sites and their relative importance is given in Tables 56 through 59. Note that "must have" items are highlighted in red in the tables.

Table 56: Scoring matrix items (business and financing)

Business and Financing	Importance
Are the organization operating the host site and the host site itself financially stable?	High
Are there perceived schedule risks for getting the site ready according to the schedule?	Medium
Does the host site organization have a track record working / contracting with DOE?	Medium
Does the organization have a successful track record with doing DOE projects?	Medium
Does the organization have a well laid out plan for performing the project and supporting the bid?	High
Does the power industry support the site?	Medium
Does the site have proximity to an International airport and accommodations?	Low
Does the site have special labor limitations or issues?	Medium
Does the site have suitable insurance to cover normal operational risks?	Low
Does the site have the support of the local and / or state governments?	Medium
Is the host willing to provide cost share?	High
Is the organization willing to and capable of contracting with other organizations?	Low
Is there a perceived risk of the host site withdrawing from the project?	High
Is there available local or state government funding for the site?	High
Is there risk associated with the cost share, e.g., is it from a source that may be hard to verify or has contingencies?	High
What is the perceived total cost of the site compared to others? (Federal Cost?)	High

Table 57: Scoring matrix items (environmental and permitting)

Environmental and Permitting	Importance
Are there any other concerns with accessing / providing consumables?	Low
Are there any perceived HSE issues or construction permitting concerns?	High
Are there concerns around air permitting for the site?	High
Are there concerns around water permitting for the site?	Medium
Has the site done a recent NEPA study?	Medium

Table 58: Scoring matrix items (operations)

Operations	Importance
Are there any noise restrictions that could limit hours of operation and/or construction?	Low
Are there any security risks for the host site?	Low
Cost of operating the site?	High
Does the organization have a successful track record in doing pilot-scale testing?	Medium
Does the organization have experience with any of the core components of the system?	Medium
Does the site have existing staff to support the project through all phases?	High
Does the site have the ability to support full 24/7 operations?	High
Does the site location have weather-related or altitude concerns?	Medium
Does the site, its existing equipment (if any), and its staff support long-term operations?	Medium
Is the skillset needed to perform maintenance available from the site or nearby?	Medium
Is there a risk of changes in future operations that could impact the test plan?	Medium

Table 59: Scoring matrix items (physical attributes)

Physical Attributes	Importance
Are there perceived construction risks / access issues?	Medium
Does the host site have access to coal delivery and coal handling?	Medium
Does the site have a potential need for process steam and/or power?	Medium
Would any existing buildings/structures be used or modified?	Medium
Does the site have existing infrastructure that can be used?	High
Does the site have ready access to coal?	High
Does the site have ready availability to all required utilities?	High
Does the site have sufficient plot space and are there no space restrictions?	High
Does the site have the ability to provide power to the grid?	Low
Does the site have the ability to utilize CO_2 or access to a nearby CO_2 pipeline?	Low

To obtain the information needed to assess the host sites, several actions were taken by the team:

- Questionnaires – These were provided to each site to provide background information and specifics on some of the items in the scoring matrix.
- Conference calls – These were held in cases where there were any questions from either side related to this exercise.
- Site Visits – Members of the project team, including both EPS and various of its sub-contractors, visited each site for detailed meetings and first-hand site inspections. Follow-up calls were held if needed to verify information or to obtain information that required time to obtain.

After accruing the required information for each site, the project team then held a half-day meeting to rate each item for the potential host sites relative to one another. The goal for each item was to spread out the ratings to differentiate between the sites. Debates were held on items as needed to come to a consensus. Results were tallied as shown in Table 60. In the table, the "No. of 5s" represents the number of items for the site that received a "5" score (the highest possible), the "No. of 4s" represents the number of items that received a "4" score (the next highest), and so forth. The "Average" is the average score for the site on the 5-point basis and finally "Total Score" is the non-dimensionalized grade on a scale from 0-100% for the site.

Table 60: Scores of potential host sites

Site	No. of 5s	No. of 4s	No. of 3s	No. of 2s	No. of 1s	No. of 0s	Average	Total
MU	22	9	5	3	2	1	4.02	84.4%
NCCC	16	7	9	6	3	1	3.57	69.0%
Painesville	11	11	10	3	6	1	3.36	68.2%
Wellington	5	3	10	12	4	8	2.26	45.7%

As can be seen in Table 60, the MU CHP plant was the clear winner, leading to its selection as the primary host site for the project. Subsequent discussions with officials at MU confirmed their interest and willingness to be the host site and to participate as a partner in the project.

The principal reasons why the MU CHP plant scored the highest and was selected as the primary host site for the project were:

- The site, the organization operating it, and the need for the power it produces are all stable, which reduced project risk.
- MU has a track record of successfully being involved in DOE projects and has an obvious interest in research of both sCO_2 power cycles and advanced coal power generation, a compelling addition to the project. The CHP plant itself has also been involved in numerous research projects.
- The university and the plant are committed to the project and see it as a great way to not only provide educational opportunities to their staff and students, but to potentially secure a reliable power generator for the future.
- Coal is readily available at the site as they already burn it, and some of the existing infrastructure can be utilized, reducing costs. Required utilities already exist as does the ability to provide power to the university or grid. The site also has the required footprint for the pilot.

- The site scored well on initial environmental reviews as there is a well-documented regulatory history at the site. No red flags were generated related to air, water, or consumables at this point.
- The facility is well maintained with an existing 24x7 operations and maintenance staff that can support the project and has been involved in construction, commissioning, and operation of similar equipment in the past, which reduces the potential schedule risk. Students and faculty will also provide resources to support the testing and operation and associated data analysis.
- The overall program costs for having the project at the site were deemed to be amongst the lowest with the ability to obtain in-kind cost share, the potential to use existing infrastructure, and the low cost of the operations and technical support being the main reasons.

2.A.iii. Environmental Analysis

The University has its own building and construction standards (based upon the International Building Code), and acts as its own regulatory authority. The MU CHP plant operation is subjected to a noise limit of 85 dB, measured at the equipment. The plant has a plan in place to mitigate background noise and limit construction activities to normal working hours.

There may be some local and student opposition to coal firing by the pilot plant at this site, but improved efficiency and emissions reductions may be well received. Some budget would need to be reserved to address public outreach and education.

2.A.iii.a. Construction (Air Contaminant Source) Permitting

Environmental permitting requirements were addressed during Phase II. Expected limits were identified at the beginning of the design phase with input from MU's environmental consultant (Burns & McDonnell). The permit application assumed the removal of three existing coal-fired boilers (units 7, 8, and 9). Since the MU CHP is an existing "major source," EPA regulations require a determination of whether a Prevention of Significant Deterioration (PSD) permit is required. While the project itself would qualify as a significant emissions increase and require a PSD permit, the EPA allows other changes in actual emissions at the site (such as the removal of units 7, 8, and 9) to be included in the accounting. The issuer of the permit (MDNR) determined that the net change for this project would be "below the significance level for PSD applicability" after accounting for the historical emissions of the units slated for removal. A copy of the draft permit which MU negotiated with Missouri Department of Natural Resources is included in Appendix IX.

2.A.iii.b. NEPA Permitting

Based upon a review of the Environmental Information Volume (EIV) that was prepared by CDM Smith and submitted to the DOE in Phase I, the DOE concluded that an Environmental Assessment would not be required. Instead, an Environmental Questionnaire (EQ) was required to be completed for the pilot plant host site, supporting a DOE determination of Categorical Exclusion for the retrofit of the host plant. With input from the project team, EPRI completed the EQ using form NETL F 451.1-1/3 to fulfill the obligations of the NEPA process. The full NEPA EQ form is included in Appendix X.

2.B. Team Status

The project team is led by EPS, with committed support co-applicants (MU and EPRI) and major subcontractors (CDM Smith, RPI, and BNI). The organizational and individual members of this team have a proven track record of successful government-funded projects.

EPS is the prime contractor for this effort and is responsible for the overall program plan, including coordinating with contract management personnel and among the team members. EPS's primary technical responsibility is the design, specification, and cost estimation of the sCO_2 power cycle and auxiliary equipment from the primary heater flanges to the generator terminals, including the heat rejection system.

MU has been selected as the host site for this program is responsible for on-site support for demolition, construction, and commissioning as well as leadership of duration operations. and will have primary responsibility for securing construction and environmental permits. MU provides guidance on plant layout, reviews drawings and specifications to assure compliance with MU codes and standards, and provides guidance on operational constraints and safety compliance.

EPRI will provides technical support for the following tasks various tasks, including updating the PHA, PTP, and TEA and leading performance testing. EPRI also coordinates relationships and investment in the utility industry.

CDM Smith, RPI, and BNI are committed subcontractors for major program scope under EPS. CDM Smith designs and supplies BOP systems and leads EPC activities. The construction contractor is determined through a competitive bid process and subcontracted to CDM Smith.

RPI designs and supplies the primary heater and AQCS equipment. BNI designs and supplies the turbomachinery.

2.C. Cost Share Status

The team was unable to secure adequate cost share commitments for Phase III.

3. Technology Commercialization Plan

This section describes the circumstances around the current coal power marketplace and how the proposed technology will be designed to respond to varying market scenarios. Factors include:

- Coal type(s)
- CO_2 constraint and/or price
- U.S. and/or international market applicability
- Estimated cost of electricity that establishes competitiveness
- Market advantage of the concept
- NG price
- Renewables penetration

The current marketplace for coal power varies widely on a regional basis, but in all cases, one or more of the following drivers impact its future viability:

- Competition against other power sources
- Drive towards low carbon
- Energy security
- Environmental regulations
- Financing
- Meeting a changing market

3.A.i. Competition

In some regions, coal remains a low-cost generator, while in others, NG-based power is typically more economical due to the availability of low-cost NG (e.g., in the U.S., NG is about half the cost of elsewhere).

3.A.ii. Drive Towards Low Carbon

179 countries have signed the Paris Agreement, whose goal is to reduce greenhouse gas (GHG) emissions. (Typically, countries have pledged to reduce CO_2 emissions on the order of 20–40% from 2012 levels.) While the U.S. has not signed the agreement, multiple states have enacted low-carbon initiatives including several that have committed to 80-90% (or higher) reductions by the 2040 to 2050 timeframe. Coal, as a fossil fuel, and one that produces double the CO_2 per MWh than NG does, is therefore a bigger target related to reducing CO_2.

3.A.iii. Energy Security

In some regions, coal is an abundant natural resource, representing energy security and reducing the need for reliance on fuels or energy from foreign countries. Finding ways to use it more effectively can be critical for these regions.

3.A.iv. Environmental Regulations

Coal emission regulations–CO, NO_x, hazardous air pollutants, mercury, particulate matter, and SO_x–vary globally, but coal universally remains a tougher permitting challenge than NG.

3.A.v. Financing

Financing is becoming more challenging for larger plants as the future power market has significant uncertainties, especially around carbon. Coal power plants are a particular challenge. Smaller plants are thought to be lower risk since they require less capital, and hence have a better opportunity for financing.

3.A.vi. Market Changes

The energy market is changing, largely due to the growth of variable renewable energy (VRE). Intermittency requires grid protection provided by dispatchable sources, which largely comes from fossil-based units. In the U.S., some coal power plants are providing such grid support, requiring them to operate more flexibly than they were designed for, which is deleterious to performance. Such operating behavior will likely also occur in other regions as VRE grows, reducing the need for base-load fossil power, while putting extra importance on their ability to provide grid resilience and dispatchable, synchronous (firm) power.

3.B. United States

New coal power has stagnated in the U.S., where coal is often not competitive with NG or presents future environmental risk. There are no known larger-scale new-build coal power projects advancing in the U.S. and some utilities have back-burnered coal or pledged to eliminate it. Several contributing factors are likely needed for a significant resurgence in new coal:

- Increase in the relative price of NG compared to coal

- Larger value for CO_2 either by regulation or for utilization
- Regulatory certainty

3.B.i. NG Price Fluctuations

While NG price increases have not been forecasted, it remains a possibility, especially as the demand for NG grows internationally and its use in other industrial market grows.

3.B.ii. CO_2 Value

If a significant market for CO_2 develops, this could help drive new coal power with carbon capture and storage (CCS). Enhanced oil recovery (EOR) remains the primary form of utilization and tapping into this market will likely be a necessity for any new coal plants with CCS in the short term. Governmental programs like 45Q provide a value for captured CO_2 as well, which aids in the overall project economics. In general, the worth of capturing CO_2 must be greater than the cost, which is not the case in most circumstances. Hence, the value must increase (perhaps by regulation) and/or the cost must decrease for coal CCS projects to be more viable.

3.B.iii. Regulatory Certainty

Uncertainty in future regulations increases risk, which makes coal power projects difficult to finance and generators more reticent to build them. Recent revisions to the Clean Air Act section 111(b) have been proposed to alter the definition of best system of emission reduction for new coal units to the most efficient demonstrated steam cycle in combination

with best operating practices, instead of requiring partial CCS as was the case in the previous version. Getting this in place and adding certainty around the low-carbon future may be important for growth in coal power.

3.C. International

3.C.i. China

China is the largest coal producer and consumer in the world and coal accounts for 70% of its total energy consumption. Although China anticipates coal capacity growth of about 19% over the next five years, this comes at a time of slowing electricity demand. As a result, some coal plants have been operating at reduced capacity factors. Due to this, and growing environmental concerns, the Chinese government has announced it will postpone building some coal plants that have received approval and halt construction of others. However, there is still a need for new power, especially in the west, and a large supply of coal exists in China. Coal plants that are efficient (a key criterion) and smaller will likely be of appeal. CO_2 utilization for EOR and enhanced gas recovery are also growing possibilities.

3.C.ii. Europe

In Western Europe, following the Paris Agreement, several countries announced plans to end coal-fired generation within their borders or set emissions reductions targets that would effectively require an end to coal without CCS: France by 2023, the United Kingdom and Austria by 2025, the Netherlands by 2030, and Germany by 2050. This makes new coal power difficult

in the region. In Eastern Europe, there is more potential for new coal as brown coal resources are abundant and cheap. Efficiency and cleanliness will be keys in this region. CCS may be a challenge, however, as underground storage is not popular, although Norway is developing a potential sink for CO_2 in the North Sea.

3.C.iii. India

India has large domestic coal reserves and recently had the largest growth in coal use of any country. India's draft National Electricity Plan indicates that the 50 GW of coal capacity in construction is sufficient to meet the country's needs for the next decade, but new coal remains a possibility. Most new coal plants proposed are supercritical units as India has imposed a carbon tax on coal, which is about \$6.25/tonne-CO_2, making efficiency important in the region. Work has also been done to locate reservoirs for CCS.

3.C.iv. Japan

As of 2018, Japan had over 44 GW of coal plants in operation, with over 6 GW permitted or in construction. Japan's climate pledge is to reduce GHG emissions by 26% from 2013 levels by 2030, so improving efficiency and potentially performing CCS are important factors in Japan. Smaller-scale plants are also likely, in part because space is an issue. Japan is very interested in novel coal power cycles, including sCO_2 power cycles.

3.C.v. South Korea

Coal produces over 40% of South Korea's power and the country still has plans for additional coal power, despite having a climate pledge with a 30% reduction in GHG emissions

by 2030. Efficiency is also important in South Korea, and they have strong interest in sCO_2 power cycles, having invested in the DOE's STEP program.

3.C.vi. Others

Coal is growing in some regions in Africa (e.g., Kenya and Zimbabwe) and Southeast Asia (e.g., Indonesia and Vietnam), which presents opportunities, although low-cost coal power will be critical in these areas. Smaller-scale plants will be a definite plus.

3.D. Technological Advantages

3.D.i. Smaller Commercial Plants

This system can be made smaller (100 MWe net or less) and still maintain relatively high efficiency and flexibility. This reduces the financing hurdle and makes the system a better fit for niche locations that lack a low-cost NG supply, where power demands are typically lower.

3.D.ii. Technology Readiness

Indirect-fired sCO_2 power cycles have been factory-tested, lowering the risk of the technology. The first commercial installation of an sCO_2 power system by Siemens using EPS technology was recently announced and is scheduled to begin operation in 2022.

3.D.iii. Potential Pairing with Energy Storage

This technology is well designed for energy storage, which can be readily integrated using a system based on a concept already being studied under a separate ARPA-E grant.

Energy storage is growing in importance as the penetration of VRE increases, as it could allow near-continuous plant operation, putting power on the grid when needed and storing energy when not. This allows the unit to run more often at its design conditions, avoiding ramping and turndown, which have negative impacts on efficiency, emissions output on a per MWh basis, and unit lifetime. Moreover, if this unit captures CO_2 for utilization (e.g., EOR), it may be required to operate nearly continuously, either to deliver an agreed-to amount of CO_2 or to improve the overall economics. With energy storage, the plant can provide CO_2 continuously while allowing power to be provided to the grid when needed. In short, energy storage can have a significant impact on the unit's competitiveness.

3.D.iv. Operational Flexibility

In addition to the potential for integrated energy storage, the proposed cycle will have improved operational flexibility characteristics, meeting those specified by DOE. Mainly this is due to the sCO_2 cycle turbomachinery being significantly smaller on a relative basis compared to that of steam-Rankine cycles, which lends itself to improved flexibility. The flexibility provided by the technology, particularly lower turn-down and faster startup times, could be key in the future marketplace even if energy storage is included, and provides the ability to not include energy storage for cases where the cost-benefit analysis is not positive.

3.E. Competition and Techno-economic Cost Targets

DOE performed a TEA for coal power plants using Powder River Basin (PRB) coal with and without CCS, as shown in Table 61, with TPC, LCOE, and CO_2 captured cost adjusted to 2019 dollars by EPRI.

Table 61: Techno-economics of various coal plants using PRB coal

Technology	Case	Size (MW_e)	Efficiency (% HHV)	TPC ($/kW)	LCOE ($/MWh)	CO_2 Captured Cost ($/tonne)
Oxy-combustion (atmospheric, supercritical)	S12F	650	31	4084	169	51
PC without CCS (supercritical)	S12A	650	38.8	2406	94.2	-
PC with CCS (supercritical)	S12B	650	27	4243	181.4	52

Based on these data from DOE, EPRI determined:

- TPC for the proposed technology to equal the LCOE of PC with CCS is $3914/kW
- TPC for the proposed technology to get the cost of CO_2 captured to $40/tonne is $2926/kW

Note that these numbers are all for larger-scale power plants and hence do not account for any diseconomies of scale when reducing to 120 MW_e. SaskPower's Boundary Dam Unit 3 installed Post-Combustion Carbon Capture (PCCC) for EOR in 2014. The resulting unit produces 110 MW_e net. The CCS retrofit cost ~$800M and $500M was used to upgrade steam conditions to 124 bar and 565°C. Add to this the cost of the original components, estimated to be $C200M, and the capital cost for a new build is roughly $10,200/kW. While this number should not be

taken as indicative (SaskPower has stated that the next CCS unit will be 65% cheaper), it acts as a cautionary tale, illustrating the higher cost of CCS at smaller scales for more conventional technology.

Another important example is the most recent coal power plant built in the U.S.: an 84-MW_{th} CHP plant at the University of Alaska Fairbanks for $248M, which equates to a TPC of ~$8000/kW. Annual fuel costs for the plant were about $5M for coal and $20M for NG. In such areas where NG supply is not available or is inconsistent, if coal can be delivered cheaply, smaller-scale coal plants have an opportunity. For the proposed technology, to account for the risk associated with less mature technology, a TPC of ~$6000/kW would be appealing. EOR opportunities will also be important in such cases.

Based on this high-level review, for the proposed system to be competitive, beyond achieving the performance characteristics that have been set for this project, Table 62 below provides cost targets for the technology in various regions and scenarios.

Table 62: Cost targets for various coal technologies in several regions and scenarios

Case	Region	Scenario	Competition	Cost Targets
1	U.S.	NG not available, coal and EOR / 45Q available	Small coal (100 MW_e)	TPC < $6000/kW
2	U.S.	NG < $4.4/MBtu (coal $2.2/MBtu) and CO_2 value of $50/tonne	Coal or NG with CCS	TPC < $3000/kW; CO_2 cost < $40/tonne
3	Africa, Asia, Europe	NG > $11.6/MMBtu (coal $2/MBtu)	Coal with CCS	LCOE< $160/MWh; TPC < $39000/kW
4	Anywhere	CO_2 value of $50/tonne	Any CCS	CO_2 cost < $50/tonne
5	Anywhere	Non-base load operation with CCS	Coal FIRST technologies	TPC < $3900/kW; CO_2 cost < $50/tonne; value for energy storage

The first four cases in Table 62 assume a base-load unit with 85% capacity factor and ~1M tonnes of CO_2 captured annually. The $50/tonne value for CO_2 is roughly a summation of EOR with 45Q credits (or 45Q credits for storage only). So, the cost targets for the technology are TPC = $3900/kW, LCOE = $160/MWh, and CO_2 cost = $50/tonne, with stretch goals of TPC = $3000/kW, LCOE = $120/MWh, and CO_2 cost = $40/tonne.

One of the short-term markets will be niche areas where NG supply is limited or unavailable without significant infrastructure investment, where coal can be supplied. In the U.S., this is largely in the west. Opportunities may also exist in Mexico. These applications will be small, perhaps smaller than 100 MW_e net (which is doable with this technology). In these cases, the capital costs must be lower than $8000/kW. The other potential short-term market is in regions where there is an EOR play, e.g., Texas and Wyoming. Generally, EOR projects must

provide ~1M tonnes of CO_2 annually to be considered, which is about what 100 MW_e net produces. This size is likely a better fit in oil and gas markets than larger plants.

In regions where NG is more expensive (e.g., Africa, Asia, and Eastern Europe), or if NG prices should rise in North America, the technology will be competing directly with more established PCCC systems for coal. In these cases, the proposed technology must have capital costs and COE that are comparable, and preferably superior (given it might be perceived to be higher risk), to this option.

Another factor is that if the value of CO_2 is increased (either by a CO_2 price or value) in comparison to the cost of CO_2 captured, then this proposed CCS technology will have more opportunities. On the flip side, since this current system does not have inherent CCS, if the region does not have a significant CO_2 policy or utilization opportunities (e.g., India or South Africa), or is not focused on low carbon but rather just cheaper power production (e.g., developing nations like Kenya), this technology could still be an option, especially at smaller scales.

3.F. Technology Gap

The proposed power plant makes extensive use of proven technologies to limit technical risk and provide a clear path to commercialization. An inventory of key plant components requiring development is shown in Table 63.

Table 63: Plant components requiring development

Subsystem	Component	Availability	TRL	Source
Power Cycle	Power Turbine	Scale from 100 MW Conceptual Design	6	Siemens
	HTC	Scale from 4 MW Pilot Design	4	BNI
	LTC	Scale from 3 MW EPS100 Design	5	BNI
	Operation and Control	Scale from 10 MW Pilot Operation	4	EPS
	Turbine Stop Valve	Scale from 10 MW Pilot Design	4	Flowserve, GE
Primary Heat Exchanger	Heat Exchanger Design	Scale from 10 MW Pilot Design	3	RPI

These components are discussed further, along with the technical development and risk abatement activities that are in place or planned.

3.F.i. Power Turbine

The sCO_2 power turbine is a modest scale-up of the 100 MW_e, 730°C inlet temperature turbine designed by Siemens during the DOE-funded "High-Efficiency Thermal Integration of Closed Supercritical CO_2 Brayton Power Cycles with Oxy-Fired Heaters" project (DE-FE0025959) [10, 20, 21]. The turbine features a dual barrel design due to the high turbine inlet temperature with an axially split outer barrel. A technology gap and risk assessment analysis were conducted by Siemens during the program. The two highest ranking risks were: (1) Rotating blade failure due to high unsteady/alternating stresses due to fluid density and pressure; (2) Material long-term compatibility with sCO_2. The identified risk mitigation strategy for these two items were: (1) Detailed transient CFD and forced response analyses to assess alternating stresses and

update design as necessary; (2) Review literature to select best candidate materials and perform additional material compatibility testing, if required.

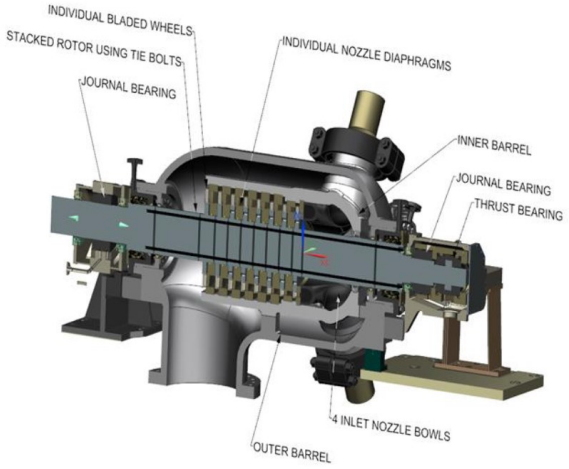


Figure 46: Siemens-designed 100 MW_e sCO_2 turbine (from DE-FE0025959)

Siemens or another OEM would be contracted to perform the design and fabrication of the power turbine.

3.F.ii. High Temperature Compressor

Sometimes called the "bypass compressor" or "re-compressor," HTC compresses CO_2 from the low-pressure outlet of the HTR to the high-pressure outlet of the LTR (effectively bypassing the LTR and CHX). The HTC operates over fluid conditions that are intermediate between the liquid-like properties at the LTC inlet and true ideal gas properties. The primary design path for the HTC is a scaled version of a turbine-driven compressor that was designed as part of this LSP program, which in turn is a derivative of the LTC design.

Alternate designs are also considered. At these conditions, the compressor could also be an industrial-style barrel-case or integrally geared multistage design. As these are commercial

devices, the technical risk of this approach is low. However, typical isentropic efficiency values of these compressors are in the 80-82% range, versus the predicted 86.4-87.3% range for the high-speed single-stage design. The efficiency of the power cycle would be approximately 1-2 percentage points lower with the industrial compressor design than the high-speed approach.

3.F.iii. Low Temperature Compressor

The LTC compresses CO_2 from the CHX outlet to the LTR high-pressure inlet. The fluid properties at the LTC inlet are high density and low compressibility—very similar to an incompressible fluid. Thus, the operating characteristics of the LTC are similar to that of a liquid CO_2 pump. EPS has previously designed, built, and successfully tested the equivalent of a 3 MW LTC in their EPS100.

Alternatively, the fluid properties are sufficiently liquid-like that EPS has approached pump suppliers such as Sulzer, Flowserve, and Ebara regarding the use of a conventional barrel-case style pump for LTC service. If sufficient suction margin is provided, this approach also appears feasible. The predicted isentropic efficiency of these pumps ranged from 76-84% at the design point, which is similar to the predicted and measured EPS100 LTC performance (78-82%).

3.F.iv. Turbine Stop Valve (High Energy Valves)

The TSV is a key component to the sCO_2 power cycle. It is exposed to the highest CO_2 temperature and pressure and must close quickly in response to system trip signals, such as the loss of generator load, to avoid a power train overspeed situation. EPS has successfully

demonstrated a Flowserve high-speed TSV in the EPS100 testing at lower CO_2 temperature. GE is developing a CO_2 TSV for the STEP program. In addition, the work that the Advanced Ultra-Supercritical (AUSC) program has conducted includes steam TSV development work that is directly relevant here.

3.F.v. Operation and Control

EPS has extensive experience in the operation and control of single turbo-compressor sCO_2 power cycles through its EPS100 development and test program [9]. The RCBC cycle has one unusual feature relative to most existing Rankine and Brayton cycles—the use of two compressors in parallel. The first (and to date only) operating RCBC configuration was the Sandia loop. In their experience, starting the two compressors presented operating challenges and required simultaneous starting of the LTC and HTC to avoid driving the compression system into surge. While this process could be used here, analysis of the Sandia configuration shows that the starting challenges could have also been resolved through the use of independent bypass (or "anti-surge") and isolation valves and controls. In addition, the transient modeling simulations that have been developed for the LSP and other projects allow for detailed operability modeling throughout the startup and other operating modes.

In EPS's previous design studies, simulations, and operational experience, the heat source has most frequently been natural gas-fired combustion turbine (CT) exhaust for combined-cycle applications. The differences between that heat source and the coal-fired heater are two-fold. First, although the heat source time constants are very long in both cases, the CT exhaust sCO_2 cycle had no control over the heat source, whereas for the coal-fired

system the heat source firing rate can be controlled according to the needs of the sCO_2 cycle. Second, the heat source temperature for the coal-fired case is much higher than the CT exhaust, thus requiring continuation of CO_2 flow following a system trip in order to maintain primary heat exchanger material temperatures to stay within limits.

3.F.vi. Primary Heat Exchanger

RPI has elected to design the majority of the heater components using austenitic stainless steel (Super 304). This material is more expensive than traditional tube materials (low chrome alloys), but still considerably less expensive than nickel-based alloys that would be required for higher turbine inlet temperatures (> 625°C).

The heat transfer design of the PHX is relatively challenging due to the higher volumetric flow rate required for an sCO_2 power cycle for the same power rating as a steam Rankine cycle. In addition, the lower pressure ratio of the sCO_2 cycle increases its sensitivity to pressure drop in the PHX relative to a steam Rankine cycle. The simultaneous management of the pressure drop and heat transfer design requires an integrated cycle-level optimization process. EPS and RPI worked to optimize this pressure drop in the design of the LSP fired heater.

The proposed heater design is based on a traditional utility-scale steam boiler, with a furnace and a separate convective backpass. The element design of the backpass is a series of serpentine elements, designed to be fully drainable. These elements are stringer supported, with the coldest fluid cooling the stringers to provide maximum strength. Economizer elements are in-line with the primary convective elements and can share the same stringers for support.

Economizer tubes are finned to maximize heat transfer and minimize the amount of material required. Bare tube economizers may be considered following additional fuel analysis to reduce potential for ash buildup and soot-blowing requirements. Due to the lower working temperatures of the economizer elements, these will be fabricated from low chrome alloys.

The furnace and backpass walls are CO_2 cooled, and will be the highest temperature components of the heater. Tube size and spacing has been selected to match known fabrication standards, but RPI has not fabricated membrane walls using Super 304. This will require additional development to ensure the panels can be effectively welded without significant warping or cracking. Field welds for this material will be minimized, due to the strict welding requirements.

To improve overall efficiency and maximize radiant absorption, RPI is including platens in the upper section of the furnace. These platens are fully drainable and are on wide spacing to prevent issues with ash bridging due to the high metal temperatures, as well as maximizing the radiant exposure. RPI does not anticipate issues with fabrication of these elements.

References

[1] U.S. Department of Energy, "Quadrennial Technology Review 2015".

[2] B. A. Pint and J. R. Keiser, "The Effect of Temperature on the sCO2 Compatibility of Conventional Structural Alloys," in *The 4th International Symposium - Supercritical CO2 Power Cycles*, Pittsburgh, Pennsylvania, 2014.

[3] F. Rouillard, F. Charton and G. Moine, "Corrosion Behaviour of Different Metallic Materials," in *SCCO2 Power Cycle Symposium*, Troy, NY, 2009.

[4] E. G. Feher, "The Supercritical Thermodynamic Power Cycle," *Energy Convers.,* p. 85–90, 1968, 8.

[5] G. Angelino, "Carbon Dioxide Condensation Cycles for Power Production," *ASME J. Eng. Power,* p. 287–296, 1968, 90(3).

[6] S. A. Wright, R. F. Radel, M. E. Vernon, G. E. Rochau and P. S. Pickard, "Operation and Analysis of a Supercritical CO2 Brayton Cycle," SANDIA, 2010, September.

[7] K. J. Kimball and E. M. Clementoni, "Supercritical Carbon Dioxide Brayton Power Cycle Development Overview," in *4th Int. Symp. – Supercrit. CO2 Power Cycles*, 2014.

[8] M. Persichilli, T. J. Held, S. Hostler and E. Zdankiewicz, "Transforming Waste Heat to Power through Development of a CO2 - Based Power Cycle," in *Electric Power Expo*, St. Petersburg, Russia, 2011.

[9] T. J. Held, "Initial Test Results of a Megawatt-Class Supercritical CO2 Heat Engine," in *The 4th International Symposium - Supercritical CO2 Power Cycles*, Pittsburgh, Pennsylvania, 2014.

[10] A. Maxson, D. Thimsen, J. Miller and T. J. Held, "High-Efficiency Thermal Integration of Closed Supercritical CO2 Brayton Power Cycles with Oxy-Fired Heaters," 2017.

[11] M. Montgomery, M. Bjurman, A. Hjornhede, H. B. Rombrecht, A. Lisk and J. Krautz, "High Temperature Corrosion Investigation in an Oxyfuel Combustion Test Rig," *Mater. an Corros.*.

[12] F. Rouillard and G. Moine, "Corrosion Behavior of Different Metallic Materials in Supercritical Carbon Dioxide at 550°C and 250 Bars," *Corrosion,* 2011, 67(9).

[13] M. Walker, A. Kruizenga, P. Weck, E. Withey and D. Fleming, "Progress in Overcoming Materials Challenges with SCO2 RCBC: Final Report," Albuquerque, 2016.

[14] V. K. Avadhanula and T. J. Held, "Transient Modeling of a Supercritical CO2 Power Cycle and Comparison with Test Data," in *ASME Turbo Expo 2017: Turbomachinery Technical Conference and Exposition*, Charlotte, NC, 2017.

[15] NETL-PUB-22580, "Quality Guidelines for Energy Systems Studies Cost Estimation Methodology for NETL Assessments of Power Plant Performance," September 2019.

[16] AACE International Recommended Practice No. 18R-97, "Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Process Industries".

[17] AACE International Recommended Practice No. 16R-90, "Conducting Technical and Economic Evaluations – As Applied for the Process and Utility Industries," 1991.

[18] NETL-PUB-22697, "Capital Cost Scaling Methodology: Revision 4 Report," Oct 2019.

[19] NETL-PUB-22458, "Fuel Prices for Selected Feedstocks in NETL Studies," Jan 2019.

[20] J. D. Miller and e. al., "Comparison of Supercritical CO2 Power Cycles to Steam Rankine Cycles in Coal-Fired Applications," in *Proceedings of ASME Turbo Expo 2017: Turbomachinery Technical Conference and Exposition*, Charlotte, North Carolina, USA, 2017.

[21] A. Maxson and et. al., "Integration of Indirect-Fired Supercritical CO2 Power Cycles with Coal-Based Heaters," in *The 6th International Symposium - Supercritical CO2 Power Cycles*, Pittsburgh, Pennsylvania, 2018.

Appendices

I. Fuel Analysis

Lab No : 201800202-003

Date Rec'd : 1/30/2018

Date Sampled 1/22/2018 to 1/26/2018

Sampled By: CLIENT

STANDARD LABORATORIES, INC.

8451 River King Drive
Freeburg, IL 62243

ANAB ACCREDITED ISO/IEC 17025 TESTING LABORATORY

Certificate # L2179.02-1 Testing

KNIGHT HAWK COAL, LLC
500 CUTLER-TRICO ROAD

PERCY, IL 62272
ATTN: STEVE A. CARTER

Date : 2/9/2018 6:45:14 AM

P.O.# : M 105457

Remark: COMPOSITE U OF MO AT COLUMBIA
ONE BUCKET UNCRUSHED
NEED EXTRA 8 MESH SAMPLE TO SEND TO KNIGHT HAWK

PROXIMATE ANALYSIS		As-Received	Dry Basis
% Moisture	D3302	11.29	******
% Ash	D3174	9.07	10.22
% Volatile	D3175	******	******
% Fixed Carbon	D3172	******	******
BTU	D5865	11338	12781
MAF BTU	D3180	14236	
% Total Sulfur	D4239	2.97	3.35
SULFUR FORMS			
% Pyritic	D2492MOD	******	******
% Sulfate	D2492MOD	******	******
% Organic	D2492MOD	******	******
% Total Sulfur	D4239	2.97	3.35
WATER SOLUBLE			
% Na2O	D8010	******	******
% K2O	D8010	******	******
* % Chlorine	ASME1974	******	******
Alkalies as Na2O	ASME1974	******	******

FUSION TEMP. OF ASH D1857 °F	Reducing	Oxidizing
I.D.	******	******
H=W	******	******
H=1/2W	******	******
FLUID	******	******

GRINDABILITY INDEX D409 ****** @ ****** % Moist.

FREE SWELLING INDEX D720 ******

* Apparent Specific Gravity of Coal	ModIC7113	******
% Equilibrium Moisture	D1412	******
* % Loss on Ignition @ 950C	D7348	******

Weight %

ULTIMATE ANALYSIS		As-Received	Dry Basis
% Moisture	D3302	11.29	******
% Carbon	D5373	63.36	71.42
% Hydrogen	D5373	4.52	5.09
% Nitrogen	D5373	1.14	1.29
% Chlorine	D6721	0.08	0.09
% Sulfur	D4239	2.97	3.35
% Ash	D3174	9.07	10.22
% Oxygen (Diff.)	D3176	7.57	8.54

(Chlorine D6721 Dry Basis ug/g 904)

MINERAL ANALYSIS D6349	% Ignited Basis
Phos. Pentoxide, P2O5	******
Silica, SiO2	******
Ferric Oxide, Fe2O3	******
Alumina, Al2O3	******
Titania, TiO2	******
Lime, CaO	******
Magnesia, MgO	******
Sulfur Trioxide, SO3	******
Potassium Oxide, K2O	******
Sodium Oxide, Na2O	******
Barium Oxide, BaO	******
Strontium Oxide, SrO	******
Manganese Dioxide, MnO2	******
Undetermined	******
Type of Ash ASME1974	******
Silica Value ASME1974	******
T250 Deg F BW	******
Base/Acid Ratio ASME1974	******
lb Ash/mm BTU	8.00
lb SO2/mm BTU	5.24
*Using 20000 as SO2 calculation factor	
Fouling Index ASME1974	******
Slagging Index ASME1974	******

(Mercury D6722 Dry Basis ug/g 0.061)

The analysis, opinions or interpretations contained in this report have been prepared at the client's direction, are based upon observations of material provided by the client and express the best judgment of Standard Laboratories, Inc. Standard Laboratories, Inc. makes no other representation or warranty, expressed or implied, regarding this report. This Certificate of Analysis may not be reproduced except in full, without the written approval of Standard Laboratories, Inc. Invalid if altered

Respectfully Submitted, Steven Arndt

* Not an Accredited Test

II. Design Report (Dispersion Modeling)

Memorandum

To: *Kevin Montesano, PE, PMP, Louis Perry & Associates*

From: *John R. Pehrson, PE, CDM Smith*

Date: *November 6, 2020*

Subject: *Echogen Large Scale Supercritical CO_2 Pilot Plant Vent Study – Final Report*

Attached for your use is the Final Echogen Large Scale Supercritical CO_2 Pilot Plant Vent Study Summary Report. The report has been edited to respond to the comments received from Echogen and the University of Missouri on October 28 and 29, 2020.

cc: David Mock, CDM Smith,
Chris L. Campbell, CDM Smith, Austin
Jeremy Gilbride, CDM Smith, Irvine

Echogen Large Scale Supercritical CO2 Pilot Plant Vent Study Report - Final

1.0 Introduction

Echogen Power Systems, LLC (Echogen) is designing a supercritical carbon dioxide (SCO_2) large scale pilot plant under a grant from the U.S. Department of Energy (USDOE). The plant is expected to be built at the University of Missouri, Columbia, campus utility plant. Louis Perry & Associates (LPA) is designing the balance of plant systems for the pilot plant. The plant will include a purge venting system for startup, as well as a number of safety relief valves for venting SCO_2 during potential upset conditions. CDM Smith was contracted to perform dispersion modeling analysis of the various purge and safety venting scenarios. Because vented pure CO_2 can result in the release of either dense (heavier than ambient air) or buoyant (lighter than air) plumes under different discharge temperatures, CDM Smith identified several screening level models that were used to provide an initial assessment of whether the discharge was dense or buoyant and estimate potential concentrations of CO_2 at locations that could be occupied by people within the impact zone of the releases.

This memorandum summarizes the scenarios analyzed in the study, describes the basic modeling programs used to conduct the analysis, identifies locations selected to represent potentially occupied sites both within the campus utility plant and off the plant property, and summarizes the CO_2 health and safety concentration thresholds used to indicate potential health impacts at the occupied locations. The dispersion modeling results are compared to the health and safety thresholds.

2.0 Vent Study Scenarios

Initially, two cases for analysis were identified by Echogen including: Case 1 - high temperature – high pressure safety valve venting, and Case 2: - manual purge venting at lower pressure and ambient temperature. A schedule of discharge conditions over time for each case was provided to the modeling team. A schematic that represents both cases is presented in **Figure 1**. The initial conditions for each case are summarized in **Table 1**. **Figures 2 and 3** graphically summarized the change in temperatures, pressures, and mass flow rates with time for Case 1 and Case 2, respectively. Five additional safety relief valves were subsequently added to study for dispersion analysis. The data provided for those valves are shown in **Table 2**. The release duration for each of these five additional valves was assumed to be 15 seconds.[1]

[1] Personal communication, Echogen (J. Mallinak) to LPA (K. Montesano) & CDM Smith (J. Pehrson), August 5, 2020, re: Vent Routing update.

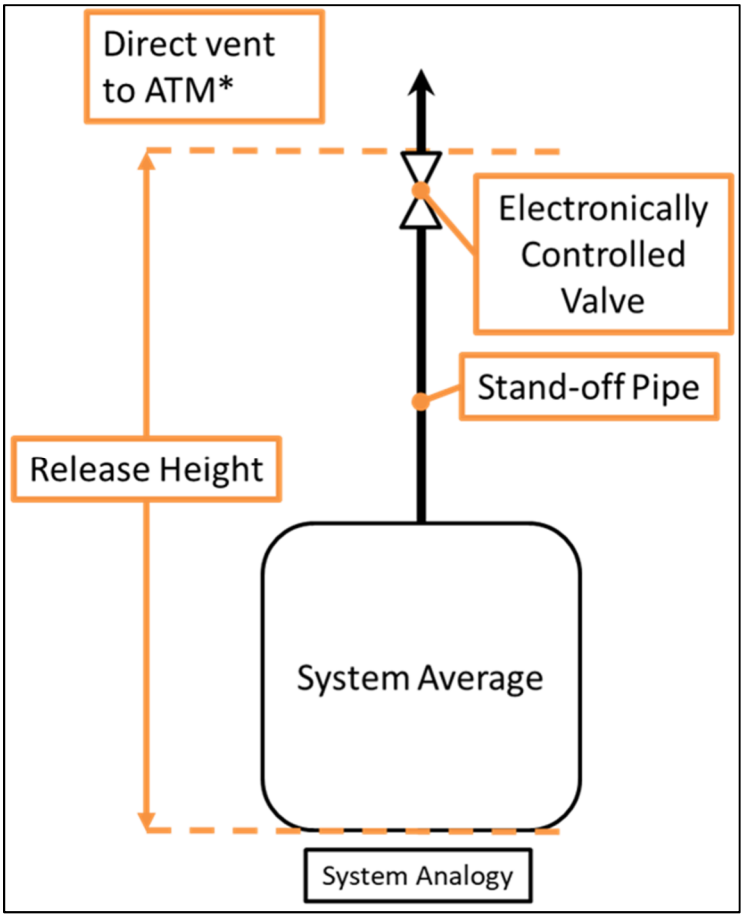


Figure 1. System Schematic for Case 1 and Case 2 Discharge Scenarios

Table 1. Case 1 and 2 Initial Conditions

Parameter	Case 1 – High Temp/Pressure Relief		Case 2 – Manual Purging	
System Conditions				
Mass	17,381.5 lb_m	7,884.2 kg	3,912.2 lb_m	1,774.6 kg
Volume	1,443.3 ft^3	40.87 m^3	1,443.3 ft^3	40.87 m^3
Pressure	3,041.3 psig	21.07 MPa	300 psig	2.17 MPa
Temperature	608.2 °F	320.1 °C	79 °F	26.0 °C
Stand-off Pipe:	NPS 8" Sch 160, revised to 30" to 36"		NPS 8" Sch 160, revised to 10" to 12"	
Length	Release Ht minus 6 ft	Release Ht minus 2 m	Release Ht minus 6 ft	Release Ht minus 2 m
Release Height	92 – 172 ft	28 - 52.5 m	92 – 172 ft	28 - 52.5 m
Valve Orifice	1.1 in^2 Cd=0.85	7.1 cm^2 Cd=0.85	1.1 in^2 Cd=0.85	7.1 cm^2 Cd=0.85
Release Duration	Approx. 32.8 minutes		Approx. 26.5 minutes	

Sources: Personal communication, Echogen (J. Mallinak) to LPA (K. Montesano), July 6, 2020, re: Echogen Pilot Plant Air Dispersion Study; and Personal communication, Echogen (J. Mallinak) to LPA (K. Montesano) & CDM Smith (J. Pehrson), August 5, 2020, re: Vent Routing update.

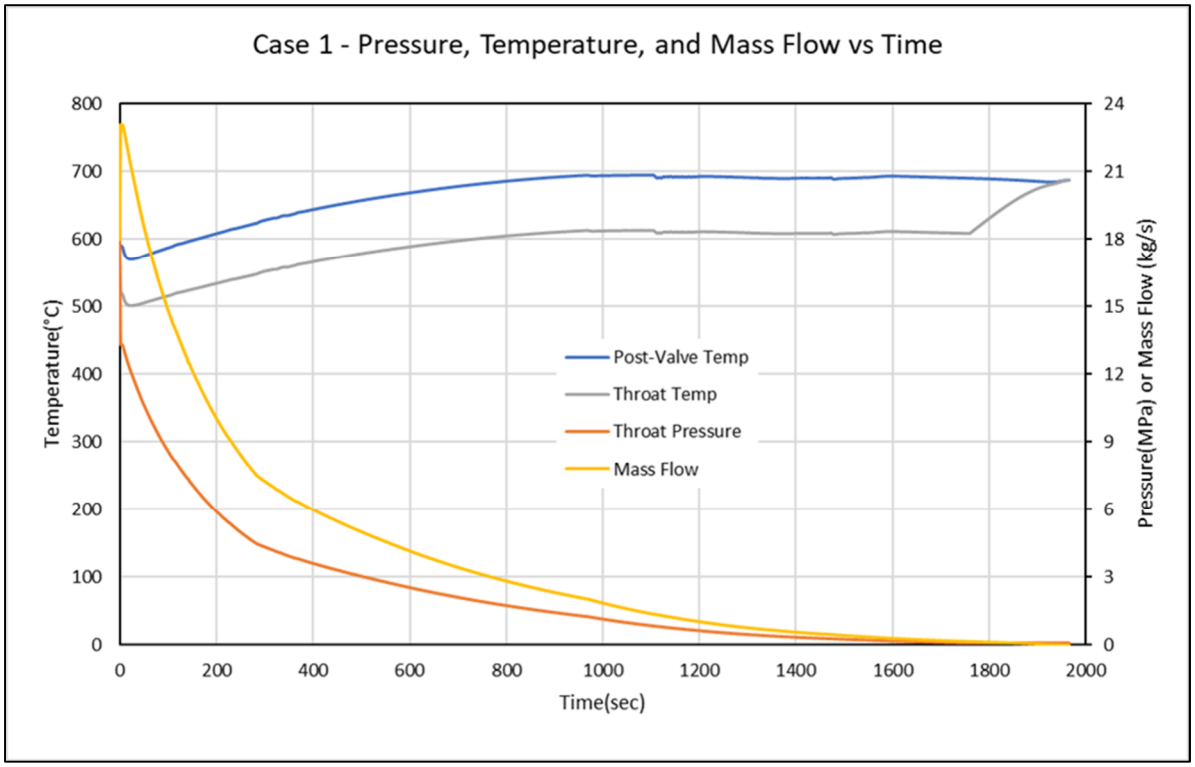


Figure 2. Case 1 Pressure, Temperature, and Mass Flow vs Time.

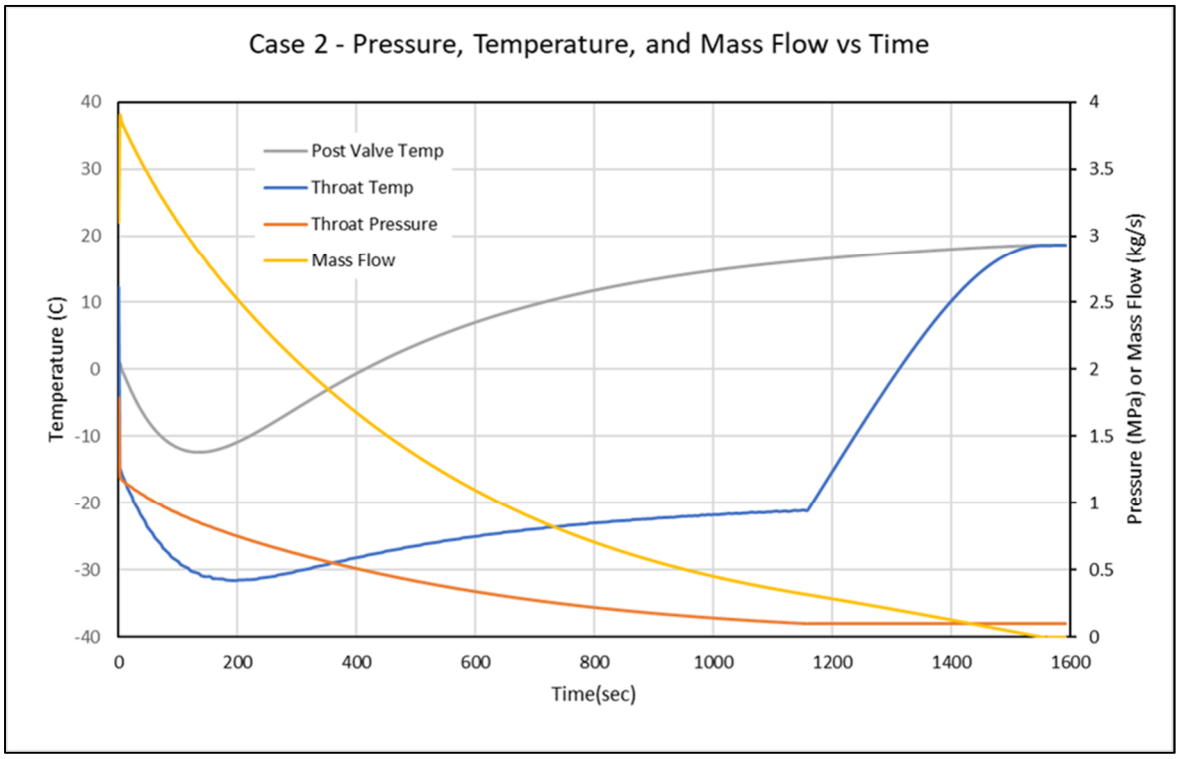


Figure 3. Case 2 Pressure, Temperature, and Mass Flow vs Time

Table 2. Large Scale Pilot Relief Valves – Discharge Conditions

Valve No.	PSV-0220	PSV-1110	PSV-1410	PSV-1430	PSV-1440
Service	LTC Discharge	Transfer Pump Discharge	HTC Discharge	Fired Heater Discharge	Condenser Inlet
Mass Flow	87.1 kg/s (192.1 lb_m/s)	7.0 kg/s (15.4 lb_m/s)	47.8 kg/s (105.4 lb_m/s)	83.9 kg/s (184.9 lb_m/s)	71.8 kg/s (158.3 lb_m/s)
Relieving/Set Parameters					
Temperarture	58 °C (137 °F)	-29 °C (-20 °F)	174 °C (346 °F)	600 °C (1,112 °F)	59 °C (139 °F)
Pressure	27.5 MPa_{abs} (3,975 psig)	10.0 MPa_{abs} (1,436 psig)	27.5 MPa_{abs} (3,975 psig)	25.8 MPa_{abs} (3,727 psig)	10.0 MPa_{abs} (1,436 psig)
Density	817.3 kg/m^3 (51.0 lb_m/ft^3)	1,099.2 kg/m^3 (68.6 lb_m/ft^3)	400.5 kg/m^3 (25.0 lb_m/ft^3)	148.5 kg/m^3 (9.27 lb_m/ft^3)	293.4 kg/m^3 (18.3 lb_m/ft^3)
Compressibility	0.54	0.20	0.81	1.05	0.54
Release Duration	15 seconds	15 seconds	15 seconds	15 seconds	15 seconds

Sources: Echogen Power Systems, EDS00120 - Large Scale Pilot Relief Valves (Revision 2), July 1, 2020; and Personal communication, Echogen (J. Mallinak) to LPA (K. Montesano) & CDM Smith (J. Pehrson), August 5, 2020, re: Vent Routing update.

3.0 Modeling Methodology

3.1 Model Selection

For screening analyses, the U.S. Environmental Protection Agency (USEPA) has developed a combination of emission and dispersion models to provide conservative estimates of air pollutant emissions and concentrations. The combination of these models is contained in the Toxics Screening Model (TSCREEN).[2] The TSCREEN model contains algorithms that estimate the emission rates of releases from a variety of potential source types including vertical discharges through vent valves on pressurized tanks or systems. Once the release type and emission rate are determined, TSCREEN algorithms select the appropriate dispersion model from the available options included with TSCREEN: SCREEN3[3] estimates concentrations from buoyant or neutrally buoyant vertical discharges, RVD[4] estimates concentrations from dense vertical discharges, and PUFF[5] estimates neutrally buoyant instantaneous releases with no momentum (such as evaporation from a contaminant spill on the ground from a ruptured tank). For this study, if a given discharge was determined to be buoyant, the more refined model AERMOD[6] was used for the dispersion analysis. AERMOD is the current USEPA dispersion model recommended for buoyant and neutrally buoyant

2 U.S. Environmental Protection Agency, "User's Guide to TSCREEN – A Model for Screening Toxic Air Pollutant Concentrations (Revised)," EPA-454/B-94-023 (Revises EPA-450/4-90-013), July 1994; and U.S. Environmental Protection Agency. "Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants (Revised)," EPA-454/R-92-024 (Revises EPA-450/4-88-009), December 1992. Available: https://www.epa.gov/scram/air-quality-dispersion-modeling-screening-models#tscreen

3 U.S. Environmental Protection Agency, "SCREEN3 Model User's Guide," EPA-454/B-95-004, September 1995. Available: https://www.epa.gov/scram/air-quality-dispersion-modeling-screening-models#screen3

4 U.S. Environmental Protection Agency, "User's Guide for RVD 2.0 – A Relief Valve Discharge Screening Model," EPA-450/4-88-024, January 1989.

5 U.S. Environmental Protection Agency, "Estimating Concentrations Downwind from an Instantaneous Puff Release," EPA-600/3-82-078, August 1982.

6 U.S. Environmental Protection Agency. Support Center for Regulatory Atmospheric Modeling (SCRAM), Air Quality Dispersion Modeling – Preferred and Recommended Models, accessed June 30, 2020. Available at: https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models#aermod

plumes. When applied, AERMOD was used in a screening mode, meaning a standard set of meteorological conditions of wind speed, atmospheric stability, and temperature was used and the wind was assumed to come from any direction. A similar set of standard meteorological conditions were applied to the dense plume modeling conducted with TSCREEN/RVD. These parameters are summarized in **Attachment I** to this report.

3.2 Emission Rate Estimates

As noted above, emission rates for Case 1 and Case 2 were provided by Echogen over the entire duration of each case in small time increments (approximately 2 seconds). This data was incorporated into the dispersion modeling analysis as follows:

For Case 1, high temperature/high pressure safety relief, the analysis of dispersion looked at three specific periods during the release: (i) the first 60 seconds - t=0 to t= 60 seconds, (ii) the next 240 seconds – t=60 to t=300 seconds; and (iii) the remainder of the release - t=300 to t=1965 seconds. The first minute sees the mass flow rate peak in the 2nd 2-second period then drop back to the mass flow rate of the 1st 2-second period by the end of the minute. In addition, the discharge temperature in the first minute is the lowest of the entire release. In the period from t=61 to t=300 seconds (2nd through 5th minute), the mass flow rate continues to drop rapidly until just before the 5th minute when a slight but noticeable change in the rate of decline is observed in the data. Finally, the remainder of the release (t=301 seconds to end of release) represents the lowest mass emission rate and highest discharge temperature. Average parameter values for each of these time periods were calculated from the provided data and incorporated into the appropriate dispersion model. The dispersion model input parameter values are summarized in **Table 3**.

Table 3. Dispersion Modeling Input Parameters for Case 1 and Case 2

Parameter	Case 1			Case 2
Release Period	Minute 1	Minutes 2 - 5	Minutes 6 – 32.8	Entire 26.5 minutes
Mass Flow, kg/s	20.394	11.304	1.864	1.088
Pre-Valve Conditions				
Avg Temperature, °K	860.9	883.9	957.1	287.8
Avg Pressure, MPa	21.145	11.769	2.018	0.616
Avg Density, kg/m^3	129.94	70.73	11.32	11.42
Valve Throat Conditions				
Avg Temperature, °K	780.8	803.4	883.3	256.0
Avg Pressure, MPa	11.963	6.605	1.147	0.345
Avg Density, kg/m^3	80.95	43.69	7.05	7.35
Avg Velocity, m/s	426.3	432.65	411.63	209.89
Post-Valve Conditions				
Avg Temperature, °K	847.9	876.7	956.1	281.0
Avg Pressure, MPa	0.100	0.100	0.100	0.100
Avg Density, kg/m^3	0.62	0.60	0.55	1.89
Avg Velocity,[a] m/s	59.4	33.7	5.96	11.69

Source: CDM Smith, 2020.

Notes:

a. Discharge vent diameter assumed to be 36 inches for Case 1, and 10 inches for Case 2.

For Case 2, manual purging, the average parameter values for the entire release period were calculated from the provided data and incorporated into the appropriate dispersion model. The dispersion model input parameter values for Case 2 are also summarized in Table 3.

For the other five pressure safety valves (PSVs), the emission rates were calculated using equations contained in the TSCREEN Workbook for gas releases from a reservoir.[7] The general approach in TSCREEN is to first determine if the flow through an orifice is choked or subcritical, if flow through the valve orifice could be two-phase – meaning some of the gas condensed as it passed through the orifice, and if the final discharge from the vent would be dense, or buoyant (or neutrally buoyant, which would also be analyzed with a buoyant plume model) relative to ambient conditions.

Applying the TSCREEN Workbook to supercritical CO_2 did require modification of one of the TSCREEN equations which was only appropriate for ideal gas. The ratio of specific heats, γ, is typically calculated as the ratio of the specific heat capacity at constant pressure, Cp, divided by the specific heat capacity at constant volume, Cv ($\gamma = Cp/Cv$). The TSCREEN equation for γ applies an ideal gas assumption that $Cv = Cp - R/MW$, where R is the universal gas constant, MW is the molecular weight of the gas (CO_2), and the heat capacity at constant pressure is provided on a mass basis (e.g., Joules/kilogram/degree Kelvin). This assumption allows calculation of γ without looking up Cv. However, the ideal gas assumption does not apply to supercritical CO_2. To obtain the correct ratio of specific heats for supercritical CO_2, Cp and Cv were obtained from the National Institute of Standards and Technology (NIST) Chemistry WebBook, SRD 69[8] for each Pre-Valve condition listed in Table 3 for Cases 1 and 2, and for the Relieving/Set condition for each PSV listed in Table 2. The appropriate γ values were calculated directly from the ratio of Cp/Cv.

In addition, the TSCREEN equation used to estimate the mass flow rate, in kg/s (Equation 4.2.3-3 in the TSCREEN Workbook), assumes the discharge coefficient, C, for the valve orifice is 0.75. However, Echogen provided the discharge coefficient for Case 1 and Case 2, both at 0.85. This value was used to overwrite the TSCREEN assumed value.

TSCREEN was used to verify that the vent valves created critical flow conditions (i.e., choke flow) at the valve throat, check for two-phase flow, and determine the density of the discharge plume relative to ambient air for Case 1, Case 2, and the five PSVs. The detailed calculations are provided in **Attachment II** to the report. **Table 4** summarizes the findings of this initial step in the analysis.

---

7 U.S. Environmental Protection Agency. "Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants (Revised)," EPA-454/R-92-024 (Revises EPA-450/4-88-009), December 1992. Section 4.2.3. Available: https://www.epa.gov/scram/air-quality-dispersion-modeling-screening-models#tscreen

8 U.S. Department of Commerce, National Institute of Standards and Technology, NIST Chemistry WebBook, SRD 69, Thermophysical Properties of Carbon dioxide, accessed August 8, 2020. Available at: https://webbook.nist.gov/cgi/fluid.cgi?ID=C124389&Action=Page

Table 4. Vent Valve Flow Conditions

Valve and Scenario	Flow	Single or Two-Phase Flow	Plume Density
Case 1, First minute	Choked	Single	Buoyant
Case 1, Minutes 2 through 5	Choked	Single	Buoyant
Case 1, Minutes 6 through end	Choked	Single	Buoyant
Case 2, Average for entire release	Choked	Single	Dense
PSV-0220, 15 second release	Choked	Two-Phase [a]	Dense
PSV-1110, 15 second release	Choked	Two-Phase [a]	Dense
PSV-1410, 15 second release	Choked	Single	Dense/Neutral [b]
PSV-1430, 15 second release	Choked	Single	Buoyant
PSV-1440, 15 second release	Choked	Two-Phase [a]	Dense

Source: CDM Smith, 2020.

Notes:

a. Using TSCREEN equations indicates that the flow is two-phase at the valve throat, but the condensed phase sublimes/evaporates before reaching the vent exit. Dispersion analysis for these dense plumes was completed using the RVD model for dense plumes with the discharge temperature set to the normal sublimation point (194.7 °K).

b. The RVD dispersion model equations are also used to check for buoyancy at both the vent exit and at the location of maximum plume rise: the discharge from PSV-1410 transitions to a neutrally buoyant plume by the time maximum plume rise is achieved. Therefore, SCREEN3 or AERMOD will be used to determine impacts from this PSV.

4.0 Threshold Concentrations

A number of CO_2 concentration thresholds were identified. Concentrations above these thresholds for the identified exposure durations associated with each threshold could be potentially harmful to human health. The thresholds identified by the National Institute for Occupational Safety and Health (NIOSH) include those identified as Immediately Dangerous to Life or Health (IDLH),[9] the 15-minute Short Term Exposure Limit (STEL), and the recommended 8-hour time-weighted average threshold limit value (TWA-TLV).[10] In addition to occupational exposure, research into the effects of exposures for a typical work day in an office environment at approximately 1,000 to 1,400 ppm indicate a decrease in cognitive skills.[11] In general, the CO_2 hazard to humans is as an asphyxiant, as the concentration of CO_2 increases the level of oxygen available for breathing decreases. A summary of concentrations, exposure times and potential effects are presented in **Table 5**.

9 Centers for Disease Control and Prevention, The National Institute for Occupational Safety and Health, Immediately Dangerous to Life or Health (IDLH) Values, Carbon dioxide, accessed September 7, 2020. Available: https://www.cdc.gov/niosh/idlh/124389.html .

10 Centers for Disease Control and Prevention, The National Institute for Occupational Safety and Health, NIOSH Pocket Guide to Chemical Hazards - Carbon dioxide, accessed September 7, 2020. Available: https://www.cdc.gov/niosh/idlh/124389.html .

11 Allen, J.G., P. MacNaughton, U. Satish, S. Santanam, J. Vallarino, & J.D. Spengler, 2016. "Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures in Office Workers; A Controlled Exposure Study of Green and Conventional Office Environments," Environmental Health Perspectives, Vol 124, No. 6, pp. 805-812.

Table 5. Carbon Dioxide Concentrations and Potential Health Effects

Carbon Dioxide Concentration		Exposure Time	Effects
Percent in Air	ppmv		
0.025-0.05%	250-500	Indefinite	Typical outdoor air concentrations.
0.10%	~1,000	Indefinite	Decreased mental performance, Sick Building Syndrome complaints
0.10-0.14%	1,000-1,400	Work day	Decreased mental performance in an office environment
0.10-0.15%	1,000-1,500	Indefinite	Recommendation of upper limit for indoor space (700 ppm above outdoor air levels)
0.50%	5,000	8 hours	NIOSH recommended time-weighted average threshold limit value
0.70%	7,000	Weeks	Acidosis
1.00%	10,000	Indefinite	Decreased mental performance, Sick Building Syndrome complaints
2.00%	20,000	Several hours	Headache, dyspnea upon mild exertion
3.00%	30,000	15 minutes	NIOSH recommended short-term exposure limit
		1 hour	Mild headache, sweating, and dyspnea at rest
4.00%	40,000	Immediate	NIOSH immediately dangerous to life or health
4.00-5.00%	40,000-50,000	Within minutes	Headache, dizziness, increased blood pressure, uncomfortable dyspnea
6.00%	60,000	1-2 minutes	Hearing and visual disturbances
		~15 minutes	Headache, dyspnea
		Several hours	Tremors
7.00-10.00%	70,000-100,000	< 3 minutes to 1 hour	Headache, increased heart rate, dyspnea, dizziness, sweating, unconsciousness
10.00-15.00%	100,000-150,000	1 to several minutes	Dizziness, drowsiness, severe muscle twitching, unconsciousness
17.00-30.00%	170,000-300,000	< 1 minute	Loss of controlled and purposeful activity, unconsciousness, convulsions, coma, death

Sources: National Institute of Occupational Health and Safety; InspectAPedia, Exposure Limits for Carbon Dioxide, Available at: https://inspectapedia.com/hazmat/Carbon%20_Dioxide_Exposure_Limits.php#:~:text=The%20occupational%20limits%20for%20CO2,on%20acidification%20of%20the%20blood; ANSI/ASHRAE Standard 62.1-2013 Ventilation for Acceptable Indoor Air Quality; Allen, J.G., P. MacNaughton, U. Satish, S. Santanam, J. Vallarino, & J.D. Spengler, 2016, Environmental Health Perspectives, Vol 124, No. 6, pp. 805-812; and Erdmann, C.A., K.C., Steiner, & M.G. Apte, 2002, "Indoor Carbon Dioxide Concentrations and Sick Building Syndrome Symptoms in the Base Study Revisited: Analysis of the 100 Building Dataset," Proceedings: Indoor Air 2002.

ppmv = parts per million by volume

dyspnea = shortness of breath

After reviewing this information, CDM Smith recommended that the modeling analysis identify potentially occupied areas where concentrations could exceed the following levels for the noted exposure durations:

- 40,000 ppmv CO_2 – Concentrations above this level at any location and averaging period
- 30,000 ppmv CO_2 – Concentrations above this level for any off-site location for any period, and concentrations above this level on-site for more the 15 minutes
- 5,000 ppmv CO_2 – Concentrations above this level for any off-site location for more than 15 minutes and concentrations above this level on-site for more than 1 hour
- 1,000 ppmv CO_2 – Concentrations above this level for any off-site location for 1 hour or more

As part of this vent study, CDM Smith did analyze several potential changes to vent heights and, for the manual purge case (Case 2), adding a vent fan to reduce CO_2 concentrations.

5.0 Receptor Locations

A number of locations both in the utility plant and in the surrounding community were analyzed for for CO_2 concentrations. The concentration thresholds used for this analysis are noted above in Section 4. Graphical information on regarding tall buildings and elevated platforms are presented in **Attachment III** to this report. The list of buildings and structures addressed in the study are summarized in **Table 6**.

The elevations of the vent heights above ground were initially assumed to start at approximately 92 ft (28 m) above ground level (0 ft above ground level referenced as the elevation of at the center of the intersection of South 5th Street and East Stewart Road). Currently, the penthouse (above the baghouse) roof is designed to be approximately 104 ft above ground level; therefore, the base case vent heights were assumed to 115 ft (35 m) above ground level to place the vent exit slightly more than 10 ft above the penthouse roof elevation. **Figure 4** indicates the approximate location of the penthouse and vents within the utility plant. Another view of the penthouse and vents is included in Attachment III.

Table 6. Receptor Distances from Vents and Elevations Above Ground

Receptor [a]	Distance from Vents (meters)	Elevation Above Ground (meters)	Building Roof or Platform Height BELOW Vent (meters) [b]
Vent	0.0	35.0	0.0
Penthouse Roof	3.0	32.0	3.0
Penthouse Platform	1.0	26.5	8.5
Existing Building S. of Penthouse	28.0	16.0	19.0
Existing Building SW. of Penthouse	32.0	32.0	3.0
Lower N. Stack Platform (Existing)	32.0	46.0	-11.0
Lower S. Stack Platform (Existing)	114.0	46.0	-11.0
Nearest Sidewalk	42.0	0.0	35.0
Mark Twain Hall	120.0	25.0	10.0
Mark Twain Hall-Elevator Penthouse	120.0	33.0	2.0
Apartments W of Mark Twain Hall	140.0	20.0	15.0
Apartments S of Mark Twain Hall	210.0	25.0	10.0
Downtown Building 1	562.0	40.0	-5.0
Downtown Building 2	800.0	45.0	-10.0
Downtown Building 3 (Memorial Union)	644.0	34.0	1.0
Downtown Building 4 (Jesse Hall)	300.0	40.0	-5.0
Downtown Building 5	574.0	39.0	-4.0
Downtown Building 6 (University Hospital)	885.0	37.0	-2.0

Source: CDM Smith, 2020.

Notes:

a. Receptors are locations that may be occupied by people, even if only briefly for maintenance activities.

b. Building roof or platform heights "below" vents that are shown with negative values are higher than the vent heights.



Figure 4. Approximate Location of Vents and Penthouse

6.0 Modeling Analysis and Results

6.1 Dense Plume Modeling and Results

As noted in Section 3.1, dense plume dispersion modeling was conducted using the RVD Version 2.0 model. The algorithms in RVD were developed from wind tunnel studies conducted on heavier than air plumes.[12] Table 4 above indicates that the following four vent valve releases should be modeled as dense plumes:

- Case 2 – Manual purging
- PSV-0220 - LTC Discharge
- PSV-1110 - Transfer Pump Discharge
- PSV-1440 – Condenser Inlet

The detailed RVD calculations for each valve are included in **Attachment IV**. Because the calculation must be done for each receptor distance and elevation, the files printed in Attachment IV provide the results of the calculation of peak ground level concentrations. The

[12] U.S. Environmental Protection Agency, 1973. Wind Tunnel Tests of Negatively Buoyant Plumes, EPA-650/3-74-003. Available at: https://nepis.epa.gov/Exe/ZyNET.exe/20015T4A.TXT?ZyActionD=ZyDocument&Client=EPA&Index=Prior+to+1976&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C70thru75%5CTxt%5C00000006%5C20015T4A.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL

summary of Case 2 base scenario dispersion results for all receptor locations noted above in Table 6 and for multiple average periods are presented in **Table 7**.

Table 7. Case 2 Base Scenario - 26.5-Minute Release from 115 ft High Vent

Receptor Location [a]	Distance from Vent	CO2 Concentration, ppm [b]		
		1-Minute Average	15-Minute Average	1-Hour Average
Penthouse Roof	3.0	0 [c]	0 [c]	0 [c]
Penthouse Platform	1.0	0 [c]	0 [c]	0 [c]
Existing Building S. of Penthouse	28.0	0 [c]	0 [c]	0 [c]
Existing Building SW. of Penthouse	32.0	23,591	13,726	4,579
Lower N. Stack Platform (Existing)	32.0	21,879	12,730	4,247
Lower S. Stack Platform (Existing)	114.0	10,148	5,904	1,970
Nearest Sidewalk	42.0	0 [c]	0 [c]	0 [c]
Mark Twain Hall-Elevator Penthouse	120.0	15,674	***9,119***	***3,042***
Mark Twain Hall	120.0	10,309	***5,998***	***2,001***
Apartments W of Mark Twain Hall	140.0	7,289	4,241	***1,415***
Apartments S of Mark Twain Hall	210.0	7,133	4,150	***1,384***
Downtown Building 4 (Jesse Hall)	300.0	4,402	2,561	854
Downtown Building 1	562.0	1,911	1,112	371
Downtown Building 5	574.0	1,858	1,081	361
Downtown Building 3 (Memorial Union)	644.0	1,592	927	309
Downtown Building 2	800.0	1,191	693	231
Downtown Building 6 (University Hospital)	885.0	1,045	608	203
Peak Ground Level Concentration	79.0	4,719	2,746	916

Source: CDM Smith, 2020.

Notes:

a. Receptor locations highlighted in light blue are on-site locations (i.e., within the campus utility plant). Receptor locations highlighted in light green are off-site locations.

b. Concentrations shown in ***bold italics*** are above the thresholds noted in Section 4 for the given averaging period and on-site or off-site location.

c. If the vent plume passes well above a given location, no calculation of concentration is made by the RVD model.

The peak CO_2 concentrations for the one-hour averaging period due to purge venting does exceed the suggested off-site 1-hour threshold identified in Section 4. Several options for reducing those impacts were analyzed, including raising the stack to 140 ft and 167 ft above ground, increasing the venting duration to reduce the mass flow rate, and adding a vent fan to increase the exit velocity and exit temperatures. The comparison of those runs is included in Attachment IV. For this preliminary design, raising the vent discharge elevation to 167 ft and adding a 1,250 cfm vent fan downstream of the valve reduced the on-site and off-site concentrations to values below the thresholds identified in Section 4. The concentrations for this design are presented in **Table 8**.

Attachment IV includes a map showing the locations of the off-site buildings and associated concentrations.

Table 8. Case 2 With 26.5-Minute Release from 167 ft High Vent and 1,250 scfm Vent Fan

Receptor Location [a]	Distance from Vent	CO2 Concentration, ppm [b]		
		1-Minute Average	15-Minute Average	1-Hour Average
Penthouse Roof	3.0	0 [c]	0 [c]	0 [c]
Penthouse Platform	1.0	0 [c]	0 [c]	0 [c]
Existing Building S. of Penthouse	28.0	0 [c]	0 [c]	0 [c]
Existing Building SW. of Penthouse	32.0	0 [c]	0 [c]	0 [c]
Lower N. Stack Platform (Existing)	32.0	0 [c]	0 [c]	0 [c]
Lower S. Stack Platform (Existing)	114.0	9,475	5,513	1,949
Nearest Sidewalk	42.0	0 [c]	0 [c]	0 [c]
Mark Twain Hall-Elevator Penthouse	120.0	5,005	2,912	977
Mark Twain Hall	120.0	3,849	2,240	751
Apartments W of Mark Twain Hall	140.0	3,112	1,810	607
Apartments S of Mark Twain Hall	210.0	2,828	1,645	552
Downtown Building 4 (Jesse Hall)	300.0	3,859	2,245	753
Downtown Building 1	562.0	2,453	1,427	479
Downtown Building 5	574.0	2,379	1,384	464
Downtown Building 3 (Memorial Union)	644.0	1,871	1,089	365
Downtown Building 2	800.0	1,486	865	290
Downtown Building 6 (University Hospital)	885.0	1,290	751	252
Peak Ground Level Concentration	175.0	1,739	1.012	339

Source: CDM Smith, 2020.

Notes:

a. Receptor locations highlighted in light blue are on-site locations (i.e., within the campus utility plant). Receptor locations highlighted in light green are off-site locations.

b. Concentrations shown in ***bold italics*** are above the thresholds noted in Section 4 for the given averaging period and on-site or off-site location.

c. If the vent plume passes well above a given location, no calculation of concentration is made by the RVD model.

The summaries of PSV-0220, PSV-1110, and PSV-1440 dispersion results for all receptor locations and multiple averaging periods are presented in **Tables 9, 10, and 11**, respectively. As shown in these tables the short-term relief venting for these dense gas releases did not exceed any of the suggested thresholds in Section 4.

Table 9. PSV-0220 – LTC Discharge Relief Vent – 15-Second Release from 115 ft High Vent

Receptor Location [a]	Distance from Vent	CO2 Concentration, ppm [b]		
		15-Second Average	1-Minute Average	5-Minute Average
Penthouse Roof	3.0	0 [c]	0 [c]	0 [c]
Penthouse Platform	1.0	0 [c]	0 [c]	0 [c]
Existing Building S. of Penthouse	28.0	0 [c]	0 [c]	0 [c]
Existing Building SW. of Penthouse	32.0	0 [c]	0 [c]	0 [c]
Lower N. Stack Platform (Existing)	32.0	0 [c]	0 [c]	0 [c]
Lower S. Stack Platform (Existing)	114.0	0 [c]	0 [c]	0 [c]
Nearest Sidewalk	42.0	0 [c]	0 [c]	0 [c]
Mark Twain Hall-Elevator Penthouse	120.0	19,455	3,686	534
Mark Twain Hall	120.0	0 [c]	0 [c]	0 [c]
Apartments W of Mark Twain Hall	140.0	17,125	3,245	470
Apartments S of Mark Twain Hall	210.0	15,504	2,937	426
Downtown Building 4 (Jesse Hall)	300.0	14,809	2,806	407
Downtown Building 1	562.0	11,668	2,211	320
Downtown Building 5	574.0	11,574	2,193	318
Downtown Building 3 (Memorial Union)	644.0	10,920	2,069	300
Downtown Building 2	800.0	10,353	1,961	284
Downtown Building 6 (University Hospital)	885.0	9,986	1,892	274
Peak Ground Level Concentration	141.0	14,888	2,821	409

Source: CDM Smith, 2020.

Notes:

a. Receptor locations highlighted in light blue are on-site locations (i.e., within the campus utility plant). Receptor locations highlighted in light green are off-site locations.

b. Concentrations shown in ***bold italics*** are above the thresholds noted in Section 4 for the given averaging period and on-site or off-site location.

c. If the vent plume passes well above a given location, no calculation of concentration is made by the RVD model.

Table 10. PSV-1110 – Transfer Pump Discharge Relief Vent – 15-Second Release from 115 ft High Vent

Receptor Location [a]	Distance from Vent	CO2 Concentration, ppm [b]		
		15-Second Average	1-Minute Average	5-Minute Average
Penthouse Roof	3.0	0 [c]	0 [c]	0 [c]
Penthouse Platform	1.0	0 [c]	0 [c]	0 [c]
Existing Building S. of Penthouse	28.0	0 [c]	0 [c]	0 [c]
Existing Building SW. of Penthouse	32.0	0 [c]	0 [c]	0 [c]
Lower N. Stack Platform (Existing)	32.0	0 [c]	0 [c]	0 [c]
Lower S. Stack Platform (Existing)	114.0	12,330	2,336	339
Nearest Sidewalk	42.0	0 [c]	0 [c]	0 [c]
Mark Twain Hall-Elevator Penthouse	120.0	11,606	2,199	319
Mark Twain Hall	120.0	9,872	1,870	271
Apartments W of Mark Twain Hall	140.0	8,558	1,621	235
Apartments S of Mark Twain Hall	210.0	7,767	1,472	213
Downtown Building 4 (Jesse Hall)	300.0	8,642	1,637	237
Downtown Building 1	562.0	6,961	1,319	191
Downtown Building 5	574.0	6,909	1,309	190
Downtown Building 3 (Memorial Union)	644.0	10,273	1,946	282
Downtown Building 2	800.0	6,090	1,154	167
Downtown Building 6 University Hospital)	885.0	5,875	1,113	161
Peak Ground Level Concentration	136.0	6,287	1,191	173

Source: CDM Smith, 2020.

Notes:

a. Receptor locations highlighted in light blue are on-site locations (i.e., within the campus utility plant). Receptor locations highlighted in light green are off-site locations.

b. Concentrations shown in ***bold italics*** are above the thresholds noted in Section 4 for the given averaging period and on-site or off-site location.

c. If the vent plume passes well above a given location, no calculation of concentration is made by the RVD model.

Table 11. PSV-1440 – Condenser Inlet Discharge Relief Vent – 15-Second Release from 115 ft High Vent

Receptor Location [a]	Distance from Vent	CO2 Concentration, ppm [b]		
		15-Second Average	1-Minute Average	5-Minute Average
Penthouse Roof	3.0	0 [c]	0 [c]	0 [c]
Penthouse Platform	1.0	0 [c]	0 [c]	0 [c]
Existing Building S. of Penthouse	28.0	0 [c]	0 [c]	0 [c]
Existing Building SW. of Penthouse	32.0	0 [c]	0 [c]	0 [c]
Lower N. Stack Platform (Existing)	32.0	0 [c]	0 [c]	0 [c]
Lower S. Stack Platform (Existing)	114.0	23,091	4,375	634
Nearest Sidewalk	42.0	0 [c]	0 [c]	0 [c]
Mark Twain Hall-Elevator Penthouse	120.0	22,345	4,234	614
Mark Twain Hall	120.0	20,774	3,936	571
Apartments W of Mark Twain Hall	140.0	18,988	3,598	521
Apartments S of Mark Twain Hall	210.0	16,789	3,181	461
Downtown Building 4 (Jesse Hall)	300.0	16,527	3,131	454
Downtown Building 1	562.0	13,088	2,480	359
Downtown Building 5	574.0	13,006	2,464	357
Downtown Building 3 (Memorial Union)	644.0	12,334	2,337	339
Downtown Building 2	800.0	11,547	2,188	317
Downtown Building 6 (University Hospital)	885.0	11,099	2,103	305
Peak Ground Level Concentration	120.0	16,883	3,199	464

Source: CDM Smith, 2020.

Notes:

a. Receptor locations highlighted in light blue are on-site locations (i.e., within the campus utility plant). Receptor locations highlighted in light green are off-site locations.

b. Concentrations shown in ***bold italics*** are above the thresholds noted in Section 4 for the given averaging period and on-site or off-site location.

c. If the vent plume passes well above a given location, no calculation of concentration is made by the RVD model.

6.2 Buoyant Plume Modeling and Results

Case 1, as noted in Section 3, was analyzed for three separate periods during the release. In each of these periods the plume was buoyant due to the very high temperature of the release. The USEPA AERMOD model was used to estimate CO_2 concentrations on the ground level and at elevated locations around the discharge vent. The resulting contours for each of the three time periods analyzed for Case 1 at three different elevations above ground are included in **Attachment V**.

The vent height is assumed to be 115 ft above ground level, and the elevated receptor analyzed were 104 ft (32 m) – height of the penthouse roof, 164 ft (50 m) – roughly the elevation of the

sampling platforms halfway up the two existing utility plant stacks, and 295 ft (90 m) – roughly the elevation of the platform at the top of the two existing stacks. **Table 12** summarizes the concentrations for each of the release periods at the elevation of the existing stack platforms. These concentrations do not exceed the thresholds listed in in Section 4. However, due to the extreme discharge temperatures under Case 1, the potential plume temperatures at these elevated receptors should be checked.

Table 12. Case 1 CO_2 Concentrations at Elevated Receptors

Elevated Receptor	Elevation (m)	CO2 Concentration, ppmv			
		1st Min	Min 2 thru 5	Final 27 Min	32 Min Avg
Penthouse Roof	32	1,851	1,869	1,009	1,143
North Stack - Lower Platform	50	14,278	9,427	3,006	4,161
North Stack - Upper Platform	90	5,207	4,474	701	1,313
South Stack - Lower Platform	50	5,034	3,811	1,454	1,861
South Stack - Upper Platform	90	4,251	3,383	392	886

Source: CDM Smith, 2020.

Because the Case 1 plumes are so buoyant, the ground level concentrations are less than 150 ppm even for the first minute of the high temperature relief venting. Finally, the concentrations at both ground level and elevated locations for PSV-1410 and PSV-1430 are also below all thresholds.

7.0 Conclusions

Seven venting scenarios were analyzed for dispersion: (i) high temperature/high pressure system venting (Case 1), (ii) manual purging of the system (Case 2), (iii) PSV-0220 release, (iv) PSV-1110 release, (v) PSV-1410 release, (vi) PSV-1430 release, and (vii) PSV-1440 release. The results of dispersion modeling indicated that only Case 2 produced concentrations that would potentially exceed health-based thresholds at off-site locations. Raising the manual purge vent height to 167 feet and adding a 1,250 scfm vent fan was shown to reduce the off-site concentrations to values below these thresholds for this preliminary design.

ATTACHMENT I

Screening Meteorological Data for Air Dispersion Analyses

	Pasquill-Gifford Atmospheric Stability					
	A	B	C	D	E	F
Wind Speed (m/s)	Very Unstable	Unstable	Slightly Unstable	Neutral	Slightly Stable	Stable
1	Evaluated	Evaluated	Evaluated	Evaluated		Evaluated
2	Evaluated	Evaluated	Evaluated	Evaluated	Evaluated	Evaluated
3	Evaluated	Evaluated	Evaluated	Evaluated	Evaluated	Evaluated
4		Evaluated	Evaluated	Evaluated	Evaluated	
5		Evaluated	Evaluated	Evaluated	Evaluated	
8			Evaluated	Evaluated		
10			Evaluated	Evaluated		
15			Evaluated	Evaluated		
20			Evaluated	Evaluated		

From Source No. 1

Table 1.2. Characteristics of Atmospheric Conditions.

Atmospheric Condition	Typical Conditions	Heat Flux	Thermal Structure	Nature of Turbulence
Unstable	Mid-Day Clear Sky Light Wind	Net Upward	Super-Adiabatic	Considerable Horizontal and Vertical
Neutral	Windy or Cloudy or Transition	Zero	Near Dry Adiabatic	Mid -Range
Stable	Nighttime Clear Sky Light Wind	Net Downward	Near Isothermal or Inversion	Damps Out Vertical

From Source No. 2

Table 2.2 Key to Pasquill stability categories.
Source: From Pasquill, 1961.

	Insolation			Night	
Surface wind speed (at 10 m) m s^{-1}	Strong	Moderate	Slight	Thinly overcast or > 4/8 low cloud	< 3/8 cloud
< 2	A	A - B	B	—	—
2 - 3	A - B	B	C	E	F
3 - 5	B	B - C	C	D	E
5 - 6	C	C - D	D	D	D
> 6	C	D	D	D	D

Notes:

1. Strong Insolation corresponds to sunny midday in midsummer in England; slight insolation to similar conditions in midwinter.
2. Night refers to the period from 1 hour before sunset to 1 hour after sunrise.
3. The neutral category D should also be used, regardless of wind speed, for overcast conditions during day or night and for any sky conditions during the hour preceding or following night as defined above.

From Source No. 2

Sources:

1. USEPA, 1992. Workbook of Screening Techniques for Assessing Imacts of Toxic Air Pollutants (Revised). EPA-454/R-92-024. Office of Air Quality Planning & Standards, Research Triangle Park. (December).

2. Turner, D.B., 1994. *Workbook of Atmospheric Dispersion Estimates - An Introduction to Dispersion Modeling, Second Edition.* Lewis Publishers, Boca Raton.

Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants (Revised)

U.S. Environmental Protection Agency, EPA-454/R-92-024, December 1992

Echogen SCO2 Vent Study - Case 01, First minute of release

TSCREEN Inputs [single-phase flow]

Parameter	Value	Units	Definition	Source // Reference
A_0	0.00071	m^2	area of valve orifice of opening in reservoir	Valve throat area from Echogen
A_1	Infinity	m^2	flow area, representing reservoir conditions; In the case of a leak from a tank (or reservoir), $A_1 \rightarrow \infty$ (and $\beta = 0$); In the case of a leak from a pipe, A_1 is the cross-sectional area of the pipe.	Appropriate TSCREEN model is dicharge from a tank
C_P	1250.28	J / (kg · K) @ T_1 & P_1	gas (contaminant) constant pressure heat capacity at T_1	National Institute of Standards and Technology (NIST) data.
D_0	0.03007	m	Equivalent diameter of hole of opening	TSCREEN
MW_{CO2}	44.01	kg / kg-mole	gas (contaminant) molecular weight (for contaminant mixtures, see TSCREEN Workbook Appedix B)	National Institute of Standards and Technology (NIST)
Q	1,283	kg	total mass release	Echogen data
Q_m	--	kg / s	mass emission rate	SPECIFY VALUE TO OVERRIDE TSCREEN CALCULATIONS (set "--" for default)
P_V	See step 2A	Pa	vapor pressure as a function of temperature	TSCREEN; Clausius-Clapeyron vapor pressure equation
P_a	100,000	Pa	ambient pressure	standard atmospheric pressure at sea level
P_1	21,144,812	Pa	reservoir pressure	Echogen data; average of time-varying pressure
R	8,314	J/(kgmol·K) or ($Pa \cdot m^3$/(kgmol·K)	gas constant	gas constant
T_b	194.75	K	contaminant normal boiling point	National Institute of Standards and Technology (NIST)
T_c	304.12	K	critical temperature (for contaminant mixtures, see TSCREEN Workbook Appedix B)	National Institute of Standards and Technology (NIST)
T_1	860.90	K	reservoir temperature	Echogen data; average of time-varying temperature
T_a	298.00	K	ambient temperature	assumed temperature for Echogen site
β	0	dimensionless	square root of (A_0 / A_1)	TSCREEN
γ	1.2352	dimensionless @T_1 & P_1	(C_P / C_V) ≈ 1 / (1 - R / (C_P · M)) @ T_1	Approximation in TSCREEN definition is inappropriate for supercritical gases. National Institute of Standards and Technology (NIST) data utilized instead.
λ	572,597	J / kg @ sublimation point	heat of vaporization at the normal boiling point	National Institute of Standards and Technology (NIST)
ρ_1	124.9763	kg / m^3 @ T_1 & P_1	contaminant density at reservoir conditions	National Institute of Standards and Technology (NIST)

TSCREEN Inputs [two-phase flow]

Parameter	Value	Units	Definition	Source // Reference
L_P	10.00	m	pipe length between reservoir and valve	TSCREEN
D_P	1.00	m	pipe diameter for pipe between reservoir and valve	TSCREEN
f	0.0045	dimensionless	pipe friction factor	TSCREEN

Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants (Revised)
U.S. Environmental Protection Agency, EPA-454/R-92-024, December 1992
Echogen SCO2 Vent Study - Case 01, First minute of release

TSCREEN Procedure

4.2.3.1 Release Rate Estimates: Gas Leaks from a Reservoir

1. Choked Flow Pressure. Estimate the choked flow pressure ($P*$) to determine if the flow is choked [Perry et al. (1984)]

Parameter	Value	Units	Definition	Source // Reference
$P*$	11,793,005	Pa	choked flow pressure = $P* = P_1 \cdot (2 / (\gamma + 1)) ^ (\gamma / (\gamma - 1))$	TSCREEN Equation 4.2.3-1
P_a	100,000	Pa	ambient pressure	standard atmospheric pressure at sea level
$P* > P_a$	**TRUE**	**→ If TRUE, flow is choked; proceed to step 2. If FALSE, flow is subcritical (not choked); proceed to step 3 [see TSCREEN Workbook].**		

2. Choked Flow. For choked flow, estimate the gas temperature ($T*$) when the pressure is $P*$, the emission rate Q_m, and the discharge temperature T_2

A. Estimate T∗

Parameter	Value	Units	Definition	Source // Reference
$T*$	770.33	K	choked flow temperature = $T* = T_1 \cdot (2 / (\gamma + 1))$	TSCREEN Equation 4.2.3-2
T_C	304.12	K	critical temperature (for contaminant mixtures, see TSCREEN Workbook Appedix B)	National Institute of Standards and Technology (NIST)
$T* > T_C$	**TRUE**	**→ If TRUE, T∗ equation 4.2.3-2 is applies, keep T∗; If FALSE, use Clausius-Clapeyron for single-component contaminants to check if contaminant condensation occurs during depressurization.**		
P_V	N/A	Pv @ $T*$	vapor pressure as a function of temperature	TSCREEN; Clausius-Clapeyron vapor pressure equation
$P*$	11,793,005	Pa	choked flow pressure = $P* = P_1 \cdot (2 / (\gamma + 1)) ^ (\gamma / (\gamma - 1))$	TSCREEN Equation 4.2.3-1
$P_V > P_a$	**TRUE**	**→ If TRUE, no contaminant condensation during depressurization and the approach is valid. If FALSE, two-phase release; proceed to step 5 [see TSCREEN Workbook section 4.2.3.2].**		

B. Emissions Rate. Estimate the emissions rate Q_m (kg/s) [Perry et al. (1984)]

Parameter	Value	Units	Definition	Source // Reference
C	0.75	dimensionless	Discharge coefficient = 0.75 when $P_a = P*$; when $P* > P_a$, C can be higher	TSCREEN Equation 4.2.3-3
Cd	0.85	dimensionless	Discharge coefficient	From Echogen, Case 1 Schematic
Q_m	17.9373	kg / s	$Q_m = C \cdot A_0 \cdot (P_1 \cdot \rho_1 \cdot \gamma \cdot (2 / (\gamma + 1)) ^ ((\gamma + 1) / (\gamma - 1))) ^ 0.5$	TSCREEN Equation 4.2.3-3
$Q_m d$	20.3289	kg / s	$Q_m d = Cd \cdot A_0 \cdot (P_1 \cdot \rho_1 \cdot \gamma \cdot (2 / (\gamma + 1)) ^ ((\gamma + 1) / (\gamma - 1))) ^ 0.5$	TSCREEN Equation 4.2.3-3, with discharge coefficient from Echogen

C. Estimate Discharge Temperature. Estimate the discharge temperature T_2 (after depressurization). T_2 is estimatd assuming the expansion from a reservoir conditions to choked conditions occurs adiabatically and reversibly; the expansion from choked conditions to atmospheric pressure is assumed to occur adiabically but not reversibly. After Lewitt (1953), assume this adiabatical expansion is 85% efficient.

Parameter	Value	Units	Definition	Source // Reference
T_2	783.91	K	discharge temperatature = $T_2 = T_1 \cdot (1 - 0.85 \cdot ((\gamma - 1) / (\gamma + 1))$	TSCREEN Equation 4.2.3-4

4. Discharge Density. Estimate the discharge density from the discharge temperature using the ideal gas law.

Parameter	Value	Units	Definition	Source // Reference
ρ_2	0.6752	kg / m^3 @ T_2 & P_a	discharge density = $\rho_2 = P_a \cdot MW_{CO2} / (R \cdot T_2)$	TSCREEN

Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants (Revised)
U.S. Environmental Protection Agency, EPA-454/R-92-024, December 1992
Echogen SCO2 Vent Study - Case 01, First minute of release

4.2.3.3 Dispersion Model Selection

7. Buoyancy Check

Parameter	Value	Units	Definition	Source // Reference
ρ_{air}	1.1664	kg / m^3	density of air = $\rho_{air} = P_a \cdot MW_{air} / (R \cdot T_a)$	TSCREEN Equation 4.2.3-22
ρ_2	0.6752	kg / m^3 @ T_2 & P*	discharge density = $\rho_2 = P_a \cdot MW_{CO2} / (R \cdot T_2)$	TSCREEN
$\rho_2 > \rho_{air}$	**FALSE**	**→ If TRUE, buoyancy is negative. For negative buoyancy, the RVD model should be used if the release is from a vertically directed jet; otherwise, the Britter-McQuaid model should be used; go to step 8 [see TSCREEN Workbook]. If FALSE, use a buoyant/neutrally buoyant model (SCREEN3 or AERMOD).**		

8. Release Duration

Parameter	Value	Units	Definition	Source // Reference
t_d	1.0517	minutes	release duration = $t_d = Q / (Q_{sd} \cdot 60)$	TSCREEN Equation 4.2.3-22

Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants (Revised)

U.S. Environmental Protection Agency, EPA-454/R-92-024, December 1992

Echogen SCO2 Vent Study - Case 01, Minutes 2 through 5 of release

TSCREEN Inputs [single-phase flow]

Parameter	Value	Units	Definition	Source // Reference
A_0	0.00071	m^2	area of valve orifice of opening in reservoir	Valve throat area from Echogen
A_1	Infinity	m^2	flow area, representing reservoir conditions; In the case of a leak from a tank (or reservoir), $A_1 \rightarrow \infty$ (and $\beta = 0$); In the case of a leak from a pipe, A_1 is the cross-sectional area of the pipe.	Appropriate TSCREEN model is dicharge from a tank
C_P	1231.37	J / (kg · K) @ T_1 & P_1	gas (contaminant) constant pressure heat capacity at T_1	National Institute of Standards and Technology (NIST) data.
D_0	0.03007	m	Equivalent diameter of hole of opening	TSCREEN
MW_{CO2}	44.01	kg / kg-mole	gas (contaminant) molecular weight (for contaminant mixtures, see TSCREEN Workbook Appedix B)	National Institute of Standards and Technology (NIST)
Q	2,704	kg	total mass release	Echogen data
Q_m	--	kg / s	mass emission rate	SPECIFY VALUE TO OVERRIDE TSCREEN CALCULATIONS (set "--" for default)
P_V	See step 2A	Pa	vapor pressure as a function of temperature	TSCREEN; Clausius-Clapeyron vapor pressure equation
P_a	100,000	Pa	ambient pressure	standard atmospheric pressure at sea level
P_1	11,769,478	Pa	reservoir pressure	Echogen data; average of time-varying pressure
R	8,314	J/(kgmol·K) or ($Pa \cdot m^3$/(kgmol·K)	gas constant	gas constant
T_b	194.75	K	contaminant normal boiling point	National Institute of Standards and Technology (NIST)
T_c	304.12	K	critical temperature (for contaminant mixtures, see TSCREEN Workbook Appedix B)	National Institute of Standards and Technology (NIST)
T_1	883.90	K	reservoir temperature	Echogen data; average of time-varying temperature
T_a	298.00	K	ambient temperature	assumed temperature for Echogen site
β	0	dimensionless	square root of (A_0 / A_1)	TSCREEN
γ	1.2126	dimensionless @T_1 & P_1	(C_P / C_V) ≈ 1 / (1 - R / (C_P · M)) @ T_1	Approximation in TSCREEN definition is inappropriate for supercritical gases. National Institute of Standards and Technology (NIST) data utilized instead.
λ	572,597	J / kg @ sublimation point	heat of vaporization at the normal boiling point	National Institute of Standards and Technology (NIST)
ρ_1	69.0236	kg / m^3 @ T_1 & P_1	contaminant density at reservoir conditions	National Institute of Standards and Technology (NIST)

TSCREEN Inputs [two-phase flow]

Parameter	Value	Units	Definition	Source // Reference
L_P	10.00	m	pipe length between reservoir and valve	TSCREEN
D_P	1.00	m	pipe diameter for pipe between reservoir and valve	TSCREEN
f	0.0045	dimensionless	pipe friction factor	TSCREEN

Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants (Revised)
U.S. Environmental Protection Agency, EPA-454/R-92-024, December 1992
Echogen SCO2 Vent Study - Case 01, Minutes 2 through 5 of release

TSCREEN Procedure

4.2.3.1 Release Rate Estimates: Gas Leaks from a Reservoir

1. Choked Flow Pressure. Estimate the choked flow pressure ($P*$) to determine if the flow is choked [Perry et al. (1984)]

Parameter	Value	Units	Definition	Source // Reference
$P*$	6,614,769	Pa	choked flow pressure = $P* = P_1 \cdot (2 / (\gamma + 1)) ^ (\gamma / (\gamma - 1))$	TSCREEN Equation 4.2.3-1
P_a	100,000	Pa	ambient pressure	standard atmospheric pressure at sea level
$P* > P_a$	**TRUE**	**→ If TRUE, flow is choked; proceed to step 2. If FALSE, flow is subcritical (not choked); proceed to step 3 [see TSCREEN Workbook].**		

2. Choked Flow. For choked flow, estimate the gas temperature ($T*$) when the pressure is $P*$, the emission rate Q_m, and the discharge temperature T_2

A. Estimate T∗

Parameter	Value	Units	Definition	Source // Reference
$T*$	798.96	K	choked flow temperature = $T* = T_1 \cdot (2 / (\gamma + 1))$	TSCREEN Equation 4.2.3-2
T_C	304.12	K	critical temperature (for contaminant mixtures, see TSCREEN Workbook Appedix B)	National Institute of Standards and Technology (NIST)
$T* > T_C$	**TRUE**	**→ If TRUE, T∗ equation 4.2.3-2 is applies, keep T∗; If FALSE, use Clausius-Clapeyron for single-component contaminants to check if contaminant condensation occurs during depressurization.**		
P_V	N/A	Pv @ $T*$	vapor pressure as a function of temperature	TSCREEN; Clausius-Clapeyron vapor pressure equation
$P*$	6,614,769	Pa	choked flow pressure = $P* = P_1 \cdot (2 / (\gamma + 1)) ^ (\gamma / (\gamma - 1))$	TSCREEN Equation 4.2.3-1
$P_V > P_a$	**TRUE**	**→ If TRUE, no contaminant condensation during depressurization and the approach is valid. If FALSE, two-phase release; proceed to step 5 [see TSCREEN Workbook section 4.2.3.2].**		

B. Emissions Rate. Estimate the emissions rate Q_m (kg/s) [Perry et al. (1984)]

Parameter	Value	Units	Definition	Source // Reference
C	0.75	dimensionless	Discharge coefficient = 0.75 when $P_a = P*$; when $P* > P_a$, C can be higher	TSCREEN Equation 4.2.3-3
Cd	0.85	dimensionless	Discharge coefficient	From Echogen, Case 1 Schematic
Q_m	9.8801	kg / s	$Q_m = C \cdot A_0 \cdot (P_1 \cdot \rho_1 \cdot \gamma \cdot (2 / (\gamma + 1)) ^ ((\gamma + 1) / (\gamma - 1))) ^ 0.5$	TSCREEN Equation 4.2.3-3
$Q_m d$	11.1974	kg / s	$Q_m d = Cd \cdot A_0 \cdot (P_1 \cdot \rho_1 \cdot \gamma \cdot (2 / (\gamma + 1)) ^ ((\gamma + 1) / (\gamma - 1))) ^ 0.5$	TSCREEN Equation 4.2.3-3, with discharge coefficient from Echogen

C. Estimate Discharge Temperature. Estimate the discharge temperature T_2 (after depressurization). T_2 is estimatd assuming the expansion from a reservoir conditions to choked conditions occurs adiabatically and reversibly; the expansion from choked conditions to atmospheric pressure is assumed to occur adiabically but not reversibly. After Lewitt (1953), assume this adiabatical expansion is 85% efficient.

Parameter	Value	Units	Definition	Source // Reference
T_2	811.70	K	discharge temperatature = $T_2 = T_1 \cdot (1 - 0.85 \cdot ((\gamma - 1) / (\gamma + 1))$	TSCREEN Equation 4.2.3-4

4. Discharge Density. Estimate the discharge density from the discharge temperature using the ideal gas law.

Parameter	Value	Units	Definition	Source // Reference
ρ_2	0.6521	kg / m^3 @ T_2 & P_a	discharge density = $\rho_2 = P_a \cdot MW_{CO2} / (R \cdot T_2)$	TSCREEN

Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants (Revised)
U.S. Environmental Protection Agency, EPA-454/R-92-024, December 1992
Echogen SCO2 Vent Study - Case 01, Minutes 2 through 5 of release

4.2.3.3 Dispersion Model Selection

7. Buoyancy Check

Parameter	Value	Units	Definition	Source // Reference
ρ_{air}	1.1664	kg / m^3	density of air = $\rho_{air} = P_a \cdot MW_{air} / (R \cdot T_a)$	TSCREEN Equation 4.2.3-22
ρ_2	0.6521	kg / m^3 @ T_2 & P*	discharge density = $\rho_2 = P_a \cdot MW_{CO2} / (R \cdot T_2)$	TSCREEN
$\rho_2 > \rho_{air}$	**FALSE**	**→ If TRUE, buoyancy is negative. For negative buoyancy, the RVD model should be used if the release is from a vertically directed jet; otherwise, the Britter-McQuaid model should be used; go to step 8 [see TSCREEN Workbook]. If FALSE, use a buoyant/neutrally buoyant model (SCREEN3 or AERMOD).**		

8. Release Duration

Parameter	Value	Units	Definition	Source // Reference
t_d	4.0250	minutes	release duration = $t_d = Q / (Q_{ad} \cdot 60)$	TSCREEN Equation 4.2.3-22

Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants (Revised)

U.S. Environmental Protection Agency, EPA-454/R-92-024, December 1992

Echogen SCO2 Vent Study - Case 01, Minutes 6 through 32.8 of release

TSCREEN Inputs [single-phase flow]

Parameter	Value	Units	Definition	Source // Reference
A_0	0.00071	m^2	area of valve orifice of opening in reservoir	Valve throat area from Echogen
A_1	Infinity	m^2	flow area, representing reservoir conditions; In the case of a leak from a tank (or reservoir), $A_1 \rightarrow \infty$ (and $\beta = 0$); In the case of a leak from a pipe, A_1 is the cross-sectional area of the pipe.	Appropriate TSCREEN model is dicharge from a tank
C_P	1226.76	J / (kg · K) @ T_1 & P_1	gas (contaminant) constant pressure heat capacity at T_1	National Institute of Standards and Technology (NIST) data.
D_0	0.03007	m	Equivalent diameter of hole of opening	TSCREEN
MW_{CO2}	44.01	kg / kg-mole	gas (contaminant) molecular weight (for contaminant mixtures, see TSCREEN Workbook Appedix B)	National Institute of Standards and Technology (NIST)
Q	3,399	kg	total mass release	Echogen data
Q_m	--	kg / s	mass emission rate	SPECIFY VALUE TO OVERRIDE TSCREEN CALCULATIONS (set "--" for default)
P_V	See step 2A	Pa	vapor pressure as a function of temperature	TSCREEN; Clausius-Clapeyron vapor pressure equation
P_a	100,000	Pa	ambient pressure	standard atmospheric pressure at sea level
P_1	2,017,625	Pa	reservoir pressure	Echogen data; average of time-varying pressure
R	8,314	J/(kgmol·K) or ($Pa \cdot m^3$/(kgmol·K)	gas constant	gas constant
T_b	194.75	K	contaminant normal boiling point	National Institute of Standards and Technology (NIST)
T_c	304.12	K	critical temperature (for contaminant mixtures, see TSCREEN Workbook Appedix B)	National Institute of Standards and Technology (NIST)
T_1	957.11	K	reservoir temperature	Echogen data; average of time-varying temperature
T_a	298.00	K	ambient temperature	assumed temperature for Echogen site
β	0	dimensionless	square root of (A_0 / A_1)	TSCREEN
γ	1.1866	dimensionless @T_1 & P_1	(C_P / C_V) ≈ 1 / (1 - R / (C_P · M)) @ T_1	Approximation in TSCREEN definition is inappropriate for supercritical gases. National Institute of Standards and Technology (NIST) data utilized instead.
λ	572,597	J / kg @ sublimation point	heat of vaporization at the normal boiling point	National Institute of Standards and Technology (NIST)
ρ_1	11.1160	kg / m^3 @ T_1 & P_1	contaminant density at reservoir conditions	National Institute of Standards and Technology (NIST)

TSCREEN Inputs [two-phase flow]

Parameter	Value	Units	Definition	Source // Reference
L_P	10.00	m	pipe length between reservoir and valve	TSCREEN
D_P	1.00	m	pipe diameter for pipe between reservoir and valve	TSCREEN
f	0.0045	dimensionless	pipe friction factor	TSCREEN

Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants (Revised)
U.S. Environmental Protection Agency, EPA-454/R-92-024, December 1992
Echogen SCO2 Vent Study - Case 01, Minutes 6 through 32.8 of release

TSCREEN Procedure

4.2.3.1 Release Rate Estimates: Gas Leaks from a Reservoir

1. Choked Flow Pressure. Estimate the choked flow pressure ($P*$) to determine if the flow is choked [Perry et al. (1984)]

Parameter	Value	Units	Definition	Source // Reference
$P*$	1,144,167	Pa	choked flow pressure = $P* = P_1 \cdot (2 / (\gamma + 1)) ^ (\gamma / (\gamma - 1))$	TSCREEN Equation 4.2.3-1
P_a	100,000	Pa	ambient pressure	standard atmospheric pressure at sea level
$P* > P_a$	**TRUE**	**→ If TRUE, flow is choked; proceed to step 2. If FALSE, flow is subcritical (not choked); proceed to step 3 [see TSCREEN Workbook].**		

2. Choked Flow. For choked flow, estimate the gas temperature ($T*$) when the pressure is $P*$, the emission rate Q_m, and the discharge temperature T_2

A. Estimate T∗

Parameter	Value	Units	Definition	Source // Reference
$T*$	875.42	K	choked flow temperature = $T* = T_1 \cdot (2 / (\gamma + 1))$	TSCREEN Equation 4.2.3-2
T_C	304.12	K	critical temperature (for contaminant mixtures, see TSCREEN Workbook Appedix B)	National Institute of Standards and Technology (NIST)
$T* > T_C$	**TRUE**	**→ If TRUE, T∗ equation 4.2.3-2 is applies, keep T∗; If FALSE, use Clausius-Clapeyron for single-component contaminants to check if contaminant condensation occurs during depressurization.**		
P_V	N/A	Pv @ $T*$	vapor pressure as a function of temperature	TSCREEN; Clausius-Clapeyron vapor pressure equation
$P*$	1,144,167	Pa	choked flow pressure = $P* = P_1 \cdot (2 / (\gamma + 1)) ^ (\gamma / (\gamma - 1))$	TSCREEN Equation 4.2.3-1
$P_V > P_a$	**TRUE**	**→ If TRUE, no contaminant condensation during depressurization and the approach is valid. If FALSE, two-phase release; proceed to step 5 [see TSCREEN Workbook section 4.2.3.2].**		

B. Emissions Rate. Estimate the emissions rate Q_m (kg/s) [Perry et al. (1984)]

Parameter	Value	Units	Definition	Source // Reference
C	0.75	dimensionless	Discharge coefficient = 0.75 when $P_a = P*$; when $P* > P_a$, C can be higher	TSCREEN Equation 4.2.3-3
Cd	0.85	dimensionless	Discharge coefficient	From Echogen, Case 1 Schematic
Q_m	1.6289	kg / s	$Q_m = C \cdot A_0 \cdot (P_1 \cdot \rho_1 \cdot \gamma \cdot (2 / (\gamma + 1)) ^ ((\gamma + 1) / (\gamma - 1))) ^ 0.5$	TSCREEN Equation 4.2.3-3
$Q_m d$	1.8461	kg / s	$Q_m d = Cd \cdot A_0 \cdot (P_1 \cdot \rho_1 \cdot \gamma \cdot (2 / (\gamma + 1)) ^ ((\gamma + 1) / (\gamma - 1))) ^ 0.5$	TSCREEN Equation 4.2.3-3, with discharge coefficient from Echogen

C. Estimate Discharge Temperature. Estimate the discharge temperature T_2 (after depressurization). T_2 is estimatd assuming the expansion from a reservoir conditions to choked conditions occurs adiabatically and reversibly; the expansion from choked conditions to atmospheric pressure is assumed to occur adiabically but not reversibly. After Lewitt (1953), assume this adiabatical expansion is 85% efficient.

Parameter	Value	Units	Definition	Source // Reference
T_2	887.67	K	discharge temperatature = $T_2 = T_1 \cdot (1 - 0.85 \cdot ((\gamma - 1) / (\gamma + 1))$	TSCREEN Equation 4.2.3-4

4. Discharge Density. Estimate the discharge density from the discharge temperature using the ideal gas law.

Parameter	Value	Units	Definition	Source // Reference
ρ_2	0.5963	kg / m^3 @ T_2 & P_a	discharge density = $\rho_2 = P_a \cdot MW_{CO2} / (R \cdot T_2)$	TSCREEN

Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants (Revised)
U.S. Environmental Protection Agency, EPA-454/R-92-024, December 1992
Echogen SCO2 Vent Study - Case 01, Minutes 6 through 32.8 of release

4.2.3.3 Dispersion Model Selection

7. Buoyancy Check

Parameter	Value	Units	Definition	Source // Reference
ρ_{air}	1.1664	kg / m^3	density of air = $\rho_{air} = P_a \cdot MW_{air} / (R \cdot T_a)$	TSCREEN Equation 4.2.3-22
ρ_2	0.5963	kg / m^3 @ T_2 & P*	discharge density = $\rho_2 = P_a \cdot MW_{CO2} / (R \cdot T_2)$	TSCREEN
$\rho_2 > \rho_{air}$	**FALSE**	**→ If TRUE, buoyancy is negative. For negative buoyancy, the RVD model should be used if the release is from a vertically directed jet; otherwise, the Britter-McQuaid model should be used; go to step 8 [see TSCREEN Workbook]. If FALSE, use a buoyant/neutrally buoyant model (SCREEN3 or AERMOD).**		

8. Release Duration

Parameter	Value	Units	Definition	Source // Reference
t_d	30.6876	minutes	release duration = $t_d = Q / (Q_{sd} \cdot 60)$	TSCREEN Equation 4.2.3-22

Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants (Revised)

U.S. Environmental Protection Agency, EPA-454/R-92-024, December 1992

Echogen SCO2 Vent Study - Case 01, First minute of release

TSCREEN Inputs [single-phase flow]

Parameter	Value	Units	Definition	Source // Reference
A_0	0.00071	m^2	area of a reservoir hole of opening	Val;ve throat area provided by Echogen
A_1	Infinity	m^2	flow area, representing reservoir conditions; In the case of a leak from a tank (or reservoir), $A_1 \rightarrow \infty$ (and $\beta = 0$); In the case of a leak from a pipe, A_1 is the cross-sectional area of the pipe.	Appropriate TSCREEN model is discharge from a tank
C_P	884.72	J / (kg · K) @ T_1 & P_1	gas (contaminant) constant pressure heat capacity at T_1	National Institute of Standards and Technology (NIST) data.
Pseudo Cp	751.99	J / (kg · K) @ T_1 & P_1		Value calculated to produce correct γ value in TSCREEN program.
D_0	0.03007	m	Equivalent diameter of hole of opening	TSCREEN
MW_{CO2}	44.01	kg / kg-mole	gas (contaminant) molecular weight (for contaminant mixtures, see TSCREEN Workbook Appedix B)	National Institute of Standards and Technology (NIST)
Q	1,734	kg	total mass release	Echogen data
Q_m	--	kg / s	mass emission rate	**SPECIFY VALUE TO OVERRIDE TSCREEN CALCULATIONS (set "--" for default)**
P_V	See step 2A	Pa	vapor pressure as a function of temperature	TSCREEN; Clausius-Clapeyron vapor pressure equation
P_a	100,000	Pa	ambient pressure	standard atmospheric pressure at sea level
P_1	616,366	Pa	reservoir pressure	Echogen data; average of time-varying pressure
R	8,314	J/(kgmol·K) or ($Pa \cdot m^3$/(kgmol·K)	gas constant	gas constant
T_b	194.75	K	contaminant normal boiling point	National Institute of Standards and Technology (NIST)
T_c	304.12	K	critical temperature (for contaminant mixtures, see TSCREEN Workbook Appedix B)	National Institute of Standards and Technology (NIST)
T_1	287.76	K	reservoir temperature	Echogen data; average of time-varying temperature
T_a	298.00	K	ambient temperature	assumed temperature for Echogen site
β	0	dimensionless	square root of (A_0 / A_1)	TSCREEN
γ	1.3355	dimensionless @T_1 & P_1	(C_P / C_V) ≈ 1 / (1 - R / (C_P · M)) @ T_1	Approximation in TSCREEN definition is inappropriate for supercritical gases. National Institute of Standards and Technology (NIST) data utilized instead.
λ	572,597	J / kg @ sublimation point	heat of vaporization at the normal boiling point	National Institute of Standards and Technology (NIST)
ρ_1	11.7520	kg / m^3 @ T_1 & P_1	contaminant density at reservoir conditions	National Institute of Standards and Technology (NIST)

TSCREEN Inputs [two-phase flow]

Parameter	Value	Units	Definition	Source // Reference
L_P	10.00	m	pipe length between reservoir and valve	TSCREEN
D_P	1.00	m	pipe diameter for pipe between reservoir and valve	TSCREEN
f	0.0045	dimensionless	pipe friction factor	TSCREEN

Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants (Revised)
U.S. Environmental Protection Agency, EPA-454/R-92-024, December 1992
Echogen SCO2 Vent Study - Case 01, First minute of release

TSCREEN Procedure

4.2.3.1 Release Rate Estimates: Gas Leaks from a Reservoir

1. Choked Flow Pressure. Estimate the choked flow pressure ($P*$) to determine if the flow is choked [Perry et al. (1984)]

Parameter	Value	Units	Definition	Source // Reference
$P*$	332,461	Pa	choked flow pressure = $P* = P_1 \cdot (2 / (\gamma + 1)) ^ (\gamma / (\gamma - 1))$	TSCREEN Equation 4.2.3-1
P_a	100,000	Pa	ambient pressure	standard atmospheric pressure at sea level
$P* > P_a$	**TRUE**	**→ If TRUE, flow is choked; proceed to step 2. If FALSE, flow is subcritical (not choked); proceed to step 3 [see TSCREEN Workbook].**		

2. Choked Flow. For choked flow, estimate the gas temperature ($T*$) when the pressure is $P*$, the emission rate Q_m, and the discharge temperature T_2

A. Estimate T∗

Parameter	Value	Units	Definition	Source // Reference
$T*$	246.42	K	choked flow temperature = $T* = T_1 \cdot (2 / (\gamma + 1))$	TSCREEN Equation 4.2.3-2
T_C	304.12	K	critical temperature (for contaminant mixtures, see TSCREEN Workbook Appedix B)	National Institute of Standards and Technology (NIST)
$T* > T_C$	**FALSE**	**→ If TRUE, T∗ equation 4.2.3-2 is applies, keep T∗; If FALSE, use Clausius-Clapeyron for single-component contaminants to check if contaminant condensation occurs during depressurization.**		
P_V	2,648,693	Pa @ $T*$	vapor pressure = $P_v = 101325 \cdot \exp [(\lambda MW_{CO2} / R) \cdot (1/T_b - 1/T*)]$	TSCREEN; Clausius-Clapeyron vapor pressure equation, page 4-36.
$P*$	332,461	Pa	choked flow pressure = $P* = P_1 \cdot (2 / (\gamma + 1)) ^ (\gamma / (\gamma - 1))$	TSCREEN Equation 4.2.3-1
$P_V > P_a$	**TRUE**	**→ If TRUE, no contaminant condensation during depressurization and the approach is valid. If FALSE, two-phase release; proceed to step 5 [see TSCREEN Workbook section 4.2.3.2].**		

B. Emissions Rate. Estimate the emissions rate Q_m (kg/s) [Perry et al. (1984)]

Parameter	Value	Units	Definition	Source // Reference
C	0.75	dimensionless	discharge coefficient = 0.75, where $P_a = P*$; when $P* > P_a$, C can be higher	TSCREEN Equation 4.2.3-3
Cd	0.85	dimensionless	discharge coefficient	From Echogen, Case 2 Schematic
Q_m	0.9654	kg / s	$Q_m = C \cdot A_0 \cdot (P_1 \cdot \rho_1 \cdot \gamma \cdot (2 / (\gamma + 1)) ^ ((\gamma + 1) / (\gamma - 1))) ^ 0.5$	TSCREEN Equation 4.2.3-3
$Q_m d$	1.0941	kg / s	$Q_m d = Cd \cdot A_0 \cdot (P_1 \cdot \rho_1 \cdot \gamma \cdot (2 / (\gamma + 1)) ^ ((\gamma + 1) / (\gamma - 1))) ^ 0.5$	TSCREEN Equation 4.2.3-3

C. Estimate Discharge Temperature. Estimate the discharge temperature T_2 (after depressurization). T_2 is estimatd assuming the expansion from a reservoir conditions to choked conditions occurs adiabatically and reversibly; the expansion from choked conditions to atmospheric pressure is assumed to occur adiabically but not reversibly. After Lewitt (1953), assume this adiabatical expansion is 85% efficient.

Parameter	Value	Units	Definition	Source // Reference
T_2	252.63	K	discharge temperatature = $T_2 = T_1 \cdot (1 - 0.85 \cdot ((\gamma - 1) / (\gamma + 1))$	TSCREEN Equation 4.2.3-4

4. Discharge Density. Estimate the discharge density from the discharge temperature using the ideal gas law.

Parameter	Value	Units	Definition	Source // Reference
ρ_2	2.0953	kg / m^3 @ T_2 & P_a	discharge density = $\rho_2 = P_a \cdot MW_{CO2} / (R \cdot T_2)$	TSCREEN

Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants (Revised)
U.S. Environmental Protection Agency, EPA-454/R-92-024, December 1992
Echogen SCO2 Vent Study - Case 01, First minute of release

TSCREEN Procedure

4.2.3.3 Dispersion Model Selection

7. Buoyancy Check

Parameter	Value	Units	Definition	Source // Reference
ρ_{air}	1.1664	kg / m^3	density of air = $\rho_{air} = P_a \cdot MW_{air} / (R \cdot T_a)$	TSCREEN Equation 4.2.3-22
ρ_2	2.0953	kg / m^3 @ T_2 & P∗	discharge density = $\rho_2 = P_a \cdot MW_{CO2} / (R \cdot T_2)$	TSCREEN
$\rho_2 > \rho_{air}$	**TRUE**	**→ If TRUE, buoyancy is negative. For negative buoyancy, the RVD model should be used if the release is from a vertically directed jet; otherwise, the Britter-McQuaid model should be used; go to step 8 [see TSCREEN Workbook].**		

8. Release Duration

Parameter	Value	Units	Definition	Source // Reference
t_d	26.4109	minutes	release duration = $t_d = Q / (Q_{md} \cdot 60)$	TSCREEN Equation 4.2.3-22

CO2 Vent Study - Spring Relief Valves

Relief Valve No.	**PSV-0220**			
Service	**LTC Discharge**			
Process Fluid =	CO_2	Units	References	Notes
CO2 Molecular Weight, MW_{CO2} =	44.01	kg/kgmol	[1]	TSCREEN input parameter.
Mass Flow, Qm =	87.1	kg/s	[1]	TSCREEN calculates mass flow, valve throat area selected to match this value.
Set Temp, T1 =	331.15	^oK	[1]	TSCREEN input parameter.
Set Pressure, P1 =	27,500,000	Pa_{abs}	[1]	TSCREEN input parameter.
Set Density, ρ1 =	817.3	kg/m^3	[1]	TSCREEN input parameter. (Density = 818.6 kg/m3 per NIST[2])
Set Compressibility, Z1 =	0.54		[1]	Not used in TSCREEN. (Z=1 for Ideal Gas)
Specific Heat Capacity, Cp1 =	2,075.7	J/(kg ^oK)	[2]	TSCREEN input parameter, value from NIST.
Pseudo Cp1 =	335.9	J/(kg ^oK)	[5]	Value calculated to produce correct k1 value in TSCREEN (not needed for calculations below)
Ratio of Specific Heats, k1 =	2.286		[2]	k1 = Cp1/Cv1, Cp1 and Cv1 values from NIST [2]
Enthalpy, H1 =	307,957.0	J/kg	[2]	
Release Duration, t_{rel} =	15.0	sec	[3]	Assumed, based in Reference [3].
PSV Orifice Area, Ao =	0.0014866	m2	[5]	Iterated to produce Qm in TSCREEN model
Additional Modeling Inputs:				
Universal Gas Constant, R =	8,314	J/(kgmol ^oK)	[4]	TSCREEN input parameter. (= 8314 Pa m3 / (kgmol ^oK)
Freezing Temp @ 1 atm, Tb =	194.75	^oK	[2]	TSCREEN input parameter.
Heat of Sublimation, λ =	572,604	J/kg	[2]	TSCREEN input parameter (λ at 1 atm and 194.8 ^oK)
Ambient Temp, T_a =	298	^oK	[5]	TSCREEN input parameter. Adjusted Ta to ___^oK to force PUFF modeling.
Ambient (Discharge) Press, P2 = P_a =	100,000	Pa	[1]	TSCREEN input parameter.
Air Molecular Weight, MW_{Air} =	28.96	kg/kgmol	[4]	TSCREEN input parameter.
Ambient Density, ρa =	1.169	kg/m^3	[4]	P_a MW_{air} / (R Ta)
Discharge Pipe Length, L2 =	10	ft	[5]	TSCREEN input parameter.
Discharge Pipe (Vent) Diameter, D2 =	18	inches	[5]	TSCREEN input parameter.
Pipe Friction Factor, f =	0.0045		[4]	TSCREEN input parameter. Value assumed in TSCREEN Model for turbulent pipe flow.
Check for Choked Flow:				
Critical Pressure, P* =	11,377,778	Pa	[4]	P* = P1 * [2 / (k1 + 1)]^(k1/(k1-1)), TSCREEN Equation 4.3.2-1
Is P* > P_a ?	Yes		[4]	Yes, flow is choked: use TSCREEN Eq 4.3.2-2 for T*.
Check for Condensation/Freezing at Choke Point:				
1st Iteration Temperature @ P*, T* =	201.58	^oK	[4]	T* = T1 * [2 / (k1 + 1)], TSCREEN Equation 4.3.2-2
Is T* > Tc?	No		[4]	No, check for potential condensation in flow.
Vapor Pressure @ T*, Pv =	169,408	Pa	[4]	Pv = P_a * exp[(k1 MW_{CO2} / R) (1 / Tb - 1/T*)], Clausius-Clapeyron vapor pressure equation
Is Pv < P*?	Yes		[4]	Yes, condensation does occur. Use two-phase discharge calculation in Section 4.2.3.2.

CO2 Vent Study - Spring Relief Valves

Relief Valve No.	**PSV-0220**			
Service	**LTC Discharge**			
Process Fluid =	CO_2	Units	References	Notes
Estimation of Two-Phase Flow Parameters at Choke Point				
2nd Interation Temperature @ P*, T* =	279.89	^oK	[4]	T* = 1 / { 1/Tb - [(R / λ MW_{CO2}) ln (P* / P_a)] }, Clausius-Clapeyron equation solved for T*
Vapor Fraction, X* =	1.089		[4]	X* = 1 + (T* / λ MW_{CO2}) * [MW_{CO2} Cp1 ln (T1 / T*) - R ln (P1 / P*)], TSCREEN Equation 4.3.2-8
Enthalpy change, H1-H* =	55,360	J/kg	[4]	H1-H* = Cp1 (T1 - T*) + λ (1 - X*), TSCREEN Equation 4.3.2-9
Density @ P* & T*, ρ* =	201.92	kg/m3	[4]	ρ* = 1 / { X* [(R T*) / (P* MW_{CO2})] + [(1 - X*) / ρ1] }, TSCREEN Equation 4.3.2-10
Check Qm =	87.01	kg/s	[4]	Qm = Ao ρ2 { 2 * 0.85 * [(H1 - H*) / (1 + (4 f L2 / D2))] }$^{(1/2)}$
Estimation of Temperature, Pressure and Density at Vent Exit				
1st Interation Exit Temp, T2 =	194.75	^oK	[4]	T2 = 1 / { 1 / Tb - [(R / λ MW_{CO2}) ln (P_a / P_a)] }, Clausius-Clapeyron equation solved for T2
Vapor Fraction, X2 =	1.398		[4]	X2 = X* + Cp1 (T* - T2) / λ, TSCREEN Equation 4.3.2-13
Is 1 >= X2 >= 0?	No		[4]	No, recalculate T2 with Eq 4.3.2-15 and calculate density with Eq. 4.3.2-16
2nd Interation Exit Temp, T2 =	255.30	^oK	[4]	T2 = T* + λ (1 - X*) / Cp1, TSCREEN Equation 4.3.2-15
Compressibility (1st iter of T2), Z2 =	0.9790	(approx.)	[6]	Z = $Z^{(0)}$ + ω$Z^{(1)}$
Density @ P_a & T2(1st iter), ρ2 =	2.776	kg/m3	[5]	P_a MW_{CO2} / (Z R T2), for 1st iteration T2.
Density @ P_a & T2(2nd iter), $ρ2_{NIST}$ =	2.123	kg/m3	[2]	NIST value for 2nd iteration T2
Is ρ2 > ρa?	Yes		[4]	Yes, negative buoyancy - use RVD model for vertical discharge vent.
Ratio of Specific Heats @ P_a & T2, k2 =	1.367	(1st T2 iter)	[2] & [5]	k2 = Cp2/Cv2, Power curve fit ($k=a*x^b$) of NIST data (217 - 360^oK)
Check for Sonic Velocity at Discharge Conditions				
(1st T2 iteration value) $V2_{sonic1}$ =	221.86	m/s	[2]	$V2_{sonic1}$ = Sqrt (k2 Pa / ρ2)
(2nd T2 iteration value) $V2_{sonic2}$ =	249.98	m/s	[2]	NIST value.
Vent Flow Area, A2 =	0.16417	m2	[5]	A2 = (D2 / 2)^2 * π
Discharge Velocity (1st iter), V2 =	191.09	m/s	[5]	V2 = Qm / ρ2 / A2, from 1st iteration of T2
Discharge Velocity (2nd iter), V2 =	249.96	m/s	[5]	V2 = Qm / $ρ2_{NIST}$ / A2, from 2nd interation of T2

Summary of Discharge Conditions for RVD model			
Mass Flow, Qm =	87.1	kg/s	
Discharge Temp, T2 =	194.75	^oK	1st Iteration
Discharge Temp, T2 =	255.30	^oK	2nd Iteration
Ambient (Discharge) Press, P2 = P_a =	100,000	Pa	
Density @ P_a & T2, ρ2 =	2.776	kg/m3	1st Iteration
Density @ P_a & T2, $ρ2_{NIST}$ =	2.123	kg/m3	2nd Iteration
Discharge Velocity (1st iter), V2 =	191.09	m/s	
Discharge Velocity (2nd iter), V2 =	249.96	m/s	
Discharge Pipe (Vent) Diameter, D2 =	18	inches	
Total Discharge Mass, Q_{tot} =	1306.5	kg	

CO2 Vent Study - Spring Relief Valves

Relief Valve No.	**PSV-0220**			
Service	**LTC Discharge**			
Process Fluid =	CO_2	Units	References	Notes

Sources:

[1] Echogen Power Systems. EDS00120 Large Scale Pilot Relief Valves. Revision No. 02. April 22, 2020.

[2] Lemmon, E.W., M.O. McLinden and D.G. Friend. "Thermophysical Properties of Fluid Systems," *NIST Chemistry WebBook, NIST Standard Reference Database No.60*. Eds. P.J. Lindstrom and W.G. https://doi.org/10.18434/T4D303

[3] Echogen Power Systems (J. Mallinak). Email to CDM Smith (J. Pehrson and K. Montesano). August 5, 2020. Re: Vent Routing update.

[4] U.S. Environmental Protection Agency. *Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants (Revised)*. EPA-454/R-92-024. December 1992.

[5] CDM Smith calculations.

[6] Reid, R.C., J.M. Prausnitz, and B.E. Poling. *The Properties of Liquids and Gases, Fourth Edition*. New York. 1987.

CO2 Vent Study - Spring Relief Valves

Relief Valve No. **PSV-1110**
Service **Transfer Pump Discharge**

Process Fluid =	CO_2	Units	References	Notes
CO2 Molecular Weight, MW_{CO2} =	44.01	kg/kgmol	[1]	TSCREEN input parameter.
Mass Flow, Qm =	7.0	kg/s	[1]	TSCREEN calculates mass flow, valve throat area selected to match this value.
Set Temp, T1 =	244.15	^oK	[1]	TSCREEN input parameter.
Set Pressure, P1 =	10,000,000	Pa_{abs}	[1]	TSCREEN input parameter.
Set Density, ρ1 =	1099.2	kg/m^3	[1]	TSCREEN input parameter.
Set Compressibility, Z1 =	0.15		[1]	Not used in TSCREEN. (Z=1 for Ideal Gas)
Specific Heat Capacity, Cp1 =	1,964.4	J/(kg ^oK)	[2]	TSCREEN input parameter, value from NIST.
Pseudo Cp1 =	365.4	J/(kg ^oK)	[5]	Value calculated to produce correct k1 value in TSCREEN (not needed for calculations below)
Ratio of Specific Heats, k1 =	2.070		[2]	k1 = Cp1/Cv1, Cp1 and Cv1 values from NIST [2]
Enthalpy, H1 =	136,015.0	J/kg	[2]	
Release Duration, t_{rel} =	15.0	sec	[3]	Assumed, based in Reference [3].
PSV Orifice Area, Ao =	0.0003080	m2	[5]	Iterated to produce Qm in TSCREEN model
Additional Modeling Inputs:				
Universal Gas Constant, R =	8,314	J/(kgmol ^oK)	[4]	TSCREEN input parameter. (= 8314 Pa m3 / (kgmol ^oK)
Heat of Sublimation, λ =	572,604	J/kg	[2]	TSCREEN input parameter (λ at 1 atm and 194.8 ^oK)
Freezing Temp @ 1 atm, Tb =	194.8	^oK	[2]	TSCREEN input parameter.
Ambient Temp, T_a =	298	^oK	[5]	TSCREEN input parameter. Adjusted Ta to ___ ^oK to force PUFF modeling.
Ambient (Discharge) Press, P2 = P_a =	101,325	Pa	[1]	TSCREEN input parameter.
Air Molecular Weight, MW_{Air} =	28.9	kg/kgmol	[4]	TSCREEN input parameter.
Ambient Density, ρa =	1.182	kg/m^3	[4]	P_a MW_{air} / (R Ta)
Discharge Pipe Length, L2 =	10	ft	[5]	TSCREEN input parameter.
Discharge Pipe (Vent) Diameter, D2 =	6	inches	[5]	TSCREEN input parameter.
Pipe Friction Factor, f =	0.0045		[4]	TSCREEN input parameter. Value assumed in TSCREEN Model for turbulent pipe flow.
Check for Choked Flow:				
Critical Pressure, P* =	4,364,352	Pa	[4]	P* = P1 * [2 / (k1 + 1)]^(k1/(k1-1)), TSCREEN Equation 4.3.2-1
Is P* > P_a ?	Yes		[4]	Yes, flow is choked: use TSCREEN Eq 4.3.2-2 for T*.
Check for Condensation/Freezing at Choke Point:				
1st Iteration Temperature @ P*, T* =	159.04	^oK	[4]	T* = T1 * [2 / (k1 + 1)], TSCREEN Equation 4.3.2-2
Is T* > Tc?	No		[4]	No, check for potential condensation in flow.
Vapor Pressure @ T*, Pv =	3,035	Pa	[4]	Pv = P_a * exp[(k1 MW_{CO2} / R) (1 / Tb - 1/T*)], Clausius-Clapeyron vapor pressure equation
Is Pv < P*?	Yes		[4]	Yes, condensation does occur. Use two-phase discharge calculation in Section 4.2.3.2.

CO2 Vent Study - Spring Relief Valves

Relief Valve No. PSV-1110
Service Transfer Pump Discharge

Process Fluid =	CO_2	Units	References	Notes
Estimation of Two-Phase Flow Parameters at Choke Point				
2nd Interation Temperature @ P*, T* =	256.85	^oK	[4]	$T^* = 1 / \{ 1/Tb - [(R / \lambda\ MW_{CO2}) \ln (P^* / P_a)] \}$, Clausius-Clapeyron equation solved for T*
Vapor Fraction, X* =	0.885		[4]	$X^* = 1 + (T^* / \lambda\ MW_{CO2}) * [MW_{CO2}\ Cp1 \ln (T1 / T^*) - R \ln (P1 / P^*)]$, TSCREEN Equation 4.3.2-8
Enthalpy change, H1-H* =	40,868	J/kg	[4]	$H1-H^* = Cp1 (T1 - T^*) + \lambda (1 - X^*)$, TSCREEN Equation 4.3.2-9
Density @ P* & T*, ρ* =	100.56	kg/m3	[4]	$\rho^* = 1 / \{ X^* [(R\ T^*) / (P^*\ MW_{CO2})] + [(1 - X^*) / \rho 1] \}$, TSCREEN Equation 4.3.2-10
Check Qm =	7.00	kg/s	[4]	$Qm = Ao\ \rho 2 \{ 2 * 0.85 * [(H1 - H^*) / (1 + (4\ f\ L2 / D2))] \}^{(1/2)}$
Estimation of Temperature, Pressure and Density at Vent Exit				
1st Interation Exit Temp, T2 =	194.75	^oK	[4]	$T2 = 1 / \{ 1 / Tb - [(R / \lambda\ MW_{CO2}) \ln (P_a / P_a)] \}$, Clausius-Clapeyron equation solved for T2
Vapor Fraction, X2 =	1.098		[4]	$X2 = X^* + Cp1 (T^* - T2) / \lambda$, TSCREEN Equation 4.3.2-13
Is 1 >= X2 >= 0?	No		[4]	No, recalculate T2 with Eq 4.3.2-15 and calculate density with Eq. 4.3.2-16
2nd Interation Exit Temp, T2 =	290.35	^oK	[4]	$T2 = T^* + \lambda (1 - X^*) / Cp1$, TSCREEN Equation 4.3.2-15
Compressibility (1st iter of T2), Z2 =	0.9790	(approx.)	[6]	$Z = Z^{(0)} + \omega Z^{(1)}$
Density @ P_a & T2, ρ2 =	2.776	kg/m3	[5]	$P_a\ MW_{CO2} / (Z\ R\ T2)$
Density @ P_a & T2, $\rho 2_{NIST}$ =	1.859	kg/m3	[2]	NIST value.
Is ρ2 > ρa?	Yes		[4]	Yes, negative buoyancy - use RVD model for vertical discharge vent.
Ratio of Specific Heats @ P_a & T2, k2 =	1.367	(1st T2 iter)	[2] & [5]	k2 = Cp2/Cv2, Power curve fit ($k=a*x^b$) of NIST data (217 - 360^oK)
Check for Sonic Velocity at Discharge Conditions				
(1st T2 iteration value) $V2_{sonic1}$ =	221.86	m/s	[2]	$V2_{sonic1} = Sqrt (k2\ Pa / \rho 2)$
(2nd T2 iteration value) $V2_{sonic2}$ =	265.276	m/s	[2]	NIST value.
Vent Flow Area, A2 =	0.01824	m2	[5]	$A2 = (D2 / 2)^2 * \pi$
Discharge Velocity (1st iter), V2 =	138.22	m/s	[5]	V2 = Qm / ρ2 / A2, from 1st iteration of T2
Discharge Velocity (2nd iter), V2 =	206.41	m/s	[5]	V2 = Qm / $\rho 2_{NIST}$ / A2, from 2nd interation of T2

Summary of Discharge Conditions for RVD model			
Mass Flow, Qm =	7.0	kg/s	
Discharge Temp, T2 =	194.75	^oK	1st Iteration
Discharge Temp, T2 =	290.35	^oK	2nd Iteration
Ambient (Discharge) Press, P2 = P_a =	100,000	Pa	
Density @ P_a & T2, ρ2 =	2.776	kg/m3	1st Iteration
Density @ P_a & T2, $\rho 2_{NIST}$ =	1.859	kg/m3	2nd Iteration
Discharge Velocity (1st iter), V2 =	138.22	m/s	
Discharge Velocity (2nd iter), V2 =	206.41	m/s	
Discharge Pipe (Vent) Diameter, D2 =	6	inches	
Total Discharge Mass, Q_{tot} =	105	kg	

CO2 Vent Study - Spring Relief Valves

Relief Valve No. PSV-1110
Service Transfer Pump Discharge

Process Fluid =	CO_2	Units	References	Notes

Sources:

[1] Echogen Power Systems. EDS00120 Large Scale Pilot Relief Valves. Revision No. 02. April 22, 2020.

[2] Lemmon, E.W., M.O. McLinden and D.G. Friend. "Thermophysical Properties of Fluid Systems," *NIST Chemistry WebBook, NIST Standard Reference Database No.60* . Eds. P.J. Lindstrom and https://doi.org/10.18434/T4D303

[3] Echogen Power Systems (J. Mallinak). Email to CDM Smith (J. Pehrson and K. Montesano). August 5, 2020. Re: Vent Routing update.

[4] U.S. Environmental Protection Agency. *Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants (Revised)* . EPA-454/R-92-024. December 1992.

[5] CDM Smith calculations.

[6] Reid, R.C., J.M. Prausnitz, and B.E. Poling. *The Properties of Liquids and Gases, Fourth Edition* . New York. 1987.

CO2 Vent Study - Spring Relief Valves

Relief Valve No.	**PSV-1410**			
Service	**HTC Discharge**			
Process Fluid =	CO_2	Units	References	Notes
CO2 Molecular Weight, MW_{CO2} =	44.01	kg/kgmol	[1]	TSCREEN input parameter.
Mass Flow, Qm =	47.8	kg/s	[1]	TSCREEN calculates mass flow, valve throat area selected to match this value.
Set Temp, T1 =	447.15	^{o}K	[1]	TSCREEN input parameter.
Set Pressure, P1 =	27,500,000	Pa_{abs}	[1]	TSCREEN input parameter.
Set Density, ρ1 =	400.5	kg/m^3	[1]	TSCREEN input parameter. (Density = 818.6 kg/m3 per NIST[2])
Set Compressibility, Z1 =	0.81		[1]	Not used in TSCREEN. (Z=1 for Ideal Gas)
Specific Heat Capacity, Cp1 =	1,619.6	J/(kg ^{o}K)	[2]	TSCREEN input parameter, value from NIST.
Pseudo Cp1 =	420.0	J/(kg ^{o}K)	[5]	Value calculated to produce correct k1 value in TSCREEN (not needed for calculations below)
Ratio of Specific Heats, k1 =	1.817		[2]	k1 = Cp1/Cv1, Cp1 and Cv1 values from NIST [2]
Enthalpy, H1 =	535,774.0	J/kg	[2]	
Release Duration, t_{rel} =	15.0	sec	[3]	Assumed, based in Reference [3].
PSV Orifice Area, Ao =	0.00080118	m2	[5]	Iterated to produce Qm in TSCREEN model
Additional Modeling Inputs:				
Universal Gas Constant, R =	8,314	J/(kgmol ^{o}K)	[4]	TSCREEN input parameter. (= 8314 Pa m3 / (kgmol ^{o}K)
Heat of Sublimation, λ =	572,604	J/kg	[2]	TSCREEN input parameter (λ at 1 atm and 194.8 ^{o}K)
Freezing Temp @ 1 atm, Tb =	194.8	^{o}K	[2]	TSCREEN input parameter.
Ambient Temp, T_a =	298	^{o}K	[5]	TSCREEN input parameter. Adjusted Ta to ___^{o}K to force PUFF modeling.
Ambient (Discharge) Press, P2 = P_a =	101,325	Pa	[1]	TSCREEN input parameter.
Air Molecular Weight, MW_{Air} =	28.9	kg/kgmol	[4]	TSCREEN input parameter.
Ambient Density, ρa =	1.182	kg/m^3	[4]	P_a MW_{air} / (R Ta)
Discharge Pipe Length, L2 =	10	ft	[5]	TSCREEN input parameter.
Discharge Pipe (Vent) Diameter, D2 =	16	inches	[5]	TSCREEN input parameter.
Pipe Friction Factor, f =	0.0045		[4]	TSCREEN input parameter. Value assumed in TSCREEN Model for turbulent pipe flow.
Check for Choked Flow:				
Critical Pressure, P* =	12,836,379	Pa	[4]	P* = P1 * [2 / (k1 + 1)]^(k1/(k1-1)), TSCREEN Equation 4.3.2-1
Is P* > P_a ?	Yes		[4]	Yes, flow is choked: use TSCREEN Eq 4.3.2-2 for T*.
Check for Condensation/Freezing at Choke Point:				
1st Iteration Temperature @ P*, T* =	317.41	^{o}K	[4]	T* = T1 * [2 / (k1 + 1)], TSCREEN Equation 4.3.2-2
Is T* > Tc?	Yes		[4]	Yes, continue to Step 2B for emission rate calculation.

CO2 Vent Study - Spring Relief Valves

Relief Valve No.	**PSV-1410**			
Service	**HTC Discharge**			
Process Fluid =	CO_2	Units	References	Notes
Check Emission Rate, Estimate Discharge Temperature and Density				
Qm =	**47.100**	kg/s	[4]	Qm = C Ao { p1 ρ1 k1 [2 / (k1 + 1)]$^{[(k1+1)/(k1-1)]}$ }$^{(1/2)}$; C = 0.75 or more. TSCREEN Equation 4.3.2-3
Discharge Temp, T2 =	**336.87**	^{o}K	[4]	T2 = T1 [1 - 0.85 ((k1- 1) / (k1 + 1))], TSCREEN Equation 4.3.2-4
Density @ P_a & T2, ρ2 =	1.5922	kg/m3	[4]	P_a MW_{CO2} / (R T2), Ideal Gas Law
Is ρ2 > ρa?	Yes		[4]	Yes, negative buoyancy - use RVD model for vertical discharge vent.
Check for Sonic Velocity at Discharge Conditions				
$V2_{sonic}$ =	284.1	m/s	[2]	NIST value.
Vent Flow Area, A2 =	0.12972	m2	[5]	A2 = (D2 / 2)^2 * π
Discharge Velocity, V2 =	231.44	m/s	[5]	V2 = Qm / ρ2 / A2

Summary of Inputs for RVD Model:		
Mass Flow, Qm =	47.8	kg/s
Discharge Temp, T2 =	336.87	^{o}K
Ambient (Discharge) Press, P2 = P_a =	100,000	Pa
Density @ P_a & T2, ρ2 =	1.592	kg/m3
Discharge Velocity, V2 =	231.44	m/s
Discharge Pipe (Vent) Diameter, D2 =	16	inches
Total Discharge Mass, Q_{tot} =	717.0	kg

Note: The RVD model also conducts checks of relative density of the plume at the vent exit and at the point of maximum plume rise. The plume of PSV-1410 transitions to neutral buoyancy by the time maximum plume rise is achieved. Therefore, a neutrally buoyant model was used to estimate impacts.

Sources:

[1] Echogen Power Systems. EDS00120 Large Scale Pilot Relief Valves. Revision No. 02. April 22, 2020.

[2] Lemmon, E.W., M.O. McLinden and D.G. Friend. "Thermophysical Properties of Fluid Systems," *NIST Chemistry WebBook, NIST Standard Reference Database No.60* . Eds. P.J. Lindstrom and https://doi.org/10.18434/T4D303

[3] Echogen Power Systems (J. Mallinak). Email to CDM Smith (J. Pehrson and K. Montesano). August 5, 2020. Re: Vent Routing update.

[4] U.S. Environmental Protection Agency. *Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants (Revised)* . EPA-454/R-92-024. December 1992.

[5] CDM Smith calculations.

CO2 Vent Study - Spring Relief Valves

Relief Valve No. **PSV-1430**
Service **Fired Heater Discharge**

Process Fluid =	CO_2	Units	References	Notes
CO2 Molecular Weight, MW_{CO2} =	44.01	kg/kgmol	[1]	TSCREEN input parameter.
Mass Flow, Qm =	83.9	kg/s	[1]	TSCREEN calculates mass flow, valve throat area selected to match this value.
Set Temp, T1 =	873.15	^oK	[1]	TSCREEN input parameter.
Set Pressure, P1 =	25,800,000	Pa_{abs}	[1]	TSCREEN input parameter.
Set Density, ρ1 =	148.5	kg/m^3	[1]	TSCREEN input parameter. (Density = 818.6 kg/m3 per NIST[2])
Set Compressibility, Z1 =	1.05		[1]	Not used in TSCREEN. (Z=1 for Ideal Gas)
Specific Heat Capacity, Cp1 =	1,263.0	J/(kg ^oK)	[2]	TSCREEN input parameter, value from NIST.
Pseudo Cp1 =	974.0	J/(kg ^oK)	[5]	Value calculated to produce correct k1 value in TSCREEN (not needed for calculations below)
Ratio of Specific Heats, k1 =	1.241		[2]	k1 = Cp1/Cv1, Cp1 and Cv1 values from NIST [2]
Enthalpy, H1 =	1,094,290.0	J/kg	[2]	
Release Duration, t_{rel} =	15.0	sec	[3]	Assumed, based in Reference [3].
PSV Orifice Area, Ao =	0.00275373	m2	[5]	Iterated to produce Qm in TSCREEN model
Additional Modeling Inputs:				
Universal Gas Constant, R =	8,314	J/(kgmol ^oK)	[4]	TSCREEN input parameter. (= 8314 Pa m3 / (kgmol ^oK)
Heat of Sublimation, λ =	572,604	J/kg	[2]	TSCREEN input parameter (λ at 1 atm and 194.8 ^oK)
Freezing Temp @ 1 atm, Tb =	194.8	^oK	[2]	TSCREEN input parameter.
Ambient Temp, T_a =	298	^oK	[5]	TSCREEN input parameter. Adjusted Ta to ___ ^oK to force PUFF modeling.
Ambient (Discharge) Press, P2 = P_a =	101,325	Pa	[1]	TSCREEN input parameter.
Air Molecular Weight, MW_{Air} =	28.9	kg/kgmol	[4]	TSCREEN input parameter.
Ambient Density, ρa =	1.182	kg/m^3	[4]	P_a MW_{air} / (R Ta)
Discharge Pipe Length, L2 =	15	ft	[5]	TSCREEN input parameter.
Discharge Pipe (Vent) Diameter, D2 =	24	inches	[5]	TSCREEN input parameter.
Pipe Friction Factor, f =	0.0045		[4]	TSCREEN input parameter. Value assumed in TSCREEN Model for turbulent pipe flow.
Check for Choked Flow:				
Critical Pressure, P* =	14,362,571	Pa	[4]	P* = P1 * [2 / (k1 + 1)]^(k1/(k1-1)), TSCREEN Equation 4.3.2-1
Is P* > P_a ?	Yes		[4]	Yes, flow is choked: use TSCREEN Eq 4.3.2-2 for T*.
Check for Condensation/Freezing at Choke Point:				
1st Iteration Temperature @ P*, T* =	779.38	^oK	[4]	T* = T1 * [2 / (k1 + 1)], TSCREEN Equation 4.3.2-2
Is T* > Tc?	Yes		[4]	Yes, continue to Step 2B for emission rate calculation.

CO2 Vent Study - Spring Relief Valves

Relief Valve No. PSV-1430
Service Fired Heater Discharge

Process Fluid =	CO_2	Units	References	Notes
Check Emission Rate, Estimate Discharge Temperature and Density				
Qm =	**83.900**	kg/s	[4]	Qm = C Ao { p1 ρ1 k1 [2 / (k1 + 1)]$^{[(k1+1)/(k1-1)]}$}$^{(1/2)}$; C = 0.75 or more. TSCREEN Equation 4.3.2-3
Discharge Temp, T2 =	**793.44**	^{o}K	[4]	T2 = T1 [1 - 0.85 ((k1- 1) / (k1 + 1))], TSCREEN Equation 4.3.2-4
Density @ P_a & T2, ρ2 =	0.6760	kg/m3	[4]	P_a MW_{CO2} / (R T2), Ideal Gas Law
Is ρ2 > ρa?	No		[4]	No, neutrally buoyant - use AERMOD or SCREEN3.
Check for Sonic Velocity at Discharge Conditions				
$V2_{sonic}$ =	423.123	m/s	[2]	NIST value.
Vent Flow Area, A2 =	0.29186	m2	[5]	A2 = (D2 / 2)^2 * π
Discharge Velocity, V2 =	425.25	m/s	[5]	V2 = Qm / ρ2 / A2

Summary of Inputs:

Mass Flow, Qm =	83.9	kg/s
Discharge Temp, T2 =	793.44	^{o}K
Ambient (Discharge) Press, P2 = P_a =	100,000	Pa
Density @ P_a & T2, ρ2 =	0.676	kg/m3
Discharge Velocity, V2 =	425.25	m/s
Discharge Pipe (Vent) Diameter, D2 =	24	inches

Sources:

[1] Echogen Power Systems. EDS00120 Large Scale Pilot Relief Valves. Revision No. 02. April 22, 2020.

[2] Lemmon, E.W., M.O. McLinden and D.G. Friend. "Thermophysical Properties of Fluid Systems," *NIST Chemistry WebBook, NIST Standard Reference Database No.60*. Eds. P.J. Lindstrom and https://doi.org/10.18434/T4D303

[3] Echogen Power Systems (J. Mallinak). Email to CDM Smith (J. Pehrson and K. Montesano). August 5, 2020. Re: Vent Routing update.

[4] U.S. Environmental Protection Agency. *Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants (Revised)*. EPA-454/R-92-024. December 1992.

[5] CDM Smith calculations.

CO2 Vent Study - Spring Relief Valves

Relief Valve No.	**PSV-1440**			
Service	**Condenser Inlet**			
Process Fluid =	CO_2	Units	References	Notes
CO2 Molecular Weight, MW_{CO2} =	44.01	kg/kgmol	[1]	TSCREEN input parameter.
Mass Flow, Qm =	71.8	kg/s	[1]	TSCREEN calculates mass flow, valve throat area selected to match this value.
Set Temp, T1 =	332.15	°K	[1]	TSCREEN input parameter.
Set Pressure, P1 =	10,000,000	Pa_{abs}	[1]	TSCREEN input parameter.
Set Density, ρ1 =	293.4	kg/m^3	[1]	TSCREEN input parameter.
Set Compressibility, Z1 =	0.54		[1]	Not used in TSCREEN. (Z=1 for Ideal Gas)
Specific Heat Capacity, Cp1 =	3,170.4	J/(kg °K)	[2]	TSCREEN input parameter, value from NIST.
Pseudo Cp1 =	269.3	J/(kg °K)	[5]	Value calculated to produce correct k1 value in TSCREEN (not needed for calculations below)
Ratio of Specific Heats, k1 =	3.350		[2]	k1 = Cp1/Cv1, Cp1 and Cv1 values from NIST [2]
Enthalpy, H1 =	421,917.0	J/kg	[2]	
Release Duration, t_{rel} =	15.0	sec	[3]	Assumed, based in Reference [3].
PSV Orifice Area, Ao =	0.0034810	m2	[5]	Iterated to produce Qm in TSCREEN model
Additional Modeling Inputs:				
Universal Gas Constant, R =	8,314	J/(kgmol °K)	[4]	TSCREEN input parameter. (= 8314 Pa m3 / (kgmol °K)
Heat of Sublimation, λ =	572,604	J/kg	[2]	TSCREEN input parameter (λ at 1 atm and 194.8 °K)
Freezing Temp @ 1 atm, Tb =	194.8	°K	[2]	TSCREEN input parameter.
Ambient Temp, T_a =	298	°K	[5]	TSCREEN input parameter. Adjusted Ta to ___°K to force PUFF modeling.
Ambient (Discharge) Press, P2 = P_a =	101,325	Pa	[1]	TSCREEN input parameter.
Air Molecular Weight, MW_{Air} =	28.9	kg/kgmol	[4]	TSCREEN input parameter.
Ambient Density, ρa =	1.182	kg/m^3	[4]	P_a MW_{air} / (R Ta)
Discharge Pipe Length, L2 =	10	ft	[5]	TSCREEN input parameter.
Discharge Pipe (Vent) Diameter, D2 =	18	inches	[5]	TSCREEN input parameter.
Pipe Friction Factor, f =	0.0045		[4]	TSCREEN input parameter. Value assumed in TSCREEN Model for turbulent pipe flow.
Check for Choked Flow:				
Critical Pressure, P* =	3,303,313	Pa	[4]	P* = P1 * [2 / (k1 + 1)]^(k1/(k1-1)), TSCREEN Equation 4.3.2-1
Is P* > P_a ?	Yes		[4]	Yes, flow is choked: use TSCREEN Eq 4.3.2-2 for T*.
Check for Condensation/Freezing at Choke Point:				
1st Iteration Temperature @ P*, T* =	152.72	°K	[4]	T* = T1 * [2 / (k1 + 1)], TSCREEN Equation 4.3.2-2
Is T* > Tc?	No		[4]	No, check for potential condensation in flow.
Vapor Pressure @ T*, Pv =	1,379	Pa	[4]	Pv = P_a * exp[(k1 MW_{CO2} / R) (1 / Tb - 1/T*)], Clausius-Clapeyron vapor pressure equation
Is Pv < P*?	Yes		[4]	Yes, condensation does occur. Use two-phase discharge calculation in Section 4.2.3.2.

CO2 Vent Study - Spring Relief Valves

Relief Valve No.	**PSV-1440**			
Service	**Condenser Inlet**			
Process Fluid =	CO_2	Units	References	Notes
Estimation of Two-Phase Flow Parameters at Choke Point				
2nd Interation Temperature @ P*, T* =	250.93	°K	[4]	T* = 1 / { 1/Tb - [(R / λ MW_{CO2}) ln (P* / P_a)] }, Clausius-Clapeyron equation solved for T*
Vapor Fraction, X* =	1.298		[4]	X* = 1 + (T* / λ MW_{CO2}) * [MW_{CO2} Cp1 ln (T1 / T*) - R ln (P1 / P*)], TSCREEN Equation 4.3.2-8
Enthalpy change, H1-H* =	86,928	J/kg	[4]	H1-H* = Cp1 (T1 - T*) + λ (1 - X*), TSCREEN Equation 4.3.2-9
Density @ P* & T*, ρ* =	56.79	kg/m3	[4]	ρ* = 1 / { X* [(R T*) / (P* MW_{CO2})] + [(1 - X*) / ρ1] }, TSCREEN Equation 4.3.2-10
Check Qm =	71.80	kg/s	[4]	Qm = Ao ρ2 { 2 * 0.85 * [(H1 - H*) / (1 + (4 f L2 / D2))] }$^{(1/2)}$
Estimation of Temperature, Pressure and Density at Vent Exit				
1st Interation Exit Temp, T2 =	194.75	°K	[4]	T2 = 1 / { 1 / Tb - [(R / λ MW_{CO2}) ln (P_a / P_a)] }, Clausius-Clapeyron equation solved for T2
Vapor Fraction, X2 =	1.609		[4]	X2 = X* + Cp1 (T* - T2) / λ, TSCREEN Equation 4.3.2-13
Is 1 >= X2 >= 0?	No		[4]	No, recalculate T2 with Eq 4.3.2-15 and calculate density with Eq. 4.3.2-16
2nd Interation Exit Temp, T2 =	197.12	°K	[4]	T2 = T* + λ (1 - X*) / Cp1, TSCREEN Equation 4.3.2-15
Compressibility (1st iter of T2), Z2 =	0.9790	(approx.)	[6]	Z = $Z^{(0)}$ + ω$Z^{(1)}$
Density @ P_a & T2(1st iter), ρ2 =	2.776	kg/m3	[5]	P_a MW_{CO2} / (Z R T2)
Density @ P_a & T2(2nd iter), ρ2 =	2.743	kg/m3	[5]	P_a MW_{CO2} / (Z R T2)
Is ρ2 > ρa?	Yes		[4]	Yes, negative buoyancy - use RVD model for vertical discharge vent.
Ratio of Specific Heats @ P_a & T2, k2 =	1.367	(1st T2 iter)	[2] & [5]	k2 = Cp2/Cv2, Power curve fit (k=a*x^b) of NIST data (217 - 360°K)
Ratio of Specific Heats @ P_a & T2, k2 =	1.365	(2nd T2 iter)	[2] & [5]	k2 = Cp2/Cv2, Power curve fit (k=a*x^b) of NIST data (217 - 360°K)
Check for Sonic Velocity at Discharge Conditions				
(1st T2 iteration value) $V2_{sonic1}$ =	221.86	m/s	[2]	$V2_{sonic1}$ = Sqrt (k2 Pa / ρ2)
(2nd T2 iteration value) $V2_{sonic2}$ =	223.04	m/s	[5]	V2sonic = SQRT(γ_2 * P_a / ρ_2)
Vent Flow Area, A2 =	0.16417	m2	[5]	A2 = (D2 / 2)^2 * π
Discharge Velocity (1st iter), V2 =	157.52	m/s	[5]	V2 = Qm / ρ2 / A2, from 1st iteration of T2
Discharge Velocity (2nd iter), V2 =	159.44	m/s	[5]	V2 = Qm / ρ2 / A2, from 2nd interation of T2

Summary of Discharge Conditions for RVD model			
Mass Flow, Qm =	71.8	kg/s	
Discharge Temp, T2 =	194.75	°K	1st Iteration
Discharge Temp, T2 =	197.12	°K	2nd Iteration
Ambient (Discharge) Press, P2 = P_a =	100,000	Pa	
Density @ P_a & T2, ρ2 =	2.776	kg/m3	1st Iteration
Density @ P_a & T2, $\rho2_{NIST}$ =	2.743	kg/m3	2nd Iteration
Discharge Velocity (1st iter), V2 =	157.52	m/s	
Discharge Velocity (2nd iter), V2 =	159.44	m/s	
Discharge Pipe (Vent) Diameter, D2 =	18	inches	
Total Discharge Mass, Q_{tot} =	1077.0	kg	

CO2 Vent Study - Spring Relief Valves

Relief Valve No.	**PSV-1440**			
Service	**Condenser Inlet**			
Process Fluid =	CO_2	Units	References	Notes

Sources:

[1] Echogen Power Systems. EDS00120 Large Scale Pilot Relief Valves. Revision No. 02. April 22, 2020.

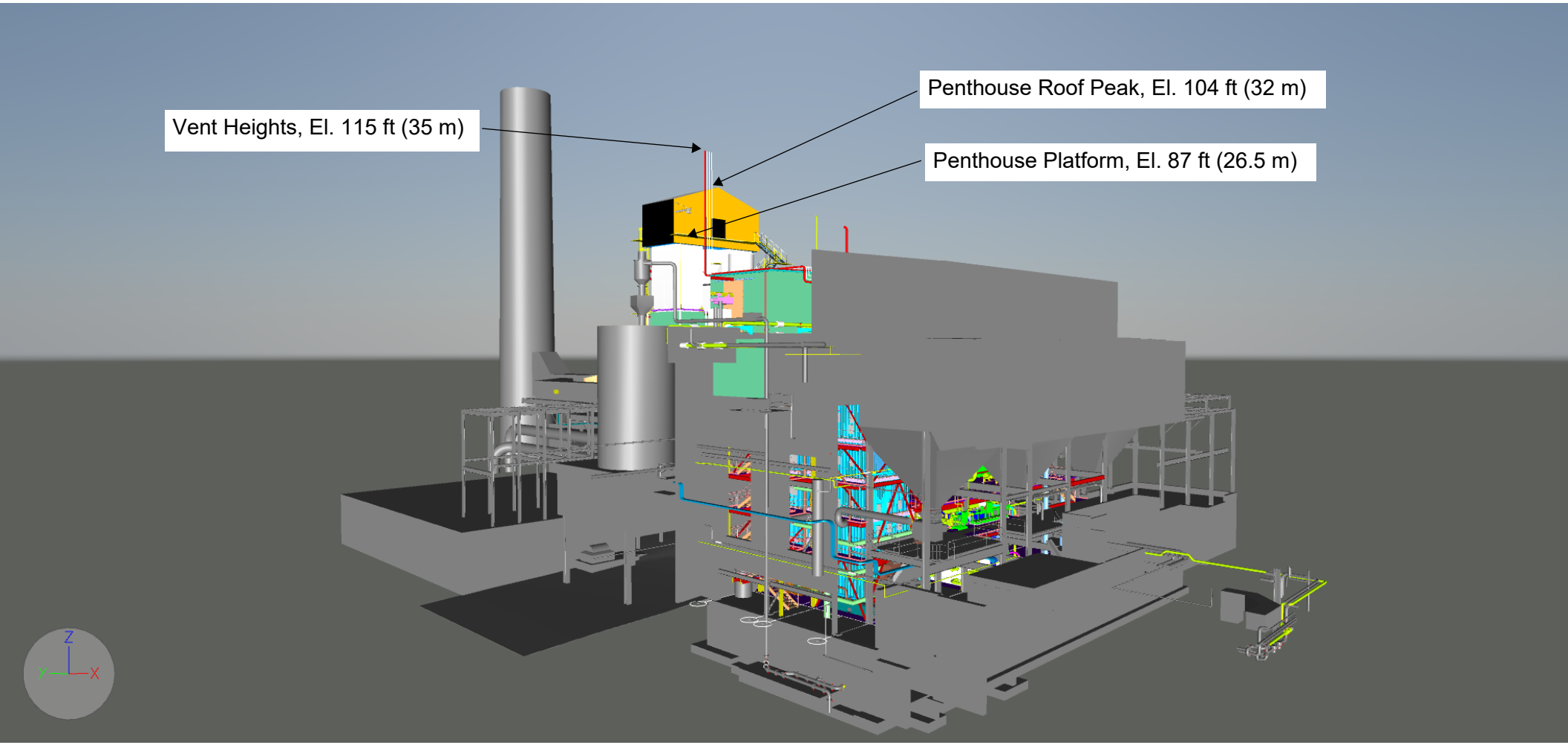
[2] Lemmon, E.W., M.O. McLinden and D.G. Friend. "Thermophysical Properties of Fluid Systems," *NIST Chemistry WebBook, NIST Standard Reference Database No.60* . Eds. P.J. Lindstrom and W.G. https://doi.org/10.18434/T4D303

[3] Echogen Power Systems (J. Mallinak). Email to CDM Smith (J. Pehrson and K. Montesano). August 5, 2020. Re: Vent Routing update.

[4] U.S. Environmental Protection Agency. *Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants (Revised)* . EPA-454/R-92-024. December 1992.

[5] CDM Smith calculations.

[6] Reid, R.C., J.M. Prausnitz, and B.E. Poling. *The Properties of Liquids and Gases, Fourth Edition* . New York. 1987.


Vent Heights, El. 115 ft (35 m)
Penthouse Roof Peak, El. 104 ft (32 m)
Penthouse Platform, El. 87 ft (26.5 m)
Z
Y
X



SECURITY

PUBLIC ☐
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

NO.	DATE	REVISION	BY
.	.	.	.
.	.	.	.
.	.	.	.
A	07/16/2020	ISSUED FOR REFERENCE	.

ECHOGEN power systems

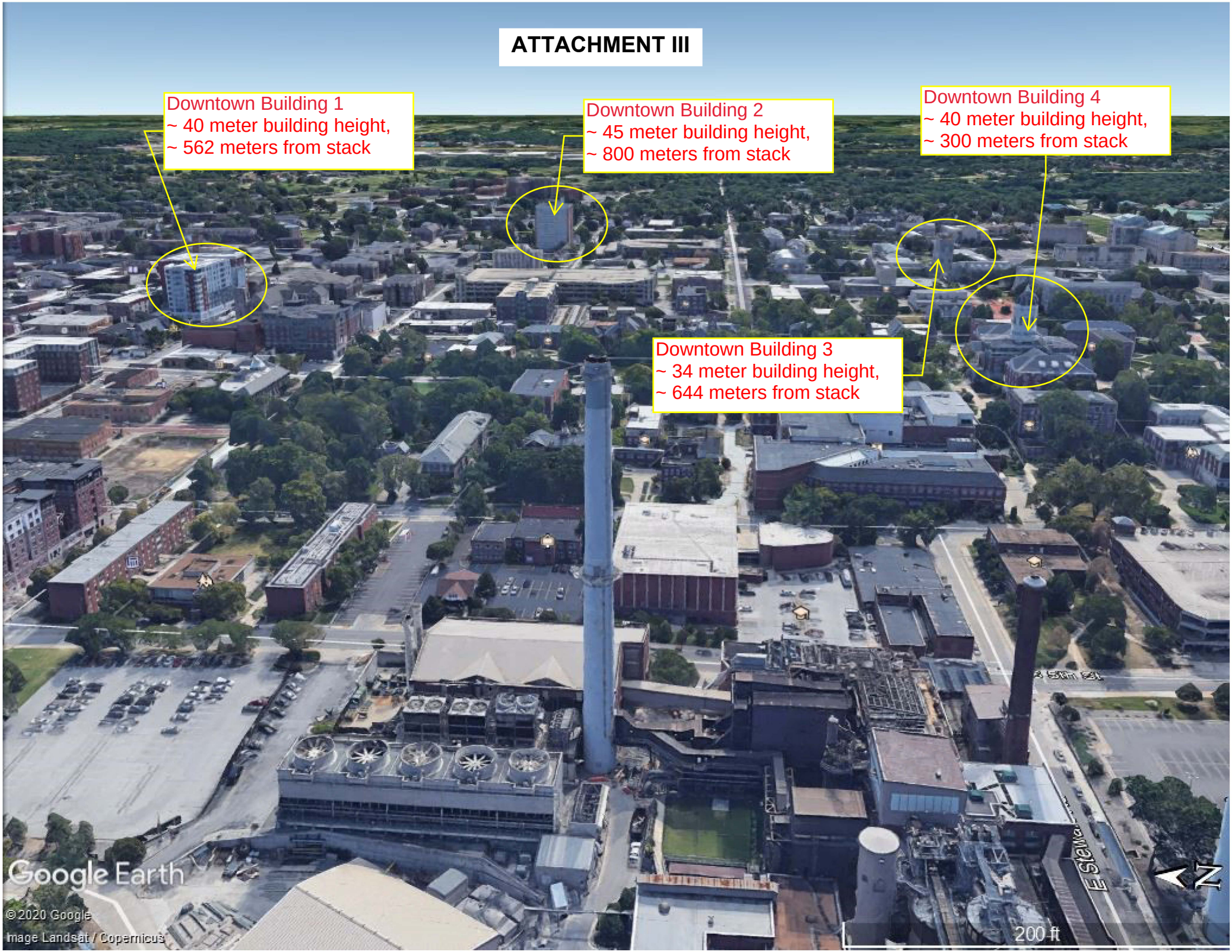
405 S. High Street, Akron OH, 44311 USA

PIPING
EXTERIOR BUILDING VIEW
ELEVATION REFERENCES

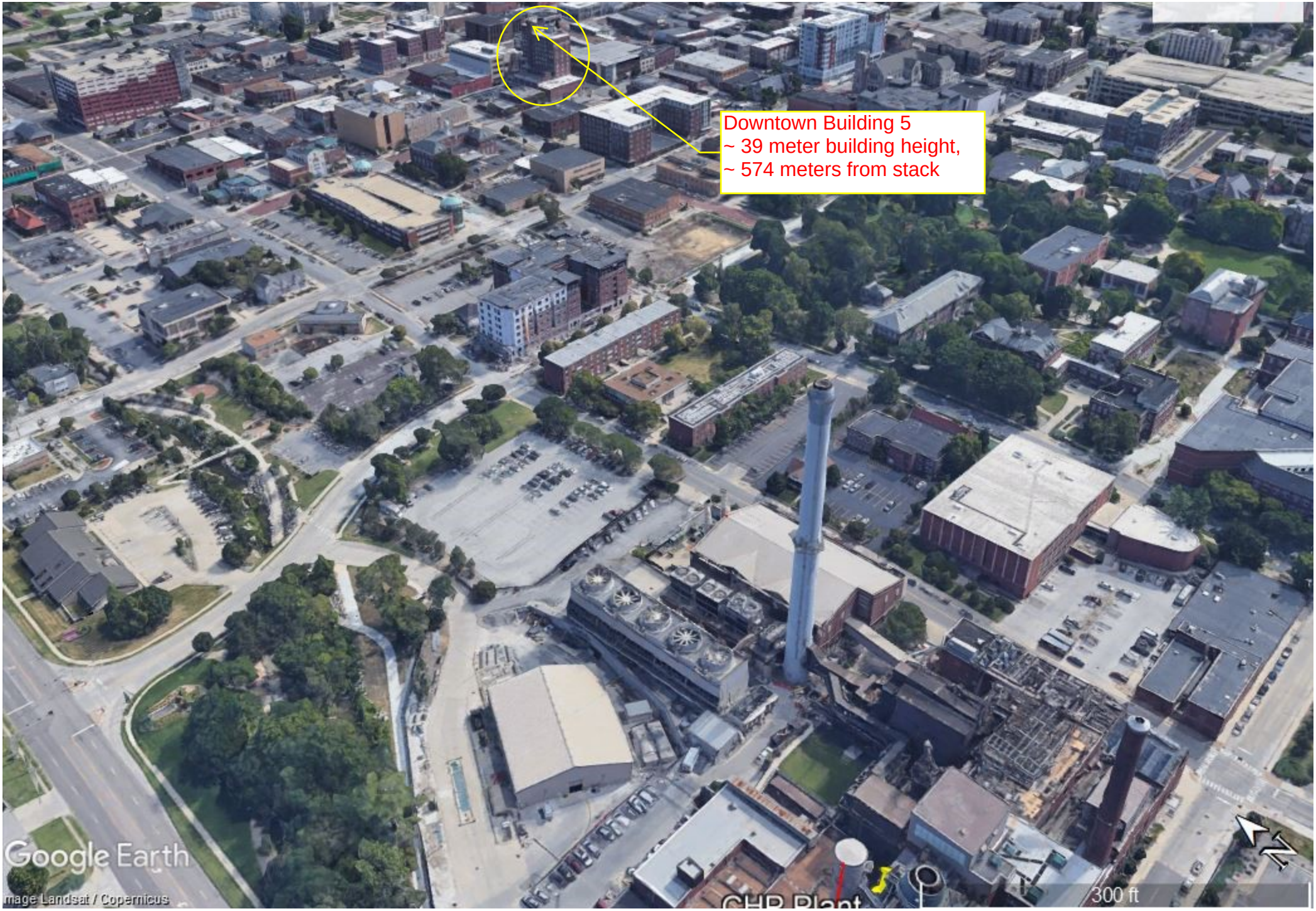
DATE	DRAWN	CHK'D.
07/16/2020	BB	.
SCALE		APPROVED
N/A		.

SK-200

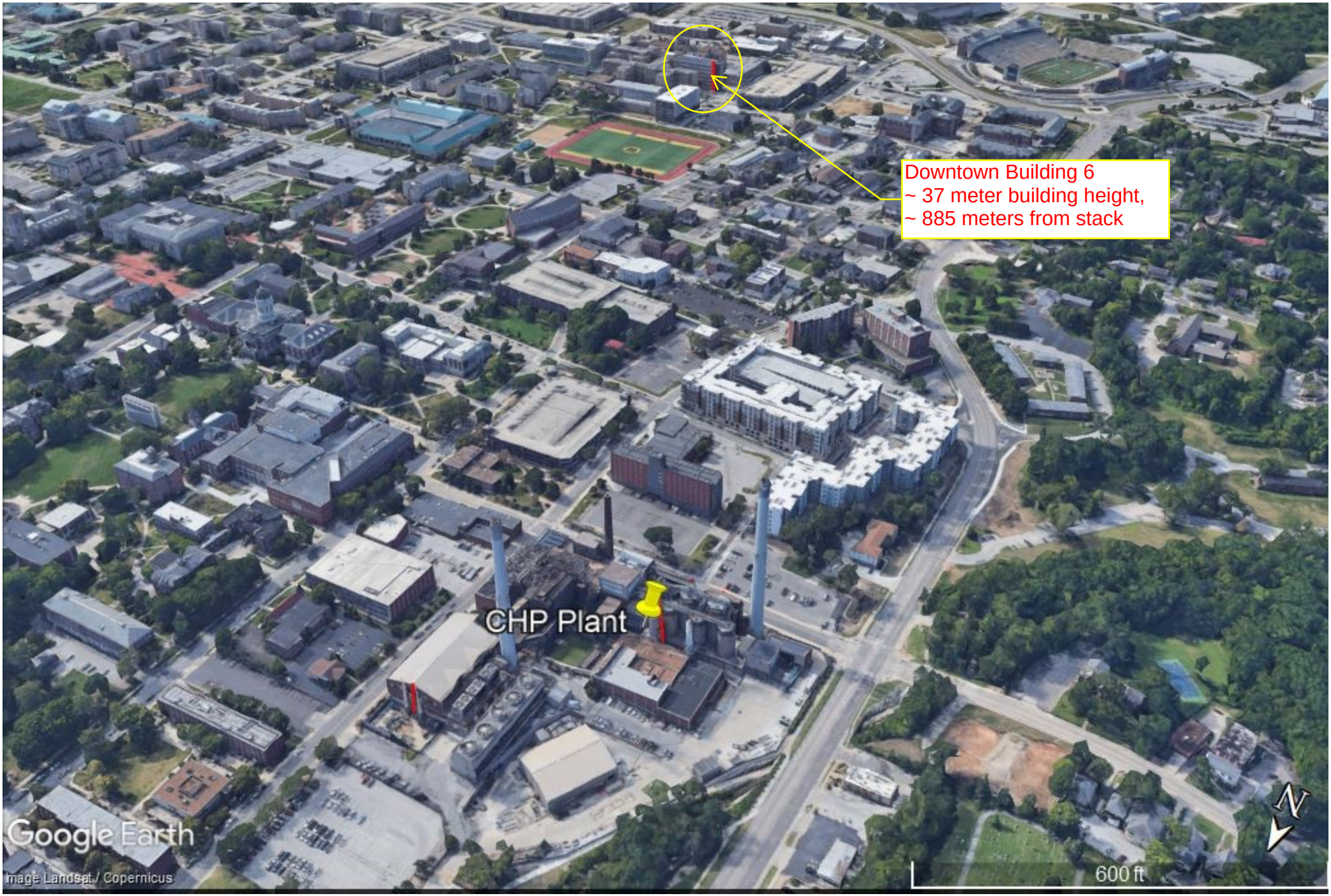
ATTACHMENT III



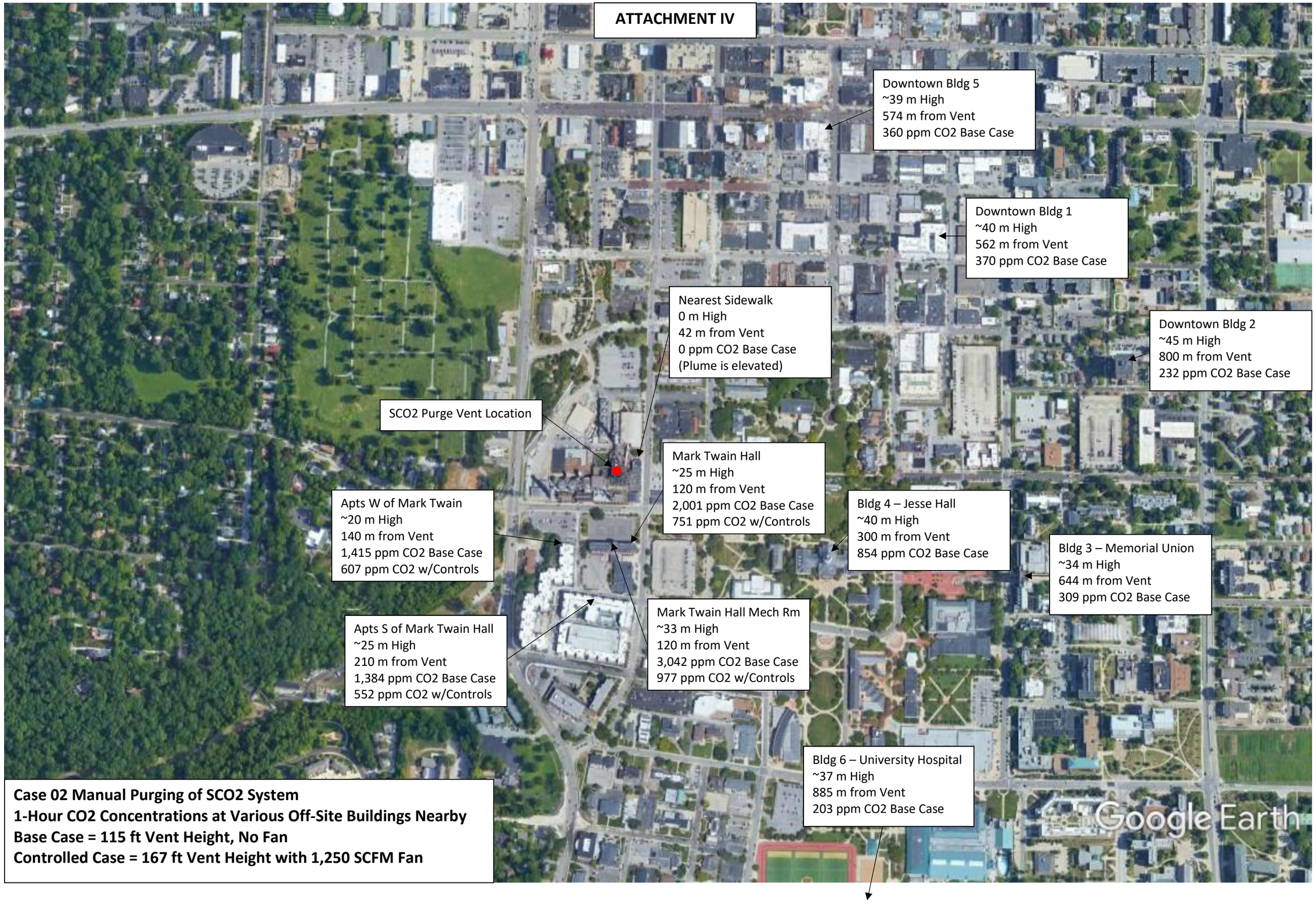
ATTACHMENT III



ATTACHMENT III



ATTACHMENT IV



Case 02 Manual Purging of SCO2 System
1-Hour CO2 Concentrations at Various Off-Site Buildings Nearby
Base Case = 115 ft Vent Height, No Fan
Controlled Case = 167 ft Vent Height with 1,250 SCFM Fan

Case 02, Continuous Purge - Summary of Scenario Results

Receptor	Receptor Dist from vent (m)	Recepter Elevation BELOW Vent (m)	Recepter Elevation ABOVE Ground (m)	Scenario 02, 26.5 min Release, 115 ft Vent Ht: 1-min Average CO2 Conc. ppmv	15-min Average CO2 Conc. ppmv	60-min Average CO2 Conc. ppmv
Penthouse Roof	3	3.0	32.0	0	0	0
Penthouse Platform	1	8.5	26.5	0	0	0
Existing Bldg S. of Penthouse	28	19.0	16.0	0	0	0
Lower N. Stack Platform (Existing)	32	-11.0	46.0	21,879	12,730	4,247
Existing Bldg SW. of Penthouse	32	10.0	25.0	23,591	13,726	4,579
Lower S. Stack Platform (Existing)	114	-11.0	46.0	10,148	5,904	1,970
Nearest Sidewalk	42	35.0	0.0	0	0	0
Mark Twain Hall-Elevator Penthouse	120	2.0	33.0	15,674	9,119	3,042
Mark Twain Hall	120	10.0	25.0	10,309	5,998	2,001
Apprtmts W of Mark Twain Hall	140	15.0	20.0	7,289	4,241	1,415
Apprtmts S of Mark Twain Hall	210	10.0	25.0	7,133	4,150	1,384
Downtown Bldg 4 (Jesse Hall)	300	-5.0	40.0	4,402	2,561	854
Downtown Bldg 1	562	-5.0	40.0	1,907	1,109	370
Downtown Bldg 5	574	-4.0	39.0	1,854	1,079	360
Downtown Bldg 3 (Memorial Union)	644	1.0	34.0	1,592	927	309
Downtown Bldg 2	800	-10.0	45.0	1,195	695	232
Downtown Bldg 6 (University Hospital)	885	-2.0	37.0	1,045	608	203
Peak Concentration on Ground:	79	35.0	0.0	4,719	2,746	916

Receptor	Receptor Dist from vent (m)	Recepter Elevation BELOW Vent (m)	Recepter Elevation ABOVE Ground (m)	Scenario 03, 60 min Release, 115 ft Vent Ht: 1-min Average CO2 Conc. ppmv	15-min Average CO2 Conc. ppmv	60-min Average CO2 Conc. ppmv	Scenario 04, 120 min Release, 115 ft Vent Ht: 1-min Average CO2 Conc. ppmv	15-min Average CO2 Conc. ppmv	60-min Average CO2 Conc. ppmv
Penthouse Roof	3	3.0	32.0	0	0	0	0	0	0
Penthouse Platform	1	8.5	26.5	0	0	0	0	0	0
Existing Bldg S. of Penthouse	28	19.0	16.0	0	0	0	0	0	0
Lower N. Stack Platform (Existing)	32	-11.0	46.0	12,561	7,308	5,538	7,049	4,101	3,108
Existing Bldg SW. of Penthouse	32	10.0	25.0	16,725	9,731	7,375	11,499	6,690	5,070
Lower S. Stack Platform (Existing)	114	-11.0	46.0	6,189	3,601	2,729	3,733	2,172	1,646
Nearest Sidewalk	42	35.0	0.0	0	0	0	0	0	0
Mark Twain Hall-Elevator Penthouse	120	2.0	33.0	10,689	6,219	4,713	5,414	3,150	2,387
Mark Twain Hall	120	10.0	25.0	7,140	4,154	3,148	5,074	2,952	2,237
Apprtmts W of Mark Twain Hall	140	15.0	20.0	4,821	2,805	2,126	3,156	1,836	1,391
Apprtmts S of Mark Twain Hall	210	10.0	25.0	4,797	2,791	2,115	2,592	1,508	1,143
Downtown Bldg 4 (Jesse Hall)	300	-5.0	40.0	3,102	1,805	1,368	1,626	946	717
Downtown Bldg 1	562	-5.0	40.0	1,355	788	597	717	417	316
Downtown Bldg 5	574	-4.0	39.0	1,320	768	582	697	406	308
Downtown Bldg 3 (Memorial Union)	644	1.0	34.0	1,134	660	500	601	349	265
Downtown Bldg 2	800	-10.0	45.0	853	496	376	453	263	200
Downtown Bldg 6 (University Hospital)	885	-2.0	37.0	747	435	330	396	231	175
Peak Concentration on Ground:	79	35.0	0.0	2,465	1,434	1,087	1,347	784	594

Case 02, Continuous Purge - Summary of Scenario Results

Receptor	Receptor Dist from vent (m)	Recepter Elevation BELOW Vent (m)	Recepter Elevation ABOVE Ground (m)	Scenario 05, 26.5 min Release, 140 ft Vent Ht: 1-min Average CO2 Conc. ppmv	Scenario 05, 26.5 min Release, 140 ft Vent Ht: 15-min Average CO2 Conc. ppmv	Scenario 05, 26.5 min Release, 140 ft Vent Ht: 60-min Average CO2 Conc. ppmv	Scenario 07, 26.5 min Release, 140 ft Vent Ht w Fan: 1-min Average CO2 Conc. ppmv	Scenario 07, 26.5 min Release, 140 ft Vent Ht w Fan: 15-min Average CO2 Conc. ppmv	Scenario 07, 26.5 min Release, 140 ft Vent Ht w Fan: 60-min Average CO2 Conc. ppmv
Penthouse Roof	3	11.0	32.0	0	0	0	0	0	0
Penthouse Platform	1	16.5	26.5	0	0	0	0	0	0
Existing Bldg S. of Penthouse	28	27.0	16.0	0	0	0	0	0	0
Lower N. Stack Platform (Existing)	32	-3.0	46.0	43,019	25,029	8,396	23,711	13,796	4,628
Existing Bldg SW. of Penthouse	32	18.0	25.0	0	0	0	0	0	0
Lower S. Stack Platform (Existing)	114	-3.0	46.0	18,838	10,960	3,676	15,185	8,835	2,964
Nearest Sidewalk	42	43.0	0.0	0	0	0	0	0	0
Mark Twain Hall-Elevator Penthouse	120	10.0	33.0	10,433	6,070	2,036	6,723	3,911	1,312
Mark Twain Hall	120	18.0	25.0	6,457	3,757	1,260	5,006	2,912	977
Apprtmts W of Mark Twain Hall	140	23.0	20.0	4,641	2,700	906	3,922	2,282	765
Apprtmts S of Mark Twain Hall	210	18.0	25.0	4,783	2,783	934	3,562	2,072	695
Downtown Bldg 4 (Jesse Hall)	300	3.0	40.0	4,795	2,790	936	5,606	3,262	1,094
Downtown Bldg 1	562	3.0	40.0	2,052	1,194	401	2,216	1,289	432
Downtown Bldg 5	574	4.0	39.0	1,995	1,161	389	2,148	1,250	419
Downtown Bldg 3 (Memorial Union)	644	9.0	34.0	1,707	993	333	1,827	1,063	357
Downtown Bldg 2	800	-2.0	45.0	1,278	744	249	1,348	784	263
Downtown Bldg 6 (University Hospital)	885	6.0	37.0	1,119	651	218	1,172	682	229
Peak Concentration on Ground:	79	43.0	0.0	3,200	1,862	624	2,233	1,299	436

Receptor	Receptor Dist from vent (m)	Recepter Elevation BELOW Vent (m)	Recepter Elevation ABOVE Ground (m)	Scenario 06, 26.5 min Release, 167 ft Vent Ht: 1-min Average CO2 Conc. ppmv	Scenario 06, 26.5 min Release, 167 ft Vent Ht: 15-min Average CO2 Conc. ppmv	Scenario 06, 26.5 min Release, 167 ft Vent Ht: 60-min Average CO2 Conc. ppmv	Scenario 08, 26.5 min Release, 167 ft Vent Ht w Fan: 1-min Average CO2 Conc. ppmv	Scenario 08, 26.5 min Release, 167 ft Vent Ht w Fan: 15-min Average CO2 Conc. ppmv	Scenario 08, 26.5 min Release, 167 ft Vent Ht w Fan: 60-min Average CO2 Conc. ppmv
Penthouse Roof	3	19.0	32.0	0	0	0	0	0	0
Penthouse Platform	1	24.5	26.5	0	0	0	0	0	0
Existing Bldg S. of Penthouse	28	35.0	16.0	0	0	0	0	0	0
Lower N. Stack Platform (Existing)	32	5.0	46.0	34,571	20,114	6,747	0	0	0
Existing Bldg SW. of Penthouse	32	26.0	25.0	0	0	0	0	0	0
Lower S. Stack Platform (Existing)	114	5.0	46.0	16,567	9,639	3,233	9,475	5,513	1,849
Nearest Sidewalk	42	51.0	0.0	0	0	0	0	0	0
Mark Twain Hall-Elevator Penthouse	120	18.0	33.0	6,335	3,686	1,236	5,005	2,912	977
Mark Twain Hall	120	26.0	25.0	5,065	2,947	988	3,849	2,240	751
Apprtmts W of Mark Twain Hall	140	31.0	20.0	Not Modeled			3,112	1,810	607
Apprtmts S of Mark Twain Hall	210	26.0	25.0				2,828	1,645	552
Downtown Bldg 4 (Jesse Hall)	300	11.0	40.0				3,859	2,245	753
Downtown Bldg 1	562	11.0	40.0				2,453	1,427	479
Downtown Bldg 5	574	12.0	39.0				2,379	1,384	464
Downtown Bldg 3 (Memorial Union)	644	17.0	34.0				1,871	1,089	365
Downtown Bldg 2	800	6.0	45.0				1,486	865	290
Downtown Bldg 6 (University Hospital)	885	14.0	37.0				1,290	751	252
Peak Concentration on Ground:	79	51.0	0.0	2,379	1,384	464	1,739	1,012	339

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - Case 02, Scenario 2, Baseline 26.5 min release time

Note: The wind speeds at stack height elevation are based on a 35 meter stack (cell V35). The value of Hs in cell B19 can be adjusted to represent receptors at elevations above ground level, e.g., setting Hs to 3 meters indicates the receptor is 3 meters below the vent exit, or setting Hs to 35 meters indicates the receptor is on ground level. The actual stack height above ground can be adjusted in cell V35.

RVD Inputs

Parameter	Value	Units	Definition	Source // Reference
P_a	100,000	Pa	ambient pressure	standard atmospheric pressure at sea level
T_2	252.63	K	discharge temperatature = $T_2 = T_1 \cdot (1 - 0.85 \cdot ((\gamma - 1) / (\gamma + 1))$	See TSCREEN calculations
T_a	298.00	K	ambient temperature	See TSCREEN calculations
ρ_2	2.0953	kg / m3 @ T_2 & P*	discharge density = $\rho_2 = P_a \cdot MWCO2 / (R \cdot T_2)$	See TSCREEN calculations
ρ_{air}	1.1664	kg / m3	density of air = ρair = $P_a \cdot MWair / (R \cdot T_a)$	See TSCREEN calculations
γ_2	1.3219	dimensionless @T_2 & P_2	$(C_P / C_V) \approx 1 / (1 - R / (C_P \cdot M))$ @ T_2	National Institute of Standards and Technology (NIST) data utilized instead.
Q_m	1.0941	kg / s	mass emission rate	See TSCREEN calculations
$V2_{sonic}$	248.98	m / s	V2sonic = SQRT(γ_2 * P_a / ρ_2)	--[n/a]
D_{vent}	10	inch	vent diameter	Echogen data
A_{vent}	0.0507	m^2	vent flow area	Echogen data; presumed circular vent
V2	10.3053	m / s	discharge velocity	--[n/a]
g	9.80665	m / s^2	acceleration due to gravity	--[n/a]
H_S	35.0	m	stack height	Echogen data
u_0 / u_{10}	0.06	dimensionless	friction velocity (m / s) to the wind speed at 10m (m / s)	RVD 2.0 model assumption for all Atmospheric Stability Classes
MW_{CO2}	44.01	kg / kg-mole	gas (contaminant) molecular weight (for contaminant mixtures, see TSCREEN Workbook Appedix B)	See TSCREEN calculations
t_d	26.4109	minutes	release duration = td = $Q / (Q_m d \cdot 60)$	See TSCREEN calculations

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - Case 02, Scenario 2, Baseline 26.5 min release time

Step 1. Check for dominance of dense gas effects at release point.

Source Region (Rural or Urban)?: Rural

Atmospheric Stability Class	A	B	C	D	E	F	Source // Reference
Wind Profile Exponent (P)	0.07	0.07	0.10	0.15	0.35	0.55	Recommended Power-law exponents for Urban and Rural Wind Profiles, Table 6-2 http://www.webmet.com/met_monitoring/625.HTML

Wind Velocity at the Top of the Stack (u) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	1.092	1.092	1.133	1.207	--n/a	1.992	RVD 2.0 - Equation 2. Wind Velocity at the Top of the Stack $u = u_{10} \cdot (H_S / 10) \cdot P$
2	2.183	2.183	2.267	2.413	3.101	3.984	
3	3.275	3.275	3.400	3.620	4.651	5.975	
4	--n/a	4.367	4.534	4.827	6.201	--n/a	
5	--n/a	5.458	5.667	6.034	7.752	--n/a	
8	--n/a	--n/a	9.068	9.654	--n/a	--n/a	
10	--n/a	--n/a	11.335	12.067	--n/a	--n/a	
15	--n/a	--n/a	17.002	18.101	--n/a	--n/a	
20	--n/a	--n/a	22.669	24.135	--n/a	--n/a	

Stack Exit Richardson Number (Ri_0) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	4,085	4,085	3,935	3,696	--n/a	2,239	RVD 2.0 - Equation 1. Stack Exit Richardson Number $Ri_0 = (g (\rho_2 / \rho_a - 1) \cdot Q_m) / (u \cdot D_{vent} \cdot \rho_2 \cdot u_{10}^{(2)} (u_0 / u_{10})^{(2)})$
2	511	511	492	462	360	280	
3	151	151	146	137	107	83	
4	--n/a	64	61	58	45	--n/a	
5	--n/a	33	31	30	23	--n/a	
8	--n/a	--n/a	8	7	--n/a	--n/a	
10	--n/a	--n/a	4	4	--n/a	--n/a	
15	--n/a	--n/a	1	1	--n/a	--n/a	
20	--n/a	--n/a	0	0	--n/a	--n/a	

Plume Buoyancy at Stack Exit by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	Dense	Dense	Dense	Dense	--n/a	Dense	RVD 2.0 - Plume Buoyancy at Stack Exit If $Ri_0 > 30$ then plume is considered to behave as a dense gas at the release point Note: Neutral conditions are evaluated using alternate model.
2	Dense	Dense	Dense	Dense	Dense	Dense	
3	Dense	Dense	Dense	Dense	Dense	Dense	
4	--n/a	Dense	Dense	Dense	Dense	--n/a	
5	--n/a	Dense	Dense	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 2, Baseline 26.5 min release time

Step 2. Assess atmospheric dilution of the plume resulting from entrainment effects during the rise of plume to its maximum height.

Height from the top of the stack to the middle of the plume at its point of maximum rise (Δh) under laminar wind conditions by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	3.6	3.6	3.6	3.5	--n/a	3.0	RVD 2.0 - Equation 3. Height from the top of the stack to the middle of the plume at its point of maximum rise under laminar wind conditions. $\Delta h = 1.32 \cdot R_V^{(1/3)} \cdot SG^{(1/3)} \cdot Fr^{(2/3)} \cdot D_{vent}$ RVD 2.0 - Equation 4. Vertical Densimetric Froude Number $Fr = V2 / (g \cdot D_{vent} \cdot (1 - \rho_a / \rho_2))^{(1/2)}$ RVD 2.0 - Equation 4a $R_V = V2 / u$
2	2.9	2.9	2.8	2.8	2.6	2.4	
3	2.5	2.5	2.5	2.4	2.2	2.1	
4	--n/a	2.3	2.3	2.2	2.0	--n/a	
5	--n/a	2.1	2.1	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Height from the top of the stack to the middle of the plume at its point of maximum rise (Δh) under quiescent atmospheric conditions (no wind)

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
0	6.5	6.5	6.5	6.5	6.5	6.5	RVD 2.0 - Equation 5. Height from the top of the stack to the middle of the plume at its point of maximum rise under quiescent atmospheric conditions (no wind) $\Delta h = 2.96 \cdot Fr \cdot D_{vent}$

Plume dilution ratio at maximum plume rise (D_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	7.4	7.4	7.5	7.7	--n/a	9.3	RVD 2.0 - Equation 6. Plume dilution ratio at maximum plume rise. $D_h = 5.67 \cdot 10^{(-2)} \cdot u \cdot D_{vent}^{(2)} / Q_m \cdot (\Delta h_{min} / D_{vent})^{(1.85)} \cdot (MW_{CO2} / T_a)$ Note: Basic code in RVD for TSCREEN uses a corrected equation, below: $D_h = 5.67 \cdot u \cdot D_{vent}^{(2)} / Q_m \cdot (\Delta h_{min} / D_{vent})^{(1.85)} \cdot (MW_{CO2} / T_a)$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	9.6	9.6	9.8	10.0	11.0	12.1	
3	11.3	11.3	11.4	11.7	12.9	14.2	
4	--n/a	12.6	12.8	13.1	14.4	--n/a	
5	--n/a	13.7	13.9	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 2, Baseline 26.5 min release time

Plume-equivalent molecular weight at maximum plume rise (MW_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	30.997	30.997	30.968	30.920	--[n/a]	30.578	RVD 2.0 - Equation 7. Plume-equivalent molecular weight at maximum plume rise. $MW_h = (MW_{CO2} + 28.96 \cdot (D_h - 1)) / D_h$
2	30.522	30.522	30.499	30.463	30.325	30.200	
3	30.297	30.297	30.278	30.247	30.129	30.022	
4	--[n/a]	30.157	30.140	30.112	30.007	--[n/a]	
5	--[n/a]	30.059	30.043	Neutral	Neutral	--[n/a]	Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
8	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

Plume temperature at maximum plume rise (T_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	289.280	289.280	289.397	289.588	--[n/a]	290.980	RVD 2.0 - Equation 8. Plume temperature at maximum plume rise. $T_h = T_a - (MW_{CO2} / MW_h) \cdot (T_a - T_z) / D_h$
2	291.211	291.211	291.303	291.454	292.027	292.551	
3	292.145	292.145	292.225	292.356	292.853	293.308	
4	--[n/a]	292.732	292.804	292.923	293.372	--[n/a]	
5	--[n/a]	293.148	293.215	Neutral	Neutral	--[n/a]	Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
8	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

Fractional density ratio at maximum plume rise (δ) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	0.103	0.103	0.101	0.099	--[n/a]	0.081	RVD 2.0 - Equation 9. Fractional density ratio at maximum plume rise. $\delta = ((MW_h / 28.96) \cdot (T_a / T_z)) - 1$
2	0.078	0.078	0.077	0.076	0.069	0.062	
3	0.067	0.067	0.066	0.065	0.059	0.053	
4	--[n/a]	0.060	0.059	0.058	0.052	--[n/a]	
5	--[n/a]	0.055	0.054	Neutral	Neutral	--[n/a]	Note: A calculated frational density ratio greater than 0.005 indicates that dense gas behavior dominates the subsequent plume transport and RVD is appropriate for plume touchdown and ground level concentration calculations. A calculated frational density ratio less than or equal to 0.005 indicates neutrally-buoyant plume behavior which should be addressed using an alternate model.
8	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - Case 02, Scenario 2, Baseline 26.5 min release time

Step 3. Concentration Estimates at Plume Touchdown

Ambient concentration at plume touchdown (maximum ground-level concentration) (C_T) in units of µg / m^3 by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	3,695,858	3,695,858	3,574,429	3,380,524	--n/a	2,154,827	RVD 2.0 - Equation 10. Ambient concentration at plume touchdown (maximum ground-level concentration). $C_T = 6.0 \cdot 10^{(9)} \cdot Q_m / u \cdot ((2 \cdot \Delta h + H_S))^{(-2.0)}$ Note: Basic code in RVD for TSCREEN uses a different equation, below: $C_T = 5.1 \cdot 10^{(9)} \cdot Q_m \cdot ((2 \cdot \Delta h + HS))^{(-1.95)} / (u \cdot D_{vent}^{(0.05)})$ These values represents the 1-hour concentrations from a continuous emission source. If the emissions occur for less than 1 hour, or if the averaging period of concern is less than 1 hour, use the values calculated below in Step 4.
2	1,982,660	1,982,660	1,916,100	1,809,947	1,439,546	1,143,212	
3	1,369,085	1,369,085	1,322,620	1,248,565	990,662	784,957	
4	--n/a	1,050,235	1,014,341	957,157	758,260	--n/a	
5	--n/a	853,930	824,597	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Ambient concentration at plume touchdown (maximum ground-level concentration) (C_T) in units of ppmV by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	2,081	2,081	2,012	1,903	--n/a	1,213	Conversion from µg/m^3 to ppmV These values represents the 1-hour concentrations from a continuous emission source. If the emissions occur for less than 1 hour, or if the averaging period of concern is less than 1 hour, use the values calculated below in Step 4.
2	1,116	1,116	1,079	1,019	810	644	
3	771	771	745	703	558	442	
4	--n/a	591	571	539	427	--n/a	
5	--n/a	481	464	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Downwind distance to plume touchdown in units of meters (X_T) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	79	79	83	91	--n/a	185	RVD 2.0 - Equation 11. Downwind distance to plume touchdown. $X_T = D_{vent} \cdot Fr^{(2)} / R_V + 0.56 \cdot D_{vent} \cdot Fr_H / R_V^{(1/2)} \cdot C_1$ RVD 2.0 - Equation 12 $C_1 = ((\Delta h / D_{vent})^{(3)} \cdot ((2 + H_S / \Delta h)^{(3)} - 1))^{(1/2)}$ RVD 2.0 - Equation 13. Horizontal densimetric Froude number $Fr_H = u / (g \cdot D_{vent} \cdot (\rho_{air} / \rho_2 - 1))^{(1/2)}$ Note: Basic code in RVD for TSCREEN uses a corrected equation for Fr_H, below: $Fr_H = u * (((\rho_{air} / (\rho_2 - \rho_{air})) / (g \ D_{vent}))^{(1/2)}$
2	210	210	222	243	347	496	
3	375	375	396	433	620	889	
4	--n/a	566	598	654	938	--n/a	
5	--n/a	781	824	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 2, Baseline 26.5 min release time

Step 4. Concentration Estimates for Release Times Less Than the Averaging Period or Averaging Periods Less Than 60 Minutes

User-Specified Averaging Time (t_a):	15	min

Calculated Release Duration (t_d):	26.4109	min

Note: See TSCREEN for release duration calculation.

Ambient concentration at plume touchdown (maximum ground-level concentration) including correction factors for user-specified averaging time and calculated release duration (C_{TF}) in units of ppmV by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	2,746	2,746	2,655	2,511	--n/a	1,601	RVD 2.0 - Equation 16. Correction factor if release duration is less than the averaging time. $C_{TF} = C \cdot (t_d / t_a)$
2	1,473	1,473	1,423	1,345	1,069	849	
3	1,017	1,017	983	928	736	583	
4	--n/a	780	754	711	563	--n/a	
5	--n/a	634	613	Neutral	Neutral	--n/a	RVD 2.0 - Equation 17. Correction factor if averaging time is less than 60 minutes. $C_{TF} = C \cdot (60 / t_a)^{(0.2)}$
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	where C_{TF} = the corrected touchdown concentration, C_T.
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Receptor	Receptor Dist from vent (m)	Recepter Elevation BELOW Vent (m)	Recepter Elevation ABOVE Ground (m)	1-min Average CO2 Conc. ppmv	15-min Average CO2 Conc. ppmv	60-min Average CO2 Conc. ppmv
Penthouse Roof	3	3.0	32.0	0	0	0
Penthouse Platform	1	8.5	26.5	0	0	0
Existing Bldg S. of Penthouse	28	19.0	16.0	0	0	0
Lower N. Stack Platform (Existing)	32	-11.0	46.0	21,879	*12,730*	4,247
Existing Bldg SW. of Penthouse	32	10.0	25.0	23,591	13,726	4,579
Lower S. Stack Platform (Existing)	114	-11.0	46.0	10,148	*5,904*	1,970
Nearest Sidewalk	42	35.0	0.0	0	0	0
Mark Twain Hall-Elevator Penthouse	120	2.0	33.0	15,674	9,119	3,042
Mark Twain Hall	120	10.0	25.0	10,309	5,998	2,001
Apprtmts W of Mark Twain Hall	140	15.0	20.0	7,289	4,241	1,415
Apprtmts S of Mark Twain Hall	210	10.0	25.0	7,133	4,150	1,384
Downtown Bldg 4	300	-5.0	40.0	4,402	2,561	854
Downtown Bldg 1	562	-5.0	40.0	1,907	1,109	370
Downtown Bldg 5	574	-4.0	39.0	1,854	1,079	360
Downtown Bldg 3	644	1.0	34.0	1,592	927	309
Downtown Bldg 2	800	-10.0	45.0	1,195	695	232
Downtown Bldg 6	885	-2.0	37.0	1,045	608	203
Peak Concentration on Ground:	79	35.0	0.0	4,719	2,746	916

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - Case 02, Scenario 03 (60-min release time, 115 ft Vent))

Note: The wind speeds at stack height elevation are based on a 35 meter stack (cell V35). The value of Hs in cell B19 can be adjusted to represent receptors at elevations above ground level, e.g., setting Hs to 3 meters indicates the receptor is 3 meters below the vent exit, or setting Hs to 35 meters indicates the receptor is on ground level. The actual stack height above ground can be adjusted in cell V35.

RVD Inputs

Parameter	Value	Units	Definition	Source // Reference
P_a	101,325	Pa	ambient pressure	standard atmospheric pressure at sea level
T_2	252.63	K	discharge temperatature = $T_2 = T_1 \cdot (1 - 0.85 \cdot ((\gamma - 1) / (\gamma + 1))$	See TSCREEN calculations
T_a	298.00	K	ambient temperature	See TSCREEN calculations
ρ_2	2.1230	kg / m3 @ T_2 & P*	discharge density = $\rho_2 = P_a \cdot MWCO2 / (R \cdot T_2)$	See TSCREEN calculations
ρ_{air}	1.1819	kg / m3	density of air = $\rho air = P_a \cdot MWair / (R \cdot T_a)$	See TSCREEN calculations
γ_2	1.3219	dimensionless @T_2 & P_2	$(C_P / C_V) \approx 1 / (1 - R / (C_P \cdot M))$ @ T_2	National Institute of Standards and Technology (NIST) data utilized instead.
Q_m	0.4810	kg / s	mass emission rate	See TSCREEN calculations
$V2_{sonic}$	248.98	m / s	V2sonic = SQRT($\gamma_2 * P_a / \rho_2$)	--n/a
D_{vent}	10	inch	vent diameter	Echogen data
A_{vent}	0.0507	m^2	vent flow area	Echogen data; presumed circular vent
V2	4.4712	m / s	discharge velocity	--n/a
g	9.80665	m / s^2	acceleration due to gravity	--n/a
H_S	10.0	m	stack height	Echogen data
u_0 / u_{10}	0.06	dimensionless	friction velocity (m / s) to the wind speed at 10m (m / s)	RVD 2.0 model assumption for all Atmospheric Stability Classes
MW_{CO2}	44.01	kg / kg-mole	gas (contaminant) molecular weight (for contaminant mixtures, see TSCREEN Workbook Appedix B)	See TSCREEN calculations
t_d	60.0763	minutes	release duration = td = $Q / (Q_m \cdot 60)$	See TSCREEN calculations

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 03 (60-min release time, 115 ft Vent))

Step 1. Check for dominance of dense gas effects at release point.

Source Region (Rural or Urban)?: Rural

Atmospheric Stability Class	A	B	C	D	E	F	Source // Reference
Wind Profile Exponent (P)	0.07	0.07	0.10	0.15	0.35	0.55	Recommended Power-law exponents for Urban and Rural Wind Profiles, Table 6-2 http://www.webmet.com/met_monitoring/625.HTML

Wind Velocity at the Top of the Stack (u) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	1.092	1.092	1.133	1.207	--n/a	1.992	RVD 2.0 - Equation 2. Wind Velocity at the Top of the Stack $u = u_{10} \cdot (H_S / 10) \cdot P$
2	2.183	2.183	2.267	2.413	3.101	3.984	
3	3.275	3.275	3.400	3.620	4.651	5.975	
4	--n/a	4.367	4.534	4.827	6.201	--n/a	
5	--n/a	5.458	5.667	6.034	7.752	--n/a	
8	--n/a	--n/a	9.068	9.654	--n/a	--n/a	
10	--n/a	--n/a	11.335	12.067	--n/a	--n/a	
15	--n/a	--n/a	17.002	18.101	--n/a	--n/a	
20	--n/a	--n/a	22.669	24.135	--n/a	--n/a	

Stack Exit Richardson Number (Ri_0) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	1,773	1,773	1,707	1,603	--n/a	971	RVD 2.0 - Equation 1. Stack Exit Richardson Number $Ri_0 = (g (\rho_2 / \rho_a - 1) \cdot Q_m) / (u \cdot D_{vent} \cdot \rho_2 \cdot u_{10}^{(2)} (u_0 / u_{10})^{(2)})$
2	222	222	213	200	156	121	
3	66	66	63	59	46	36	
4	--n/a	28	27	25	20	--n/a	
5	--n/a	14	14	13	10	--n/a	
8	--n/a	--n/a	3	3	--n/a	--n/a	
10	--n/a	--n/a	2	2	--n/a	--n/a	
15	--n/a	--n/a	1	0	--n/a	--n/a	
20	--n/a	--n/a	0	0	--n/a	--n/a	

Plume Buoyancy at Stack Exit by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	Dense	Dense	Dense	Dense	--n/a	Dense	RVD 2.0 - Plume Buoyancy at Stack Exit If Ri_0 > 30 then plume is considered to behave as a dense gas at the release point Note: Neutral conditions are evaluated using alternate model.
2	Dense	Dense	Dense	Dense	Dense	Dense	
3	Dense	Dense	Dense	Dense	Dense	Dense	
4	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - Case 02, Scenario 03 (60-min release time, 115 ft Vent))

Step 2. Assess atmospheric dilution of the plume resulting from entrainment effects during the rise of plume to its maximum height.

Height from the top of the stack to the middle of the plume at its point of maximum rise (Δh) under laminar wind conditions by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	1.7	1.7	1.7	1.7	--[n/a]	1.4	RVD 2.0 - Equation 3. Height from the top of the stack to the middle of the plume at its point of maximum rise under laminar wind conditions. $\Delta h = 1.32 \cdot R_V^{(1/3)} \cdot SG^{(1/3)} \cdot Fr^{(2/3)} \cdot D_{vent}$ RVD 2.0 - Equation 4. Vertical Densimetric Froude Number $Fr = V2 / (g \cdot D_{vent} \cdot (1 - \rho_a / \rho_2))^{(1/2)}$ RVD 2.0 - Equation 4a $R_V = V2 / u$
2	1.4	1.4	1.3	1.3	1.2	1.1	
3	1.2	1.2	1.2	1.1	1.1	1.0	
4	--[n/a]	Neutral	Neutral	Neutral	Neutral	--[n/a]	
5	--[n/a]	Neutral	Neutral	Neutral	Neutral	--[n/a]	
8	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

Height from the top of the stack to the middle of the plume at its point of maximum rise (Δh) under quiescent atmospheric conditions (no wind)

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
0	3.2	3.2	3.2	3.2	3.2	3.2	RVD 2.0 - Equation 5. Height from the top of the stack to the middle of the plume at its point of maximum rise under quiescent atmospheric conditions (no wind) $\Delta h = 2.96 \cdot Fr \cdot D_{vent}$

Plume dilution ratio at maximum plume rise (D_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	4.2	4.2	4.2	4.3	--[n/a]	5.3	RVD 2.0 - Equation 6. Plume dilution ratio at maximum plume rise. $D_h = 5.67 \cdot 10^{(-2)} \cdot u \cdot D_{vent}^{(2)} / Q_m \cdot (\Delta h_{min} / D_{vent})^{(1.85)} \cdot (MW_{CO2} / T_a)$ Note: Basic code in RVD for TSCREEN uses a corrected equation, below: $D_h = 5.67 \cdot u \cdot D_{vent}^{(2)} / Q_m \cdot (\Delta h_{min} / D_{vent})^{(1.85)} \cdot (MW_{CO2} / T_a)$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	5.5	5.5	5.5	5.7	6.2	6.9	
3	6.4	6.4	6.5	6.6	7.3	8.0	
4	--[n/a]	Neutral	Neutral	Neutral	Neutral	--[n/a]	
5	--[n/a]	Neutral	Neutral	Neutral	Neutral	--[n/a]	
8	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 03 (60-min release time, 115 ft Vent))

Plume-equivalent molecular weight at maximum plume rise (MW_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	32.557	32.557	32.505	32.421	--n/a	31.816	RVD 2.0 - Equation 7. Plume-equivalent molecular weight at maximum plume rise. $MW_h = (MW_{CO2} + 28.96 \cdot (D_h - 1)) / D_h$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	31.718	31.718	31.678	31.614	31.371	31.150	
3	31.321	31.321	31.287	31.232	31.024	30.835	
4	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Plume temperature at maximum plume rise (T_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	283.341	283.341	283.528	283.835	--n/a	286.088	RVD 2.0 - Equation 8. Plume temperature at maximum plume rise. $T_h = T_a - (MW_{CO2} / MW_h) \cdot (T_a - T_2) / D_h$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	286.464	286.464	286.615	286.863	287.804	288.672	
3	288.000	288.000	288.132	288.349	289.174	289.933	
4	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Fractional density ratio at maximum plume rise (δ) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	0.182	0.182	0.180	0.175	--n/a	0.144	RVD 2.0 - Equation 9. Fractional density ratio at maximum plume rise. $\delta = ((MW_h / 28.96) \cdot (T_a / T_2)) - 1$ Note: A calculated frational density ratio greater than 0.005 indicates that dense gas behavior dominates the subsequent plume transport and RVD is appropriate for plume touchdown and ground level concentration calculations. A calculated frational density ratio less than or equal to 0.005 indicates neutrally-buoyant plume behavior which should be addressed using an alternate model.
2	0.139	0.139	0.137	0.134	0.122	0.110	
3	0.119	0.119	0.117	0.115	0.104	0.094	
4	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - Case 02, Scenario 03 (60-min release time, 115 ft Vent))

Step 3. Concentration Estimates at Plume Touchdown

Ambient concentration at plume touchdown (maximum ground-level concentration) (C_T) in units of µg / m^3 by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	15,204,591	15,204,591	14,734,877	13,982,251	--n/a	9,141,112	RVD 2.0 - Equation 10. Ambient concentration at plume touchdown (maximum ground-level concentration). $C_T = 6.0 \cdot 10^{(9)} \cdot Q_m / u \cdot ((2 \cdot \Delta h + H_S))^{(-2.0)}$ Note: Basic code in RVD for TSCREEN uses a different equation, below: $C_T = 5.1 \cdot 10^{(9)} \cdot Q_m \cdot ((2 \cdot \Delta h + HS))^{(-1.95)} / (u \cdot D_{vent}^{(0.05)})$ These values represents the 1-hour concentrations from a continuous emission source. If the emissions occur for less than 1 hour, or if the averaging period of concern is less than 1 hour, use the values calculated below in Step 4.
2	8,447,504	8,447,504	8,178,292	7,747,659	6,231,617	5,001,551	
3	5,940,636	5,940,636	5,748,260	5,440,808	4,361,323	3,489,172	
4	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Ambient concentration at plume touchdown (maximum ground-level concentration) (C_T) in units of ppmV by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	8,448	8,448	8,187	7,769	--n/a	5,079	Conversion from µg/m^3 to ppmV These values represents the 1-hour concentrations from a continuous emission source. If the emissions occur for less than 1 hour, or if the averaging period of concern is less than 1 hour, use the values calculated below in Step 4.
2	4,694	4,694	4,544	4,305	3,462	2,779	
3	3,301	3,301	3,194	3,023	2,423	1,939	
4	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Downwind distance to plume touchdown in units of meters (X_T) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	22	22	23	25	--n/a	50	RVD 2.0 - Equation 11. Downwind distance to plume touchdown. $X_T = D_{vent} \cdot Fr^{(2)} / R_V + 0.56 \cdot D_{vent} \cdot Fr_H / R_V^{(1/2)} \cdot C_1$ RVD 2.0 - Equation 12 $C_1 = ((\Delta h / D_{vent})^{(3)} \cdot ((2 + H_S / \Delta h)^{(3)} - 1))^{(1/2)}$ RVD 2.0 - Equation 13. Horizontal densimetric Froude number $Fr_H = u / (g \cdot D_{vent} \cdot (\rho_{air} / \rho_2 - 1))^{(1/2)}$ Note: Basic code in RVD for TSCREEN uses a corrected equation for Fr_H, below: $Fr_H = u * (((\rho_{air} / (\rho_2 - \rho_{air})) / (g \ D_{vent}))^{(1/2)}$
2	57	57	60	65	92	131	
3	100	100	105	114	162	231	
4	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 03 (60-min release time, 115 ft Vent))

Step 4. Concentration Estimates for Release Times Less Than the Averaging Period or Averaging Periods Less Than 60 Minutes

User-Specified Averaging Time (t_a):	15	min

Calculated Release Duration (t_d):	60.0763	min

Note: See TSCREEN for release duration calculation.

Ambient concentration at plume touchdown (maximum ground-level concentration) including correction factors for user-specified averaging time and calculated release duration (C_{TF}) in units of ppmV by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	11,147	11,147	10,803	10,251	--n/a	6,702	RVD 2.0 - Equation 16. Correction factor if release duration is less than the averaging time. $C_{TF} = C \cdot (t_d / t_a)$
2	6,193	6,193	5,996	5,680	4,569	3,667	
3	4,355	4,355	4,214	3,989	3,197	2,558	
4	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	RVD 2.0 - Equation 17. Correction factor if averaging time is less than 60 minutes. $C_{TF} = C \cdot (60 / t_a)^{(0.2)}$
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	where C_{TF} = the corrected touchdown concentration, C_T.
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Receptor	Receptor Dist from vent (m)	Recepter Elevation BELOW Vent (m)	Recepter Elevation ABOVE Ground (m)	1-min Average CO2 Conc. ppmv	15-min Average CO2 Conc. ppmv	60-min Average CO2 Conc. ppmv
Penthouse Roof	3	3.0	32.0	0	0	0
Penthouse Platform	5	8.5	26.5	0	0	0
Existing Bldg S. of Penthouse	28	19.0	16.0	0	0	0
Lower N. Stack Platform (Existing)	32	-11.0	46.0	12,561	7,308	5,538
Existing Bldg SW. of Penthouse	32	10.0	25.0	16,725	9,731	7,375
Lower S. Stack Platform (Existing)	114	-11.0	46.0	6,189	3,601	2,729
Nearest Sidewalk	42	35.0	0.0	0	0	0
Mark Twain Hall-Elevator Penthouse	120	2.0	33.0	10,689	6,219	4,713
Mark Twain Hall	120	10.0	25.0	7,140	4,154	3,148
Apprtmts W of Mark Twain Hall	140	15.0	20.0	4,821	2,805	2,126
Apprtmts S of Mark Twain Hall	210	10.0	25.0	4,797	2,791	2,115
Downtown Bldg 4	300	-5.0	40.0	3,102	1,805	1,368
Downtown Bldg 1	562	-5.0	40.0	1,355	788	597
Downtown Bldg 5	574	-4.0	39.0	1,320	768	582
Downtown Bldg 3	644	1.0	34.0	1,134	660	500
Downtown Bldg 2	800	-10.0	45.0	853	496	376
Downtown Bldg 6	885	-2.0	37.0	747	435	330
Peak Concentration on Ground:	102	35.0	0.0	2,465	1,434	1,087

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - Case 02, Scenario 04 (120-min release time, 115 ft Vent ht)

Note: The wind speeds at stack height elevation are based on a 35 meter stack (cell V35). The value of Hs in cell B19 can be adjusted to represent receptors at elevations above ground level, e.g., setting Hs to 3 meters indicates the receptor is 3 meters below the vent exit, or setting Hs to 35 meters indicates the receptor is on ground level. The actual stack height above ground can be adjusted in cell V35.

RVD Inputs

Parameter	Value	Units	Definition	Source // Reference
P_a	101,325	Pa	ambient pressure	standard atmospheric pressure at sea level
T_2	252.63	K	discharge temperatature = $T_2 = T_1 \cdot (1 - 0.85 \cdot ((\gamma - 1) / (\gamma + 1))$	See TSCREEN calculations
T_a	298.00	K	ambient temperature	See TSCREEN calculations
ρ_2	2.1230	kg / m3 @ T_2 & P*	discharge density = $\rho_2 = P_a \cdot MWCO2 / (R \cdot T_2)$	See TSCREEN calculations
ρ_{air}	1.1819	kg / m3	density of air = $\rho air = P_a \cdot MWair / (R \cdot T_a)$	See TSCREEN calculations
γ_2	1.3219	dimensionless @T_2 & P_2	$(C_P / C_V) \approx 1 / (1 - R / (C_P \cdot M))$ @ T_2	National Institute of Standards and Technology (NIST) data utilized instead.
Q_m	0.2405	kg / s	mass emission rate	See TSCREEN calculations
$V2_{sonic}$	248.98	m / s	V2sonic = SQRT(γ_2 * P_a / ρ_2)	--[n/a]
D_{vent}	10	inch	vent diameter	Echogen data
A_{vent}	0.0507	m^2	vent flow area	Echogen data; presumed circular vent
V2	2.2356	m / s	discharge velocity	--[n/a]
g	9.80665	m / s^2	acceleration due to gravity	--[n/a]
H_S	10.0	m	stack height	Echogen data
u_0 / u_{10}	0.06	dimensionless	friction velocity (m / s) to the wind speed at 10m (m / s)	RVD 2.0 model assumption for all Atmospheric Stability Classes
MW_{CO2}	44.01	kg / kg-mole	gas (contaminant) molecular weight (for contaminant mixtures, see TSCREEN Workbook Appedix B)	See TSCREEN calculations
t_d	120.1526	minutes	release duration = td = Q / ($Q_m \cdot 60$)	See TSCREEN calculations

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 04 (120-min release time, 115 ft Vent ht)

Step 1. Check for dominance of dense gas effects at release point.

Source Region (Rural or Urban)?: Rural

Atmospheric Stability Class	A	B	C	D	E	F	Source // Reference
Wind Profile Exponent (P)	0.07	0.07	0.10	0.15	0.35	0.55	Recommended Power-law exponents for Urban and Rural Wind Profiles, Table 6-2 http://www.webmet.com/met_monitoring/625.HTML

Wind Velocity at the Top of the Stack (u) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	1.092	1.092	1.133	1.207	--n/a	1.992	RVD 2.0 - Equation 2. Wind Velocity at the Top of the Stack $u = u_{10} \cdot (H_S / 10) \cdot P$
2	2.183	2.183	2.267	2.413	3.101	3.984	
3	3.275	3.275	3.400	3.620	4.651	5.975	
4	--n/a	4.367	4.534	4.827	6.201	--n/a	
5	--n/a	5.458	5.667	6.034	7.752	--n/a	
8	--n/a	--n/a	9.068	9.654	--n/a	--n/a	
10	--n/a	--n/a	11.335	12.067	--n/a	--n/a	
15	--n/a	--n/a	17.002	18.101	--n/a	--n/a	
20	--n/a	--n/a	22.669	24.135	--n/a	--n/a	

Stack Exit Richardson Number (Ri_0) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	886	886	854	802	--n/a	486	RVD 2.0 - Equation 1. Stack Exit Richardson Number $Ri_0 = (g (\rho_2 / \rho_a - 1) \cdot Q_m) / (u \cdot D_{vent} \cdot \rho_2 \cdot u_{10}^{(2)} (u_0 / u_{10})^{(2)})$
2	111	111	107	100	78	61	
3	33	33	32	30	23	18	
4	--n/a	14	13	13	10	--n/a	
5	--n/a	7	7	6	5	--n/a	
8	--n/a	--n/a	2	2	--n/a	--n/a	
10	--n/a	--n/a	1	1	--n/a	--n/a	
15	--n/a	--n/a	0	0	--n/a	--n/a	
20	--n/a	--n/a	0	0	--n/a	--n/a	

Plume Buoyancy at Stack Exit by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	Dense	Dense	Dense	Dense	--n/a	Dense	RVD 2.0 - Plume Buoyancy at Stack Exit If Ri_0 > 30 then plume is considered to behave as a dense gas at the release point Note: Neutral conditions are evaluated using alternate model.
2	Dense	Dense	Dense	Dense	Dense	Dense	
3	Dense	Dense	Dense	Neutral	Neutral	Neutral	
4	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 04 (120-min release time, 115 ft Vent ht)

Step 2. Assess atmospheric dilution of the plume resulting from entrainment effects during the rise of plume to its maximum height.

Height from the top of the stack to the middle of the plume at its point of maximum rise (Δh) under laminar wind conditions by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	0.9	0.9	0.8	0.8	--[n/a]	0.7	RVD 2.0 - Equation 3. Height from the top of the stack to the middle of the plume at its point of maximum rise under laminar wind conditions. $\Delta h = 1.32 \cdot R_V^{(1/3)} \cdot SG^{(1/3)} \cdot Fr^{(2/3)} \cdot D_{vent}$ RVD 2.0 - Equation 4. Vertical Densimetric Froude Number $Fr = V2 / (g \cdot D_{vent} \cdot (1 - \rho_a / \rho_2))^{(1/2)}$ RVD 2.0 - Equation 4a $R_V = V2 / u$
2	0.7	0.7	0.7	0.7	0.6	0.6	
3	0.6	0.6	0.6	Neutral	Neutral	Neutral	
4	--[n/a]	Neutral	Neutral	Neutral	Neutral	--[n/a]	
5	--[n/a]	Neutral	Neutral	Neutral	Neutral	--[n/a]	
8	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

Height from the top of the stack to the middle of the plume at its point of maximum rise (Δh) under quiescent atmospheric conditions (no wind)

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
0	1.6	1.6	1.6	1.6	1.6	1.6	RVD 2.0 - Equation 5. Height from the top of the stack to the middle of the plume at its point of maximum rise under quiescent atmospheric conditions (no wind) $\Delta h = 2.96 \cdot Fr \cdot D_{vent}$

Plume dilution ratio at maximum plume rise (D_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	2.3	2.3	2.4	2.4	--[n/a]	2.9	RVD 2.0 - Equation 6. Plume dilution ratio at maximum plume rise. $D_h = 5.67 \cdot 10^{(-2)} \cdot u \cdot D_{vent}^{(2)} / Q_m \cdot (\Delta h_{min} / D_{vent})^{(1.85)} \cdot (MW_{CO2} / T_a)$ Note: Basic code in RVD for TSCREEN uses a corrected equation, below: $D_h = 5.67 \cdot u \cdot D_{vent}^{(2)} / Q_m \cdot (\Delta h_{min} / D_{vent})^{(1.85)} \cdot (MW_{CO2} / T_a)$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	3.0	3.0	3.1	3.1	3.5	3.8	
3	3.5	3.5	3.6	Neutral	Neutral	Neutral	
4	--[n/a]	Neutral	Neutral	Neutral	Neutral	--[n/a]	
5	--[n/a]	Neutral	Neutral	Neutral	Neutral	--[n/a]	
8	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 04 (120-min release time, 115 ft Vent ht)

Plume-equivalent molecular weight at maximum plume rise (MW_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	35.443	35.443	35.350	35.199	--[n/a]	34.108	RVD 2.0 - Equation 7. Plume-equivalent molecular weight at maximum plume rise. $MW_h = (MW_{CO2} + 28.96 \cdot (D_h - 1)) / D_h$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	33.930	33.930	33.859	33.743	33.305	32.907	
3	33.215	33.215	33.154	Neutral	Neutral	Neutral	
4	--[n/a]	Neutral	Neutral	Neutral	Neutral	--[n/a]	
5	--[n/a]	Neutral	Neutral	Neutral	Neutral	--[n/a]	
8	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

Plume temperature at maximum plume rise (T_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	273.729	273.729	274.014	274.482	--[n/a]	277.972	RVD 2.0 - Equation 8. Plume temperature at maximum plume rise. $T_h = T_a - (MW_{CO2} / MW_h) \cdot (T_a - T_2) / D_h$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	278.563	278.563	278.801	279.192	280.689	282.085	
3	281.003	281.003	281.215	Neutral	Neutral	Neutral	
4	--[n/a]	Neutral	Neutral	Neutral	Neutral	--[n/a]	
5	--[n/a]	Neutral	Neutral	Neutral	Neutral	--[n/a]	
8	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

Fractional density ratio at maximum plume rise (δ) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	0.332	0.332	0.328	0.320	--[n/a]	0.263	RVD 2.0 - Equation 9. Fractional density ratio at maximum plume rise. $\delta = ((MW_h / 28.96) \cdot (T_a / T_2)) - 1$ Note: A calculated frational density ratio greater than 0.005 indicates that dense gas behavior dominates the subsequent plume transport and RVD is appropriate for plume touchdown and ground level concentration calculations. A calculated frational density ratio less than or equal to 0.005 indicates neutrally-buoyant plume behavior which should be addressed using an alternate model.
2	0.253	0.253	0.250	0.244	0.221	0.200	
3	0.216	0.216	0.213	Neutral	Neutral	Neutral	
4	--[n/a]	Neutral	Neutral	Neutral	Neutral	--[n/a]	
5	--[n/a]	Neutral	Neutral	Neutral	Neutral	--[n/a]	
8	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - Case 02, Scenario 04 (120-min release time, 115 ft Vent ht)

Step 3. Concentration Estimates at Plume Touchdown

Ambient concentration at plume touchdown (maximum ground-level concentration) (C_T) in units of µg / m^3 by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	9,919,725	9,919,725	9,587,831	9,058,406	--n/a	5,729,789	RVD 2.0 - Equation 10. Ambient concentration at plume touchdown (maximum ground-level concentration). $C_T = 6.0 \cdot 10^{(9)} \cdot Q_m / u \cdot ((2 \cdot \Delta h + H_S))^{(-2.0)}$ Note: Basic code in RVD for TSCREEN uses a different equation, below: $C_T = 5.1 \cdot 10^{(9)} \cdot Q_m \cdot ((2 \cdot \Delta h + HS))^{(-1.95)} / (u \cdot D_{vent}^{(0.05)})$ These values represents the 1-hour concentrations from a continuous emission source. If the emissions occur for less than 1 hour, or if the averaging period of concern is less than 1 hour, use the values calculated below in Step 4.
2	5,265,076	5,265,076	5,085,632	4,799,707	3,804,704	3,012,024	
3	3,615,934	3,615,934	3,491,549	Neutral	Neutral	Neutral	
4	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Ambient concentration at plume touchdown (maximum ground-level concentration) (C_T) in units of ppmV by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	5,512	5,512	5,327	5,033	--n/a	3,184	Conversion from µg/m^3 to ppmV These values represents the 1-hour concentrations from a continuous emission source. If the emissions occur for less than 1 hour, or if the averaging period of concern is less than 1 hour, use the values calculated below in Step 4.
2	2,925	2,925	2,826	2,667	2,114	1,674	
3	2,009	2,009	1,940	Neutral	Neutral	Neutral	
4	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Downwind distance to plume touchdown in units of meters (X_T) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	25	25	26	28	--n/a	58	RVD 2.0 - Equation 11. Downwind distance to plume touchdown. $X_T = D_{vent} \cdot Fr^{(2)} / R_V + 0.56 \cdot D_{vent} \cdot Fr_H / R_V^{(1/2)} \cdot C_1$ RVD 2.0 - Equation 12 $C_1 = ((\Delta h / D_{vent})^{(3)} \cdot ((2 + H_S / \Delta h)^{(3)} - 1))^{(1/2)}$ RVD 2.0 - Equation 13. Horizontal densimetric Froude number $Fr_H = u / (g \cdot D_{vent} \cdot (\rho_{air} / \rho_2 - 1))^{(1/2)}$ Note: Basic code in RVD for TSCREEN uses a corrected equation for Fr_H, below: $Fr_H = u * (((\rho_{air} / (\rho_2 - \rho_{air})) / (g \ D_{vent}))^{(1/2)}$
2	66	66	70	77	110	157	
3	119	119	125	Neutral	Neutral	Neutral	
4	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 04 (120-min release time, 115 ft Vent ht)

Step 4. Concentration Estimates for Release Times Less Than the Averaging Period or Averaging Periods Less Than 60 Minutes

User-Specified Averaging Time (t_a):	15	min

Calculated Release Duration (t_d):	120.1526	min

Note: See TSCREEN for release duration calculation.

Ambient concentration at plume touchdown (maximum ground-level concentration) including correction factors for user-specified averaging time and calculated release duration (C_{TF}) in units of ppmV by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	7,273	7,273	7,029	6,641	--n/a	4,201	RVD 2.0 - Equation 16. Correction factor if release duration is less than the averaging time. $C_{TF} = C \cdot (t_d / t_a)$
2	3,860	3,860	3,729	3,519	2,789	2,208	
3	2,651	2,651	2,560	Neutral	Neutral	Neutral	
4	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	RVD 2.0 - Equation 17. Correction factor if averaging time is less than 60 minutes. $C_{TF} = C \cdot (60 / t_a)^{(0.2)}$
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	where C_{TF} = the corrected touchdown concentration, C_T.
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Receptor	Receptor Dist from vent (m)	Recepter Elevation BELOW Vent (m)	Recepter Elevation ABOVE Ground (m)	1-min Average CO2 Conc. ppmv	15-min Average CO2 Conc. ppmv	60-min Average CO2 Conc. ppmv
Penthouse Roof	3	3.0	32.0	0	0	0
Penthouse Platform	5	8.5	26.5	0	0	0
Existing Bldg S. of Penthouse	28	19.0	16.0	0	0	0
Lower N. Stack Platform (Existing)	32	-11.0	46.0	7,049	4,101	3,108
Existing Bldg SW. of Penthouse	32	10.0	25.0	11,499	6,690	5,070
Lower S. Stack Platform (Existing)	114	-11.0	46.0	3,733	2,172	1,646
Nearest Sidewalk	42	35.0	0.0	0	0	0
Mark Twain Hall-Elevator Penthouse	120	2.0	33.0	5,414	3,150	2,387
Mark Twain Hall	120	10.0	25.0	5,074	2,952	2,237
Apprtmts W of Mark Twain Hall	140	15.0	20.0	3,156	1,836	1,391
Apprtmts S of Mark Twain Hall	210	10.0	25.0	2,592	1,508	1,143
Downtown Bldg 4	300	-5.0	40.0	1,626	946	717
Downtown Bldg 1	562	-5.0	40.0	717	417	316
Downtown Bldg 5	574	-4.0	39.0	697	406	308
Downtown Bldg 3	644	1.0	34.0	601	349	265
Downtown Bldg 2	800	-10.0	45.0	453	263	200
Downtown Bldg 6	885	-2.0	37.0	396	231	175
Peak Concentration on Ground:	134	35.0	0.0	1,347	784	594

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - Case 02, Scenario 05 (26.5 min release time, 140 ft Vent)

Note: The wind speeds at stack height elevation are based on a 43 meter stack (cell V35). The value of Hs in cell B19 can be adjusted to represent receptors at elevations above ground level, e.g., setting Hs to 3 meters indicates the receptor is 3 meters below the vent exit, or setting Hs to 35 meters indicates the receptor is on ground level. The actual stack height above ground can be adjusted in cell V35.

RVD Inputs

Parameter	Value	Units	Definition	Source // Reference
P_a	101,325	Pa	ambient pressure	standard atmospheric pressure at sea level
T_2	252.63	K	discharge temperatature = $T_2 = T_1 \cdot (1 - 0.85 \cdot ((\gamma - 1) / (\gamma + 1))$	See TSCREEN calculations
T_a	298.00	K	ambient temperature	See TSCREEN calculations
ρ_2	2.1230	kg / m3 @ T_2 & P*	discharge density = $\rho_2 = P_a \cdot MWCO2 / (R \cdot T_2)$	See TSCREEN calculations
ρ_{air}	1.1819	kg / m3	density of air = $\rho air = P_a \cdot MWair / (R \cdot T_a)$	See TSCREEN calculations
γ_2	1.3219	dimensionless @T_2 & P_2	$(C_P / C_V) \approx 1 / (1 - R / (C_P \cdot M))$ @ T_2	National Institute of Standards and Technology (NIST) data utilized instead.
Q_m	1.0881	kg / s	mass emission rate	See TSCREEN calculations
$V2_{sonic}$	248.98	m / s	V2sonic = $SQRT(\gamma_2 * P_a / \rho_2)$	--[n/a]
D_{vent}	10	inch	vent diameter	Echogen data
A_{vent}	0.0507	m^2	vent flow area	Echogen data; presumed circular vent
V2	10.1146	m / s	discharge velocity	--[n/a]
g	9.80665	m / s^2	acceleration due to gravity	--[n/a]
H_S	43.0	m	stack height	Echogen data
u_0 / u_{10}	0.06	dimensionless	friction velocity (m / s) to the wind speed at 10m (m / s)	RVD 2.0 model assumption for all Atmospheric Stability Classes
MW_{CO2}	44.01	kg / kg-mole	gas (contaminant) molecular weight (for contaminant mixtures, see TSCREEN Workbook Appedix B)	See TSCREEN calculations
t_d	26.5570	minutes	release duration = td = $Q / (Q_m \cdot 60)$	See TSCREEN calculations

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 05 (26.5 min release time, 140 ft Vent)

Step 1. Check for dominance of dense gas effects at release point.

Source Region (Rural or Urban)?: Rural

Atmospheric Stability Class	A	B	C	D	E	F	Source // Reference
Wind Profile Exponent (P)	0.07	0.07	0.10	0.15	0.35	0.55	Recommended Power-law exponents for Urban and Rural Wind Profiles, Table 6-2 http://www.webmet.com/met_monitoring/625.HTML

Wind Velocity at the Top of the Stack (u) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	1.107	1.107	1.157	1.245	--n/a	2.231	RVD 2.0 - Equation 2. Wind Velocity at the Top of the Stack $u = u_{10} \cdot (H_S / 10) \cdot P$
2	2.215	2.215	2.314	2.489	3.332	4.461	
3	3.322	3.322	3.471	3.734	4.998	6.692	
4	--n/a	4.430	4.628	4.978	6.665	--n/a	
5	--n/a	5.537	5.785	6.223	8.331	--n/a	
8	--n/a	--n/a	9.256	9.957	--n/a	--n/a	
10	--n/a	--n/a	11.570	12.446	--n/a	--n/a	
15	--n/a	--n/a	17.356	18.669	--n/a	--n/a	
20	--n/a	--n/a	23.141	24.891	--n/a	--n/a	

Stack Exit Richardson Number (Ri_0) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	3,952	3,952	3,783	3,517	--n/a	1,962	RVD 2.0 - Equation 1. Stack Exit Richardson Number $Ri_0 = (g (\rho_2 / \rho_a - 1) \cdot Q_m) / (u \cdot D_{vent} \cdot \rho_2 \cdot u_{10}^{(2)} (u_0 / u_{10})^{(2)})$
2	494	494	473	440	328	245	
3	146	146	140	130	97	73	
4	--n/a	62	59	55	41	--n/a	
5	--n/a	32	30	28	21	--n/a	
8	--n/a	--n/a	7	7	--n/a	--n/a	
10	--n/a	--n/a	4	4	--n/a	--n/a	
15	--n/a	--n/a	1	1	--n/a	--n/a	
20	--n/a	--n/a	0	0	--n/a	--n/a	

Plume Buoyancy at Stack Exit by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	Dense	Dense	Dense	Dense	--n/a	Dense	RVD 2.0 - Plume Buoyancy at Stack Exit If Ri_0 > 30 then plume is considered to behave as a dense gas at the release point Note: Neutral conditions are evaluated using alternate model.
2	Dense	Dense	Dense	Dense	Dense	Dense	
3	Dense	Dense	Dense	Dense	Dense	Dense	
4	--n/a	Dense	Dense	Dense	Dense	--n/a	
5	--n/a	Dense	Dense	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 05 (26.5 min release time, 140 ft Vent)

Step 2. Assess atmospheric dilution of the plume resulting from entrainment effects during the rise of plume to its maximum height.

Height from the top of the stack to the middle of the plume at its point of maximum rise (Δh) under laminar wind conditions by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	3.9	3.9	3.8	3.7	--[n/a]	3.1	RVD 2.0 - Equation 3. Height from the top of the stack to the middle of the plume at its point of maximum rise under laminar wind conditions. $\Delta h = 1.32 \cdot R_V^{(1/3)} \cdot SG^{(1/3)} \cdot Fr^{(2/3)} \cdot D_{vent}$ RVD 2.0 - Equation 4. Vertical Densimetric Froude Number $Fr = V2 / (g \cdot D_{vent} \cdot (1 - \rho_a / \rho_2))^{(1/2)}$ RVD 2.0 - Equation 4a $R_V = V2 / u$
2	3.1	3.1	3.0	2.9	2.7	2.4	
3	2.7	2.7	2.6	2.6	2.3	2.1	
4	--[n/a]	2.4	2.4	2.3	2.1	--[n/a]	
5	--[n/a]	2.3	2.2	Neutral	Neutral	--[n/a]	
8	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

Height from the top of the stack to the middle of the plume at its point of maximum rise (Δh) under quiescent atmospheric conditions (no wind)

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
0	7.2	7.2	7.2	7.2	7.2	7.2	RVD 2.0 - Equation 5. Height from the top of the stack to the middle of the plume at its point of maximum rise under quiescent atmospheric conditions (no wind) $\Delta h = 2.96 \cdot Fr \cdot D_{vent}$

Plume dilution ratio at maximum plume rise (D_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	8.4	8.4	8.6	8.8	--[n/a]	11.0	RVD 2.0 - Equation 6. Plume dilution ratio at maximum plume rise. $D_h = 5.67 \cdot 10^{(-2)} \cdot u \cdot D_{vent}^{(2)} / Q_m \cdot (\Delta h_{min} / D_{vent})^{(1.85)} \cdot (MW_{CO2} / T_a)$ Note: Basic code in RVD for TSCREEN uses a corrected equation, below: $D_h = 5.67 \cdot u \cdot D_{vent}^{(2)} / Q_m \cdot (\Delta h_{min} / D_{vent})^{(1.85)} \cdot (MW_{CO2} / T_a)$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	11.0	11.0	11.2	11.5	12.8	14.4	
3	12.8	12.8	13.0	13.4	15.0	16.8	
4	--[n/a]	14.3	14.6	15.0	16.8	--[n/a]	
5	--[n/a]	15.6	15.9	Neutral	Neutral	--[n/a]	
8	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 05 (26.5 min release time, 140 ft Vent)

Plume-equivalent molecular weight at maximum plume rise (MW_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	30.747	30.747	30.717	30.669	--n/a	30.326	RVD 2.0 - Equation 7. Plume-equivalent molecular weight at maximum plume rise. $MW_h = (MW_{CO2} + 28.96 \cdot (D_h - 1)) / D_h$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	30.330	30.330	30.307	30.270	30.132	30.008	
3	30.133	30.133	30.113	30.082	29.963	29.857	
4	--n/a	30.010	29.993	29.965	29.858	--n/a	
5	--n/a	29.924	29.908	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Plume temperature at maximum plume rise (T_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	290.288	290.288	290.409	290.606	--n/a	292.021	RVD 2.0 - Equation 8. Plume temperature at maximum plume rise. $T_h = T_a - (MW_{CO2} / MW_h) \cdot (T_a - T_2) / D_h$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	292.006	292.006	292.101	292.257	292.841	293.368	
3	292.835	292.835	292.918	293.053	293.559	294.014	
4	--n/a	293.356	293.430	293.552	294.008	--n/a	
5	--n/a	293.724	293.793	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Fractional density ratio at maximum plume rise (δ) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	0.090	0.090	0.088	0.086	--n/a	0.069	RVD 2.0 - Equation 9. Fractional density ratio at maximum plume rise. $\delta = ((MW_h / 28.96) \cdot (T_a / T_2)) - 1$ Note: A calculated frational density ratio greater than 0.005 indicates that dense gas behavior dominates the subsequent plume transport and RVD is appropriate for plume touchdown and ground level concentration calculations. A calculated frational density ratio less than or equal to 0.005 indicates neutrally-buoyant plume behavior which should be addressed using an alternate model.
2	0.069	0.069	0.068	0.066	0.059	0.053	
3	0.059	0.059	0.058	0.056	0.050	0.045	
4	--n/a	0.053	0.052	0.050	0.045	--n/a	
5	--n/a	0.048	0.048	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 05 (26.5 min release time, 140 ft Vent)

Step 3. Concentration Estimates at Plume Touchdown

Ambient concentration at plume touchdown (maximum ground-level concentration) (C_T) in units of µg / m^3 by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	2,539,318	2,539,318	2,441,067	2,285,420	--n/a	1,342,412	RVD 2.0 - Equation 10. Ambient concentration at plume touchdown (maximum ground-level concentration). $C_T = 6.0 \cdot 10^{(9)} \cdot Q_m / u \cdot ((2 \cdot \Delta h + H_S))^{(-2.0)}$ Note: Basic code in RVD for TSCREEN uses a different equation, below: $C_T = 5.1 \cdot 10^{(9)} \cdot Q_m \cdot ((2 \cdot \Delta h + HS))^{(-1.95)} / (u \cdot D_{vent}{}^{(0.05)})$ These values represents the 1-hour concentrations from a continuous emission source. If the emissions occur for less than 1 hour, or if the averaging period of concern is less than 1 hour, use the values calculated below in Step 4.
2	1,351,062	1,351,062	1,297,778	1,213,479	926,488	706,091	
3	929,026	929,026	892,033	833,548	634,833	482,705	
4	--n/a	710,715	682,239	637,240	484,545	--n/a	
5	--n/a	576,725	553,515	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Ambient concentration at plume touchdown (maximum ground-level concentration) (C_T) in units of ppmV by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	1,411	1,411	1,356	1,270	--n/a	746	Conversion from µg/m^3 to ppmV These values represents the 1-hour concentrations from a continuous emission source. If the emissions occur for less than 1 hour, or if the averaging period of concern is less than 1 hour, use the values calculated below in Step 4.
2	751	751	721	674	515	392	
3	516	516	496	463	353	268	
4	--n/a	395	379	354	269	--n/a	
5	--n/a	320	308	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Downwind distance to plume touchdown in units of meters (X_T) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	107	107	114	126	--n/a	290	RVD 2.0 - Equation 11. Downwind distance to plume touchdown. $X_T = D_{vent} \cdot Fr^{(2)} / R_V + 0.56 \cdot D_{vent} \cdot Fr_H / R_V{}^{(1/2)} \cdot C_1$ RVD 2.0 - Equation 12 $C_1 = ((\Delta h / D_{vent})^{(3)} \cdot ((2 + H_S / \Delta h)^{(3)} - 1))^{(1/2)}$ RVD 2.0 - Equation 13. Horizontal densimetric Froude number $Fr_H = u / (g \cdot D_{vent} \cdot (\rho_{air} / \rho_2 - 1))^{(1/2)}$ Note: Basic code in RVD for TSCREEN uses a corrected equation for Fr_H, below: $Fr_H = u * (((\rho_{air} / (\rho_2 - \rho_{air})) / (g \ D_{vent}))^{(1/2)}$
2	287	287	305	339	515	784	
3	513	513	546	606	924	1,409	
4	--n/a	776	827	918	1,401	--n/a	
5	--n/a	1,071	1,141	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 05 (26.5 min release time, 140 ft Vent)

Step 4. Concentration Estimates for Release Times Less Than the Averaging Period or Averaging Periods Less Than 60 Minutes

User-Specified Averaging Time (t_a):	15	min

Calculated Release Duration (t_d):	26.5570	min

Note: See TSCREEN for release duration calculation.

Ambient concentration at plume touchdown (maximum ground-level concentration) including correction factors for user-specified averaging time and calculated release duration (C_{TF}) in units of ppmV by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	1,862	1,862	1,790	1,676	--n/a	984	RVD 2.0 - Equation 16. Correction factor if release duration is less than the averaging time. $C_{TF} = C \cdot (t_d / t_a)$
2	991	991	951	890	679	518	
3	681	681	654	611	465	354	
4	--n/a	521	500	467	355	--n/a	
5	--n/a	423	406	Neutral	Neutral	--n/a	RVD 2.0 - Equation 17. Correction factor if averaging time is less than 60 minutes. $C_{TF} = C \cdot (60 / t_a)^{(0.2)}$
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	where C_{TF} = the corrected touchdown concentration, C_T.
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Receptor	Receptor Dist from vent (m)	Recepter Elevation BELOW Vent (m)	Recepter Elevation ABOVE Ground (m)	1-min Average CO2 Conc. ppmv	15-min Average CO2 Conc. ppmv	60-min Average CO2 Conc. ppmv
Penthouse Roof	3	11.0	32.0	0	0	0
Penthouse Platform	5	16.5	26.5	0	0	0
Existing Bldg S. of Penthouse	28	27.0	16.0	0	0	0
Lower N. Stack Platform (Existing)	32	-3.0	46.0	43,019	25,029	8,396
Existing Bldg SW. of Penthouse	32	18.0	25.0	0	0	0
Lower S. Stack Platform (Existing)	114	-3.0	46.0	18,838	10,960	3,676
Nearest Sidewalk	42	43.0	0.0	0	0	0
Mark Twain Hall-Elevator Penthouse	120	10.0	33.0	10,433	6,070	2,036
Mark Twain Hall	120	18.0	25.0	6,457	3,757	1,260
Apprtmts W of Mark Twain Hall	140	23.0	20.0	4,641	2,700	906
Apprtmts S of Mark Twain Hall	210	18.0	25.0	4,783	2,783	934
Downtown Bldg 4	300	3.0	40.0	4,795	2,790	936
Downtown Bldg 1	562	3.0	40.0	2,052	1,194	401
Downtown Bldg 5	574	4.0	39.0	1,995	1,161	389
Downtown Bldg 3	644	9.0	34.0	1,707	993	333
Downtown Bldg 2	800	-2.0	45.0	1,278	744	249
Downtown Bldg 6	885	6.0	37.0	1,119	651	218
Peak Concentration on Ground:	107	43.0	0.0	3,200	1,862	624

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - Case 02, Scenario 06 (26.5 min release time, 167 ft Vent)

Note: The wind speeds at stack height elevation are based on a 51 meter stack (cell V35). The value of Hs in cell B19 can be adjusted to represent receptors at elevations above ground level, e.g., setting Hs to 3 meters indicates the receptor is 3 meters below the vent exit, or setting Hs to 51 meters indicates the receptor is on ground level. The actual stack height above ground can be adjusted in cell V35.

RVD Inputs

Parameter	Value	Units	Definition	Source // Reference
P_a	101,325	Pa	ambient pressure	standard atmospheric pressure at sea level
T_2	252.63	K	discharge temperatature = $T_2 = T_1 \cdot (1 - 0.85 \cdot ((\gamma - 1) / (\gamma + 1))$	See TSCREEN calculations
T_a	298.00	K	ambient temperature	See TSCREEN calculations
ρ_2	2.1230	kg / m3 @ T_2 & P*	discharge density = $\rho_2 = P_a \cdot MWCO2 / (R \cdot T_2)$	See TSCREEN calculations
ρ_{air}	1.1819	kg / m3	density of air = ρair = $P_a \cdot MWair / (R \cdot T_a)$	See TSCREEN calculations
γ_2	1.3219	dimensionless @T_2 & P_2	$(C_P / C_V) \approx 1 / (1 - R / (C_P \cdot M))$ @ T_2	National Institute of Standards and Technology (NIST) data utilized instead.
Q_m	1.0881	kg / s	mass emission rate	See TSCREEN calculations
$V2_{sonic}$	248.98	m / s	V2sonic = SQRT(γ_2 * P_a / ρ_2)	--[n/a]
D_{vent}	10	inch	vent diameter	Echogen data
A_{vent}	0.0507	m^2	vent flow area	Echogen data; presumed circular vent
V2	10.1146	m / s	discharge velocity	--[n/a]
g	9.80665	m / s^2	acceleration due to gravity	--[n/a]
H_S	51.0	m	stack height	Echogen data
u_0 / u_{10}	0.06	dimensionless	friction velocity (m / s) to the wind speed at 10m (m / s)	RVD 2.0 model assumption for all Atmospheric Stability Classes
MW_{CO2}	44.01	kg / kg-mole	gas (contaminant) molecular weight (for contaminant mixtures, see TSCREEN Workbook Appedix B)	See TSCREEN calculations
t_d	26.5570	minutes	release duration = td = Q / ($Q_m \cdot 60$)	See TSCREEN calculations

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 06 (26.5 min release time, 167 ft Vent)

Step 1. Check for dominance of dense gas effects at release point.

Source Region (Rural or Urban)?: Rural

Atmospheric Stability Class	A	B	C	D	E	F	Source // Reference
Wind Profile Exponent (P)	0.07	0.07	0.10	0.15	0.35	0.55	Recommended Power-law exponents for Urban and Rural Wind Profiles, Table 6-2 http://www.webmet.com/met_monitoring/625.HTML

Wind Velocity at the Top of the Stack (u) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	1.121	1.121	1.177	1.277	--n/a	2.450	RVD 2.0 - Equation 2. Wind Velocity at the Top of the Stack $u = u_{10} \cdot (H_S / 10) \cdot P$
2	2.242	2.242	2.354	2.554	3.537	4.900	
3	3.362	3.362	3.531	3.831	5.306	7.350	
4	--n/a	4.483	4.708	5.107	7.075	--n/a	
5	--n/a	5.604	5.885	6.384	8.843	--n/a	
8	--n/a	--n/a	9.416	10.215	--n/a	--n/a	
10	--n/a	--n/a	11.769	12.768	--n/a	--n/a	
15	--n/a	--n/a	17.654	19.153	--n/a	--n/a	
20	--n/a	--n/a	23.539	25.537	--n/a	--n/a	

Stack Exit Richardson Number (Ri_0) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	3,905	3,905	3,719	3,428	--n/a	1,787	RVD 2.0 - Equation 1. Stack Exit Richardson Number $Ri_0 = (g (\rho_2 / \rho_a - 1) \cdot Q_m) / (u \cdot D_{vent} \cdot \rho_2 \cdot u_{10}^{(2)} (u_0 / u_{10})^{(2)})$
2	488	488	465	429	309	223	
3	145	145	138	127	92	66	
4	--n/a	61	58	54	39	--n/a	
5	--n/a	31	30	27	20	--n/a	
8	--n/a	--n/a	7	7	--n/a	--n/a	
10	--n/a	--n/a	4	3	--n/a	--n/a	
15	--n/a	--n/a	1	1	--n/a	--n/a	
20	--n/a	--n/a	0	0	--n/a	--n/a	

Plume Buoyancy at Stack Exit by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	Dense	Dense	Dense	Dense	--n/a	Dense	RVD 2.0 - Plume Buoyancy at Stack Exit If Ri_0 > 30 then plume is considered to behave as a dense gas at the release point Note: Neutral conditions are evaluated using alternate model.
2	Dense	Dense	Dense	Dense	Dense	Dense	
3	Dense	Dense	Dense	Dense	Dense	Dense	
4	--n/a	Dense	Dense	Dense	Dense	--n/a	
5	--n/a	Dense	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - Case 02, Scenario 06 (26.5 min release time, 167 ft Vent)

Step 2. Assess atmospheric dilution of the plume resulting from entrainment effects during the rise of plume to its maximum height.

Height from the top of the stack to the middle of the plume at its point of maximum rise (Δh) under laminar wind conditions by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	3.8	3.8	3.8	3.7	--[n/a]	3.0	RVD 2.0 - Equation 3. Height from the top of the stack to the middle of the plume at its point of maximum rise under laminar wind conditions. $\Delta h = 1.32 \cdot R_V^{(1/3)} \cdot SG^{(1/3)} \cdot Fr^{(2/3)} \cdot D_{vent}$ RVD 2.0 - Equation 4. Vertical Densimetric Froude Number $Fr = V2 / (g \cdot D_{vent} \cdot (1 - \rho_a / \rho_2))^{(1/2)}$ RVD 2.0 - Equation 4a $R_V = V2 / u$
2	3.0	3.0	3.0	2.9	2.6	2.3	
3	2.7	2.7	2.6	2.5	2.3	2.1	
4	--[n/a]	2.4	2.4	2.3	2.1	--[n/a]	
5	--[n/a]	2.2	Neutral	Neutral	Neutral	--[n/a]	
8	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

Height from the top of the stack to the middle of the plume at its point of maximum rise (Δh) under quiescent atmospheric conditions (no wind)

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
0	7.2	7.2	7.2	7.2	7.2	7.2	RVD 2.0 - Equation 5. Height from the top of the stack to the middle of the plume at its point of maximum rise under quiescent atmospheric conditions (no wind) $\Delta h = 2.96 \cdot Fr \cdot D_{vent}$

Plume dilution ratio at maximum plume rise (D_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	8.5	8.5	8.6	8.9	--[n/a]	11.4	RVD 2.0 - Equation 6. Plume dilution ratio at maximum plume rise. $D_h = 5.67 \cdot 10^{(-2)} \cdot u \cdot D_{vent}^{(2)} / Q_m \cdot (\Delta h_{min} / D_{vent})^{(1.85)} \cdot (MW_{CO2} / T_a)$ Note: Basic code in RVD for TSCREEN uses a corrected equation, below: $D_h = 5.67 \cdot u \cdot D_{vent}^{(2)} / Q_m \cdot (\Delta h_{min} / D_{vent})^{(1.85)} \cdot (MW_{CO2} / T_a)$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	11.0	11.0	11.2	11.6	13.1	14.9	
3	12.9	12.9	13.1	13.6	15.4	17.4	
4	--[n/a]	14.4	14.7	15.1	17.1	--[n/a]	
5	--[n/a]	15.7	Neutral	Neutral	Neutral	--[n/a]	
8	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 06 (26.5 min release time, 167 ft Vent)

Plume-equivalent molecular weight at maximum plume rise (MW_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	30.739	30.739	30.706	30.652	--n/a	30.278	RVD 2.0 - Equation 7. Plume-equivalent molecular weight at maximum plume rise. $MW_h = (MW_{CO2} + 28.96 \cdot (D_h - 1)) / D_h$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	30.324	30.324	30.299	30.257	30.105	29.971	
3	30.128	30.128	30.106	30.071	29.940	29.825	
4	--n/a	30.006	29.986	29.955	29.838	--n/a	
5	--n/a	29.920	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Plume temperature at maximum plume rise (T_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	290.321	290.321	290.455	290.674	--n/a	292.223	RVD 2.0 - Equation 8. Plume temperature at maximum plume rise. $T_h = T_a - (MW_{CO2} / MW_h) \cdot (T_a - T_2) / D_h$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	292.032	292.032	292.138	292.310	292.953	293.526	
3	292.858	292.858	292.950	293.099	293.656	294.151	
4	--n/a	293.376	293.459	293.594	294.096	--n/a	
5	--n/a	293.743	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Fractional density ratio at maximum plume rise (δ) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	0.090	0.090	0.088	0.085	--n/a	0.066	RVD 2.0 - Equation 9. Fractional density ratio at maximum plume rise. $\delta = ((MW_h / 28.96) \cdot (T_a / T_2)) - 1$ Note: A calculated frational density ratio greater than 0.005 indicates that dense gas behavior dominates the subsequent plume transport and RVD is appropriate for plume touchdown and ground level concentration calculations. A calculated frational density ratio less than or equal to 0.005 indicates neutrally-buoyant plume behavior which should be addressed using an alternate model.
2	0.068	0.068	0.067	0.065	0.057	0.051	
3	0.059	0.059	0.057	0.056	0.049	0.043	
4	--n/a	0.052	0.051	0.050	0.044	--n/a	
5	--n/a	0.048	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 06 (26.5 min release time, 167 ft Vent)

Step 3. Concentration Estimates at Plume Touchdown

Ambient concentration at plume touchdown (maximum ground-level concentration) (C_T) in units of µg / m^3 by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	1,887,625	1,887,625	1,805,018	1,675,079	--n/a	916,439	RVD 2.0 - Equation 10. Ambient concentration at plume touchdown (maximum ground-level concentration). $C_T = 6.0 \cdot 10^{(9)} \cdot Q_m / u \cdot ((2 \cdot \Delta h + H_S))^{(-2.0)}$ Note: Basic code in RVD for TSCREEN uses a different equation, below: $C_T = 5.1 \cdot 10^{(9)} \cdot Q_m \cdot ((2 \cdot \Delta h + HS))^{(-1.95)} / (u \cdot D_{vent}^{(0.05)})$ These values represents the 1-hour concentrations from a continuous emission source. If the emissions occur for less than 1 hour, or if the averaging period of concern is less than 1 hour, use the values calculated below in Step 4.
2	995,552	995,552	951,259	881,679	649,822	478,007	
3	681,521	681,521	650,949	602,954	443,332	325,401	
4	--n/a	519,868	496,423	459,634	337,433	--n/a	
5	--n/a	420,977	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Ambient concentration at plume touchdown (maximum ground-level concentration) (C_T) in units of ppmV by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	1,049	1,049	1,003	931	--n/a	509	Conversion from µg/m^3 to ppmV These values represents the 1-hour concentrations from a continuous emission source. If the emissions occur for less than 1 hour, or if the averaging period of concern is less than 1 hour, use the values calculated below in Step 4.
2	553	553	529	490	361	266	
3	379	379	362	335	246	181	
4	--n/a	289	276	255	187	--n/a	
5	--n/a	234	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Downwind distance to plume touchdown in units of meters (X_T) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	135	135	145	162	--n/a	414	RVD 2.0 - Equation 11. Downwind distance to plume touchdown. $X_T = D_{vent} \cdot Fr^{(2)} / R_V + 0.56 \cdot D_{vent} \cdot Fr_H / R_V^{(1/2)} \cdot C_1$ RVD 2.0 - Equation 12 $C_1 = ((\Delta h / D_{vent})^{(3)} \cdot ((2 + H_S / \Delta h)^{(3)} - 1))^{(1/2)}$ RVD 2.0 - Equation 13. Horizontal densimetric Froude number $Fr_H = u / (g \cdot D_{vent} \cdot (\rho_{air} / \rho_2 - 1))^{(1/2)}$ Note: Basic code in RVD for TSCREEN uses a corrected equation for Fr_H, below: $Fr_H = u * (((\rho_{air} / (\rho_2 - \rho_{air})) / (g \ D_{vent}))^{(1/2)}$
2	364	364	391	440	704	1,130	
3	654	654	702	790	1,268	2,039	
4	--n/a	993	1,066	1,200	1,929	--n/a	
5	--n/a	1,373	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 06 (26.5 min release time, 167 ft Vent)

Step 4. Concentration Estimates for Release Times Less Than the Averaging Period or Averaging Periods Less Than 60 Minutes

User-Specified Averaging Time (t_a):	15	min

Calculated Release Duration (t_d):	26.5570	min

Note: See TSCREEN for release duration calculation.

Ambient concentration at plume touchdown (maximum ground-level concentration) including correction factors for user-specified averaging time and calculated release duration (C_F) in units of ppmV by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	1,384	1,384	1,323	1,228	--n/a	672	RVD 2.0 - Equation 16. Correction factor if release duration is less than the averaging time. $C_{TF} = C \cdot (t_d / t_a)$
2	730	730	697	646	476	350	
3	500	500	477	442	325	239	
4	--n/a	381	364	337	247	--n/a	
5	--n/a	309	Neutral	Neutral	Neutral	--n/a	RVD 2.0 - Equation 17. Correction factor if averaging time is less than 60 minutes. $C_{TF} = C \cdot (60 / t_a)^{(0.2)}$
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	where C_{TF} = the corrected touchdown concentration, C_T.
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Receptor	Receptor Dist from vent (m)	Recepter Elevation BELOW Vent (m)	Recepter Elevation ABOVE Ground (m)	1-min Average CO2 Conc. ppmv	15-min Average CO2 Conc. ppmv	60-min Average CO2 Conc. ppmv
Penthouse Roof	3	19.0	32.0	0	0	0
Penthouse Platform	5	24.5	26.5	0	0	0
Existing Bldg S. of Penthouse	28	35.0	16.0	0	0	0
Lower N. Stack Platform (Existing)	32	5.0	46.0	34,571	20,114	6,747
Existing Bldg SW. of Penthouse	32	26.0	25.0	0	0	0
Lower S. Stack Platform (Existing)	114	5.0	46.0	16,567	9,639	3,233
Nearest Sidewalk	42	51.0	0.0	0	0	0
Mark Twain Hall-Elevator Penthouse	120	18.0	33.0	6,335	3,686	1,236
Mark Twain Hall	120	26.0	25.0	5,065	2,947	988
Apprtmts W of Mark Twain Hall	140	31.0	20.0	0		0
Apprtmts S of Mark Twain Hall	210	26.0	25.0	0		0
Downtown Bldg 4	300	11.0	40.0	0		0
Downtown Bldg 1	562	11.0	40.0	0		0
Downtown Bldg 5	574	12.0	39.0	0		0
Downtown Bldg 3	644	17.0	34.0	0		0
Downtown Bldg 2	800	6.0	45.0	0		0
Downtown Bldg 6	885	14.0	37.0	0		0
Peak Concentration on Ground:	131	51.0	0.0	2,379	1,384	464

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - Case 02, Scenario 07, 140 ft Vent Ht, and 1250 scfm Vent Fan

Note: The wind speeds at stack height elevation are based on a 43 meter stack (cell V35). The value of Hs in cell B19 can be adjusted to represent receptors at elevations above ground level, e.g., setting Hs to 3 meters indicates the receptor is 3 meters below the vent exit, or setting Hs to 43 meters indicates the receptor is on ground level. The actual stack height above ground can be adjusted in cell V35.

RVD Inputs

Parameter	Value	Units	Definition	Source // Reference
P_a	101,325	Pa	ambient pressure	standard atmospheric pressure at sea level
T_2	272.89	K	discharge temperatature = $T_2 = T_1 \cdot (1 - 0.85 \cdot ((\gamma - 1) / (\gamma + 1))$	See TSCREEN calculations
T_a	298.00	K	ambient temperature	See TSCREEN calculations
ρ_2	1.6266	kg / m3 @ T_2 & P*	discharge density = $\rho_2 = P_a \cdot MWCO2 / (R \cdot T_2)$	See TSCREEN calculations
ρ_{air}	1.1819	kg / m3	density of air = ρair = $P_a \cdot MWair / (R \cdot T_a)$	See TSCREEN calculations
γ_2	1.3219	dimensionless @T_2 & P_2	$(C_P / C_V) \approx 1 / (1 - R / (C_P \cdot M))$ @ T_2	National Institute of Standards and Technology (NIST) data utilized instead.
Q_m	1.0881	kg / s	mass emission rate	See TSCREEN calculations
$V2_{sonic}$	248.98	m / s	V2sonic = SQRT(γ_2 * P_a / ρ_2)	--[n/a]
D_{vent}	10	inch	vent diameter	Echogen data
A_{vent}	0.0507	m^2	vent flow area	Echogen data; presumed circular vent
V2	21.9427	m / s	discharge velocity	--[n/a]
g	9.80665	m / s^2	acceleration due to gravity	--[n/a]
H_S	43.00	m	stack height	Echogen data
u_0 / u_{10}	0.06	dimensionless	friction velocity (m / s) to the wind speed at 10m (m / s)	RVD 2.0 model assumption for all Atmospheric Stability Classes
MW_{CO2}	44.01	kg / kg-mole	gas (contaminant) molecular weight (for contaminant mixtures, see TSCREEN Workbook Appedix B)	See TSCREEN calculations
t_d	26.5570	minutes	release duration = td = Q / ($Q_m \cdot 60$)	See TSCREEN calculations

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - Case 02, Scenario 07, 140 ft Vent Ht, and 1250 scfm Vent Fan

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 07, 140 ft Vent Ht, and 1250 scfm Vent Fan

Step 1. Check for dominance of dense gas effects at release point.

Source Region (Rural or Urban)?: Rural

Atmospheric Stability Class	A	B	C	D	E	F	Source // Reference
Wind Profile Exponent (P)	0.07	0.07	0.10	0.15	0.35	0.55	Recommended Power-law exponents for Urban and Rural Wind Profiles, Table 6-2 http://www.webmet.com/met_monitoring/625.HTML

Wind Velocity at the Top of the Stack (u) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	1.107	1.107	1.157	1.245	--n/a	2.231	RVD 2.0 - Equation 2. Wind Velocity at the Top of the Stack $u = u_{10} \cdot (H_S / 10) \cdot P$
2	2.215	2.215	2.314	2.489	3.332	4.461	
3	3.322	3.322	3.471	3.734	4.998	6.692	
4	--n/a	4.430	4.628	4.978	6.665	--n/a	
5	--n/a	5.537	5.785	6.223	8.331	--n/a	
8	--n/a	--n/a	9.256	9.957	--n/a	--n/a	
10	--n/a	--n/a	11.570	12.446	--n/a	--n/a	
15	--n/a	--n/a	17.356	18.669	--n/a	--n/a	
20	--n/a	--n/a	23.141	24.891	--n/a	--n/a	

Stack Exit Richardson Number (Ri_0) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	2,438	2,438	2,333	2,169	--n/a	1,210	RVD 2.0 - Equation 1. Stack Exit Richardson Number $Ri_0 = (g (\rho_2 / \rho_a - 1) \cdot Q_m) / (u \cdot D_{vent} \cdot \rho_2 \cdot u_{10}^{(2)} (u_0 / u_{10})^{(2)})$
2	305	305	292	271	203	151	
3	90	90	86	80	60	45	
4	--n/a	38	36	34	25	--n/a	
5	--n/a	20	19	17	13	--n/a	
8	--n/a	--n/a	5	4	--n/a	--n/a	
10	--n/a	--n/a	2	2	--n/a	--n/a	
15	--n/a	--n/a	1	1	--n/a	--n/a	
20	--n/a	--n/a	0	0	--n/a	--n/a	

Plume Buoyancy at Stack Exit by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	Dense	Dense	Dense	Dense	--n/a	Dense	RVD 2.0 - Plume Buoyancy at Stack Exit If Ri_0 > 30 then plume is considered to behave as a dense gas at the release point Note: Neutral conditions are evaluated using alternate model.
2	Dense	Dense	Dense	Dense	Dense	Dense	
3	Dense	Dense	Dense	Dense	Dense	Dense	
4	--n/a	Dense	Dense	Dense	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 07, 140 ft Vent Ht, and 1250 scfm Vent Fan

Step 2. Assess atmospheric dilution of the plume resulting from entrainment effects during the rise of plume to its maximum height.

Height from the top of the stack to the middle of the plume at its point of maximum rise (Δh) under laminar wind conditions by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	9.0	9.0	8.9	8.6	--n/a	7.1	RVD 2.0 - Equation 3. Height from the top of the stack to the middle of the plume at its point of maximum rise under laminar wind conditions. $\Delta h = 1.32 \cdot R_V^{(1/3)} \cdot SG^{(1/3)} \cdot Fr^{(2/3)} \cdot D_{vent}$ RVD 2.0 - Equation 4. Vertical Densimetric Froude Number $Fr = V2 / (g \cdot D_{vent} \cdot (1 - \rho_a / \rho_2))^{(1/2)}$ RVD 2.0 - Equation 4a $R_V = V2 / u$
2	7.1	7.1	7.0	6.9	6.2	5.7	
3	6.2	6.2	6.1	6.0	5.4	4.9	
4	--n/a	5.7	5.6	5.4	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Height from the top of the stack to the middle of the plume at its point of maximum rise (Δh) under quiescent atmospheric conditions (no wind)

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
0	20.0	20.0	20.0	20.0	20.0	20.0	RVD 2.0 - Equation 5. Height from the top of the stack to the middle of the plume at its point of maximum rise under quiescent atmospheric conditions (no wind) $\Delta h = 2.96 \cdot Fr \cdot D_{vent}$

Plume dilution ratio at maximum plume rise (D_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	40.3	40.3	41.0	42.2	--n/a	52.8	RVD 2.0 - Equation 6. Plume dilution ratio at maximum plume rise. $D_h = 5.67 \cdot 10^{(-2)} \cdot u \cdot D_{vent}^{(2)} / Q_m \cdot (\Delta h_{min} / D_{vent})^{(1.85)} \cdot (MW_{CO2} / T_a)$ Note: Basic code in RVD for TSCREEN uses a corrected equation, below: $D_h = 5.67 \cdot u \cdot D_{vent}^{(2)} / Q_m \cdot (\Delta h_{min} / D_{vent})^{(1.85)} \cdot (MW_{CO2} / T_a)$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	52.6	52.6	53.5	55.0	61.5	68.8	
3	61.5	61.5	62.5	64.3	71.9	80.4	
4	--n/a	68.6	69.8	71.8	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 07, 140 ft Vent Ht, and 1250 scfm Vent Fan

Plume-equivalent molecular weight at maximum plume rise (MW_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	29.333	29.333	29.327	29.317	--n/a	29.245	RVD 2.0 - Equation 7. Plume-equivalent molecular weight at maximum plume rise. $MW_h = (MW_{CO2} + 28.96 \cdot (D_h - 1)) / D_h$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	29.246	29.246	29.241	29.234	29.205	29.179	
3	29.205	29.205	29.201	29.194	29.169	29.147	
4	--n/a	29.179	29.176	29.170	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Plume temperature at maximum plume rise (T_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	297.066	297.066	297.081	297.106	--n/a	297.284	RVD 2.0 - Equation 8. Plume temperature at maximum plume rise. $T_h = T_a - (MW_{CO2} / MW_h) \cdot (T_a - T_2) / D_h$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	297.282	297.282	297.294	297.313	297.385	297.450	
3	297.384	297.384	297.394	297.411	297.473	297.528	
4	--n/a	297.448	297.457	297.472	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Fractional density ratio at maximum plume rise (δ) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	0.016	0.016	0.016	0.015	--n/a	0.012	RVD 2.0 - Equation 9. Fractional density ratio at maximum plume rise. $δ = ((MW_h / 28.96) \cdot (T_a / T_2)) - 1$ Note: A calculated frational density ratio greater than 0.005 indicates that dense gas behavior dominates the subsequent plume transport and RVD is appropriate for plume touchdown and ground level concentration calculations. A calculated frational density ratio less than or equal to 0.005 indicates neutrally-buoyant plume behavior which should be addressed using an alternate model.
2	0.012	0.012	0.012	0.012	0.011	0.009	
3	0.011	0.011	0.010	0.010	0.009	0.008	
4	--n/a	0.009	0.009	0.009	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 07, 140 ft Vent Ht, and 1250 scfm Vent Fan

Step 3. Concentration Estimates at Plume Touchdown

Ambient concentration at plume touchdown (maximum ground-level concentration) (C_T) in units of µg / m^3 by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	1,772,267	1,772,267	1,710,600	1,612,247	--[n/a]	995,640	RVD 2.0 - Equation 10. Ambient concentration at plume touchdown (maximum ground-level concentration). $C_T = 6.0 \cdot 10^{(9)} \cdot Q_m / u \cdot ((2 \cdot \Delta h + H_S))^{(-2.0)}$ Note: Basic code in RVD for TSCREEN uses a different equation, below: $C_T = 5.1 \cdot 10^{(9)} \cdot Q_m \cdot ((2 \cdot \Delta h + HS))^{(-1.95)} / (u \cdot D_{vent}^{(0.05)})$ These values represents the 1-hour concentrations from a continuous emission source. If the emissions occur for less than 1 hour, or if the averaging period of concern is less than 1 hour, use the values calculated below in Step 4.
2	1,001,489	1,001,489	965,391	907,941	708,874	551,678	
3	710,660	710,660	684,571	643,098	499,885	387,412	
4	--[n/a]	555,021	534,399	501,643	Neutral	--[n/a]	
5	--[n/a]	Neutral	Neutral	Neutral	Neutral	--[n/a]	
8	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

Ambient concentration at plume touchdown (maximum ground-level concentration) (C_T) in units of ppmV by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	985	985	950	896	--[n/a]	553	Conversion of C_T from µg/m^3 to ppmV These values represents the 1-hour concentrations from a continuous emission source. If the emissions occur for less than 1 hour, or if the averaging period of concern is less than 1 hour, use the values calculated below in Step 4.
2	556	556	536	504	394	307	
3	395	395	380	357	278	215	
4	--[n/a]	308	297	279	Neutral	--[n/a]	
5	--[n/a]	Neutral	Neutral	Neutral	Neutral	--[n/a]	
8	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

Downwind distance to plume touchdown in units of meters (X_T) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	145	145	154	169	--[n/a]	371	RVD 2.0 - Equation 11. Downwind distance to plume touchdown. $X_T = D_{vent} \cdot Fr^{(2)} / R_V + 0.56 \cdot D_{vent} \cdot Fr_H / R_V^{(1/2)} \cdot C_1$ RVD 2.0 - Equation 12 $C_1 = ((\Delta h / D_{vent})^{(3)} \cdot ((2 + H_S / \Delta h)^{(3)} - 1))^{(1/2)}$ RVD 2.0 - Equation 13. Horizontal densimetric Froude number $Fr_H = u / (g \cdot D_{vent} \cdot (\rho_{air} / \rho_2 - 1))^{(1/2)}$ Note: Basic code in RVD for TSCREEN uses a corrected equation for Fr_H, below: $Fr_H = u * (((\rho_{air} / (\rho_2 - \rho_{air})) / (g \ D_{vent}))^{(1/2)}$
2	368	368	390	431	642	960	
3	640	640	679	751	1,123	1,685	
4	--[n/a]	950	1,010	1,117	Neutral	--[n/a]	
5	--[n/a]	Neutral	Neutral	Neutral	Neutral	--[n/a]	
8	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 07, 140 ft Vent Ht, and 1250 scfm Vent Fan

Step 4. Concentration Estimates for Release Times Less Than the Averaging Period or Averaging Periods Less Than 60 Minutes

User-Specified Averaging Time (t_a):	15	min

Calculated Release Duration (t_d):	26.5570	min

Note: See TSCREEN for release duration calculation.

Ambient concentration at plume touchdown (maximum ground-level concentration) including correction factors for user-specified averaging time and calculated release duration (C_F) in units of ppmV by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	1,299	1,299	1,254	1,182	--n/a	730	RVD 2.0 - Equation 16. Correction factor if release duration is less than the averaging time. $C_{TF} = C_T \cdot (t_d / t_a)$
2	734	734	708	666	520	404	
3	521	521	502	471	366	284	
4	--n/a	407	392	368	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	RVD 2.0 - Equation 17. Correction factor if averaging time is less than 60 minutes. $C_{TF} = C_T \cdot (60 / t_a)^{(0.2)}$
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	where C_{TF} = the corrected touchdown concentration, C_T.
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Receptor	Receptor Dist from vent (m)	Recepter Elevation BELOW Vent (m)	Recepter Elevation ABOVE Ground (m)	1-min Average CO2 Conc. ppmv	15-min Average CO2 Conc. ppmv	60-min Average CO2 Conc. ppmv
Penthouse Roof	1	11.0	32.0	0	0	0
Penthouse Platform	3	16.5	26.5	0	0	0
Existing Bldg S. of Penthouse	28	27.0	16.0	0	0	0
Lower N. Stack Platform (Existing)	32	-3.0	46.0	23,711	13,796	4,628
Existing Bldg SW. of Penthouse	32	18.0	25.0	0	0	0
Lower S. Stack Platform (Existing)	114	-3.0	46.0	15,185	8,835	2,964
Nearest Sidewalk	42	43.0	0.0	0	0	0
Mark Twain Hall-Elevator Penthouse	120	10.0	33.0	6,723	3,911	1,312
Mark Twain Hall	120	18.0	25.0	5,006	2,912	977
Apprtmts W of Mark Twain Hall	140	23.0	20.0	3,922	2,282	765
Apprtmts S of Mark Twain Hall	210	18.0	25.0	3,562	2,072	695
Downtown Bldg 4	300	3.0	40.0	5,606	3,262	1,094
Downtown Bldg 1	562	3.0	40.0	2,216	1,289	432
Downtown Bldg 5	574	4.0	39.0	2,148	1,250	419
Downtown Bldg 3	644	9.0	34.0	1,827	1,063	357
Downtown Bldg 2	800	-2.0	45.0	1,348	784	263
Downtown Bldg 6	885	6.0	37.0	1,172	682	229
Peak Concentration on Ground:	145	43.0	0.0	2,233	1,299	436

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - Case 02, Scenario 08, 167 ft Vent Ht, with 1250 scfm Vent Fan

Note: The wind speeds at stack height elevation are based on a 51 meter stack (cell V35). The value of Hs in cell B19 can be adjusted to represent receptors at elevations above ground level, e.g., setting Hs to 3 meters indicates the receptor is 3 meters below the vent exit, or setting Hs to 51 meters indicates the receptor is on ground level. The actual stack height above ground can be adjusted in cell V35.

RVD Inputs

Parameter	Value	Units	Definition	Source // Reference
P_a	101,325	Pa	ambient pressure	standard atmospheric pressure at sea level
T_2	272.89	K	discharge temperatature = $T_2 = T_1 \cdot (1 - 0.85 \cdot ((\gamma - 1) / (\gamma + 1))$	See TSCREEN calculations
T_a	298.00	K	ambient temperature	See TSCREEN calculations
ρ_2	1.6266	kg / m3 @ T_2 & P*	discharge density = $\rho_2 = P_a \cdot MWCO2 / (R \cdot T_2)$	See TSCREEN calculations
ρ_{air}	1.1819	kg / m3	density of air = $\rho air = P_a \cdot MWair / (R \cdot T_a)$	See TSCREEN calculations
γ_2	1.3219	dimensionless @T_2 & P_2	$(C_P / C_V) \approx 1 / (1 - R / (C_P \cdot M))$ @ T_2	National Institute of Standards and Technology (NIST) data utilized instead.
Q_m	1.0881	kg / s	mass emission rate	See TSCREEN calculations
$V2_{sonic}$	248.98	m / s	V2sonic = SQRT(γ_2 * P_a / ρ_2)	--n/a
D_{vent}	10	inch	vent diameter	Echogen data
A_{vent}	0.0507	m^2	vent flow area	Echogen data; presumed circular vent
V2	21.9427	m / s	discharge velocity	--n/a
g	9.80665	m / s^2	acceleration due to gravity	--n/a
H_S	51.0	m	stack height	Echogen data
u_0 / u_{10}	0.06	dimensionless	friction velocity (m / s) to the wind speed at 10m (m / s)	RVD 2.0 model assumption for all Atmospheric Stability Classes
MW_{CO2}	44.01	kg / kg-mole	gas (contaminant) molecular weight (for contaminant mixtures, see TSCREEN Workbook Appedix B)	See TSCREEN calculations
t_d	26.5570	minutes	release duration = td = Q / ($Q_m \cdot 60$)	See TSCREEN calculations

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 08, 167 ft Vent Ht, with 1250 scfm Vent Fan

Step 1. Check for dominance of dense gas effects at release point.

Source Region (Rural or Urban)?: Rural

Atmospheric Stability Class	A	B	C	D	E	F	Source // Reference
Wind Profile Exponent (P)	0.07	0.07	0.10	0.15	0.35	0.55	Recommended Power-law exponents for Urban and Rural Wind Profiles, Table 6-2 http://www.webmet.com/met_monitoring/625.HTML

Wind Velocity at the Top of the Stack (u) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	1.121	1.121	1.177	1.277	--n/a	2.450	RVD 2.0 - Equation 2. Wind Velocity at the Top of the Stack $u = u_{10} \cdot (H_S / 10) \cdot P$
2	2.242	2.242	2.354	2.554	3.537	4.900	
3	3.362	3.362	3.531	3.831	5.306	7.350	
4	--n/a	4.483	4.708	5.107	7.075	--n/a	
5	--n/a	5.604	5.885	6.384	8.843	--n/a	
8	--n/a	--n/a	9.416	10.215	--n/a	--n/a	
10	--n/a	--n/a	11.769	12.768	--n/a	--n/a	
15	--n/a	--n/a	17.654	19.153	--n/a	--n/a	
20	--n/a	--n/a	23.539	25.537	--n/a	--n/a	

Stack Exit Richardson Number (Ri_0) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	2,409	2,409	2,294	2,114	--n/a	1,102	RVD 2.0 - Equation 1. Stack Exit Richardson Number $Ri_0 = (g (\rho_2 / \rho_a - 1) \cdot Q_m) / (u \cdot D_{vent} \cdot \rho_2 \cdot u_{10}^{(2)} (u_0 / u_{10})^{(2)})$
2	301	301	287	264	191	138	
3	89	89	85	78	57	41	
4	--n/a	38	36	33	24	--n/a	
5	--n/a	19	18	17	12	--n/a	
8	--n/a	--n/a	4	4	--n/a	--n/a	
10	--n/a	--n/a	2	2	--n/a	--n/a	
15	--n/a	--n/a	1	1	--n/a	--n/a	
20	--n/a	--n/a	0	0	--n/a	--n/a	

Plume Buoyancy at Stack Exit by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	Dense	Dense	Dense	Dense	--n/a	Dense	RVD 2.0 - Plume Buoyancy at Stack Exit If Ri_0 > 30 then plume is considered to behave as a dense gas at the release point Note: Neutral conditions are evaluated using alternate model.
2	Dense	Dense	Dense	Dense	Dense	Dense	
3	Dense	Dense	Dense	Dense	Dense	Dense	
4	--n/a	Dense	Dense	Dense	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 08, 167 ft Vent Ht, with 1250 scfm Vent Fan

Step 2. Assess atmospheric dilution of the plume resulting from entrainment effects during the rise of plume to its maximum height.

Height from the top of the stack to the middle of the plume at its point of maximum rise (Δh) under laminar wind conditions by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	9.0	9.0	8.8	8.6	--[n/a]	6.9	RVD 2.0 - Equation 3. Height from the top of the stack to the middle of the plume at its point of maximum rise under laminar wind conditions. $\Delta h = 1.32 \cdot R_V^{(1/3)} \cdot SG^{(1/3)} \cdot Fr^{(2/3)} \cdot D_{vent}$ RVD 2.0 - Equation 4. Vertical Densimetric Froude Number $Fr = V2 / (g \cdot D_{vent} \cdot (1 - \rho_a / \rho_2))^{(1/2)}$ RVD 2.0 - Equation 4a $R_V = V2 / u$
2	7.1	7.1	7.0	6.8	6.1	5.5	
3	6.2	6.2	6.1	5.9	5.3	4.8	
4	--[n/a]	5.6	5.5	5.4	Neutral	--[n/a]	
5	--[n/a]	Neutral	Neutral	Neutral	Neutral	--[n/a]	
8	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

Height from the top of the stack to the middle of the plume at its point of maximum rise (Δh) under quiescent atmospheric conditions (no wind)

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
0	20.0	20.0	20.0	20.0	20.0	20.0	RVD 2.0 - Equation 5. Height from the top of the stack to the middle of the plume at its point of maximum rise under quiescent atmospheric conditions (no wind) $\Delta h = 2.96 \cdot Fr \cdot D_{vent}$

Plume dilution ratio at maximum plume rise (D_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	40.5	40.5	41.3	42.6	--[n/a]	54.7	RVD 2.0 - Equation 6. Plume dilution ratio at maximum plume rise. $D_h = 5.67 \cdot 10^{(-2)} \cdot u \cdot D_{vent}^{(2)} / Q_m \cdot (\Delta h_{min} / D_{vent})^{(1.85)} \cdot (MW_{CO2} / T_a)$ Note: Basic code in RVD for TSCREEN uses a corrected equation, below: $D_h = 5.67 \cdot u \cdot D_{vent}^{(2)} / Q_m \cdot (\Delta h_{min} / D_{vent})^{(1.85)} \cdot (MW_{CO2} / T_a)$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	52.9	52.9	53.9	55.6	63.0	71.3	
3	61.7	61.7	62.9	64.9	73.5	83.3	
4	--[n/a]	68.9	70.2	72.5	Neutral	--[n/a]	
5	--[n/a]	Neutral	Neutral	Neutral	Neutral	--[n/a]	
8	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 08, 167 ft Vent Ht, with 1250 scfm Vent Fan

Plume-equivalent molecular weight at maximum plume rise (MW_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	29.331	29.331	29.325	29.313	--n/a	29.235	RVD 2.0 - Equation 7. Plume-equivalent molecular weight at maximum plume rise. $MW_h = (MW_{CO2} + 28.96 \cdot (D_h - 1)) / D_h$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	29.245	29.245	29.239	29.231	29.199	29.171	
3	29.204	29.204	29.199	29.192	29.165	29.141	
4	--n/a	29.178	29.174	29.168	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Plume temperature at maximum plume rise (T_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	297.070	297.070	297.087	297.115	--n/a	297.309	RVD 2.0 - Equation 8. Plume temperature at maximum plume rise. $T_h = T_a - (MW_{CO2} / MW_h) \cdot (T_a - T_2) / D_h$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	297.285	297.285	297.298	297.320	297.399	297.469	
3	297.387	297.387	297.398	297.417	297.485	297.545	
4	--n/a	297.451	297.461	297.477	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Fractional density ratio at maximum plume rise (δ) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	0.016	0.016	0.016	0.015	--n/a	0.012	RVD 2.0 - Equation 9. Fractional density ratio at maximum plume rise. $\delta = ((MW_h / 28.96) \cdot (T_a / T_2)) - 1$ Note: A calculated frational density ratio greater than 0.005 indicates that dense gas behavior dominates the subsequent plume transport and RVD is appropriate for plume touchdown and ground level concentration calculations. A calculated frational density ratio less than or equal to 0.005 indicates neutrally-buoyant plume behavior which should be addressed using an alternate model.
2	0.012	0.012	0.012	0.012	0.010	0.009	
3	0.010	0.010	0.010	0.010	0.009	0.008	
4	--n/a	0.009	0.009	0.009	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 08, 167 ft Vent Ht, with 1250 scfm Vent Fan

Step 3. Concentration Estimates at Plume Touchdown

Ambient concentration at plume touchdown (maximum ground-level concentration) (C_T) in units of µg / m^3 by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	1,379,828	1,379,828	1,324,836	1,237,739	--[n/a]	711,648	RVD 2.0 - Equation 10. Ambient concentration at plume touchdown (maximum ground-level concentration). $C_T = 6.0 \cdot 10^{(9)} \cdot Q_m / u \cdot ((2 \cdot \Delta h + H_S))^{(-2.0)}$ Note: Basic code in RVD for TSCREEN uses a different equation, below: $C_T = 5.1 \cdot 10^{(9)} \cdot Q_m \cdot ((2 \cdot \Delta h + HS))^{(-1.95)} / (u \cdot D_{vent}^{(0.05)})$ These values represents the 1-hour concentrations from a continuous emission source. If the emissions occur for less than 1 hour, or if the averaging period of concern is less than 1 hour, use the values calculated below in Step 4.
2	768,180	768,180	736,587	686,660	517,358	388,403	
3	540,797	540,797	518,193	482,512	361,939	270,603	
4	--[n/a]	420,142	402,394	374,401	Neutral	--[n/a]	
5	--[n/a]	Neutral	Neutral	Neutral	Neutral	--[n/a]	
8	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

Ambient concentration at plume touchdown (maximum ground-level concentration) (C_T) in units of ppmV by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	767	767	736	688	--[n/a]	395	Conversion of C_T from µg/m^3 to ppmV These values represents the 1-hour concentrations from a continuous emission source. If the emissions occur for less than 1 hour, or if the averaging period of concern is less than 1 hour, use the values calculated below in Step 4.
2	427	427	409	382	287	216	
3	300	300	288	268	201	150	
4	--[n/a]	233	224	208	Neutral	--[n/a]	
5	--[n/a]	Neutral	Neutral	Neutral	Neutral	--[n/a]	
8	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

Downwind distance to plume touchdown in units of meters (X_T) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	175	175	187	209	--[n/a]	510	RVD 2.0 - Equation 11. Downwind distance to plume touchdown. $X_T = D_{vent} \cdot Fr^{(2)} / R_V + 0.56 \cdot D_{vent} \cdot Fr_H / R_V^{(1/2)} \cdot C_1$ RVD 2.0 - Equation 12 $C_1 = ((\Delta h / D_{vent})^{(3)} \cdot ((2 + H_S / \Delta h)^{(3)} - 1))^{(1/2)}$ RVD 2.0 - Equation 13. Horizontal densimetric Froude number $Fr_H = u / (g \cdot D_{vent} \cdot (\rho_{air} / \rho_2 - 1))^{(1/2)}$ Note: Basic code in RVD for TSCREEN uses a corrected equation for Fr_H, below: $Fr_H = u * (((\rho_{air} / (\rho_2 - \rho_{air})) / (g \ D_{vent}))^{(1/2)}$
2	451	451	483	540	848	1,336	
3	790	790	846	947	1,493	2,361	
4	--[n/a]	1,179	1,263	1,415	Neutral	--[n/a]	
5	--[n/a]	Neutral	Neutral	Neutral	Neutral	--[n/a]	
8	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model

U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989

Echogen SCO2 Vent Study - Case 02, Scenario 08, 167 ft Vent Ht, with 1250 scfm Vent Fan

Step 4. Concentration Estimates for Release Times Less Than the Averaging Period or Averaging Periods Less Than 60 Minutes

User-Specified Averaging Time (t_a):	15	min

Calculated Release Duration (t_d):	26.5570	min

Note: See TSCREEN for release duration calculation.

Ambient concentration at plume touchdown (maximum ground-level concentration) including correction factors for user-specified averaging time and calculated release duration (C_{TF}) in units of ppmV by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	1,012	1,012	971	907	--n/a	522	RVD 2.0 - Equation 16. Correction factor if release duration is less than the averaging time. $C_{TF} = C_T \cdot (t_d / t_a)$
2	563	563	540	503	379	285	
3	396	396	380	354	265	198	
4	--n/a	308	295	274	Neutral	--n/a	
5	--n/a	Neutral	Neutral	Neutral	Neutral	--n/a	RVD 2.0 - Equation 17. Correction factor if averaging time is less than 60 minutes. $C_{TF} = C_T \cdot (60 / t_a)^{(0.2)}$
8	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
10	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	where C_{TF} = the corrected touchdown concentration, C_T.
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Receptor	Receptor Dist from vent (m)	Recepter Elevation BELOW Vent (m)	Recepter Elevation ABOVE Ground (m)	1-min Average CO2 Conc. ppmv	15-min Average CO2 Conc. ppmv	60-min Average CO2 Conc. ppmv
Penthouse Roof	1	19.0	32.0	0	0	0
Penthouse Platform	3	24.5	26.5	0	0	0
Existing Bldg S. of Penthouse	28	35.0	16.0	0	0	0
Lower N. Stack Platform (Existing)	32	5.0	46.0	0	0	0
Existing Bldg SW. of Penthouse	32	26.0	25.0	0	0	0
Lower S. Stack Platform (Existing)	114	5.0	46.0	9,475	5,513	1,849
Nearest Sidewalk	42	51.0	0.0	0	0	0
Mark Twain Hall-Elevator Penthouse	120	18.0	33.0	5,005	2,912	977
Mark Twain Hall	120	26.0	25.0	3,849	2,240	751
Apprtmts W of Mark Twain Hall	140	31.0	20.0	3,112	1,810	607
Apprtmts S of Mark Twain Hall	210	26.0	25.0	2,828	1,645	552
Downtown Bldg 4	300	11.0	40.0	3,859	2,245	753
Downtown Bldg 1	562	11.0	40.0	2,453	1,427	479
Downtown Bldg 5	574	12.0	39.0	2,379	1,384	464
Downtown Bldg 3	644	17.0	34.0	1,871	1,089	365
Downtown Bldg 2	800	6.0	45.0	1,486	865	290
Downtown Bldg 6	885	14.0	37.0	1,290	751	252
Peak Concentration on Ground:	175	51.0	0.0	1,739	1,012	339

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - PSV-1110 (Average values for 15 second release time)
1st Iteration of Discharge Temperature (T2)

Note: The wind speeds at stack height elevation are based on a 35 meter stack. The value of Hs in cell B19 can be adjusted to represent receptors at elevations above ground level, i.e. setting Hs to 3 meters indicates the receptor is 3 meters below the vent exit, or setting Hs to 35 meters indicates the receptor is on ground level. The actual stack height above ground is adjusted in cell V35.

RVD Inputs

Parameter	Value	Units	Definition	Source // Reference
P_a	101,325	Pa	ambient pressure	standard atmospheric pressure at sea level
T_2	194.75	K	discharge temperatature = $T_2 = T_1 \cdot (1 - 0.85 \cdot ((\gamma - 1) / (\gamma + 1))$	See TSCREEN calculations
T_a	298.00	K	ambient temperature	See TSCREEN calculations
ρ_2	2.8140	kg / m3 @ T_2 & P*	discharge density = $\rho_2 = P_a \cdot MWCO2 / (R \cdot T_2)$	See TSCREEN calculations
ρ_{air}	1.1819	kg / m3	density of air = pair = $P_a \cdot MWair / (R \cdot T_a)$	See TSCREEN calculations
γ_2	1.3666	dimensionless @T_2 & P_2	$(C_P / C_V) \approx 1 / (1 - R / (C_P \cdot M))$ @ T_2	National Institute of Standards and Technology (NIST) data utilized instead.
Q_m	7.0	kg / s	mass emission rate	See TSCREEN calculations
$V2_{sonic}$	221.83	m / s	V2sonic = SQRT(γ_2 * P_a / ρ_2)	--n/a
D_{vent}	6	inch	vent diameter	Echogen data
A_{vent}	0.0182	m^2	vent flow area	Echogen data; presumed circular vent
V2	136.37	m / s	discharge velocity	--n/a
g	9.807	m / s^2	acceleration due to gravity	--n/a
H_S	10	m	stack height	Echogen data
u_0 / u_{10}	0.06	dimensionless	friction velocity (m / s) to the wind speed at 10m (m / s)	RVD 2.0 model assumption for all Atmospheric Stability Classes
MW_{CO2}	44.01	kg / kg-mole	gas (contaminant) molecular weight (for contaminant mixtures, see TSCREEN Workbook Appedix B)	See TSCREEN calculations
t_d	0.250	minutes	release duration = td = Q / ($Q_m \cdot 60$)	See TSCREEN calculations

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - PSV-1110 (Average values for 15 second release time)
1st Iteration of Discharge Temperature (T2)

Step 1. Check for dominance of dense gas effects at release point.

Source Region (Rural or Urban)?: Rural

Atmospheric Stability Class	A	B	C	D	E	F	Source // Reference
Wind Profile Exponent (P)	0.07	0.07	0.10	0.15	0.35	0.55	Recommended Power-law exponents for Urban and Rural Wind Profiles, Table 6-2 http://www.webmet.com/met_monitoring/625.HTML

Wind Velocity at the Top of the Stack (u) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	1.092	1.092	1.133	1.207	--n/a	1.992	RVD 2.0 - Equation 2. Wind Velocity at the Top of the Stack $u = u_{10} \cdot (H_S / 10) \cdot P$
2	2.183	2.183	2.267	2.413	3.101	3.984	
3	3.275	3.275	3.400	3.620	4.651	5.975	
4	--n/a	4.367	4.534	4.827	6.201	--n/a	
5	--n/a	5.458	5.667	6.034	7.752	--n/a	
8	--n/a	--n/a	9.068	9.654	--n/a	--n/a	
10	--n/a	--n/a	11.335	12.067	--n/a	--n/a	
15	--n/a	--n/a	17.002	18.101	--n/a	--n/a	
20	--n/a	--n/a	22.669	24.135	--n/a	--n/a	

Stack Exit Richardson Number (Ri_0) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	56,244	56,244	54,169	50,880	--n/a	30,826	RVD 2.0 - Equation 1. Stack Exit Richardson Number $Ri_0 = (g (\rho_2 / \rho_a - 1) \cdot Q_m) / (u \cdot D_{vent} \cdot \rho_2 \cdot u_{10}^{(2)} (u_0 / u_{10})^{(2)})$
2	7,030	7,030	6,771	6,360	4,950	3,853	
3	2,083	2,083	2,006	1,884	1,467	1,142	
4	--n/a	879	846	795	619	--n/a	
5	--n/a	450	433	407	317	--n/a	
8	--n/a	--n/a	106	99	--n/a	--n/a	
10	--n/a	--n/a	54	51	--n/a	--n/a	
15	--n/a	--n/a	16	15	--n/a	--n/a	
20	--n/a	--n/a	7	6	--n/a	--n/a	

Plume Buoyancy at Stack Exit by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	Dense	Dense	Dense	Dense	--n/a	Dense	RVD 2.0 - Plume Buoyancy at Stack Exit If Ri_0 > 30 then plume is considered to behave as a dense gas at the release point Note: Neutral conditions are evaluated using alternate model.
2	Dense	Dense	Dense	Dense	Dense	Dense	
3	Dense	Dense	Dense	Dense	Dense	Dense	
4	--n/a	Dense	Dense	Dense	Dense	--n/a	
5	--n/a	Dense	Dense	Dense	Dense	--n/a	
8	--n/a	--n/a	Dense	Dense	--n/a	--n/a	
10	--n/a	--n/a	Dense	Dense	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - PSV-1110 (Average values for 15 second release time)
1st Iteration of Discharge Temperature (T2)

Step 2. Assess atmospheric dilution of the plume resulting from entrainment effects during the rise of plume to its maximum height.

Height from the top of the stack to the middle of the plume at its point of maximum rise (Δh) under laminar wind conditions by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	37	37	37	36	--[n/a]	31	RVD 2.0 - Equation 3. Height from the top of the stack to the middle of the plume at its point of maximum rise under laminar wind conditions. $\Delta h = 1.32 \cdot R_v^{(1/3)} \cdot SG^{(1/3)} \cdot Fr^{(2/3)} \cdot D_{vent}$ RVD 2.0 - Equation 4. Vertical Densimetric Froude Number $Fr = V2 / (g \cdot D_{vent} \cdot (1 - \rho_a / \rho_2))^{(1/2)}$ RVD 2.0 - Equation 4a $R_v = V2 / u$
2	30	30	29	29	26	24	
3	26	26	26	25	23	21	
4	--[n/a]	24	23	23	21	--[n/a]	
5	--[n/a]	22	22	21	19	--[n/a]	
8	--[n/a]	--[n/a]	18	18	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	17	17	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

Height from the top of the stack to the middle of the plume at its point of maximum rise (Δh) under quiescent atmospheric conditions (no wind)

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
0	66	66	66	66	66	66	RVD 2.0 - Equation 5. Height from the top of the stack to the middle of the plume at its point of maximum rise under quiescent atmospheric conditions (no wind) $\Delta h = 2.96 \cdot Fr \cdot D_{vent}$

Plume dilution ratio at maximum plume rise (D_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	79.6	79.6	80.8	82.8	--[n/a]	100.3	RVD 2.0 - Equation 6. Plume dilution ratio at maximum plume rise. $D_h = 5.67 \cdot 10^{(-2)} \cdot u \cdot D_{vent}^{(2)} / Q_m \cdot (\Delta h_{min} / D_{vent})^{(1.85)} \cdot (MW_{CO2} / T_a)$ Note: Basic code in RVD for TSCREEN uses a corrected equation, below: $D_h = 5.67 \cdot u \cdot D_{vent}^{(2)} / Q_m \cdot (\Delta h_{min} / D_{vent})^{(1.85)} \cdot (MW_{CO2} / T_a)$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	103.9	103.9	105.4	108.0	118.8	130.8	
3	121.4	121.4	123.1	126.1	138.8	152.8	
4	--[n/a]	135.5	137.5	140.8	155.0	--[n/a]	
5	--[n/a]	147.6	149.8	153.4	168.9	--[n/a]	
8	--[n/a]	--[n/a]	179.3	183.7	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	195.3	200.1	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - PSV-1110 (Average values for 15 second release time)
1st Iteration of Discharge Temperature (T2)

Plume-equivalent molecular weight at maximum plume rise (MW_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	29.149	29.149	29.146	29.142	--n/a	29.110	RVD 2.0 - Equation 7. Plume-equivalent molecular weight at maximum plume rise. $MW_h = (MW_{CO2} + 28.96 \cdot (D_h - 1)) / D_h$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	29.105	29.105	29.103	29.099	29.087	29.075	
3	29.084	29.084	29.082	29.079	29.068	29.058	
4	--n/a	29.071	29.069	29.067	29.057	--n/a	
5	--n/a	29.062	29.060	29.058	29.049	--n/a	
8	--n/a	--n/a	29.044	29.042	--n/a	--n/a	
10	--n/a	--n/a	29.037	29.035	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Plume temperature at maximum plume rise (T_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	296.04	296.04	296.07	296.12	--n/a	296.44	RVD 2.0 - Equation 8. Plume temperature at maximum plume rise. $T_h = T_a - (MW_{CO2} / MW_h) \cdot (T_a - T_2) / D_h$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	296.50	296.50	296.52	296.55	296.69	296.81	
3	296.71	296.71	296.73	296.76	296.87	296.98	
4	--n/a	296.85	296.86	296.89	296.99	--n/a	
5	--n/a	296.94	296.96	296.98	297.07	--n/a	
8	--n/a	--n/a	297.13	297.15	--n/a	--n/a	
10	--n/a	--n/a	297.20	297.22	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Fractional density ratio at maximum plume rise (δ) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	0.013	0.013	0.013	0.013	--n/a	0.010	RVD 2.0 - Equation 9. Fractional density ratio at maximum plume rise. $\delta = ((MW_h / 28.96) \cdot (T_a / T_2)) - 1$ Note: A calculated frational density ratio greater than 0.005 indicates that dense gas behavior dominates the subsequent plume transport and RVD is appropriate for plume touchdown and ground level concentration calculations. A calculated frational density ratio less than or equal to 0.005 indicates neutrally-buoyant plume behavior which should be addressed using an alternate model.
2	0.010	0.010	0.010	0.010	0.009	0.008	
3	0.009	0.009	0.009	0.008	0.008	0.007	
4	--n/a	0.008	0.008	0.007	0.007	--n/a	
5	--n/a	0.007	0.007	0.007	0.006	--n/a	
8	--n/a	--n/a	0.006	0.006	--n/a	--n/a	
10	--n/a	--n/a	0.005	0.005	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - PSV-1110 (Average values for 15 second release time)
1st Iteration of Discharge Temperature (T2)

Step 3. Concentration Estimates at Plume Touchdown

Ambient concentration at plume touchdown (maximum ground-level concentration) (C_T) in units of µg / m^3 by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	6,263,568	6,263,568	6,163,799	6,000,605	--n/a	4,824,960	RVD 2.0 - Equation 10. Ambient concentration at plume touchdown (maximum ground-level concentration). $C_T = 6.0 \cdot 10^{(9)} \cdot Q_m / u \cdot ((2 \cdot \Delta h + H_S))^{(-2.0)}$ Note: Basic code in RVD for TSCREEN uses a different equation, below: $C_T = 5.1 \cdot 10^{(9)} \cdot Q_m \cdot ((2 \cdot \Delta h + HS))^{(-1.95)} / (u \cdot D_{vent}^{(0.05)})$ These values represents the 1-hour concentrations from a continuous emission source. If the emissions occur for less than 1 hour, or if the averaging period of concern is less than 1 hour, use the values calculated below in Step 4.
2	4,632,775	4,632,775	4,556,042	4,430,592	3,958,073	3,529,505	
3	3,860,904	3,860,904	3,795,324	3,688,147	3,284,927	2,919,962	
4	--n/a	3,382,728	3,324,174	3,228,508	2,868,937	--n/a	
5	--n/a	3,047,580	2,994,018	2,906,530	2,577,964	--n/a	
8	--n/a	--n/a	2,388,823	2,316,633	--n/a	--n/a	
10	--n/a	--n/a	2,140,033	2,074,278	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Ambient concentration at plume touchdown (maximum ground-level concentration) (C_T) in units of ppmV by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	3,480	3,480	3,425	3,334	--n/a	2,681	Conversion from µg/m^3 to ppmV These values represents the 1-hour concentrations from a continuous emission source. If the emissions occur for less than 1 hour, or if the averaging period of concern is less than 1 hour, use the values calculated below in Step 4.
2	2,574	2,574	2,531	2,462	2,199	1,961	
3	2,145	2,145	2,109	2,049	1,825	1,622	
4	--n/a	1,880	1,847	1,794	1,594	--n/a	
5	--n/a	1,693	1,664	1,615	1,432	--n/a	
8	--n/a	--n/a	1,327	1,287	--n/a	--n/a	
10	--n/a	--n/a	1,189	1,153	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - PSV-1110 (Average values for 15 second release time)
1st Iteration of Discharge Temperature (T2)

Downwind distance to plume touchdown in units of meters (X_T) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	99	99	103	110	--n/a	186	RVD 2.0 - Equation 11. Downwind distance to plume touchdown. $X_T = D_{vent} \cdot Fr^{(2)} / R_V + 0.56 \cdot D_{vent} \cdot Fr_H / R_V^{(1/2)} \cdot C_1$
2	205	205	213	228	297	388	
3	315	315	328	351	459	600	RVD 2.0 - Equation 12 $C_1 = ((\Delta h / D_{vent})^{(3)} \cdot ((2 + H_S / \Delta h)^{(3)} - 1))^{(1/2)}$
4	--n/a	429	446	477	625	--n/a	
5	--n/a	545	567	607	795	--n/a	RVD 2.0 - Equation 13. Horizontal densimetric Froude number $Fr_H = u / (g \cdot D_{vent} \cdot (\rho_{air} / \rho_2 - 1))^{(1/2)}$
8	--n/a	--n/a	943	1,009	--n/a	--n/a	
10	--n/a	--n/a	1,203	1,288	--n/a	--n/a	Note: Basic code in RVD for TSCREEN uses a corrected equation for Fr_H, below: $Fr_H = u * (((\rho_{air} / (\rho_2 - \rho_{air})) / (g \ D_{vent}))^{(1/2)}$
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Step 4. Concentration Estimates at Downwind Distances after Touchdown

User-Specified Averaging Time (t_a):	1	min

Calculated Release Duration (t_d):		0.2500	min

Note: See TSCREEN for release duration calculation.

Ambient concentration at plume touchdown (maximum ground-level concentration) including correction factors for user-specified averaging time and calculated release duration (C_{TF}) in units of ppmV by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	1,973	1,973	1,942	1,890	--n/a	1,520	RVD 2.0 - Equation 16. Correction factor if release duration is less than the averaging time. $C_{TF} = C \cdot (t_d / t_a)$
2	1,459	1,459	1,435	1,396	1,247	1,112	
3	1,216	1,216	1,196	1,162	1,035	920	RVD 2.0 - Equation 17. Correction factor if averaging time is less than 60 minutes. $C_{TF} = C \cdot (60 / t_a)^{(0.2)}$
4	--n/a	1,066	1,047	1,017	904	--n/a	
5	--n/a	960	943	916	812	--n/a	where C_{TF} = the corrected touchdown concentration, C_T.
8	--n/a	--n/a	753	730	--n/a	--n/a	
10	--n/a	--n/a	674	653	--n/a	--n/a	
15	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Receptor	Receptor Dist from vent (m)	Recepter Elevation BELOW Vent (m)	Recepter Elevation ABOVE Ground (m)	15-sec Average CO2 Conc. ppmv	1-min Average CO2 Conc. ppmv	5-min Average CO2 Conc. ppmv	15-min Average CO2 Conc. ppmv
Penthouse Roof	3	3.0	32.0	0	0	0	0
Penthouse Platform	5	8.5	26.5	0	0	0	0
Existing Bldg S. of Penthouse	28	19.0	16.0	0	0	0	0
Lower N. Stack Platform (Existing)	32	-11.0	46.0	0	0	0	0
Existing Bldg SW. of Penthouse	32	3.0	32.0	0	0	0	0
Nearest Sidewalk	42	35.0	0.0	0	0	0	0
Lower S. Stack Platform (Existing)	114	-11.0	46.0	12,330	2,336	339	91
Mark Twain Hall-Elevator Penthouse	120	2.0	33.0	11,606	2,199	319	85
Mark Twain Hall	120	10.0	25.0	9,872	1,870	271	73
Apprtmts W of Mark Twain Hall	140	15.0	20.0	8,558	1,621	235	63
Apprtmts S of Mark Twain Hall	210	10.0	25.0	7,767	1,472	213	57
Downtown Bldg 4	300	-5.0	40.0	8,642	1,637	237	64
Downtown Bldg 1	562	-5.0	40.0	6,961	1,319	191	51
Downtown Bldg 5	574	-4.0	39.0	6,909	1,309	190	51
Downtown Bldg 3	644	1.0	34.0	10,273	1,946	282	75
Downtown Bldg 2	800	-10.0	45.0	6,090	1,154	167	45
Downtown Bldg 6	885	-2.0	37.0	5,875	1,113	161	43
Peak Concentration:	136	35.0	0.0	6,287	1,191	173	46

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - PSV-0220 (Average values for 15 second release time)
1st Iteration of Discharge Temperature (T2)

Note: The wind speeds at stack height elevation are based on a 35 meter stack. The value of Hs in cell B19 can be adjusted to represent receptors at elevations above ground level, i.e. setting Hs to 3 meters indicates the receptor is 3 meters below the vent exit, or setting Hs to 35 meters indicates the receptor is on ground level. The actual stack height above ground is adjusted in cell V35.

RVD Inputs

Parameter	Value	Units	Definition	Source // Reference
P_a	101,325	Pa	ambient pressure	standard atmospheric pressure at sea level
T_2	194.75	K	discharge temperatature = $T_2 = T_1 \cdot (1 - 0.85 \cdot ((\gamma - 1) / (\gamma + 1))$	See TSCREEN calculations
T_a	298.00	K	ambient temperature	See TSCREEN calculations
ρ_2	2.8140	kg / m3 @ T_2 & P*	discharge density = $\rho_2 = P_a \cdot MWCO2 / (R \cdot T_2)$	See TSCREEN calculations
ρ_{air}	1.1844	kg / m3	density of air = $\rho air = P_a \cdot MWair / (R \cdot T_a)$	See TSCREEN calculations
γ_2	1.3666	dimensionless @T_2 & P_2	$(C_P / C_V) \approx 1 / (1 - R / (C_P \cdot M))$ @ T_2	National Institute of Standards and Technology (NIST) data utilized instead.
Q_m	87.1	kg / s	mass emission rate	See TSCREEN calculations
$V2_{sonic}$	221.83	m / s	V2sonic = SQRT($\gamma_2 * P_a / \rho_2$)	--n/a
D_{vent}	18	inch	vent diameter	Echogen data
A_{vent}	0.1642	m^2	vent flow area	Echogen data; presumed circular vent
V2	188.53	m / s	discharge velocity	--n/a
g	9.807	m / s^2	acceleration due to gravity	--n/a
H_S	0.0	m	stack height	Echogen data
u_0 / u_{10}	0.06	dimensionless	friction velocity (m / s) to the wind speed at 10m (m / s)	RVD 2.0 model assumption for all Atmospheric Stability Classes
MW_{CO2}	44.01	kg / kg-mole	gas (contaminant) molecular weight (for contaminant mixtures, see TSCREEN Workbook Appedix B)	See TSCREEN calculations
t_d	0.250	minutes	release duration = td = $Q / (Q_m \cdot 60)$	See TSCREEN calculations

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - PSV-0220 (Average values for 15 second release time)
1st Iteration of Discharge Temperature (T2)

Step 1. Check for dominance of dense gas effects at release point.

Source Region (Rural or Urban)?: Rural

Atmospheric Stability Class	A	B	C	D	E	F	Source // Reference
Wind Profile Exponent (P)	0.07	0.07	0.10	0.15	0.35	0.55	Recommended Power-law exponents for Urban and Rural Wind Profiles, Table 6-2 http://www.webmet.com/met_monitoring/625.HTML

Wind Velocity at the Top of the Stack (u) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	1.092	1.092	1.133	1.207	--n/a	1.992	RVD 2.0 - Equation 2. Wind Velocity at the Top of the Stack $u = u_{10} \cdot (H_S / 10) \cdot P$
2	2.183	2.183	2.267	2.413	3.101	3.984	
3	3.275	3.275	3.400	3.620	4.651	5.975	
4	--n/a	4.367	4.534	4.827	6.201	--n/a	
5	--n/a	5.458	5.667	6.034	7.752	--n/a	
8	--n/a	--n/a	9.068	9.654	--n/a	--n/a	
10	--n/a	--n/a	11.335	12.067	--n/a	--n/a	
15	--n/a	--n/a	17.002	18.101	--n/a	--n/a	
20	--n/a	--n/a	22.669	24.135	--n/a	--n/a	

Stack Exit Richardson Number (Ri_o) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	232,445	232,445	223,871	210,279	--n/a	127,400	RVD 2.0 - Equation 1. Stack Exit Richardson Number $Ri_0 = (g (\rho_2 / \rho_a - 1) \cdot Q_m) / (u \cdot D_{vent} \cdot \rho_2 \cdot u_{10}^{(2)} (u_0 / u_{10})^{(2)})$
2	29,056	29,056	27,984	26,285	20,459	15,925	
3	8,609	8,609	8,292	7,788	6,062	4,719	
4	--n/a	3,632	3,498	3,286	2,557	--n/a	
5	--n/a	1,860	1,791	1,682	1,309	--n/a	
8	--n/a	--n/a	437	411	--n/a	--n/a	
10	--n/a	--n/a	224	210	--n/a	--n/a	
15	--n/a	--n/a	66	62	--n/a	--n/a	
20	--n/a	--n/a	28	26	--n/a	--n/a	

Plume Buoyancy at Stack Exit by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	Dense	Dense	Dense	Dense	--n/a	Dense	RVD 2.0 - Plume Buoyancy at Stack Exit If Ri_0 > 30 then plume is considered to behave as a dense gas at the release point Note: Neutral conditions are evaluated using alternate model.
2	Dense	Dense	Dense	Dense	Dense	Dense	
3	Dense	Dense	Dense	Dense	Dense	Dense	
4	--n/a	Dense	Dense	Dense	Dense	--n/a	
5	--n/a	Dense	Dense	Dense	Dense	--n/a	
8	--n/a	--n/a	Dense	Dense	--n/a	--n/a	
10	--n/a	--n/a	Dense	Dense	--n/a	--n/a	
15	--n/a	--n/a	Dense	Dense	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - PSV-0220 (Average values for 15 second release time)
1st Iteration of Discharge Temperature (T2)

Step 2. Assess atmospheric dilution of the plume resulting from entrainment effects during the rise of plume to its maximum height.

Height from the top of the stack to the middle of the plume at its point of maximum rise (Δh) under laminar wind conditions by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	107	107	106	104	--[n/a]	88	RVD 2.0 - Equation 3. Height from the top of the stack to the middle of the plume at its point of maximum rise under laminar wind conditions. $\Delta h = 1.32 \cdot R_V^{(1/3)} \cdot SG^{(1/3)} \cdot Fr^{(2/3)} \cdot D_{vent}$ RVD 2.0 - Equation 4. Vertical Densimetric Froude Number $Fr = V2 / (g \cdot D_{vent} \cdot (1 - \rho_a / \rho_2))^{(1/2)}$ RVD 2.0 - Equation 4a $R_V = V2 / u$
2	85	85	84	82	76	70	
3	74	74	73	72	66	61	
4	--[n/a]	68	67	65	60	--[n/a]	
5	--[n/a]	63	62	61	56	--[n/a]	
8	--[n/a]	--[n/a]	53	52	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	49	48	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	43	42	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

Height from the top of the stack to the middle of the plume at its point of maximum rise (Δh) under quiescent atmospheric conditions (no wind)

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
0	158	158	158	158	158	158	RVD 2.0 - Equation 5. Height from the top of the stack to the middle of the plume at its point of maximum rise under quiescent atmospheric conditions (no wind) $\Delta h = 2.96 \cdot Fr \cdot D_{vent}$

Plume dilution ratio at maximum plume rise (D_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	53.3	53.3	54.0	55.3	--[n/a]	67.1	RVD 2.0 - Equation 6. Plume dilution ratio at maximum plume rise. $D_h = 5.67 \cdot 10^{(-2)} \cdot u \cdot D_{vent}^{(2)} / Q_m \cdot (\Delta h_{min} / D_{vent})^{(1.85)} \cdot (MW_{CO2} / T_a)$ Note: Basic code in RVD for TSCREEN uses a corrected equation, below: $D_h = 5.67 \cdot u \cdot D_{vent}^{(2)} / Q_m \cdot (\Delta h_{min} / D_{vent})^{(1.85)} \cdot (MW_{CO2} / T_a)$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	69.5	69.5	70.5	72.2	79.5	87.5	
3	81.1	81.1	82.3	84.3	92.8	102.2	
4	--[n/a]	90.6	91.9	94.2	103.6	--[n/a]	
5	--[n/a]	98.7	100.1	102.6	112.9	--[n/a]	
8	--[n/a]	--[n/a]	119.9	122.8	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	130.6	133.8	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	152.6	156.3	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - PSV-0220 (Average values for 15 second release time)
1st Iteration of Discharge Temperature (T2)

Plume-equivalent molecular weight at maximum plume rise (MW_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	29.243	29.243	29.239	29.232	--n/a	29.184	RVD 2.0 - Equation 7. Plume-equivalent molecular weight at maximum plume rise. $MW_h = (MW_{CO2} + 28.96 \cdot (D_h - 1)) / D_h$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	29.177	29.177	29.174	29.168	29.149	29.132	
3	29.145	29.145	29.143	29.138	29.122	29.107	
4	--n/a	29.126	29.124	29.120	29.105	--n/a	
5	--n/a	29.112	29.110	29.107	29.093	--n/a	
8	--n/a	--n/a	29.086	29.083	--n/a	--n/a	
10	--n/a	--n/a	29.075	29.072	--n/a	--n/a	
15	--n/a	--n/a	29.059	29.056	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Plume temperature at maximum plume rise (T_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	295.08	295.08	295.12	295.19	--n/a	295.68	RVD 2.0 - Equation 8. Plume temperature at maximum plume rise. $T_h = T_a - (MW_{CO2} / MW_h) \cdot (T_a - T_2) / D_h$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	295.76	295.76	295.79	295.84	296.04	296.22	
3	296.08	296.08	296.11	296.15	296.32	296.47	
4	--n/a	296.28	296.30	296.34	296.49	--n/a	
5	--n/a	296.42	296.44	296.48	296.62	--n/a	
8	--n/a	--n/a	296.70	296.73	--n/a	--n/a	
10	--n/a	--n/a	296.80	296.83	--n/a	--n/a	
15	--n/a	--n/a	296.98	297.00	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Fractional density ratio at maximum plume rise (δ) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	0.020	0.020	0.019	0.019	--n/a	0.016	RVD 2.0 - Equation 9. Fractional density ratio at maximum plume rise. $\delta = ((MW_h / 28.96) \cdot (T_a / T_2)) - 1$ Note: A calculated frational density ratio greater than 0.005 indicates that dense gas behavior dominates the subsequent plume transport and RVD is appropriate for plume touchdown and ground level concentration calculations. A calculated frational density ratio less than or equal to 0.005 indicates neutrally-buoyant plume behavior which should be addressed using an alternate model.
2	0.015	0.015	0.015	0.015	0.013	0.012	
3	0.013	0.013	0.013	0.012	0.011	0.010	
4	--n/a	0.012	0.011	0.011	0.010	--n/a	
5	--n/a	0.011	0.010	0.010	0.009	--n/a	
8	--n/a	--n/a	0.009	0.009	--n/a	--n/a	
10	--n/a	--n/a	0.008	0.008	--n/a	--n/a	
15	--n/a	--n/a	0.007	0.007	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - PSV-0220 (Average values for 15 second release time)
1st Iteration of Discharge Temperature (T2)

Step 3. Concentration Estimates at Plume Touchdown

Ambient concentration at plume touchdown (maximum ground-level concentration) (C_T) in units of µg / m^3 by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	12,021,729	12,021,729	11,864,630	11,607,348	--n/a	9,740,102	RVD 2.0 - Equation 10. Ambient concentration at plume touchdown (maximum ground-level concentration). $C_T = 6.0 \cdot 10^{(9)} \cdot Q_m / u \cdot ((2 \cdot \Delta h + H_S))^{(-2.0)}$ Note: Basic code in RVD for TSCREEN uses a different equation, below: $C_T = 5.1 \cdot 10^{(9)} \cdot Q_m \cdot ((2 \cdot \Delta h + HS))^{(-1.95)} / (u \cdot D_{vent}^{(0.05)})$ These values represents the 1-hour concentrations from a continuous emission source. If the emissions occur for less than 1 hour, or if the averaging period of concern is less than 1 hour, use the values calculated below in Step 4.
2	9,432,057	9,432,057	9,308,800	9,106,941	8,342,338	7,641,929	
3	8,184,167	8,184,167	8,077,217	7,902,065	7,238,621	6,630,878	
4	--n/a	7,400,242	7,303,537	7,145,161	6,545,265	--n/a	
5	--n/a	6,844,275	6,754,834	6,608,357	6,053,531	--n/a	
8	--n/a	--n/a	5,730,239	5,605,980	--n/a	--n/a	
10	--n/a	--n/a	5,299,736	5,184,812	--n/a	--n/a	
15	--n/a	--n/a	4,598,564	4,498,846	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Ambient concentration at plume touchdown (maximum ground-level concentration) (C_T) in units of ppmV by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	6,680	6,680	6,592	6,449	--n/a	5,412	Conversion from µg/m^3 to ppmV These values represents the 1-hour concentrations from a continuous emission source. If the emissions occur for less than 1 hour, or if the averaging period of concern is less than 1 hour, use the values calculated below in Step 4.
2	5,241	5,241	5,172	5,060	4,635	4,246	
3	4,547	4,547	4,488	4,391	4,022	3,684	
4	--n/a	4,112	4,058	3,970	3,637	--n/a	
5	--n/a	3,803	3,753	3,672	3,364	--n/a	
8	--n/a	--n/a	3,184	3,115	--n/a	--n/a	
10	--n/a	--n/a	2,945	2,881	--n/a	--n/a	
15	--n/a	--n/a	2,555	2,500	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - PSV-0220 (Average values for 15 second release time)
1st Iteration of Discharge Temperature (T2)

Downwind distance to plume touchdown in units of meters (X_T) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	118	118	122	130	--n/a	215	RVD 2.0 - Equation 11. Downwind distance to plume touchdown. $X_T = D_{vent} \cdot Fr^{(2)} / R_V + 0.56 \cdot D_{vent} \cdot Fr_H / R_V^{(1/2)} \cdot C_1$
2	235	235	244	260	334	429	
3	353	353	367	390	501	644	RVD 2.0 - Equation 12 $C_1 = ((\Delta h / D_{vent})^{(3)} \cdot ((2 + H_S / \Delta h)^{(3)} - 1))^{(1/2)}$
4	--n/a	471	489	520	668	--n/a	
5	--n/a	588	611	650	836	--n/a	RVD 2.0 - Equation 13. Horizontal densimetric Froude number $Fr_H = u / (g \cdot D_{vent} \cdot (\rho_{air} / \rho_2 - 1))^{(1/2)}$
8	--n/a	--n/a	977	1,041	--n/a	--n/a	Note: Basic code in RVD for TSCREEN uses a corrected equation for Fr_H, below: $Fr_H = u * (((\rho_{air} / (\rho_2 - \rho_{air})) / (g \ D_{vent}))^{(1/2)}$
10	--n/a	--n/a	1,222	1,301	--n/a	--n/a	
15	--n/a	--n/a	1,833	1,951	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Step 4. Concentration Estimates at Downwind Distances after Touchdown

User-Specified Averaging Time (t_a):	1	min

Calculated Release Duration (t_d):		0.2500	min

Note: See TSCREEN for release duration calculation.

Ambient concentration at plume touchdown (maximum ground-level concentration) including correction factors for user-specified averaging time and calculated release duration (C_{TF}) in units of ppmV by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	3,787	3,787	3,738	3,657	--n/a	3,068	RVD 2.0 - Equation 16. Correction factor if release duration is less than the averaging time. $C_{TF} = C \cdot (t_d / t_a)$
2	2,971	2,971	2,933	2,869	2,628	2,407	
3	2,578	2,578	2,545	2,489	2,280	2,089	RVD 2.0 - Equation 17. Correction factor if averaging time is less than 60 minutes. $C_{TF} = C \cdot (60 / t_a)^{(0.2)}$
4	--n/a	2,331	2,301	2,251	2,062	--n/a	
5	--n/a	2,156	2,128	2,082	1,907	--n/a	where C_{TF} = the corrected touchdown concentration, C_T.
8	--n/a	--n/a	1,805	1,766	--n/a	--n/a	
10	--n/a	--n/a	1,670	1,633	--n/a	--n/a	
15	--n/a	--n/a	1,449	1,417	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Receptor	Receptor Dist from vent (m)	Recepter Elevation BELOW Vent (m)	Recepter Elevation ABOVE Ground (m)	15-sec Average CO2 Conc. ppmv	1-min Average CO2 Conc. ppmv	5-min Average CO2 Conc. ppmv	15-min Average CO2 Conc. ppmv
Penthouse Roof	3	3.0	32.0	0	0	0	0
Penthouse Platform	1	8.5	26.5	0	0	0	0
Existing Bldg S. of Penthouse	28	19.0	16.0	0	0	0	0
Lower N. Stack Platform (Existing)	32	-11.0	46.0	0	0	0	0
Existing Bldg SW. of Penthouse	32	3.0	32.0	0	0	0	0
Lower S. Stack Platform (Existing)	114	-11.0	46.0	0	0	0	0
Nearest Sidewalk	42	35.0	0.0	0	0	0	0
Mark Twain Hall-Elevator Penthouse	120	2.0	33.0	19,455	3,686	534	143
Mark Twain Hall	120	10.0	25.0	0	0	0	0
Apprtmts W of Mark Twain Hall	140	15.0	20.0	17,125	3,245	470	126
Apprtmts S of Mark Twain Hall	210	10.0	25.0	15,504	2,937	426	114
Downtown Bldg 4	300	-5.0	40.0	14,809	2,806	407	109
Downtown Bldg 1	562	-5.0	40.0	11,668	2,211	320	86
Downtown Bldg 5	574	-4.0	39.0	11,574	2,193	318	85
Downtown Bldg 3	644	1.0	34.0	10,920	2,069	300	80
Downtown Bldg 2	800	-10.0	45.0	10,353	1,961	284	76
Downtown Bldg 6	885	-2.0	37.0	9,986	1,892	274	73
Peak Concentration:	141	35.0	0.0	14,888	2,821	409	109

0

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - PSV-1440 (Average values for 15 second release time)
1st Iteration of Discharge Temperature (T2)

Note: The wind speeds at stack height elevation are based on a 35 meter stack. The value of Hs in cell B19 can be adjusted to represent receptors at elevations above ground level, i.e. setting Hs to 3 meters indicates the receptor is 3 meters below the vent exit, or setting Hs to 35 meters indicates the receptor is on ground level. The actual stack height above ground is adjusted in cell Q36.

RVD Inputs

Parameter	Value	Units	Definition	Source // Reference
P_a	101,325	Pa	ambient pressure	standard atmospheric pressure at sea level
T_2	194.75	K	discharge temperatature = $T_2 = T_1 \cdot (1 - 0.85 \cdot ((\gamma - 1) / (\gamma + 1))$	See TSCREEN calculations
T_a	298.00	K	ambient temperature	See TSCREEN calculations
ρ_2	2.8140	kg / m3 @ T_2 & P*	discharge density = $\rho_2 = P_a \cdot MWCO2 / (R \cdot T_2)$	See TSCREEN calculations
ρ_{air}	1.1819	kg / m3	density of air = pair = $P_a \cdot MWair / (R \cdot T_a)$	See TSCREEN calculations
γ_2	1.3645	dimensionless @T_2 & P_2	$(C_P / C_V) \approx 1 / (1 - R / (C_P \cdot M))$ @ T_2	National Institute of Standards and Technology (NIST) data utilized instead.
Q_m	71.8	kg / s	mass emission rate	See TSCREEN calculations
$V2_{sonic}$	221.83	m / s	V2sonic = SQRT(γ_2 * P_a / ρ_2)	--n/a
D_{vent}	18	inch	vent diameter	Echogen data
A_{vent}	0.1642	m^2	vent flow area	Echogen data; presumed circular vent
V2	155.42	m / s	discharge velocity	--n/a
g	9.807	m / s^2	acceleration due to gravity	--n/a
H_S	10	m	stack height	Echogen data
u_0 / u_{10}	0.06	dimensionless	friction velocity (m / s) to the wind speed at 10m (m / s)	RVD 2.0 model assumption for all Atmospheric Stability Classes
MW_{CO2}	44.01	kg / kg-mole	gas (contaminant) molecular weight (for contaminant mixtures, see TSCREEN Workbook Appedix B)	See TSCREEN calculations
t_d	0.250	minutes	release duration = td = $Q / (Q_m \cdot 60)$	See TSCREEN calculations

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - PSV-1440 (Average values for 15 second release time)
1st Iteration of Discharge Temperature (T2)

Step 1. Check for dominance of dense gas effects at release point.

Source Region (Rural or Urban)?: Rural

Atmospheric Stability Class	A	B	C	D	E	F	Source // Reference
Wind Profile Exponent (P)	0.07	0.07	0.10	0.15	0.35	0.55	Recommended Power-law exponents for Urban and Rural Wind Profiles, Table 6-2 http://www.webmet.com/met_monitoring/625.HTML

Wind Velocity at the Top of the Stack (u) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	1.092	1.092	1.133	1.207	--n/a	1.992	RVD 2.0 - Equation 2. Wind Velocity at the Top of the Stack $u = u_{10} \cdot (H_S / 10) \cdot P$
2	2.183	2.183	2.267	2.413	3.101	3.984	
3	3.275	3.275	3.400	3.620	4.651	5.975	
4	--n/a	4.367	4.534	4.827	6.201	--n/a	
5	--n/a	5.458	5.667	6.034	7.752	--n/a	
8	--n/a	--n/a	9.068	9.654	--n/a	--n/a	
10	--n/a	--n/a	11.335	12.067	--n/a	--n/a	
15	--n/a	--n/a	17.002	18.101	--n/a	--n/a	
20	--n/a	--n/a	22.669	24.135	--n/a	--n/a	

Stack Exit Richardson Number (Ri_0) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	192,301	192,301	185,208	173,963	--n/a	105,397	RVD 2.0 - Equation 1. Stack Exit Richardson Number $Ri_0 = (g (\rho_2 / \rho_a - 1) \cdot Q_m) / (u \cdot D_{vent} \cdot \rho_2 \cdot u_{10}^{(2)} (u_0 / u_{10})^{(2)})$
2	24,038	24,038	23,151	21,745	16,926	13,175	
3	7,122	7,122	6,860	6,443	5,015	3,904	
4	--n/a	3,005	2,894	2,718	2,116	--n/a	
5	--n/a	1,538	1,482	1,392	1,083	--n/a	
8	--n/a	--n/a	362	340	--n/a	--n/a	
10	--n/a	--n/a	185	174	--n/a	--n/a	
15	--n/a	--n/a	55	52	--n/a	--n/a	
20	--n/a	--n/a	23	22	--n/a	--n/a	

Plume Buoyancy at Stack Exit by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	Dense	Dense	Dense	Dense	--n/a	Dense	RVD 2.0 - Plume Buoyancy at Stack Exit If Ri_0 > 30 then plume is considered to behave as a dense gas at the release point Note: Neutral conditions are evaluated using alternate model.
2	Dense	Dense	Dense	Dense	Dense	Dense	
3	Dense	Dense	Dense	Dense	Dense	Dense	
4	--n/a	Dense	Dense	Dense	Dense	--n/a	
5	--n/a	Dense	Dense	Dense	Dense	--n/a	
8	--n/a	--n/a	Dense	Dense	--n/a	--n/a	
10	--n/a	--n/a	Dense	Dense	--n/a	--n/a	
15	--n/a	--n/a	Dense	Dense	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - PSV-1440 (Average values for 15 second release time)
1st Iteration of Discharge Temperature (T2)

Step 2. Assess atmospheric dilution of the plume resulting from entrainment effects during the rise of plume to its maximum height.

Height from the top of the stack to the middle of the plume at its point of maximum rise (Δh) under laminar wind conditions by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	88	88	87	86	--[n/a]	72	RVD 2.0 - Equation 3. Height from the top of the stack to the middle of the plume at its point of maximum rise under laminar wind conditions. $\Delta h = 1.32 \cdot R_v^{(1/3)} \cdot SG^{(1/3)} \cdot Fr^{(2/3)} \cdot D_{vent}$ RVD 2.0 - Equation 4. Vertical Densimetric Froude Number $Fr = V2 / (g \cdot D_{vent} \cdot (1 - \rho_a / \rho_2))^{(1/2)}$ RVD 2.0 - Equation 4a $R_v = V2 / u$
2	70	70	69	68	62	57	
3	61	61	61	59	55	50	
4	--[n/a]	56	55	54	50	--[n/a]	
5	--[n/a]	52	51	50	46	--[n/a]	
8	--[n/a]	--[n/a]	44	43	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	41	40	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	35	35	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

Height from the top of the stack to the middle of the plume at its point of maximum rise (Δh) under quiescent atmospheric conditions (no wind)

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
0	130	130	130	130	130	130	RVD 2.0 - Equation 5. Height from the top of the stack to the middle of the plume at its point of maximum rise under quiescent atmospheric conditions (no wind) $\Delta h = 2.96 \cdot Fr \cdot D_{vent}$

Plume dilution ratio at maximum plume rise (D_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	45.2	45.2	45.9	47.0	--[n/a]	56.9	RVD 2.0 - Equation 6. Plume dilution ratio at maximum plume rise. $D_h = 5.67 \cdot 10^{(-2)} \cdot u \cdot D_{vent}^{(2)} / Q_m \cdot (\Delta h_{min} / D_{vent})^{(1.85)} \cdot (MW_{CO2} / T_a)$ Note: Basic code in RVD for TSCREEN uses a corrected equation, below: $D_h = 5.67 \cdot u \cdot D_{vent}^{(2)} / Q_m \cdot (\Delta h_{min} / D_{vent})^{(1.85)} \cdot (MW_{CO2} / T_a)$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	59.0	59.0	59.8	61.3	67.5	74.3	
3	68.9	68.9	69.9	71.6	78.8	86.7	
4	--[n/a]	76.9	78.0	79.9	88.0	--[n/a]	
5	--[n/a]	83.8	85.0	87.1	95.8	--[n/a]	
8	--[n/a]	--[n/a]	101.8	104.3	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	110.9	113.6	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	129.5	132.7	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

Plume-equivalent molecular weight at maximum plume rise (MW_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	29.293	29.293	29.288	29.280	--[n/a]	29.224	RVD 2.0 - Equation 7. Plume-equivalent molecular weight at maximum plume rise. $MW_h = (MW_{CO2} + 28.96 \cdot (D_h - 1)) / D_h$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	29.215	29.215	29.212	29.206	29.183	29.163	
3	29.178	29.178	29.175	29.170	29.151	29.133	
4	--[n/a]	29.156	29.153	29.148	29.131	--[n/a]	
5	--[n/a]	29.140	29.137	29.133	29.117	--[n/a]	
8	--[n/a]	--[n/a]	29.108	29.104	--[n/a]	--[n/a]	
10	--[n/a]	--[n/a]	29.096	29.093	--[n/a]	--[n/a]	
15	--[n/a]	--[n/a]	29.076	29.073	--[n/a]	--[n/a]	
20	--[n/a]	--[n/a]	Neutral	Neutral	--[n/a]	--[n/a]	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - PSV-1440 (Average values for 15 second release time)
1st Iteration of Discharge Temperature (T2)

Plume temperature at maximum plume rise (T_h) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	294.57	294.57	294.62	294.70	--n/a	295.27	RVD 2.0 - Equation 8. Plume temperature at maximum plume rise. $T_h = T_a - (MW_{CO2} / MW_h) \cdot (T_a - T_2) / D_h$ Note: A calculated dilution ratio of less than 1 was assumed to be 1 (no dilution).
2	295.36	295.36	295.40	295.46	295.69	295.90	
3	295.74	295.74	295.77	295.82	296.02	296.20	
4	--n/a	295.97	296.00	296.05	296.23	--n/a	
5	--n/a	296.14	296.17	296.21	296.37	--n/a	
8	--n/a	--n/a	296.47	296.50	--n/a	--n/a	
10	--n/a	--n/a	296.59	296.62	--n/a	--n/a	
15	--n/a	--n/a	296.79	296.82	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Fractional density ratio at maximum plume rise (δ) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	0.023	0.023	0.023	0.022	--n/a	0.018	RVD 2.0 - Equation 9. Fractional density ratio at maximum plume rise. $\delta = ((MW_h / 28.96) \cdot (T_a / T_2)) - 1$ Note: A calculated frational density ratio greater than 0.005 indicates that dense gas behavior dominates the subsequent plume transport and RVD is appropriate for plume touchdown and ground level concentration calculations. A calculated frational density ratio less than or equal to 0.005 indicates neutrally-buoyant plume behavior which should be addressed using an alternate model.
2	0.018	0.018	0.018	0.017	0.016	0.014	
3	0.015	0.015	0.015	0.015	0.013	0.012	
4	--n/a	0.014	0.013	0.013	0.012	--n/a	
5	--n/a	0.013	0.012	0.012	0.011	--n/a	
8	--n/a	--n/a	0.010	0.010	--n/a	--n/a	
10	--n/a	--n/a	0.009	0.009	--n/a	--n/a	
15	--n/a	--n/a	0.008	0.008	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Step 3. Concentration Estimates at Plume Touchdown

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - PSV-1440 (Average values for 15 second release time)
1st Iteration of Discharge Temperature (T2)

Ambient concentration at plume touchdown (maximum ground-level concentration) (C_T) in units of µg / m^3 by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	12,969,940	12,969,940	12,783,632	12,478,610	--n/a	10,269,222	RVD 2.0 - Equation 10. Ambient concentration at plume touchdown (maximum ground-level concentration). $C_T = 6.0 \cdot 10^{(9)} \cdot Q_m / u \cdot ((2 \cdot \Delta h + H_S))^{(-2.0)}$ Note: Basic code in RVD for TSCREEN uses a different equation, below: $C_T = 5.1 \cdot 10^{(9)} \cdot Q_m \cdot ((2 \cdot \Delta h + HS))^{(-1.95)} / (u \cdot D_{vent}^{(0.05)})$ These values represents the 1-hour concentrations from a continuous emission source. If the emissions occur for less than 1 hour, or if the averaging period of concern is less than 1 hour, use the values calculated below in Step 4.
2	9,905,618	9,905,618	9,760,214	9,522,195	8,621,997	7,799,614	
3	8,436,077	8,436,077	8,310,429	8,104,771	7,327,242	6,617,378	
4	--n/a	7,516,427	7,403,210	7,217,917	6,517,593	--n/a	
5	--n/a	6,866,340	6,761,953	6,591,124	5,945,638	--n/a	
8	--n/a	--n/a	5,570,838	5,427,076	--n/a	--n/a	
10	--n/a	--n/a	5,073,542	4,941,181	--n/a	--n/a	
15	--n/a	--n/a	4,269,047	4,155,299	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Ambient concentration at plume touchdown (maximum ground-level concentration) (C_T) in units of ppmV by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	7,206	7,206	7,103	6,933	--n/a	5,706	Conversion from µg/m^3 to ppmV These values represents the 1-hour concentrations from a continuous emission source. If the emissions occur for less than 1 hour, or if the averaging period of concern is less than 1 hour, use the values calculated below in Step 4.
2	5,504	5,504	5,423	5,291	4,791	4,334	
3	4,687	4,687	4,618	4,503	4,071	3,677	
4	--n/a	4,176	4,113	4,010	3,621	--n/a	
5	--n/a	3,815	3,757	3,662	3,304	--n/a	
8	--n/a	--n/a	3,095	3,015	--n/a	--n/a	
10	--n/a	--n/a	2,819	2,745	--n/a	--n/a	
15	--n/a	--n/a	2,372	2,309	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

User's Guide for RVD 2.0 - A Relief Valve Discharge Screening Model
U.S. Environmental Protection Agency, EPA-450/4-88-024, January 1989
Echogen SCO2 Vent Study - PSV-1440 (Average values for 15 second release time)
1st Iteration of Discharge Temperature (T2)

Downwind distance to plume touchdown in units of meters (X_T) by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	103	103	107	115	--n/a	191	RVD 2.0 - Equation 11. Downwind distance to plume touchdown. $X_T = D_{vent} \cdot Fr^{(2)} / R_V + 0.56 \cdot D_{vent} \cdot Fr_H / R_V^{(1/2)} \cdot C_1$
2	210	210	219	233	302	390	
3	319	319	332	354	458	594	RVD 2.0 - Equation 12 $C_1 = ((\Delta h / D_{vent})^{(3)} \cdot ((2 + H_S / \Delta h)^{(3)} - 1))^{(1/2)}$
4	--n/a	429	446	476	617	--n/a	
5	--n/a	541	562	600	778	--n/a	RVD 2.0 - Equation 13. Horizontal densimetric Froude number $Fr_H = u / (g \cdot D_{vent} \cdot (\rho_{air} / \rho_2 - 1))^{(1/2)}$
8	--n/a	--n/a	916	977	--n/a	--n/a	
10	--n/a	--n/a	1,156	1,234	--n/a	--n/a	Note: Basic code in RVD for TSCREEN uses a corrected equation for Fr_H, below: $Fr_H = u * (((\rho_{air} / (\rho_2 - \rho_{air})) / (g \ D_{vent}))^{(1/2)}$
15	--n/a	--n/a	1,767	1,887	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Step 4. Concentration Estimates at Downwind Distances after Touchdown

User-Specified Averaging Time (t_a):	1	min

Calculated Release Duration (t_d):		0.2500	min

Note: See TSCREEN for release duration calculation.

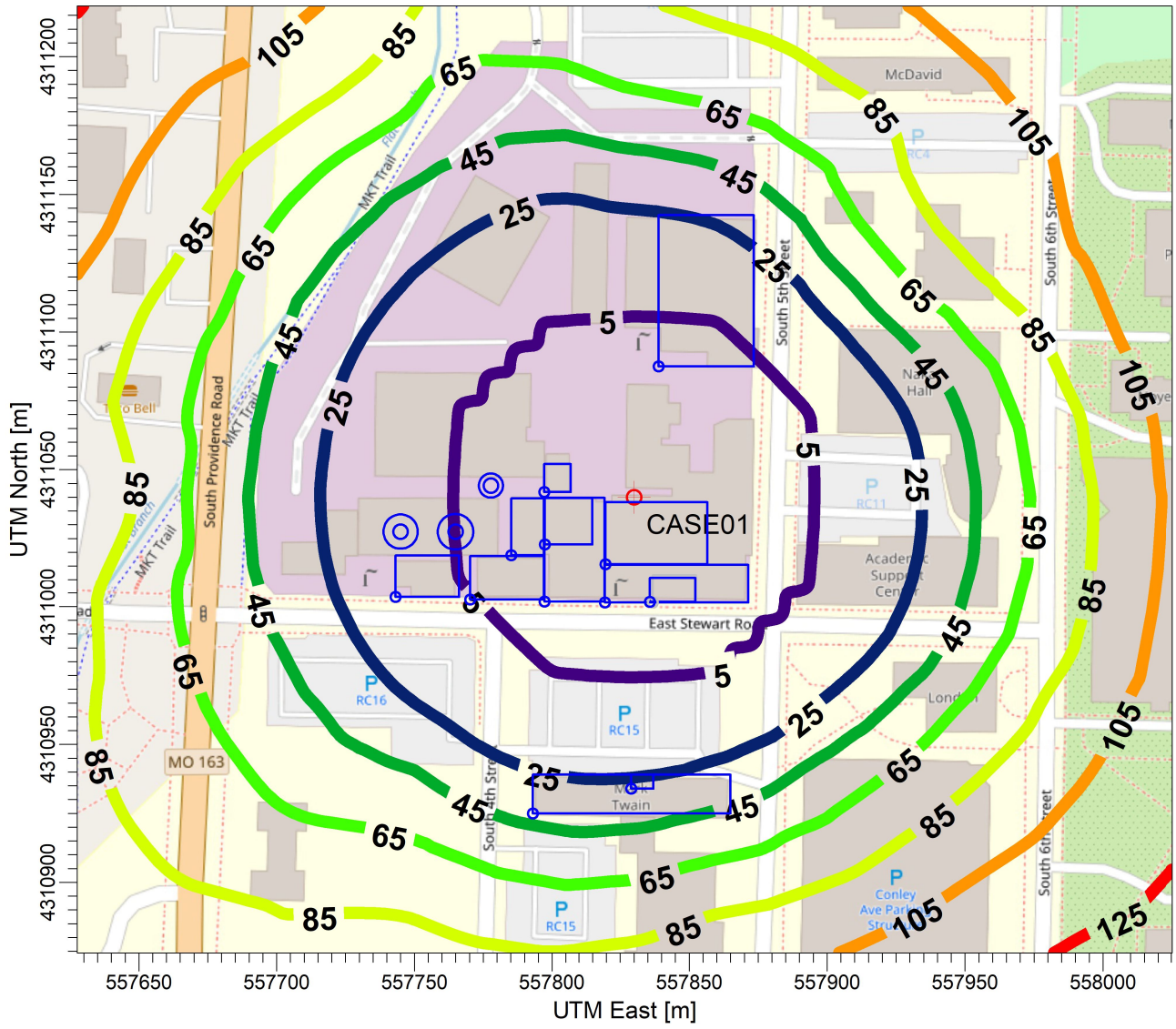
Ambient concentration at plume touchdown (maximum ground-level concentration) including correction factors for user-specified averaging time and calculated release duration (C_{TF}) in units of ppmV by Wind Speed @ 10 meters above ground and Atmospheric Stability Class

Wind Speed @ 10m (u_{10})	P-G Atmospheric Stability Classes						Source // Reference
m/s	A	B	C	D	E	F	
1	4,086	4,086	4,027	3,931	--n/a	3,235	RVD 2.0 - Equation 16. Correction factor if release duration is less than the averaging time. $C_{TF} = C \cdot (t_d / t_a)$
2	3,121	3,121	3,075	3,000	2,716	2,457	
3	2,658	2,658	2,618	2,553	2,308	2,085	RVD 2.0 - Equation 17. Correction factor if averaging time is less than 60 minutes. $C_{TF} = C \cdot (60 / t_a)^{(0.2)}$
4	--n/a	2,368	2,332	2,274	2,053	--n/a	
5	--n/a	2,163	2,130	2,076	1,873	--n/a	where C_{TF} = the corrected touchdown concentration, C_T.
8	--n/a	--n/a	1,755	1,710	--n/a	--n/a	
10	--n/a	--n/a	1,598	1,557	--n/a	--n/a	
15	--n/a	--n/a	1,345	1,309	--n/a	--n/a	
20	--n/a	--n/a	Neutral	Neutral	--n/a	--n/a	

Receptor	Receptor Dist from vent (m)	Recepter Elevation BELOW Vent (m)	Recepter Elevation ABOVE Ground (m)	15-sec Average CO2 Conc. ppmv	1-min Average CO2 Conc. ppmv	5-min Average CO2 Conc. ppmv	15-min Average CO2 Conc. ppmv
Penthouse Roof	3	3.0	32.0	0	0	0	0
Penthouse Platform	5	8.5	26.5	0	0	0	0
Existing Bldg S. of Penthouse	28	19.0	16.0	0	0	0	0
Lower N. Stack Platform (Existing)	32	-11.0	46.0	0	0	0	0
Existing Bldg SW. of Penthouse	32	3.0	32.0	0	0	0	0
Nearest Sidewalk	42	35.0	0.0	0	0	0	0
Lower S. Stack Platform (Existing)	114	-11.0	46.0	23,091	4,375	634	170
Mark Twain Hall-Elevator Penthouse	120	2.0	33.0	22,345	4,234	614	164
Mark Twain Hall	120	10.0	25.0	20,774	3,936	571	153
Apprtmts W of Mark Twain Hall	140	15.0	20.0	18,988	3,598	521	140
Apprtmts S of Mark Twain Hall	210	10.0	25.0	16,789	3,181	461	123
Downtown Bldg 4	300	-5.0	40.0	16,527	3,131	454	121
Downtown Bldg 1	562	-5.0	40.0	13,088	2,480	359	96
Downtown Bldg 5	574	-4.0	39.0	13,006	2,464	357	96
Downtown Bldg 3	644	1.0	34.0	12,334	2,337	339	91
Downtown Bldg 2	800	-10.0	45.0	11,547	2,188	317	85
Downtown Bldg 6	885	-2.0	37.0	11,099	2,103	305	82
Peak Concentration:	120	35.0	0.0	16,883	3,199	464	124

PROJECT TITLE:

Echogen Case 1, Scenario 4
1st 1 minute of release, Ground Level Conc., 115ft Stack, With Bldgs



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL PPMV

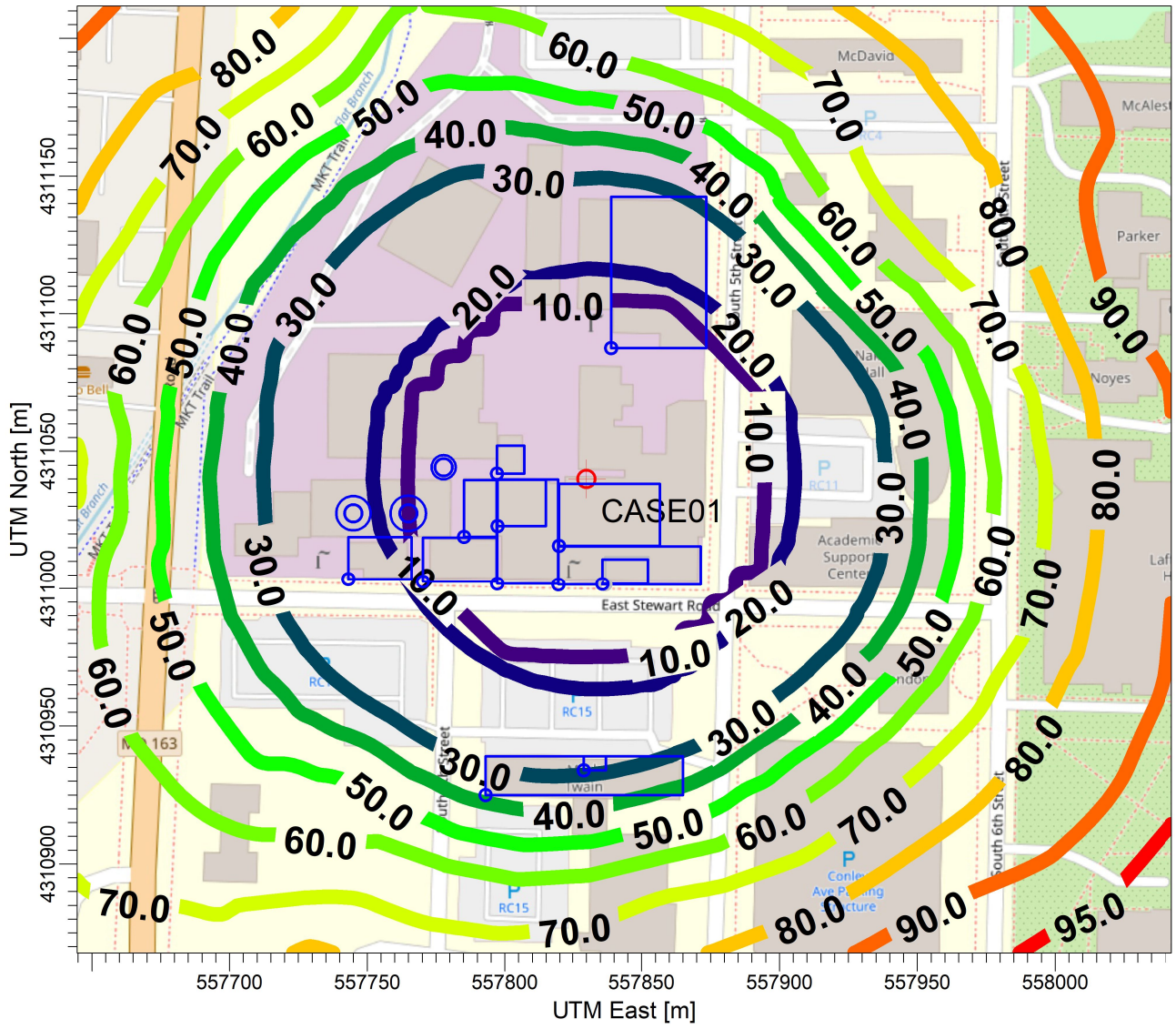
Max: 140 [PPMV] at (558022.84, 4310810.19)



COMMENTS: 1-Minute Average Conc.	SOURCES: **1**	COMPANY NAME: **CDM Smith**	
	RECEPTORS: **2205**	MODELER: **Gilbride/Pehrson**	
	OUTPUT TYPE: **Concentration**	SCALE: 1:2,500 0 0.05 km	
	MAX: **140 PPMV**	DATE: **10/7/2020**	PROJECT NO.:

PROJECT TITLE:

Echogen Case 1, Scenario 5
Next 4 minutes of release, Grnd Lvl Conc., 115ft Stack, With Bldgs



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL PPMV

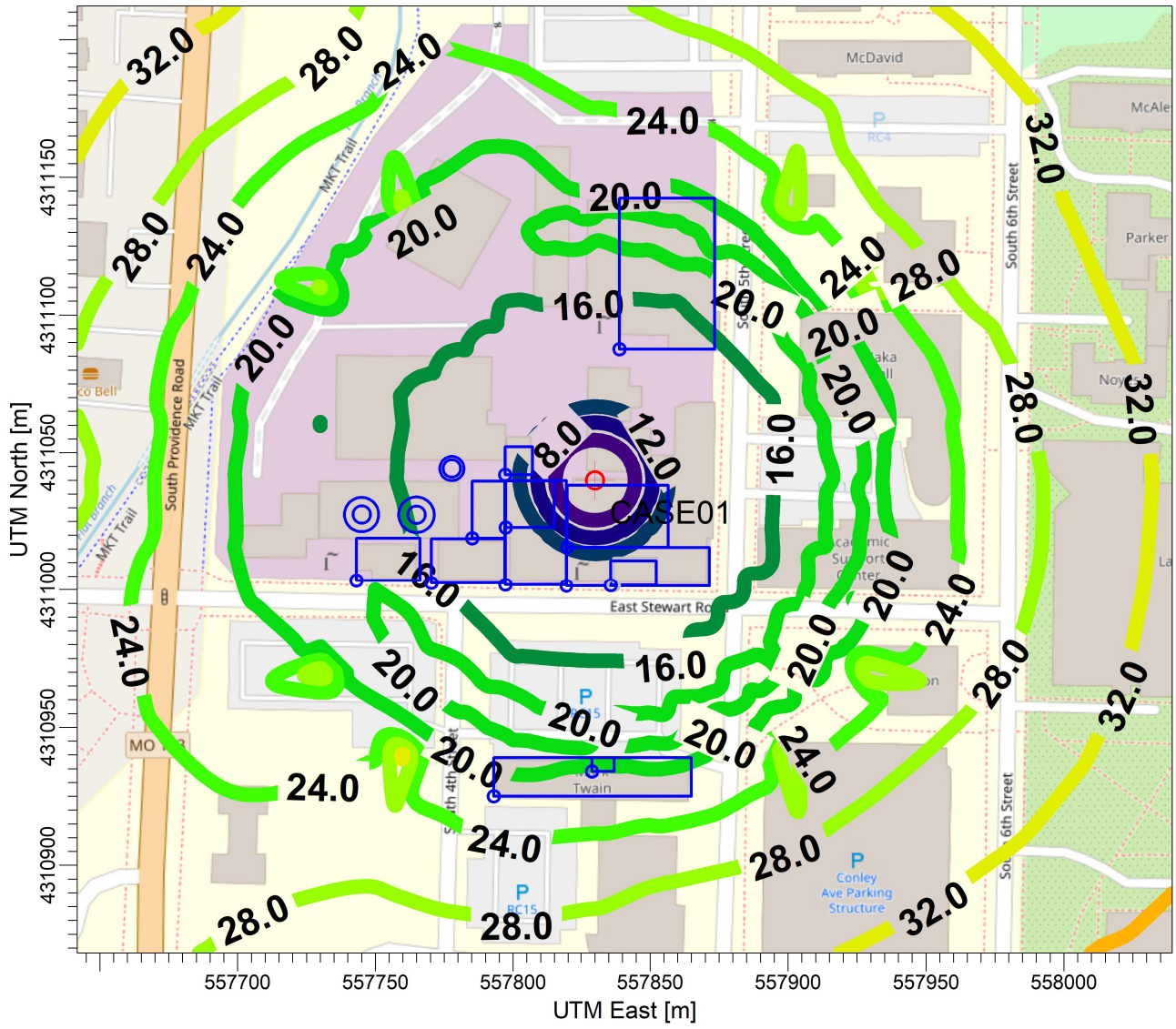
Max: 98.6 [PPMV] at (557955.00, 4310823.49)

10.0 20.0 30.0 40.0 50.0 60.0 70.0 80.0 90.0 95.0

COMMENTS: 4-Minute Average Conc.	SOURCES: **1**	COMPANY NAME: **CDM Smith**	
	RECEPTORS: **2205**	MODELER: **Gilbride/Pehrson**	
	OUTPUT TYPE: **Concentration**	SCALE: 1:2,500 0 0.05 km	
	MAX: **98.6 PPMV**	DATE: **10/7/2020**	PROJECT NO.:

PROJECT TITLE:

Echogen Case 1, Scenario 6
Final 27 miinutes of release, Grnd Lv Conc., 115ft Stack, With Bldgs



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL PPMV

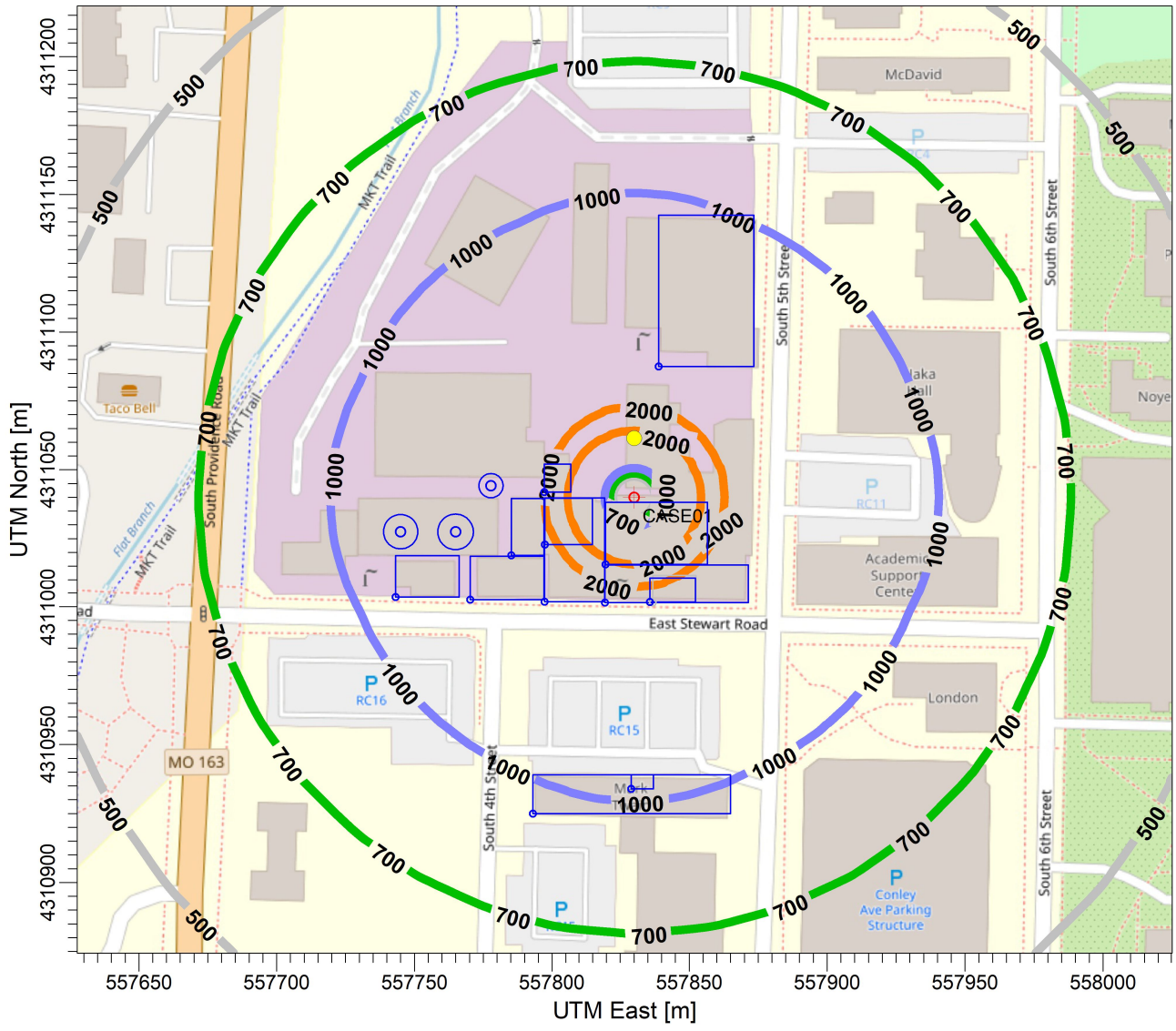
Max: 44.1 [PPMV] at (558174.72, 4310750.75)

4.0 8.0 12.0 16.0 20.0 24.0 28.0 32.0 36.0 40.0 44.0

COMMENTS: 27-Minute Average Conc.	SOURCES: **1**	COMPANY NAME: **CDM Smith**	
	RECEPTORS: **2205**	MODELER: **Gilbride/Pehrson**	
	OUTPUT TYPE: **Concentration**	SCALE: 1:2,500 0 0.05 km	
	MAX: **44.1 PPMV**	DATE: **10/7/2020**	PROJECT NO.:

PROJECT TITLE:

Echogen Case 1, Scenario 4
1st 1 miinute of release, 32m EL Conc., 115ft Stack, With Bldgs



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL PPMV

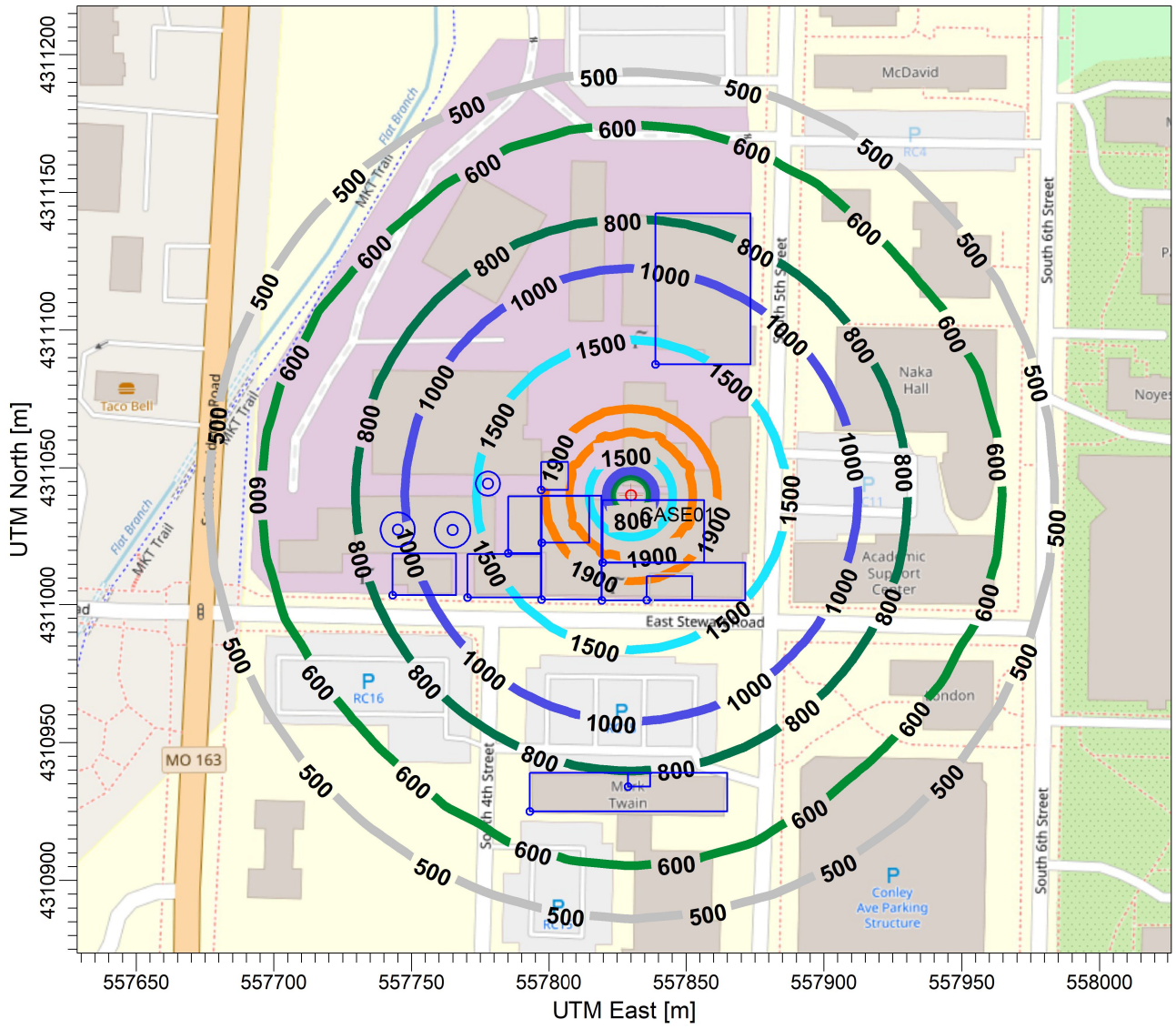
Max: 2081 [PPMV]

500 700 1000 2000

COMMENTS: 1-Minute Average Conc.	SOURCES: **1**	COMPANY NAME:	
	RECEPTORS: **2206**	MODELER:	
	OUTPUT TYPE: **Concentration**	SCALE: 1:2,500 0 0.05 km	
	MAX: **2081 PPMV**	DATE: **9/21/2020**	PROJECT NO.:

PROJECT TITLE:

Echogen Case 1, Scenario 5
Next 4 minutes of release, 32m EL Conc., 115ft Stack, With Bldgs



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL PPMV

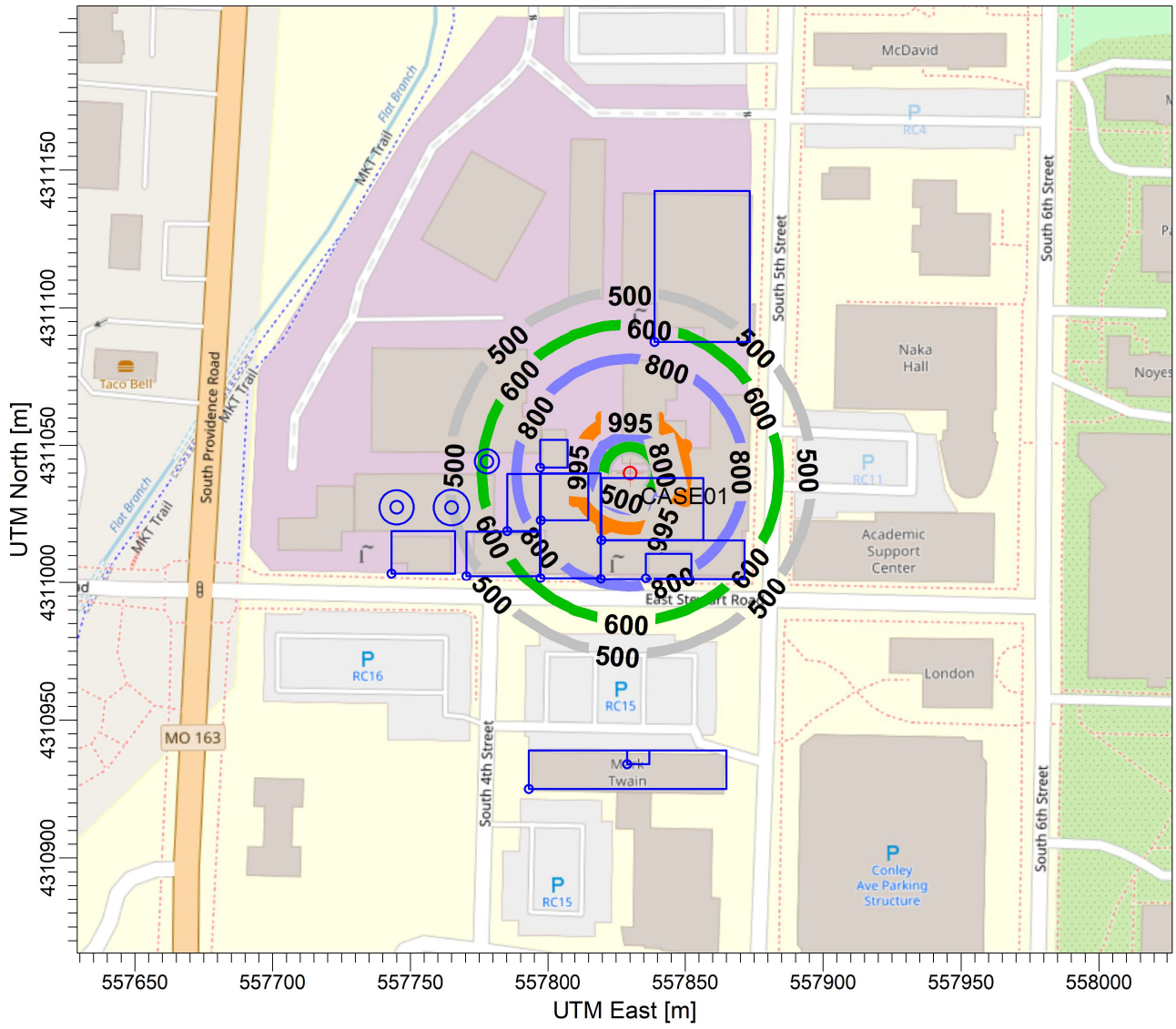
Max: 1967 [PPMV]



COMMENTS: 4-Minute Average Conc.	SOURCES: **1**	COMPANY NAME: **CDM Smith**	
	RECEPTORS: **2206**	MODELER: **Gilbride/Pehrson**	
	OUTPUT TYPE: **Concentration**	SCALE: 1:2,500 0 0.05 km	
	MAX: **1967 PPMV**	DATE: **10/7/2020**	PROJECT NO.:

PROJECT TITLE:

Echogen Case 1, Scenario 6
Final 27 miinutes of release, 32m EL Conc., 115ft Stack, With Bldgs



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL PPMV

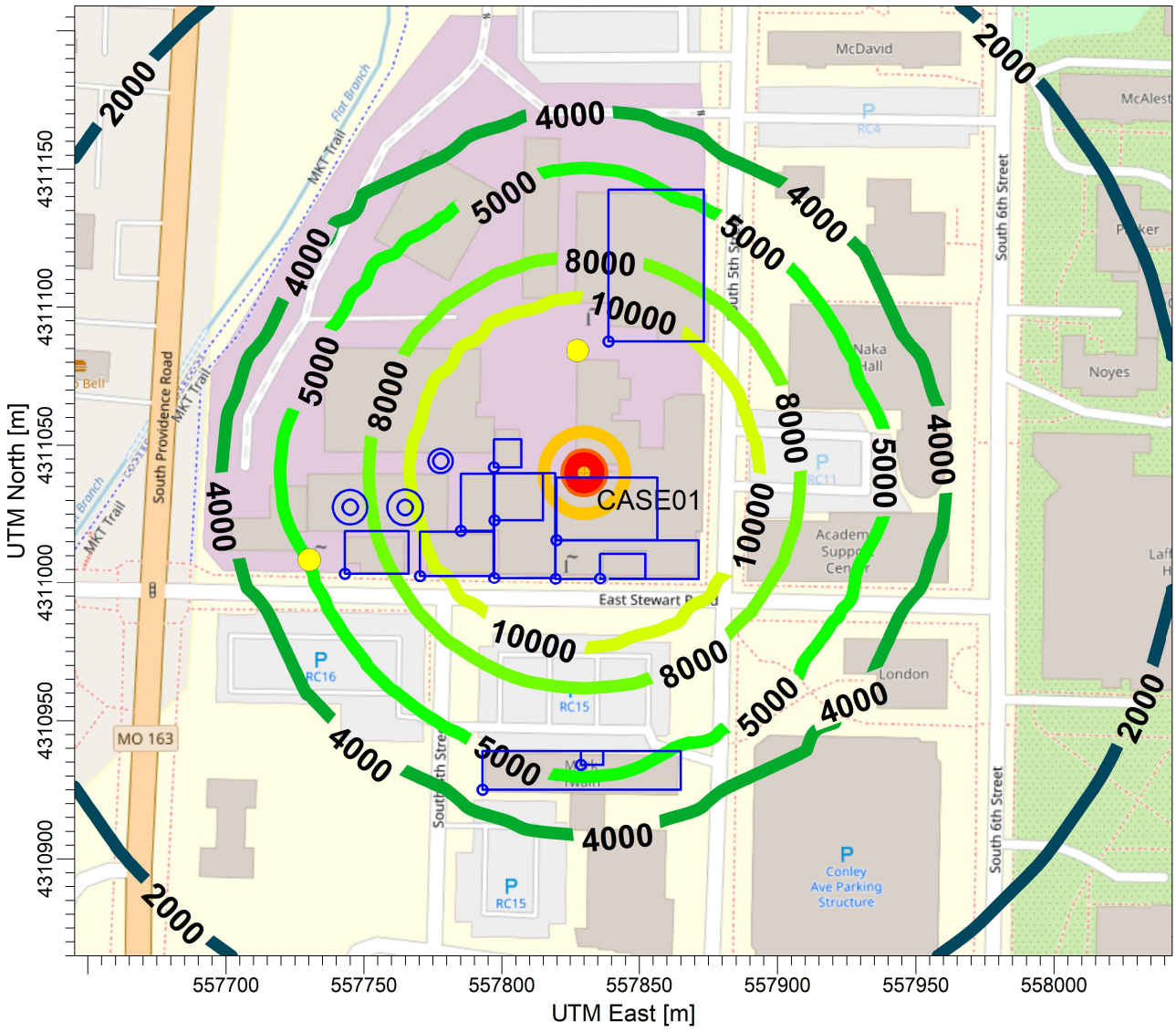
Max: 1009 [PPMV] at (557830.10, 4311061.43)

500 600 800 995

COMMENTS: 27-Minute Average Conc.	SOURCES: **1**	COMPANY NAME: **CDM Smith**	
	RECEPTORS: **2206**	MODELER: **Gilbride/Pehrson**	
	OUTPUT TYPE: **Concentration**	SCALE: 1:2,500 0 0.05 km	
	MAX: **1009 PPMV**	DATE: **10/7/2020**	PROJECT NO.:

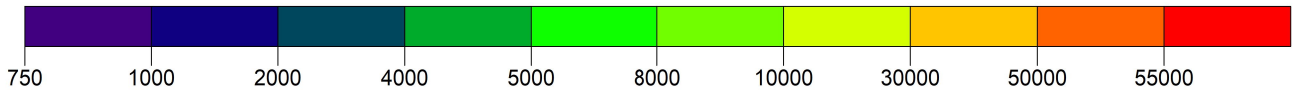
PROJECT TITLE:

Echogen Case 1, Scenario 4
1st 1 minute of release, 50m EL Conc., 115ft Stack, With Bldgs



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL PPMV

Max: 55540 [PPMV]

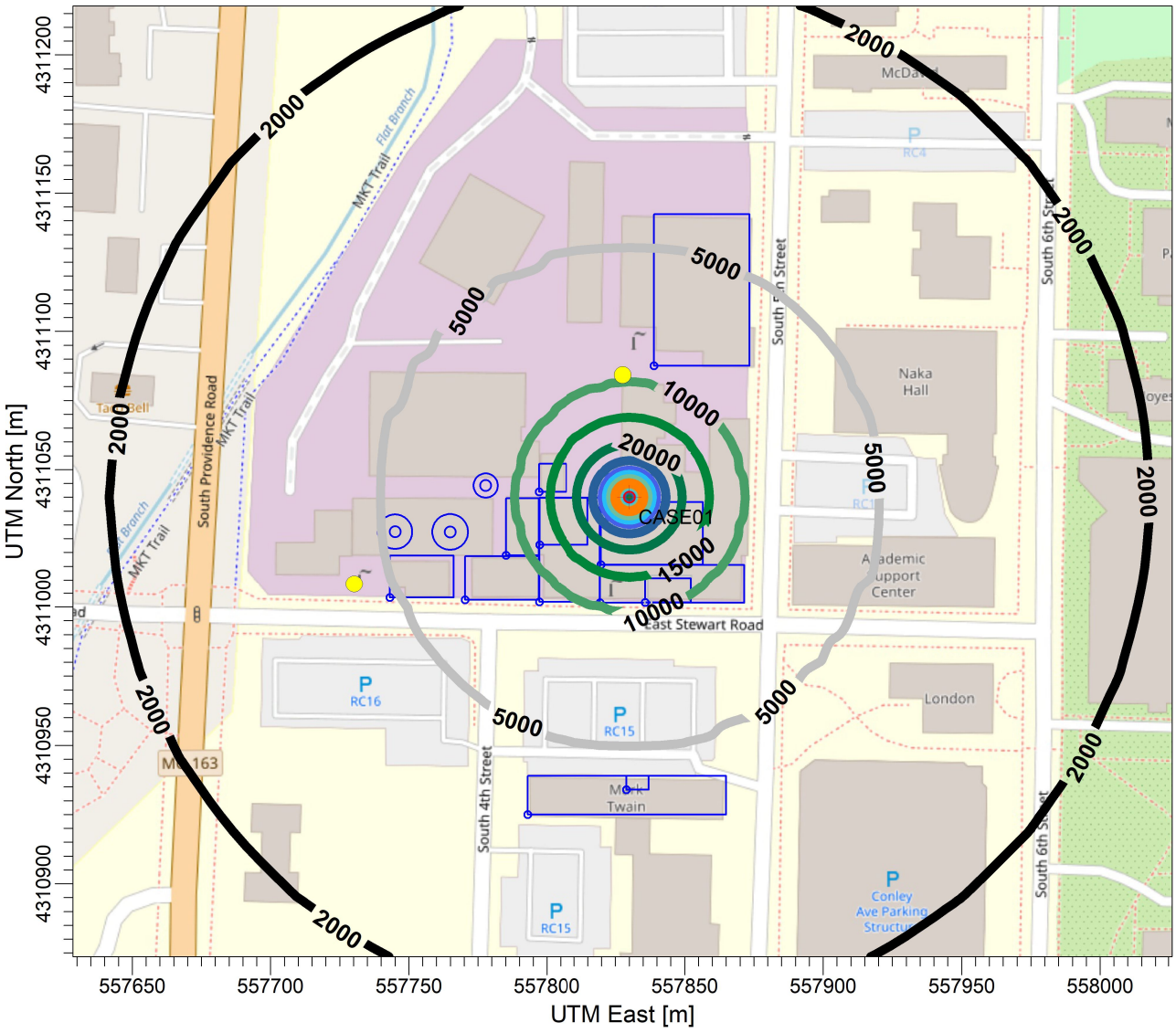


COMMENTS:	SOURCES:	COMPANY NAME:	
1-Minute Average Conc.	**1**	**CDM Smith**	
	RECEPTORS: **2207**	MODELER: **Gilbride/Pehrson**	
	OUTPUT TYPE: **Concentration**	SCALE: 1:2,500 — 0 — 0.05 km	
	MAX: **55540 PPMV**	DATE: **10/7/2020**	PROJECT NO.:

AERMOD View - Lakes Environmental Software C:\Lakes\AERMOD View\Projects\Echogen\Case01_Scen04_1stMin_115ftStk_50mEL\Case01_Scen04_1stMin_115ftStk_50mEL.isc

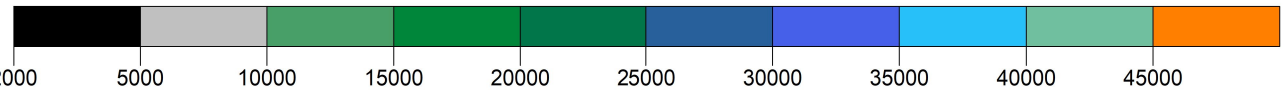
PROJECT TITLE:

Echogen Case 1, Scenario 5
Next 4 minutes of release, 50m EL Conc., 115ft Stack, With Bldgs



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL PPMV

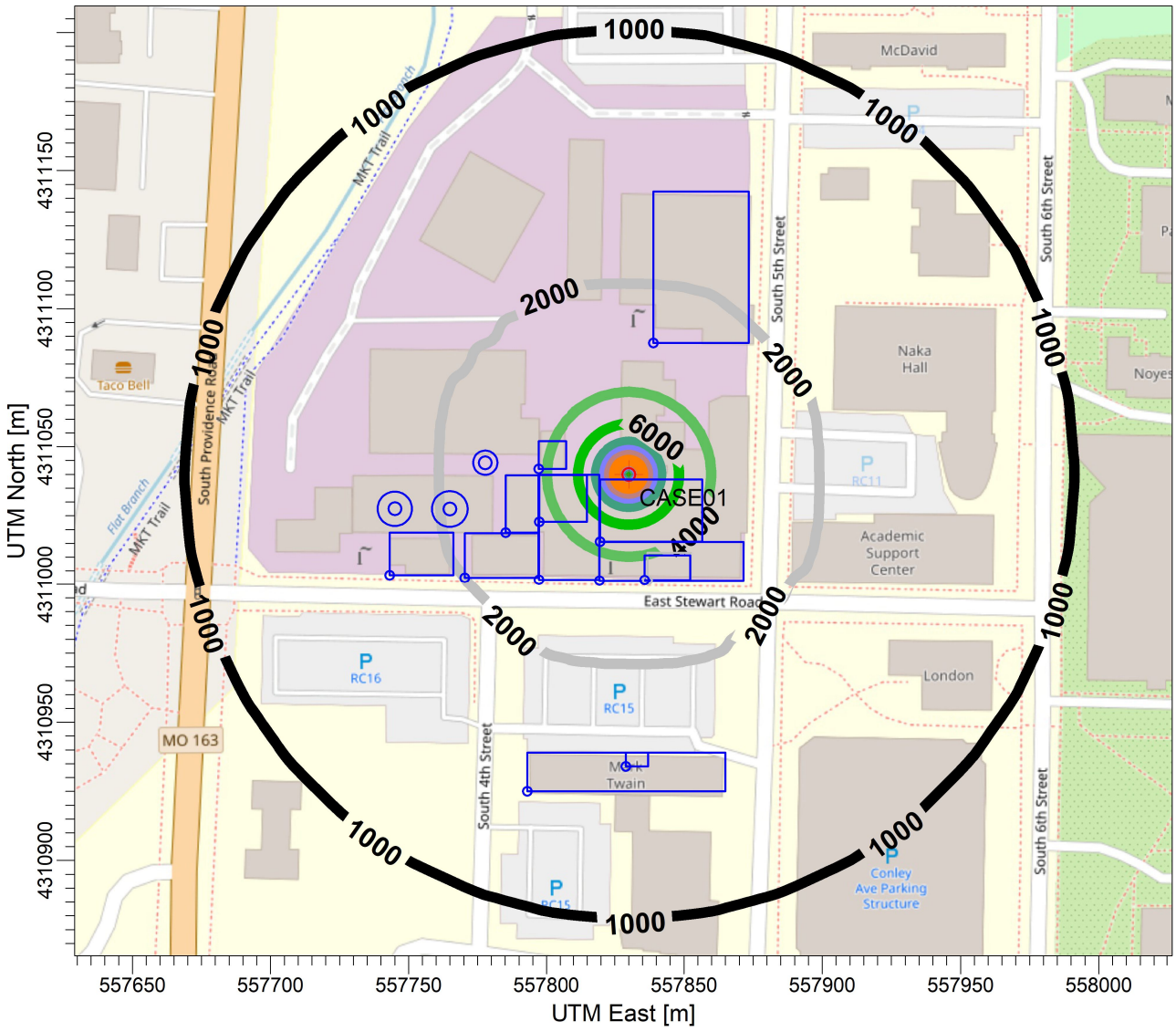
Max: 45658 [PPMV]



COMMENTS: 4-Minute Average Conc.	SOURCES: **1**	COMPANY NAME: **CDM Smith**	
	RECEPTORS: **2207**	MODELER: **Gilbride/Pehrson**	
	OUTPUT TYPE: **Concentration**	SCALE: 1:2,500 0 0.05 km	
	MAX: **45658 PPMV**	DATE: **10/7/2020**	PROJECT NO.:

PROJECT TITLE:

Echogen Case 1, Scenario 6
Final 27 miinutes of release, 50m EL Conc., 115ft Stack, With Bldgs



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL PPMV

Max: 14209 [PPMV]

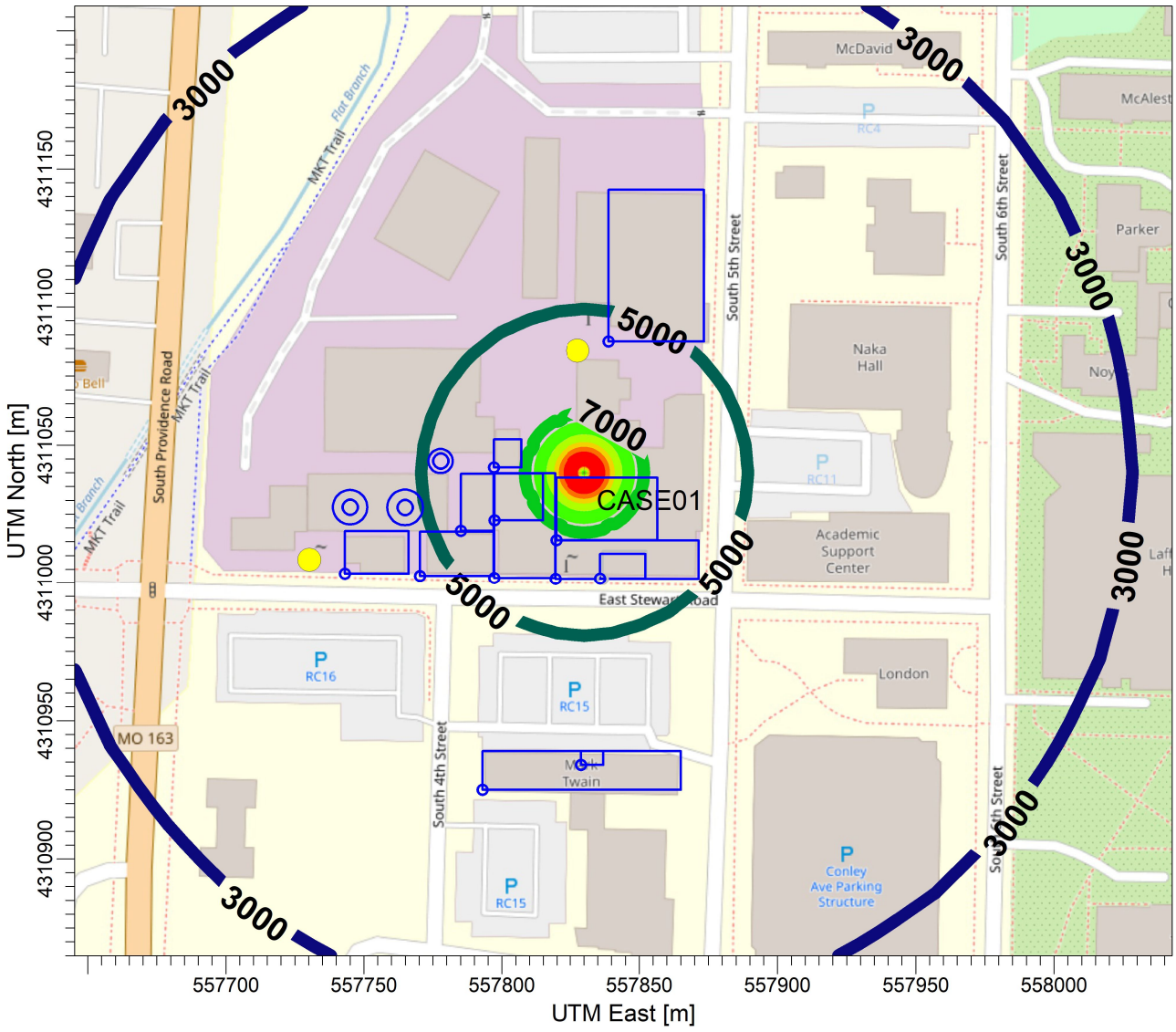
1000 2000 4000 6000 8000 10000 12000 14000

COMMENTS: 27-Minute Average Conc.	SOURCES: **1**	COMPANY NAME: **CDM Smith**	
	RECEPTORS: **2207**	MODELER: **Gilbride/Pehrson**	
	OUTPUT TYPE: **Concentration**	SCALE: 1:2,500 0 0.05 km	
	MAX: **14209 PPMV**	DATE: **10/7/2020**	PROJECT NO.:

AERMOD View - Lakes Environmental Software C:\Lakes\AERMOD View\Projects\Echogen\Case01_Scen06_27Min_115ftStk_50mEL\Case01_Scen06_27Min_115ftStk_50mEL.isc

PROJECT TITLE:

Echogen Case 1, Scenario 4
1st 1 minute of release, 90m EL Conc., 115ft Stack, With Bldgs



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL PPMV

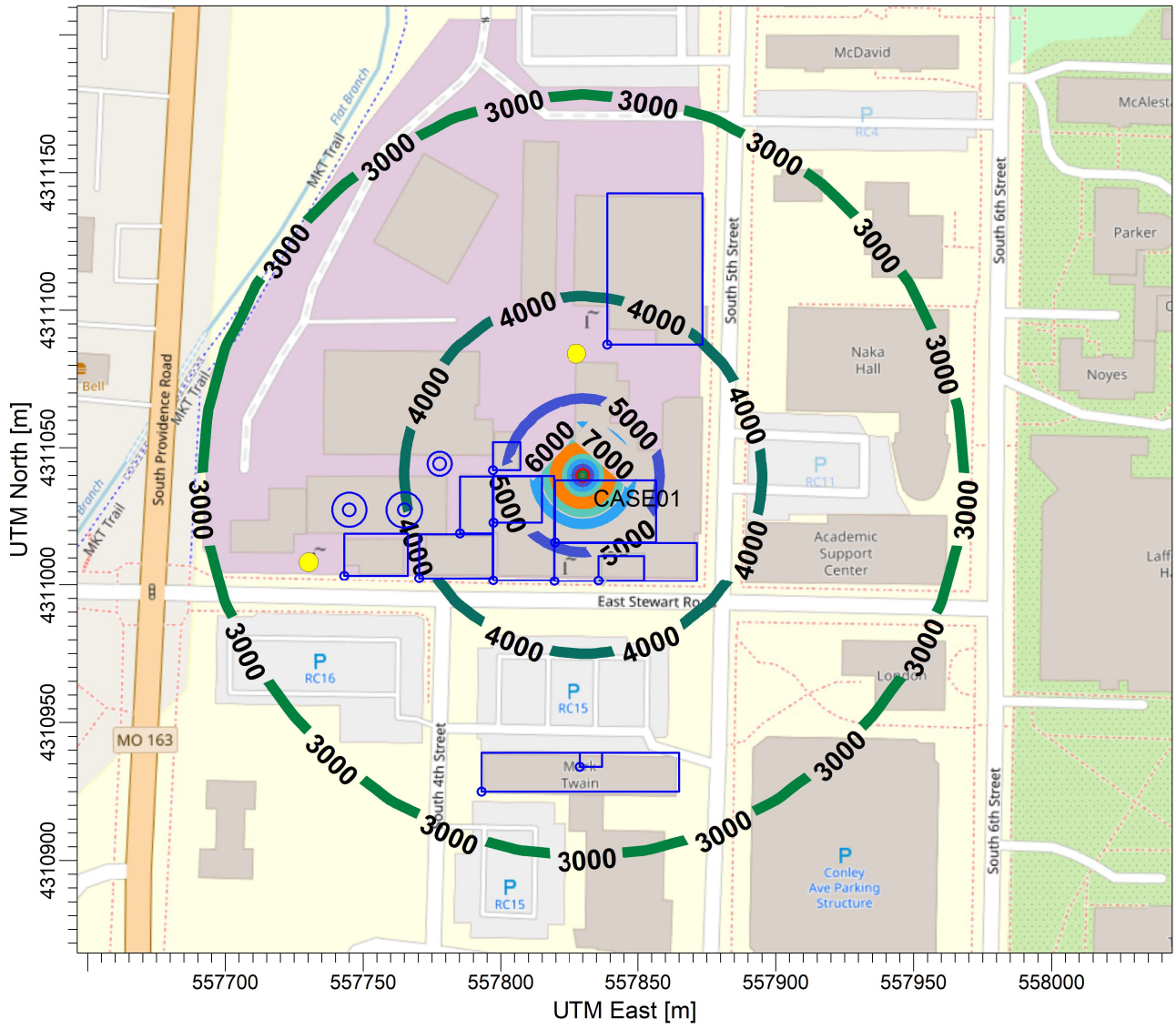
Max: 17503 [PPMV]

1000 3000 5000 7000 9000 11000 13000 15000 17000

COMMENTS: 1-Minute Average Conc.	SOURCES: **1**	COMPANY NAME: **CDM Smith**	
	RECEPTORS: **2207**	MODELER: **Gilbride/Pehrson**	
	OUTPUT TYPE: **Concentration**	SCALE: 1:2,500 0 0.05 km	
	MAX: **17503 PPMV**	DATE: **10/7/2020**	PROJECT NO.:

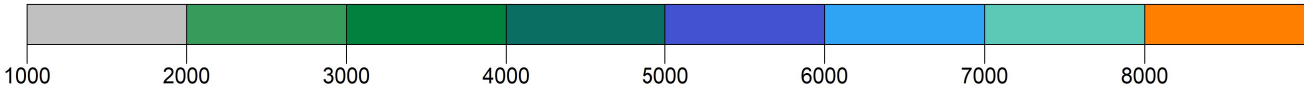
PROJECT TITLE:

Echogen Case 1, Scenario 5
Next 4 minutes of release, 90m EL Conc., 115ft Stack, With Bldgs



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL PPMV

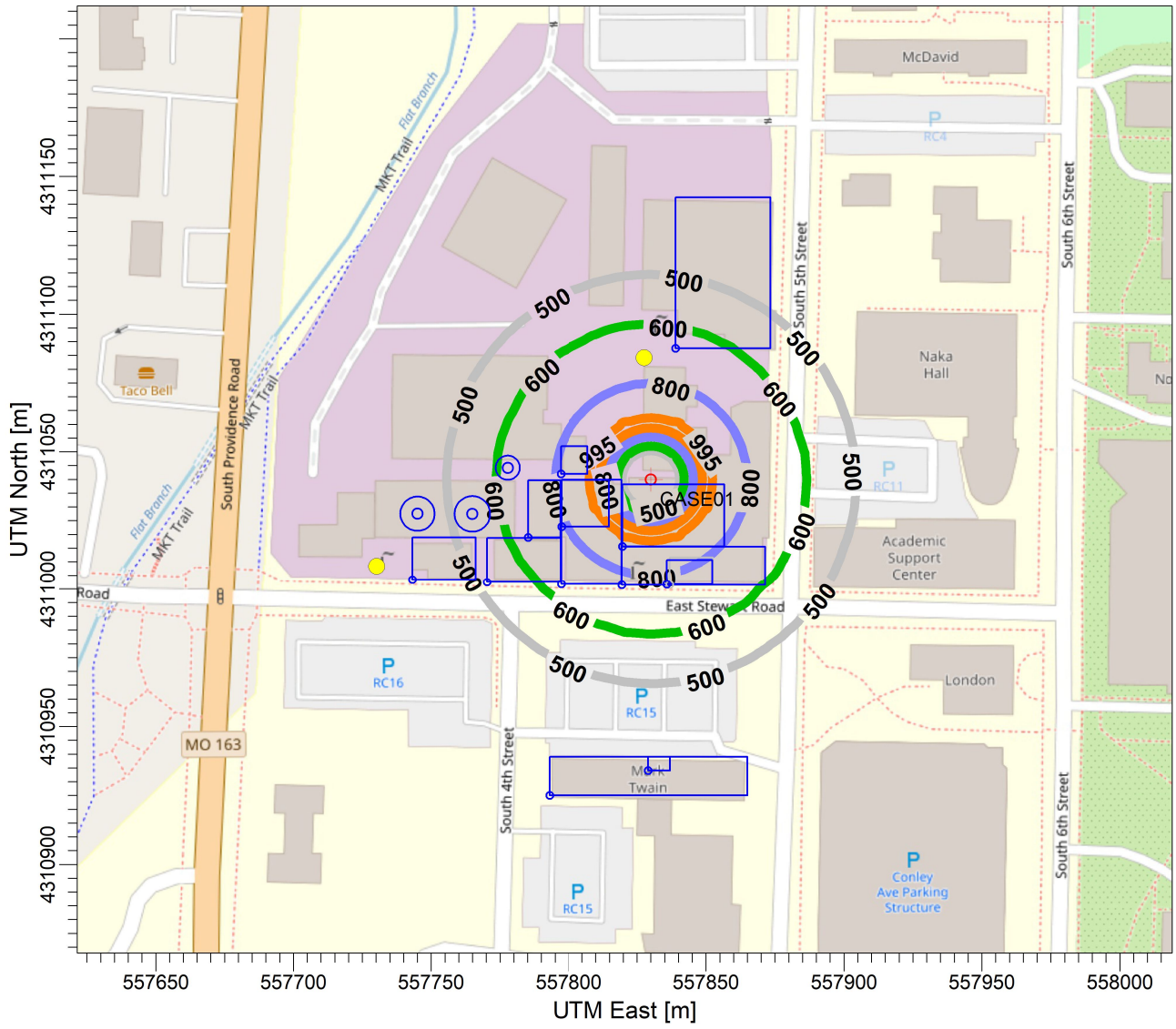
Max: 8131 [PPMV]



COMMENTS: 4-Minute Average Conc.	SOURCES: **1**	COMPANY NAME: **CDM Smith**	
	RECEPTORS: **2207**	MODELER: **Gilbride/Pehrson**	
	OUTPUT TYPE: **Concentration**	SCALE: 1:2,500 0 0.05 km	
	MAX: **8131 PPMV**	DATE: **10/7/2020**	PROJECT NO.:

PROJECT TITLE:

Echogen Case 1, Scenario 6
Final 27 miinutes of release, 90m EL Conc., 115ft Stack, With Bldgs



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL PPMV

Max: 1072 [PPMV]

500 600 800 995

COMMENTS: 27-Minute Average Conc.	SOURCES: **1**	COMPANY NAME: **CDM Smith**	
	RECEPTORS: **2207**	MODELER: **Gilbride/Pehrson**	
	OUTPUT TYPE: **Concentration**	SCALE: 1:2,500 0 0.05 km	
	MAX: **1072 PPMV**	DATE: **10/7/2020**	PROJECT NO.:

III. Design Drawings (Balance of Plant)

ECHOGEN POWER SYSTEMS
THE UNIVERSITY OF MISSOURI CHP PLANT
LARGE SCALE SC02 SYSTEM PHASE 2

GENERAL DRAWINGS

DWG NO	DESCRIPTION
G-001	COVER SHEET

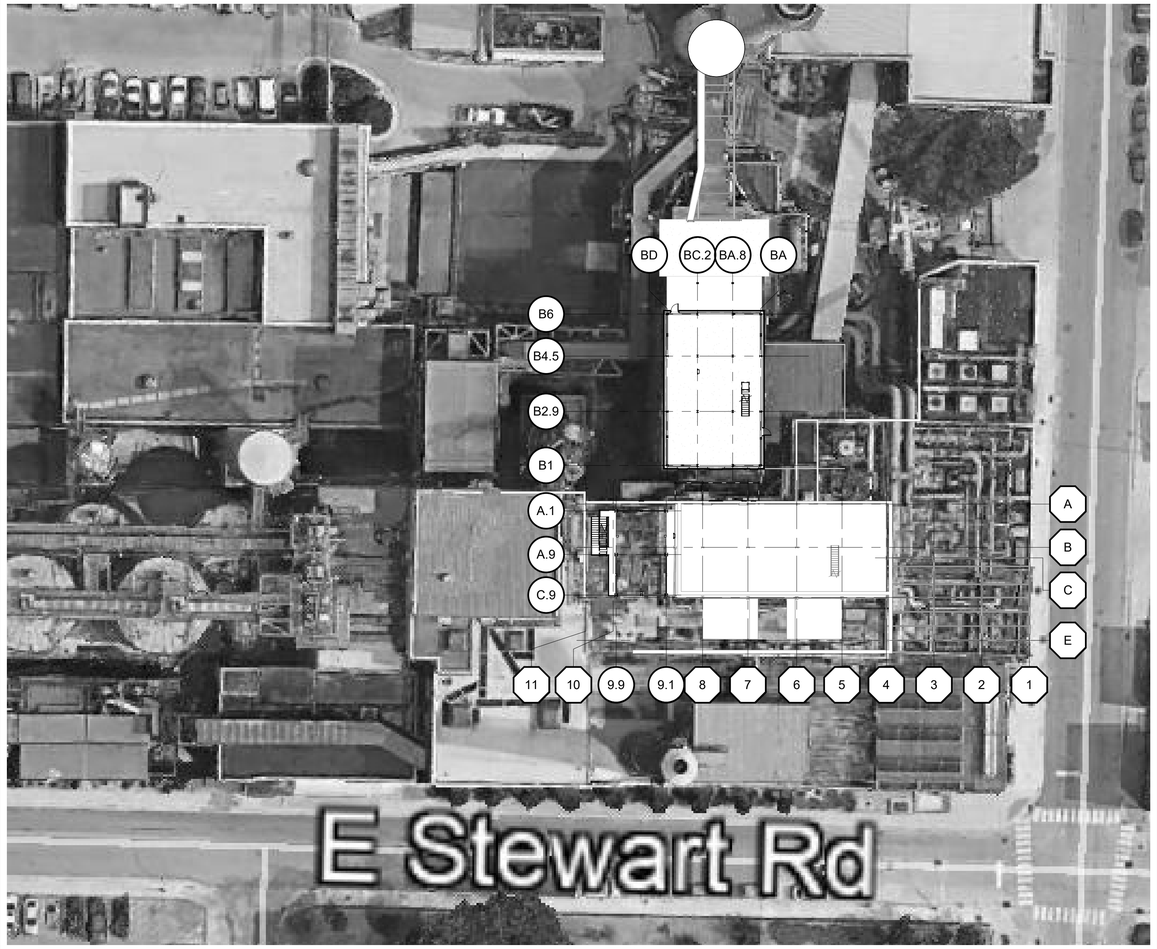
CIVIL DRAWINGS

DWG NO	DESCRIPTION
C-101	LAYDOWN/SITE PLAN
C-102	E STEWART RD PLAN & PROFILE
C-103	GENERAL NOTES & DETAILS
C-104	MSE WALL DETAILS SHEET 1
C-105	MSE WALL DETAILS SHEET 2
C-106	TRAFFIC CONTROL PLAN

STRUCTURAL DRAWINGS

DWG NO	DESCRIPTION
S-001	DESIGN CRITERIA, GENERAL NOTES AND LEGEND
S-002	SCHEDULE OF SPECIAL INSPECTIONS
S-101	EXIST BOILER ROOM FOUNDATION PLAN & SECTIONS
S-102	OPERATOR FLOOR DEMOLITION PLAN @ EL 697'-11"
S-103	OPERATOR FLOOR FRAMING PLAN @ EL 697'-11"
S-104	FRAMING PLANS @ EL 704'-2" & 712'-0"
S-105	FRAMING PLANS @ EL 715'-0", 720'-6" & 721'-5"
S-106	FRAMING PLANS @ EL 728'-10" & 737'-6"
S-107	FRAMING PLANS @ EL 749'-2" & 759'-8"
S-108	BAGHOUSE FRAMING PLAN @ EL 736'-0"
S-109	BAGHOUSE FRAMING PLANS @ EL 743'-4" & 751'-4"
S-110	BAGHOUSE ROOF FRAMING PLANS
S-111	BAGHOUSE FRAMING PLANS @ EL 738'-0", 762'-9 1/2" & 787'-4"
S-201	FIRE HEATER FRAMING ELEVATIONS @ COL LN A.1, C.9, 9.1 & 9.9
S-202	BAGHOUSE FRAMING ELEVATIONS SHT 1
S-203	BAGHOUSE FRAMING ELEVATIONS SHT 2
S-204	EXIST BOILER BLDG FRAMING ELEVATIONS
S-701	FOUNDATION DETAILS
S-702	BEAM AND HORIZONTAL BRACE CONNECTION DETAILS
S-703	VERTICAL AND KNEE BRACE DETAILS
S-704	STAIR AND ROOF FRAMING DETAILS
S-705	RAILING DETAILS
S-706	GIRT, OUTRIGGER AND MONORAIL DETAILS

PROJECT KEY PLAN



ARCHITECTURAL DRAWINGS

DWG NO	DESCRIPTION
A-115	FLOOR PLAN - EXISTING BAGHOUSE LEVEL
A-117	FLOOR PLAN - PLATFORM LEVEL 752'-6"
A-118	FLOOR PLAN - PLATFORM LEVEL 763'-2 1/2"
A-119	ROOF PLAN
A-201	EXTERIOR ELEVATIONS
A-202	EXTERIOR ELEVATIONS
A-301	BUILDING SECTIONS
A-701	MISCELLANEOUS DETAILS / SCHEDULES

MECHANICAL DRAWINGS

DWG NO	DESCRIPTION
M-100	EQUIPMENT ARRANGEMENT @ BASEMENT LEVEL
M-101	EQUIPMENT ARRANGEMENT @ OPERATING LEVEL
M-102	EQUIPMENT ARRANGEMENT @ MEZZANINE LEVEL
M-103	EQUIPMENT ARRANGEMENT @ OUTSIDE PLATFORM MAIN LEVEL
M-104	EQUIPMENT ARRANGEMENT @ OUTSIDE PLATFORM INTERM LEVEL
M-105	EQUIPMENT ARRANGEMENT @ OUTSIDE PLATFORM UPPER LEVEL
M-201	AIRFLOW DIAGRAM

PIPING DRAWINGS

DWG NO	DESCRIPTION
P-100	PIPING 3D VIEW @ BASEMENT LEVEL
P-101	PIPING 3D VIEW @ OPERATING LEVEL (GAS SUPPLY)
P-102	PIPING 3D VIEW @ OPERATING LEVEL
P-103	PIPING 3D VIEW @ BAY 9
P-104	PIPING 3D VIEW @ MEZZANINE LEVEL
P-105	PIPING 3D VIEW @ OUTSIDE NORTH WALL
P-106	PIPING 3D VIEW @ OUTSIDE BELOW BAG HOUSE DECK
P-107	PIPING 3D VIEW @ BAG HOUSE BELOW MAIN LEVEL
P-108	PIPING 3D VIEW @ BAG HOUSE DECK SECOND LEVEL
P-109	PIPING 3D VIEW @ BAG HOUSE DECK UPPER LEVEL
P-110	PIPING 3D VIEW @ OUTSIDE NORTHEAST WALL
P-111	PIPING 3D VIEW @ NORTH DEARATOR

ELECTRICAL DRAWINGS

DWG NO	DESCRIPTION
E-101-DEMO	BOILER 9 MCC SINGLE LINE DIAGRAM DEMOLITION
E-102-DEMO	BOILER 8 MCC SINGLE LINE DIAGRAM DEMOLITION
E-103-DEMO	BOILER 7 MCC SINGLE LINE DIAGRAM DEMOLITION
E-106-DEMO	480V BUS EAST & WEST BUS SINGLE LINE DIAGRAM DEMOLTION
E-201-DEMO	BOILER 7, 8 & 9 MCC ROOM INVERTER PANEL SCHEDULES DEMOLITION
E-001	GENERAL NOTES, SYMBOL LEGEND, AND DRAWING INDEX
E-101	BOILER 9 MCC SINGLE LINE DIAGRAM
E-102	BOILER 8 MCC SINGLE LINE DIAGRAM
E-103	BOILER 7 MCC SINGLE LINE DIAGRAM
E-104	AQCS MCC SINGLE LINE DIAGRAM
E-105	GENERATOR 7/8 13.8KV SINGLE LINE DIAGRAM
E-106	480V BUS EAST & WEST BUS SINGLE LINE DIAGRAM
E-201	BOILER 7, 8 & 9 MCC ROOM INVERTER PANEL SCHEDULES
E-202	AQCS PANEL SCHEDULES
E-203	BOILERHOUSE PANEL SCHEDULES
E-401	EXISTING BOILER ROOM BASEMENT FLOOR ELECTRICAL POWER PLAN
E-402	EXISTING BOILER ROOM OPERATOR FLOOR ELECTRICAL POWER PLAN
E-403	ELEVATED PLATFORM @ TOC EL 723'-5" ELECTRICAL PLAN
E-404	EXISTING BAGHOUSE FLOOR ELECTRICAL PLAN
E-405	ELEVATED PLATFORMS @ TOC EL 751'-4" ELECTRICAL PLAN
E-410	ELECTRICAL BUILDING FIRST FLOOR PLAN
E-411	WATER TREATMENT BLDG PLAN EL 702'-3"
E-412	ELECTRICAL BUILDING 1ST FLOOR PLAN
E-413	ELECTRICAL BUILDING 3RD FLOOR PLAN
E-414	ELECTRICAL BUILDING 2ND FLOOR PLAN
E-501	FURNACE SECTIONS
E-502	MISC. SECTIONS
EC-101	BALANCE OF PLANT PLC MAIN PLC
EC-201	BALANCE OF PLANT PLC REMOTE IO PANEL

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	MLB

SECURITY
PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

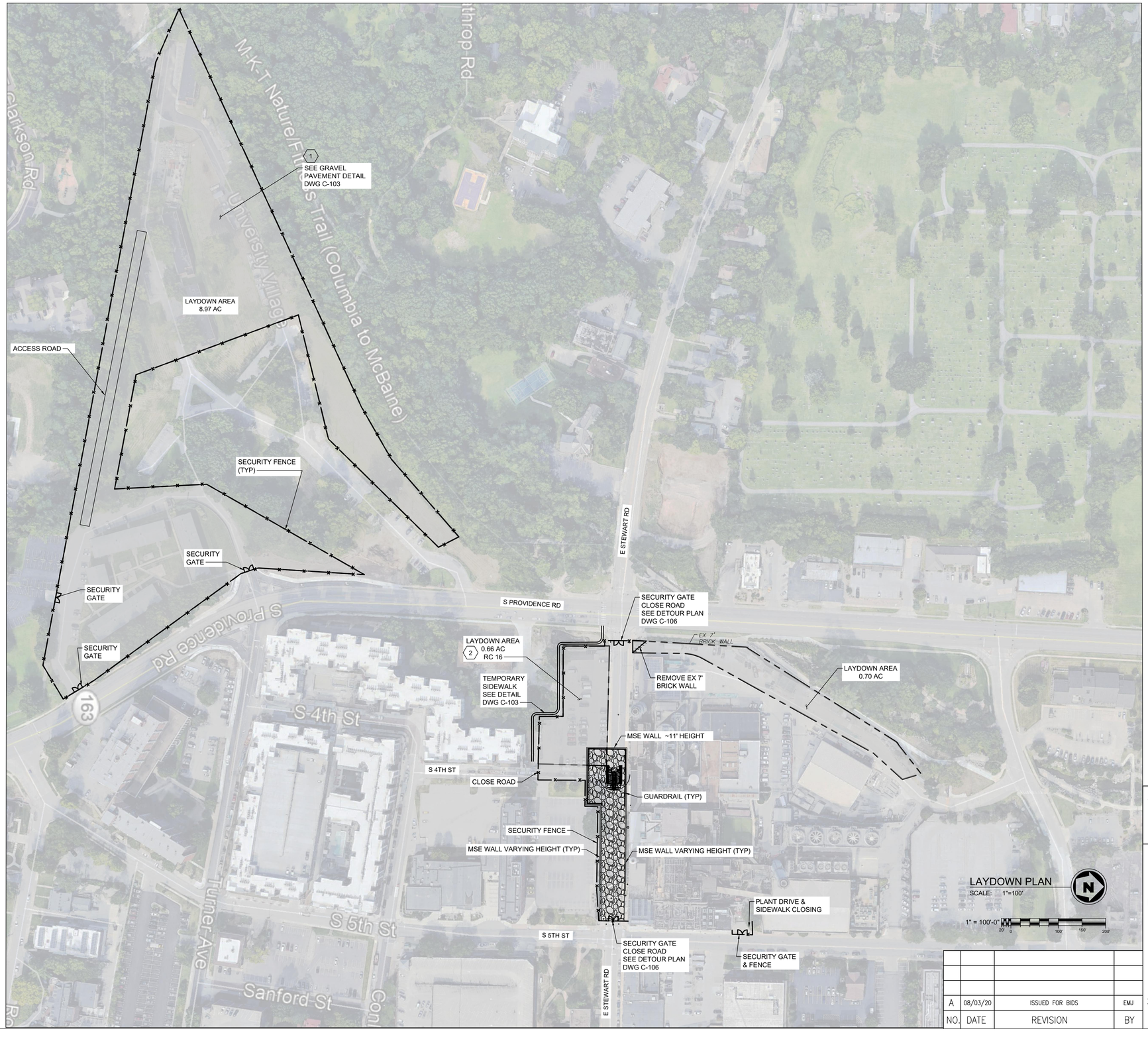
2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

GENERAL
COVER SHEET

DATE	DRAWN	CHK'D.
08/03/20	MLB	KLM
SCALE 1" = 30'-0"		APPROVED

G-001



KEY NOTES:

1. REMOVE ALL GRASS AND TOPSOIL WITHIN LAYDOWN AREA. EXPOSED SUBGRADE SHALL BE COMPACTED AND PROOF ROLLED PRIOR TO PLACEMENT OF GRAVEL SURFACE.
2. REMOVE CONCRETE PARKING BUMPERS, SIGNAGE, AND NEATLY STORE UNTIL PROJECT IS COMPLETE.

LEGEND:

CRUSHED STONE FILL

MANITOWOC 18000 CRANE
W/ TAIL SWING RADIUS.
(FOR REFERENCE)
*BOOM NOT SHOWN

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	EMJ

SECURITY

PUBLIC ☐
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

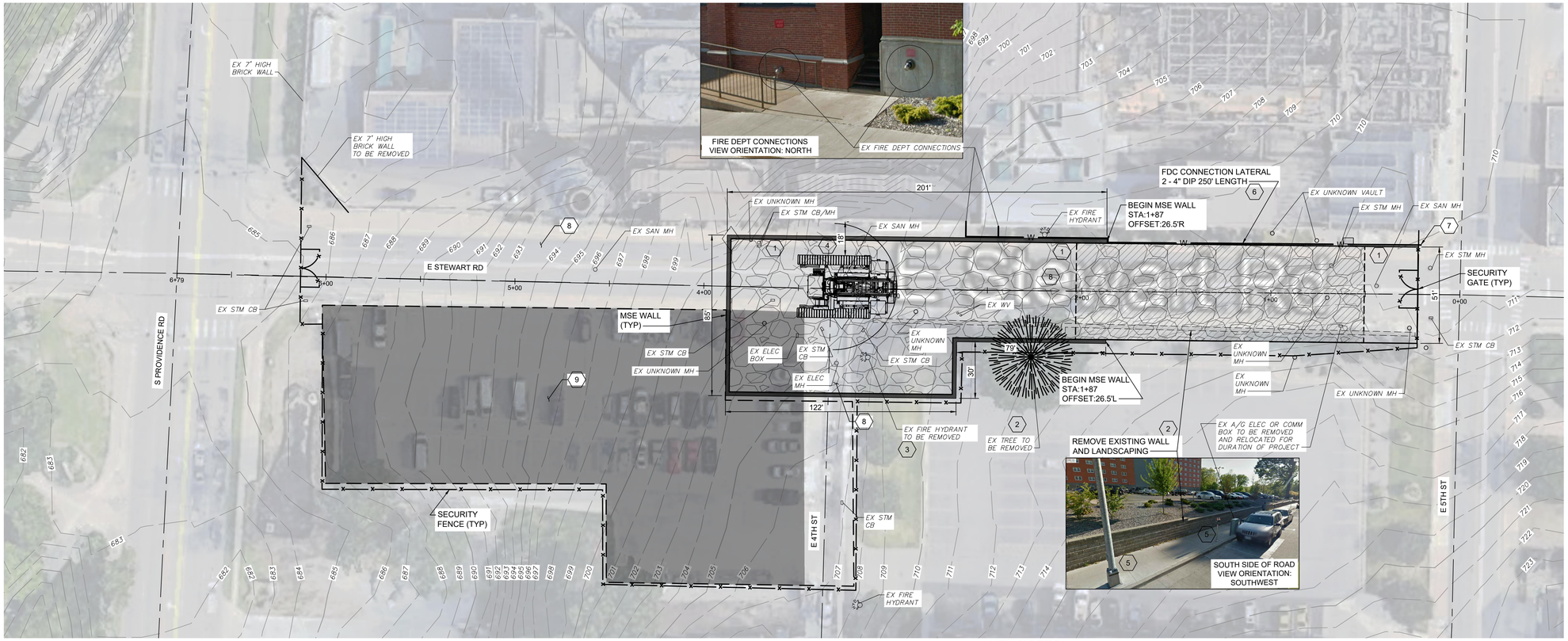
2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

CIVIL
LAYDOWN/SITE PLAN

DATE	DRAWN	CHK'D.
05/01/20	ACS	EMJ
SCALE: AS NOTED		APPROVED: EMJ

C–101



LEGEND:

- CRUSHED STONE FILL
- DEMO EXISTING PAVEMENT 2' DEPTH FROM PROP GRADE
- RC-16 PARKING AREA TO BE USED AS LAYDOWN AREA AND RESTORED PER KEYNOTE 9
- MANITOWOC 18000 CRANE W/ TAIL SWING RADIUS. (FOR REFERENCE) *BOOM NOT SHOWN

NOTES:

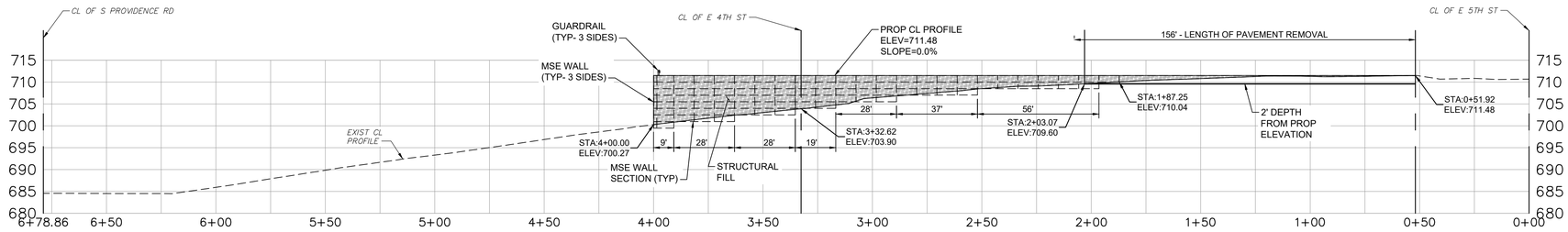
1. PROTECTION OF EXISTING UTILITIES REQUIRED. CONTRACTOR TO COVER MANHOLES AND ANY ROAD CASINGS WITH STEEL PLATES.

E STEWART RD
SCALE: 1"=30'

1" = 30'-0"

KEY NOTES:

1. SIDEWALKS TO BE DEMOLISHED ON THE NORTH SIDE OF E. STEWART RD., AS REQUIRED TO ACCOMMODATE CONSTRUCTION.
2. LANDSCAPING WALL ON SOUTH SIDE OF E. STEWART RD. TO BE CAREFULLY REMOVED, STORED, AND REINSTALLED UPON COMPLETION OF THE PROJECT. AS REQUIRED TO ACCOMMODATE CONSTRUCTION. LANDSCAPING SHALL BE REMOVED, DISPOSED OF AND REPLACED FOLLOWING CONSTRUCTION.
3. FIRE HYDRANT TO BE REMOVED, CAPPED AT FLANGE AND PROTECTED WITH A STEEL PLATE AT GRADE. STORE FIRE HYDRANT AND REINSTALL UPON COMPLETION OF PROJECT.
4. PROPOSED DISTANCE FROM EDGE OF CRANE TRACK WITH EAST-WEST ORIENTATION FROM ADJACENT BUILDING. EDGE OF CRANE TRACK SHALL BE A MINIMUM OF 10' FROM THE EDGE OF MSE WALL.
5. PARKING METERS (5) AND LIGHT POLES (2) ALONG SOUTH SIDEWALK OF THE ROAD TO BE REMOVED, STORED, AND REINSTALLED UPON COMPLETION OF THE PROJECT.
6. FIRE DEPT CONNECTION LATERALS TO BE SUPPORTED ALONG WALL. THE PIPES SHALL BE MOUNTED TO THE GROUND THE REMAINDER OF THE WAY. SEE PIPE SUPPORT DETAIL DWG C-104.
7. FDC EXTENSIONS SHALL TERMINATE AT A PIPE SUPPORT. EXTENSIONS SHALL TERMINATE WITH THE SAME CONNECTION AS THE FDC PRESENTLY HAS. PIPE SUPPORTS SHALL BE SPACED MAXIMUM 12' APART. SEE PIPE SUPPORT DETAIL ON DWG C-103.
8. REPLACE ENTIRE PAVEMENT (PER EXISTING SECTION) WITHIN THE LIMITS OF CONSTRUCTION UPON COMPLETION. EXISTING PAVEMENT APPEARS TO BE ASPHALT OVERLAY OVER CONCRETE BASE. CONTRACTOR TO CONFIRM EXISTING SECTION.
9. REMOVE ALL CONCRETE PARKING BUMPERS AND LIGHT POLES IN RC-16 PARKING AREA. REPLACE ENTIRE ASPHALT PAVEMENT (PER EXISTING SECTION) WITHIN LIMITS OF CONSTRUCTION UPON COMPLETION. REPLACE ALL CONCRETE PARKING BUMPERS AND RESTRIPE THE PAVEMENT.



E STEWART RD PROFILE

SCALE: HORIZ: 1"=30'
VERT: 1"=15'

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	EMJ

SECURITY

PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

CIVIL
E STEWART RD
PLAN & PROFILE

DATE	DRAWN	CHK'D.
05/01/20	ACS	EMJ
SCALE: AS NOTED		APPROVED: EMJ

C-102

PROJECT SPECIFICATIONS

ALL WORK REQUIRED TO COMPLETE THIS IMPROVEMENT SHALL BE PERFORMED IN STRICT ACCORDANCE WITH THE DETAILED CONSTRUCTION DRAWINGS AND SPECIFICATIONS, THE LATEST EDITION OF THE STATE OF MISSOURI DEPARTMENT OF TRANSPORTATION CONSTRUCTION AND MATERIAL SPECIFICATIONS, EXCEPT AS HEREIN AMENDED, AND PER THE CITY OF COLUMBIA REQUIREMENTS/STANDARDS. THE CONSTRUCTION DRAWINGS WILL TAKE PRECEDENCE OVER THE OTHER REQUIREMENTS. IN THE CASE OF A CONFLICT BETWEEN THE CITY AND THE MISSOURI DEPARTMENT OF TRANSPORTATION (MODOT) SPECIFICATIONS/REQUIREMENTS, THE MORE STRICT OF THE TWO SPECIFICATIONS WILL GOVERN, AS DETERMINED BY THE CITY.

PROJECT SAFETY

THE CONTRACTOR SHALL MAINTAIN A SAFE WORKING ENVIRONMENT AT THE PROJECT SITE AT ALL TIMES. THE CONTRACTOR SHALL FOLLOW ALL THE O.S.H.A. REGULATIONS REGARDING OPEN TRENCHES AND EXCAVATIONS (TRENCH SAFETY). ADEQUATE BARRICADES, WARNING LIGHTS, SIGNS, FENCING, ETC. SHALL BE ERECTED AROUND THE CONSTRUCTION AREA DURING ALL NON-WORKING HOURS TO ALERT PERSONS OF THE POTENTIAL DANGER ASSOCIATED WITH THE AREA UNDER CONSTRUCTION AS WELL AS TO PREVENT ACCESS BY UNAUTHORIZED PERSONNEL TO THE CONSTRUCTION SITE. AT NO TIME SHALL ANY PERSONNEL ENTER EXISTING STRUCTURES/CHAMBERS WITHOUT PROPER SAFETY EQUIPMENT, INCLUDING BUT NOT LIMITED TO AIR PACKS, AIR MONITORS AND/OR AIR SENSORS, BODY HARNESS WITH POSITIVE MEANS OF REMOVING A PERSON FROM THE STRUCTURE/CHAMBER. ALL WORK SHALL BE PERFORMED IN COMPLIANCE WITH APPLICABLE O.S.H.A. REQUIREMENTS INCLUDING THOSE SPECIFIED FOR ENTERING CONFINED SPACES.

UNDERGROUND UTILITIES

THE LOCATIONS OF EXISTING UNDERGROUND UTILITIES SHOWN ON THE PLANS WERE OBTAINED BY FIELD OBSERVATIONS. THE INFORMATION AS SHOWN IS BELIEVED TO BE CORRECT, HOWEVER, THE COMPLETENESS AND ACCURACY OF THIS INFORMATION CANNOT BE GUARANTEED. THE CONTRACTOR SHALL BE RESPONSIBLE TO CONTACT ALL THE VARIOUS UTILITY COMPANIES (PUBLIC AND PRIVATE) TO VERIFY THE EXISTENCE, LIMITS AND/OR LOCATION OF ANY UTILITIES WHICH MAY BE ALONG THE ROUTE OR WITHIN THE VICINITY OF THIS IMPROVEMENT.

UTILITY NOTIFICATION

AT LEAST 72 HOURS PRIOR TO COMMENCING WORK ON THIS PROJECT THE CONTRACTOR(S) SHALL NOTIFY THE ENGINEER AND THE REGISTERED UTILITY PROTECTION AGENCY/SERVICE TO BEGIN CONSTRUCTION ACTIVITY ON THIS PROJECT. PROOF OF SUCH NOTIFICATION SHALL BE FILED WITH THE ENGINEER. THE MARKING AND/OR LOCATION OF EXISTING UTILITIES SHALL BE COORDINATED TO STAY APPROXIMATELY TWO WORKING DAYS AHEAD OF THE PLANNED CONSTRUCTION. MISSOURI ONE CALL SYSTEM - UTILITIES PROTECTION SERVICE: 1-800-344-7483 (CONTACT NON-MEMBERS DIRECTLY).

PROTECTION OF UTILITIES

THE CONTRACTOR MUST PROTECT AND SUPPORT ANY EXISTING UTILITIES WITHIN OR ADJACENT TO THE PROJECT AREA. UTILITIES MUST BE KEPT IN SERVICE AT ALL TIMES.

RESTORATION OF DISTURBED AREAS

EXISTING DRIVES, PAVEMENT, SIGNS, LIGHT POLES AND OTHER APPURTENANCES DISTURBED DURING CONSTRUCTION BUT NOT SPECIFICALLY DESIGNATED FOR REMOVAL/REPLACEMENT SHALL BE RESTORED TO A CONDITION EQUAL TO THAT WHICH EXISTED PRIOR TO CONSTRUCTION AND TO COMPLETE SATISFACTION OF THE ENGINEER AND OWNER.

CLEAN UP AT END OF PROJECT

PRIOR TO FINAL ACCEPTANCE OF THE PROJECT BY THE OWNER, THE CONTRACTOR MUST ENSURE THAT ALL RECENTLY CONSTRUCTED IMPROVEMENTS AND EXISTING FEATURES IN OR ADJACENT TO THE IMPROVEMENTS ARE CLEAN AND FREE OF ANY AND ALL DEBRIS AND FUNCTIONING PROPERLY.

MAINTAINING TRAFFIC

THE CONTRACTOR SHALL SAFELY AND PROPERLY MAINTAIN TRAFFIC ADJACENT TO, AND ALONG THE PROJECT ROUTE/SITE. THE CONTRACTOR SHALL FURNISH AND MAINTAIN ALL SIGNS, FLAGS, FLAG MEN, BARRICADES, CONES, BARRELS AND INCIDENTALS NECESSARY TO SAFELY MAINTAIN TRAFFIC. ACCESS SHALL BE MAINTAINED AT ALL TIMES.

DUST CONTROL

THE CONTRACTOR SHALL BE RESPONSIBLE TO PROPERLY CONTROL DUST FROM THE PROJECT SITE AS NECESSARY/ REQUIRED TO MAINTAIN SAFE VISIBILITY WITHIN AND/OR ADJACENT TO THE SITE AND AVOID IMPACT ON DAILY OPERATIONS. METHODS FOR DUST CONTROL MUST BE APPROVED BY THE ENGINEER AND OWNER.

EXAMINATION OF SITE

THE CONTRACTOR SHALL BE RESPONSIBLE TO CLOSELY EXAMINE THE PROJECT SITE AND ALL ADJACENT AREAS AND APPRAISE HIMSELF OF ANY ITEMS AND/OR CONDITIONS THAT COULD AFFECT HIS/HER BID AND/OR ABILITY TO COMPLETE THE PROPOSED IMPROVEMENTS. THE CONTRACTOR SHALL COMPLETE A SITE VISIT/INSPECTION PRIOR TO SUBMITTING A PROPOSAL OR BID.

PROOF ROLLING

PROOF ROLLING SHALL BE PERFORMED ON THE PREPARED COMPACTED SUBGRADE OF THE PROPOSED PARKING AND DRIVE AREAS PRIOR TO PLACEMENT OF ANY PAVEMENT BASE MATERIAL. THE PROOF ROLLING SHALL BE PERFORMED IN THE PRESENCE OF THE SITE GEOTECHNICAL ENGINEER USING A FULLY LOADED TANDEM AXLE DUMP TRUCK OR OTHER APPROVED MEANS. THE PROOF ROLLING OPERATION SHALL COVER THE ENTIRE WIDTH AND LENGTH OF THE PROPOSED AREAS. THE PURPOSE OF THIS PROCEDURE IS TO DETECT SOFT, YIELDING, CONTAMINATED AND/OR UNSTABLE ZONES WITHIN THE SUBGRADE. ANY SUCH ZONES THAT ARE FOUND SHALL BE CORRECTED. THE UNSATISFACTORY AREAS SHALL BE UNDERCUT AND REPLACED WITH CLEAN APPROVED MATERIAL, OR OTHERWISE STABILIZED/CORRECTED AS APPROVED/DIRECTED BY THE GEOTECHNICAL ENGINEER. NO ADDITIONAL PAYMENT WILL BE MADE TO THE CONTRACTOR FOR CORRECTION OF UNSUITABLE AREAS LOCATED WITHIN CONSTRUCTED SUBGRADES.

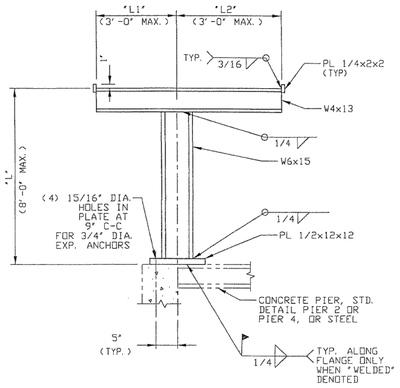
PROOF ROLLING SHALL ALSO BE PERFORMED AS SPECIFIED ABOVE ON ALL AREAS/SURFACES UPON WHICH EMBANKMENTS ARE TO BE CONSTRUCTED PRIOR TO THE PLACEMENT OF ANY EMBANKMENT/FILL.

PRE-CONSTRUCTION MEETING

A PRE-CONSTRUCTION MEETING WITH THE OWNER, CONTRACTOR AND THE CITY OF _____ IS REQUIRED FOR THIS PROJECT PRIOR TO THE START OF ANY CONSTRUCTION ACTIVITY. THE CONTRACTOR SHALL CONTACT ALL PARTIES SEVENTY-TWO (72) HOURS PRIOR TO THE ANTICIPATED MEETING DATE.

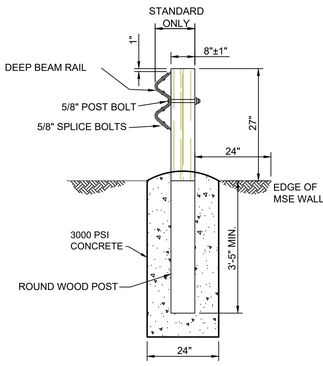
GENERAL DEMOLITION NOTES:

1. PRIOR TO STARTING DEMOLITION, THE CONTRACTOR SHALL SECURE ALL REQUIRED PERMITS AND APPROVALS.
2. CONTRACTOR SHALL REVIEW PROJECT SITE CLEARING SPECIFICATIONS PRIOR TO STARTING DEMOLITION.
3. CONTRACTOR SHALL NOTIFY CONSTRUCTION MANAGER OF WORK WHICH MAY AFFECT ADJACENT OWNER'S PROPERTY, POTENTIAL NOISE, UTILITY OUTAGE, OR DISRUPTION OF SERVICES. CONTRACTOR SHALL COORDINATE WORK ACTIVITIES WITH OWNER.
4. CONTRACTOR SHALL CLEAR AND GRUB ALL EXISTING TREES, SHRUBS, AND UNDERBRUSH TO THE LIMITS DEFINED ON THE DEMOLITION DRAWINGS. ALL MATERIALS INCLUDING, BUT NOT LIMITED TO TRUNKS, BRANCHES, STUMPS, ROOT BALLS, AND CHIPS SHALL BE DISPOSED OFF-SITE AT AN APPROVED WASTE DISPOSAL AREA.
5. CONTRACTOR SHALL SAWCUT CONCRETE AND ASPHALT MATERIAL PRIOR TO DEMOLITION.
6. CONCRETE AND ASPHALT MATERIAL DESIGNATED FOR DEMOLITION SHALL BE DISPOSED OFF-SITE AT AN APPROVED WASTE DISPOSAL AREA. ALL DEMOLITION DEBRIS SHOULD BE REMOVED FROM THE SITE AND PROPERLY RECYCLED OR DISPOSED OF.
7. THE DEMOLITION OPERATIONS SHOULD BE INSPECTED BY THE OWNER'S REPRESENTATIVE.
8. CONTRACTOR SHALL PROVIDE, ERECT, AND MAINTAIN TEMPORARY BARRIERS AND SECURITY DEVICES THROUGH THE DURATION OF THE PROJECT AS REQUIRED.
9. CONTRACTOR SHALL PREVENT MOVEMENT OR SETTLEMENT OF ADJACENT STRUCTURES AND PROVIDE BRACING AND SHORING AS REQUIRED.
10. CONTRACTOR SHALL PROTECT EXISTING SITE FEATURES WHICH ARE DENOTED AS (TO REMAIN).
11. CONTRACTOR SHALL DEMOLISH STRUCTURES INDICATED IN AN ORDERLY AND CAREFUL MANNER.
12. CONTRACTOR SHALL LEAVE AREAS OF WORK IN A CLEAN CONDITION.



PIPE SUPPORT DETAIL

SCALE: NONE



GUARDRAIL DETAIL

SCALE: NONE

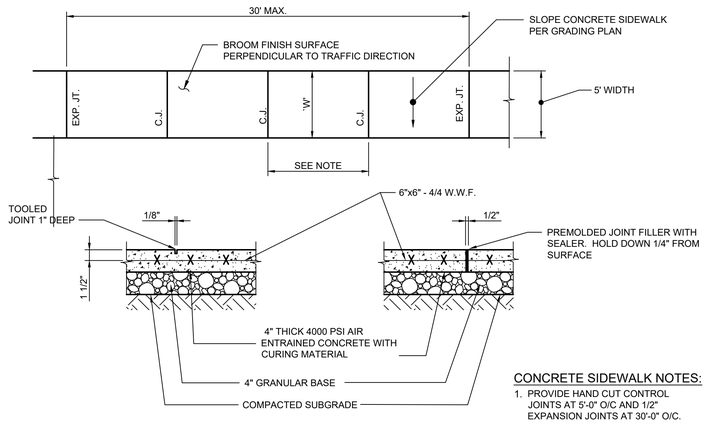
ENDTREATMENT: INSTALL AND FURNISH FLARED END SECTION AT ALL END GUARDRAILS. MAY BE ROUND (SINGLE RAIL ONLY) OR 6" x 8"

POSTS: SQUARE-SAWED PRESSURE TREATED WOOD OR WE x 9 GALVANIZED STEEL. THE SAME TYPE POST SHALL BE USED THROUGHOUT THE LENGTH OF PROJECT UNLESS OTHERWISE REQUIRED BY THE PLANS OR PERMITTED BY THE ENGINEER. ROUND POSTS SHALL BE 8" PLUS OR MINUS 1" IN DIAMETER AT THE TOP AND NOT MORE THAN 3" LARGER AT THE BUTT WITH A UNIFORM TAPER. POSTS MAY BE SET IN DRILLED HOLES OR DRIVEN TO GRADE. WOOD POST SHALL BE FABRICATED WITH SQUARE ENDS. POST SHALL BE PRESSURE-TREATED. BOLT HOLES SHALL BE BORED AND TOPS OF POSTS TRIMMED. IF REQUIRED AFTER POSTS ARE SET.

WASHERS: ALL WASHERS SHOWN ARE STANDARD GALVANIZED STEEL OF THE APPROPRIATE SIZE. WHERE LESS THAN 1' OF GRADED

EMBEDMENT DEPTH: SHOULDER WIDTH (10:1 OR FLATTER) EXTENDS BEYOND POSTS LONGER POSTS SHALL BE USED SO THAT A MINIMUM OF 5'-5" EMBEDMENT DEPTH IS PROVIDED.

NOTE: LAP ALL SPLICES IN THE DIRECTION OF TRAFFIC DISTANCE BETWEEN ROUND POSTS IS 12'-6"



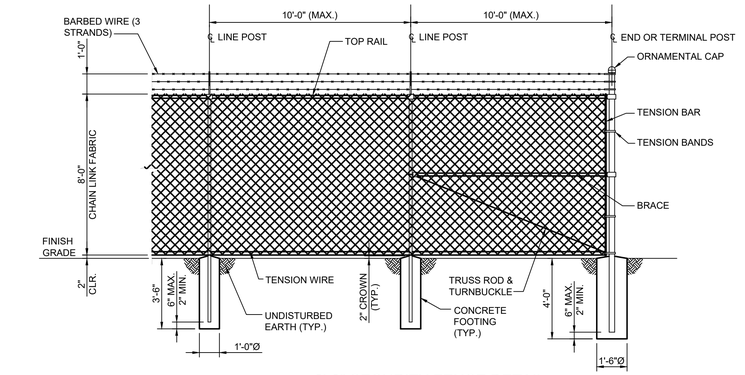
CONTROL JOINT (CJ) EXPANSION JOINT (EXP. JT)

CONCRETE SIDEWALK DETAILS

SCALE: NONE

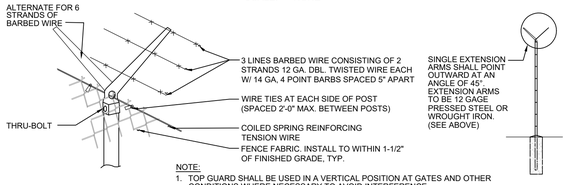
CONCRETE SIDEWALK NOTES:

1. PROVIDE HAND CUT CONTROL JOINTS AT 5'-0" O/C AND 1/2" EXPANSION JOINTS AT 30'-0" O/C.

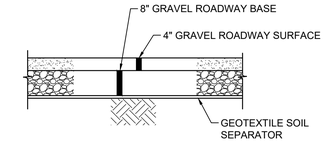


8'-0" SECURITY FENCE DETAIL

SCALE: NONE



NOTE:
1. TOP GUARD SHALL BE USED IN A VERTICAL POSITION AT GATES AND OTHER CONDITIONS WHERE NECESSARY TO AVOID INTERFERENCE.

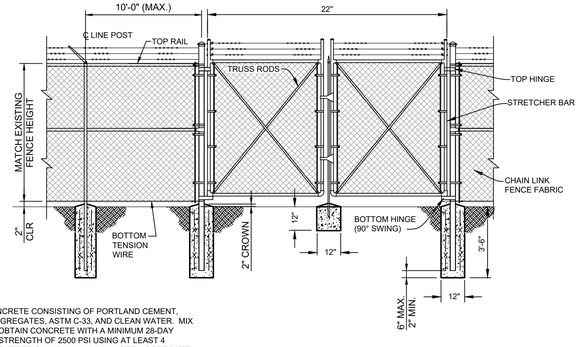


NOTES:
1. SMOOTH OUT EXISTING EXPOSED SUBGRADE AND PROOF ROLL ENTIRE AREA.
2. UNDERCUT AND BACKFILL AREAS FOUND TO BE SOFT WITH APPROVED MATERIAL.
3. PLACE GEOFABRIC OVER ENTIRE SURFACE. WOVEN GEOTEXTILE FABRIC (SOIL SEPARATOR AND STABILIZER) WEIGHT 6.8 OZ/SY, THICKNESS 28 MILS, GRAB TENSILE STRENGTH 315 LBS (THRACE-LINQ GTF 300 OR APPROVED EQUAL)
4. GRAVEL ROADWAY SURFACE PER MODOT 1007.4. GRAVEL ROADWAY BASE PER AASHTO #2 AGGREGATE.

GRAVEL PAVEMENT SECTION

SCALE: NONE

LAYDOWN AREA, GRAVEL DRIVES AND CONSTRUCTION TRAILER AREA



FENCE NOTES:
1. PROVIDE CONCRETE CONSISTING OF PORTLAND CEMENT, ASTM C-150, AGGREGATES, ASTM C-33, AND CLEAN WATER. MIX MATERIALS TO OBTAIN CONCRETE WITH A MINIMUM 28-DAY COMPRESSIVE STRENGTH OF 2500 PSI USING AT LEAST 4 SACKS OF CEMENT PER CU. YD., 1" MAXIMUM SIZE AGGREGATE, MAXIMUM 3" SLUMP, AND 2% TO 4% ENTRAINED AIR.

SECURITY FENCE ASSEMBLY DETAIL

SCALE: NONE

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	EMJ

SECURITY

PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

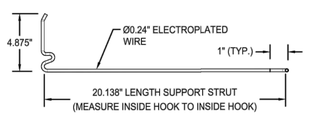
2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

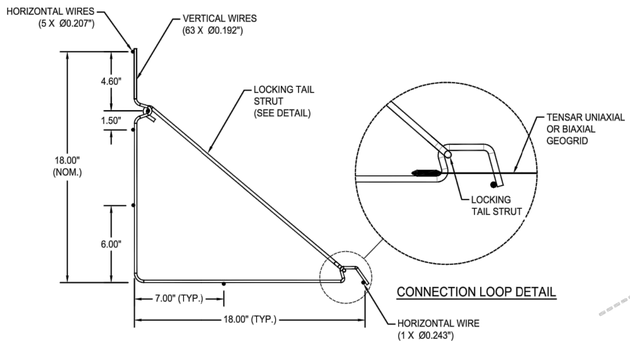
CIVIL
GENERAL NOTES AND DETAILS

DATE	DRAWN	CHK'D.
05/01/20	ACS	EMJ
SCALE: AS NOTED		APPROVED: EMJ

C-103

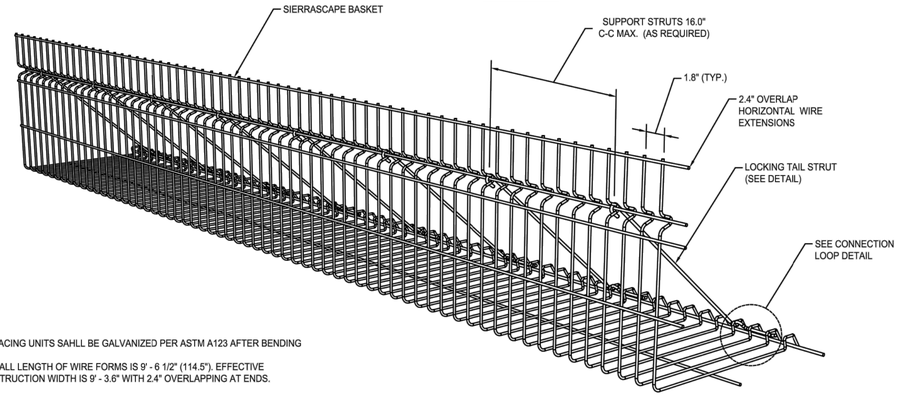


LOCKING TAIL SUPPORT STRUT DETAIL



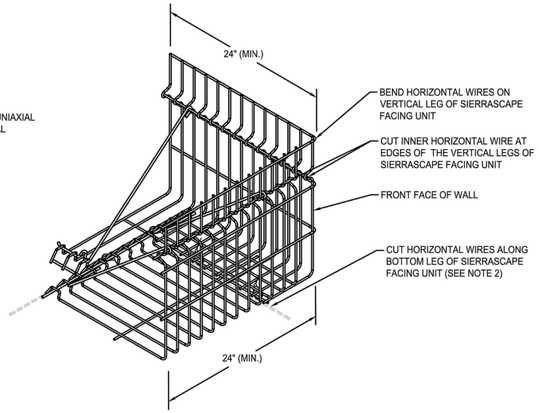
SECTION A-A

CONNECTION LOOP DETAIL



NOTES:

1. ALL FACING UNITS SAHLL BE GALVANIZED PER ASTM A123 AFTER BENDING
2. OVERALL LENGTH OF WIRE FORMS IS 9' - 6 1/2" (114.5"). EFFECTIVE CONSTRUCTION WIDTH IS 9' - 3.6" WITH 2.4" OVERLAPPING AT ENDS.

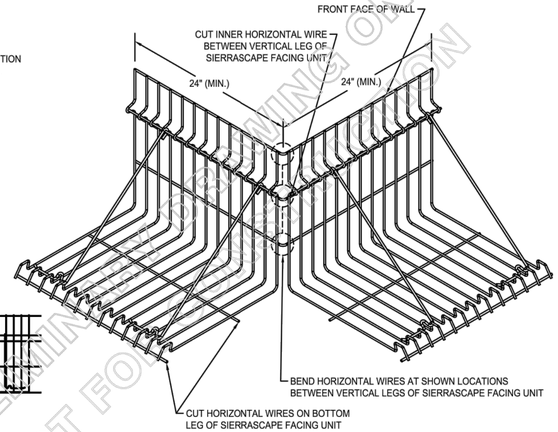


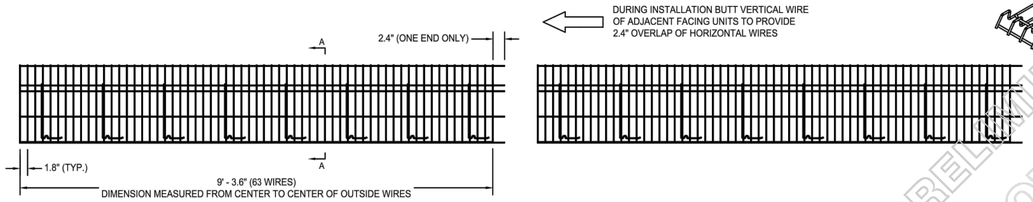
NOTE:

1. SEE SIERRASCAPE FACING UNIT DETAIL FOR FACING MATERIALS AND DIMENSIONS.
2. CUT BOTTOM LEG FROM CONNECTION LOOPS TO SECOND HORIZONTAL WIRE TO ALLOW UNCUT LEG TO OVERLAP WHEN BENDING. SECURE WITH HOG WIRE OR ZIP TIE.

SIERRASCAPE OUTSIDE CORNER UNIT

NOT TO SCALE





ELEVATION VIEW

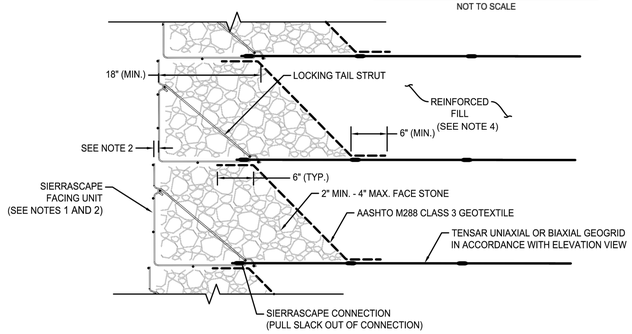
NOTE: SEE SIERRASCAPE FACING UNIT DETAIL FOR FACING MATERIALS AND DIMENSIONS

SIERRASCAPE INSIDE CORNER UNIT

NOT TO SCALE

SIERRASCAPE FACING UNIT

NOT TO SCALE

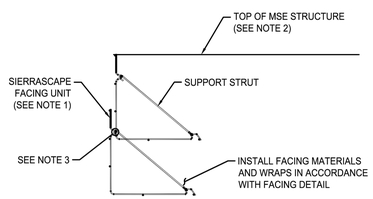


NOTES:

1. SEE SIERRASCAPE FACING UNIT DETAIL FOR FACING MATERIAL AND DIMENSIONS.
2. OFFSET AS NEEDED TO ACHIEVE OVERALL BATTER AS SHOWN IN THE CROSS-SECTIONS.
3. OPTIONAL - A THIN LAYER (2" MIN.) OF FINER STONE (1/4"-1") MAY BE PLACED AT THE TOP OF EACH UNIT TO PROVIDE A LEVEL SURFACE FOR THE UNIT ABOVE.
4. REINFORCED FILL TO BE IN ACCORDANCE WITH MODOT SECTION 1010, SELECT GRANULAR BACKFILL FOR STRUCTURAL SYSTEMS.

SIERRASCAPE STONE FACING DETAIL

NOT TO SCALE



NOTES:

1. SEE SIERRASCAPE FACING DETAIL FOR FACING MATERIALS AND DIMENSIONS.
2. SET TOPMOST SIERRASACPE UNIT INSIDE SIERRASCAPE FACING UNIT BELOW TO FOLLOW GRADE.
3. HORIZONTAL WIRES OF TOPMOST SIERRASCAPE FACING UNIT MAY BE CUT TO ALLOW INSTALLATION OVER STRUTS OF SIERRASCAPE FACING UNIT BELOW.

NESTED BASKET DETAIL (NO OFFSET)

NOT TO SCALE

PRELIMINARY DRAWING ONLY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	EMJ

SECURITY

PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

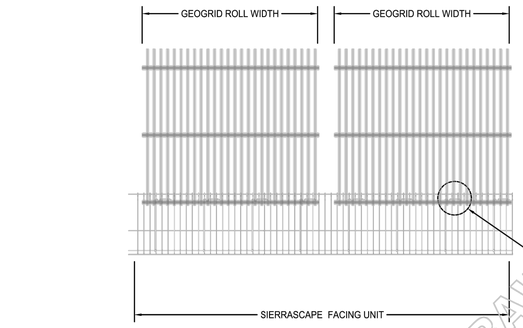
2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

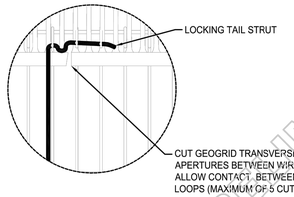
CIVIL
MSE WALL DETAILS
SHEET 1

DATE	DRAWN	CHK'D.
05/01/20	ACS	EMJ
SCALE		APPROVED
AS NOTED		EMJ

C–104



PLAN VIEW



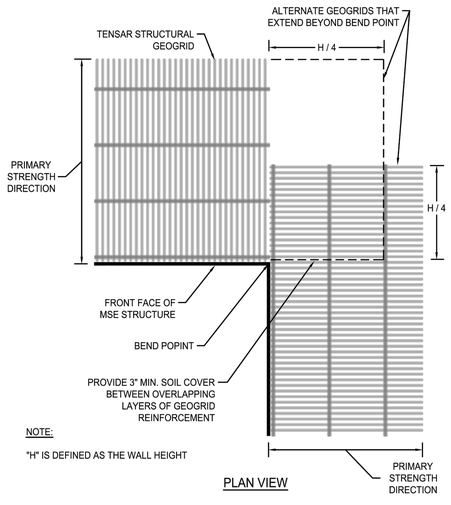
NOTES:

1. SEE SIERRASCAPE FACING UNIT DETAIL FOR FACING MATERIALS AND DIMENSIONS.
2. TWO ROLLS OF UNIAXIAL GEOGRID SHALL BE PLACED ON EACH SIERRASCAPE FACING UNIT WITH TWO GEOGRID RIBS BETWEEN EACH PAIR OF WIRE CONNECTION LOOPS.
3. DURING INSTALLATION BUTT VERTICAL WIRE OF ADJACENT FACING UNITS TO PROVIDE 2.4" OVERLAP OF HORIZONTAL WIRES.

PRELIMINARY DRAWING ONLY
NOT FOR CONSTRUCTION

TYPICAL SIERRASCAPE GEOGRID COVERAGE

NOT TO SCALE



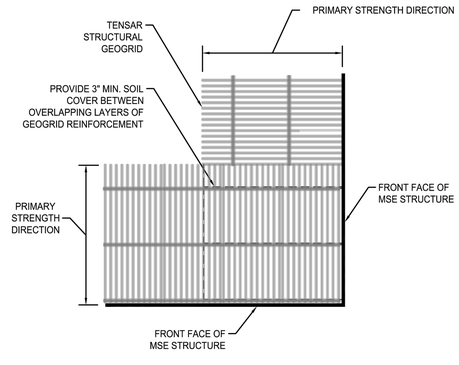
NOTE:

"H" IS DEFINED AS THE WALL HEIGHT

PLAN VIEW

GEOGRID PLACEMENT AT INSIDE CORNER DETAIL

NOT TO SCALE



PLAN VIEW

GEOGRID PLACEMENT AT OUTSIDE CORNER DETAIL

NOT TO SCALE

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	EMJ

SECURITY

PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

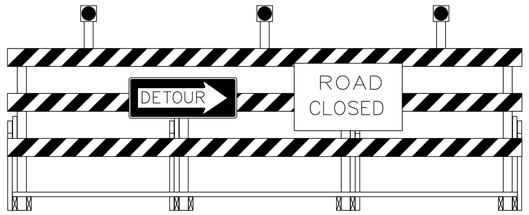
ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

CIVIL
MSE WALL DETAILS
SHEET 2

DATE	DRAWN	CHK'D.
05/01/20	ACS	EMJ
SCALE: AS NOTED		APPROVED: EMJ

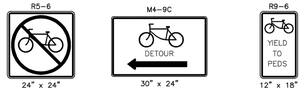
C–105

TRAFFIC CONTROL SYMBOLS

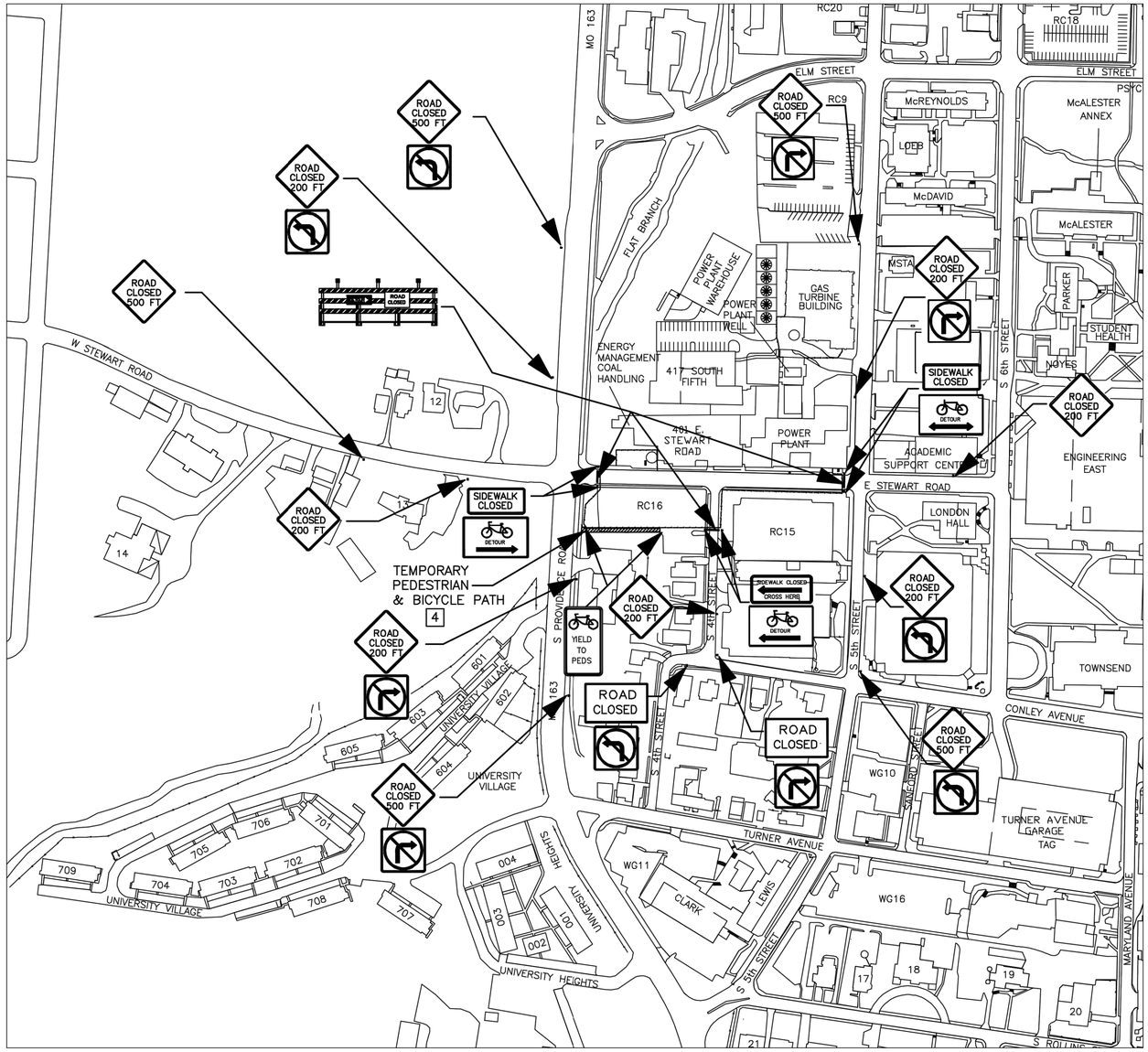








NOTES:
1. TRAFFIC CONTROL PLAN FROM PREVIOUS PROJECT AT ECHOGEN POWER PLANT.
2. COMPLY WITH MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES (LATEST EDITION), AND MODOT STANDARDS. REVIEW & COORDINATE THE TRAFFIC CONTROL PLAN AND THE INSTALLATION OF TRAFFIC CONTROL DEVICES WITH THE UNIVERSITY OF MISSOURI AND CITY OF COLUMBIA PRIOR TO PROCEEDING.



E STEWART RD
SCALE: 1"=150'

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	EMJ

SECURITY

PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

CIVIL
TRAFFIC CONTROL PLAN

DATE	DRAWN	CHK'D.
05/01/20	ACS	EMJ
SCALE: AS NOTED		APPROVED: EMJ

C–106

DESIGN CRITERIA:

GOVERNING CODES:
- INTERNATIONAL BUILDING CODE 2018
- AMERICAN SOCIETY OF CIVIL ENGINEERING (ASCE) 7-16

FLOOR LIVE LOADS:
- OPERATING FLOORS = 100 PSF
- STAIRS AND EXIT WAYS = 100 PSF
- CATWALKS FOR MAINTENANCE ACCESS = 40 PSF

ROOF LIVE LOAD:
- 20 PSF

ROOF SNOW LOAD:
- GROUND SNOW LOAD (P_g) = 20 PSF
- FLAT ROOF SNOW LOAD (P_f) = 22 PSF
- SNOW EXPOSURE FACTOR (C_e) = 1.0
- SNOW LOAD IMPORTANCE FACTOR (I) = 1.1
- THERMAL FACTOR (C_t) = 1.1

WIND DESIGN DATA:
- BASIC WIND SPEED (V) = 116 MPH (3-SECOND GUST)
- RISK CATEGORY = III
- WIND IMPORTANCE FACTOR (I) = 1.0
- WIND EXPOSURE = B
- INTERNAL PRESSURE COEFFICIENT (GC_{pi}) = ±0.18

EARTHQUAKE DESIGN DATA:
- RISK CATEGORY = III
- SEISMIC IMPORTANCE FACTOR (I) = 1.25
- MAPPED SPECTRAL RESPONSE ACCELERATIONS:
  S_s = 0.162 g
  S_1 = 0.094 g
- SOIL SITE CLASS = C
- SPECTRAL RESPONSE COEFFICIENTS:
  S_{DS} = 0.140 g
  S_{D1} = 0.094 g
- SEISMIC DESIGN CATEGORY = B
- BASIC SEISMIC FORCE RESISTING SYSTEM = STEEL SYSTEM NOT SPECIFICALLY DETAILED FOR SEISMIC RESISTANCE
- RESPONSE MODIFICATION FACTOR (R) = 3
- FIRE HEATER STRUCTURE: SEISMIC RESPONSE COEFFICIENT (Cs) = 0.054
  DESIGN BASE SHEAR (V) = 63 KIPS
  BAGHOUSE ENCLOSURE: SEISMIC RESPONSE COEFFICIENT (CS) = 0.054
  DESIGN BASE SHEAR (V) = 132 KIPS
- ANALYSIS PROCEDURE = EQUIVALENT LATERAL FORCE PROCEDURE

GEOTECHNICAL INFORMATION:
- ALL EXISTING UNDOCUMENTED FILL TO BE REMOVED FROM BENEATH THE BASE OF FOOTINGS AND THE ZONE OF INFLUENCE DOWN TO NATIVE STIFF SOIL OR BEDROCK AND REPLACED WITH SELECT SOIL, APPROVED BY GEOTECHNICAL ENGINEER, OR GRANULAR FILL. THE ZONE OF INFLUENCE BENEATH THE FOOTING IS 0.6 HORIZONTALLY FOR EACH FOOT IN DEPTH.
- DESIGN NET ALLOWABLE BEARING PRESSURE FOR SHALLOW SPREAD FOUNDATION BEARING ON STIFF NATIVE SOILS OR GRANULAR FILL ON TOP OF STIFF NATIVE SOILS = 4000psf.
- DESIGN SKIN FRICTION IN SOIL FOR CAST-IN-PLACE PIERS IS NEGLECTED
- DESIGN ALLOABLE SKIN FRICTION IN BEDROCK FOR CAST-IN-PLACE PIER UPLIFT = 2000psf.
- DESIGN ALLOWABLE END BEARING IN BEDROCK FOR CAST-IN-PLACE PIER = 30000ksf.
- FOOTINGS IN FIRE HEATER BUILDING ARE ASSUMED TO BEAR ON SOUND ROCK WITH ALLOWABLE DESIGN NET BEARING PRESSURE FOR SPREAD FOUNDATION = 15000 PSF BENEATH THE BASE OF FOOTINGS AND THE ZONE OF INFLUENCE DOWN TO BEDROCK TO BE FILLED WITH FLOWABLE FILL IF REQUIRED.

FLOOD DESIGN DATA:
- PROJECT SITE DETERMINED TO BE OUTSIDE THE 0.2% ANNUAL CHANCE FLOOD PLAIN.

GENERAL NOTES:

1. IT IS THE CONTRACTOR'S SOLE RESPONSIBILITY TO FOLLOW ALL APPLICABLE SAFETY CODES AND REGULATIONS DURING ALL PHASES OF CONSTRUCTION.
2. ALL MATERIAL AND WORKMANSHIP SHALL CONFORM TO THE 2018 INTERNATIONAL BUILDING CODE AS ADOPTED AND AMENDED BY LOCAL GOVERNING AUTHORITIES.
3. BEFORE BEGINNING WORK, THE CONTRACTOR SHALL VERIFY EXISTING CONDITIONS, DIMENSIONS & ELEVATIONS RELATED TO HIS WORK.
4. THE STRUCTURE IS DESIGNED TO BE SELF-SUPPORTING AND STABLE AFTER IT IS FULLY COMPLETE. EMPLOY ERECTION PROCEDURES WHICH WILL ENSURE THE SAFETY OF THE STRUCTURE AND ITS COMPONENT PARTS DURING ERECTION. THIS INCLUDES THE ADDITION OF WHATEVER SHORING, SHEETING, TEMPORARY BRACING, GUYS OR TIE DOWNS WHICH MIGHT BE NECESSARY; SUCH MATERIAL SHALL REMAIN THE CONTRACTOR'S PROPERTY AFTER COMPLETION OF THE PROJECT.
5. WORK THESE DRAWINGS WITH ARCHITECTURAL, MECHANICAL AND ELECTRICAL DRAWINGS.
6. IF CONFLICTS ARE ENCOUNTERED WITHIN THE DRAWINGS OR BETWEEN THE DRAWINGS AND SPECIFICATIONS, NOTIFY ENGINEER OF RECORD PRIOR TO PROCEEDING.
7. ALL DIMENSIONS INDICATED WITH (REF) AIRE FOR REFERENCE ONLY. THESE DIMENSIONS WERE DERIVED FROM EXISTING DRAWING INFORMATION OR FIELD MEASUREMENTS AND MAY VARY. IF THERE IS A DISCREPANCY INVOLVING THESE DIMENSIONS, CONTACT ENGINEER OF RECORD.
8. A QUALIFIED SPECIAL INSPECTOR SHALL BE PROVIDED. STRUCTURAL STEEL INSPECTIONS SHALL BE PROVIDED IN ACCORDANCE WITH IBC SECTION 1705.2.1 & AISC 360 CHAPTER N, INCLUDING TABLES N5.4-1 THROUGH N5.4-3 & N5.6-1 THROUGH N5.6-3. FOR OTHER MATERIAL SPECIAL INSPECTIONS, SEE "SCHEDULE OF SPECIAL INSPECTION SERVICES" ON DWG S-002.
9. ALL WORK AND MATERIALS SHALL BE IN ACCORDANCE WITH THE DRAWINGS.

FOUNDATION/CONCRETE NOTES:

1. ALL CONCRETE PLACEMENT AND REINFORCEMENT DETAILING, FABRICATION AND PLACEMENT SHALL CONFORM WITH ACI 318-14, BUILDING CODE REQUIREMENTS FOR STRUCTURAL CONCRETE; ACI 302.1R-15, GUIDE FOR CONCRETE FLOOR AND SLAB CONSTRUCTION; AND ACI 301-16, SPECIFICATIONS FOR STRUCTURAL CONCRETE.

CONCRETE MIX DESIGN

CONCRETE CLASS	CLASS A	CLASS B	CLASS C	CLASS D
APPLICATION	FILL, DUCT ENCASEMENT AND WHERE NOTED	INTERIOR STRUCTURAL CONCRETE & FOUNDATIONS	EXTERIOR STRUCTURAL CONCRETE & FOUNDATIONS	INTERIOR FLOOR SLABS
EXPOSURE CLASS	F0, S1, P0, C1	F0, S1, W0, C1	F1, S1, W0, C1	F0, S0, W0, C0
MINIMUM CEMENTITIOUS MATERIAL CONTENT	AS REQUIRED	AS REQUIRED	AS REQUIRED	560 LB/CY
MAXIMUM WATER/CEMENT RATIO	AS REQUIRED	0.50	0.50	0.55
MAXIMUM WATER SOLUBLE CHLORIDE ION (CI) IN CONCRETE (PERCENT BY WEIGHT OF CEMENT)	0.30	0.30	0.30	1.0
MINIMUM SPECIFIED 28 DAYS COMPRESSIVE STRENGTH OF CONCRETE F'c	2,500 PSI	4,000 PSI	4,000 PSI	3,000 PSI
AIR CONTENT	AS REQUIRED	AS REQUIRED	4% - 7%	AS REQUIRED
CEMENT TYPE	II	II	II	NO RESTRICTION
MAX COARSE AGGREGATE SIZE	3/4"	3/4"	3/4"	3/4"
SLUMP AT DISCHARGE	5"	3"	3"	3"
DENSITY	NORMAL	NORMAL	NORMAL	NORMAL

2. INTERIOR CONCRETE SHALL BE TROWEL FINISHED, EXTERIOR CONCRETE SHALL BE FLOAT FINISHED. EXTERIOR CONCRETE USED AS WALKING SURFACE SHALL BE BROOM FINISHED.
3. ALL REINFORCING STEEL SHALL BE DEFORMED BILLET STEEL CONFORMING TO ASTM A615, GRADE 60. STEEL WELDED PLAIN WIRE REINFORCING (WWR) SHALL CONFORM TO ASTM A1064, GRADE 65 AND SHALL BE PROVIDED IN FLAT SHEETS. ALL REINFORCING HOOKS SHOWN IN SECTIONS AND DETAILS ARE PER ACI STANDARDS UNO.
4. THE MINIMUM LENGTH OF LAP SPLICES SHALL BE AS SHOWN IN THE TABLE BELOW, UNLESS OTHERWISE SHOWN OR NOTED ON THE DRAWINGS:

CLASS B LAP SPLICE LENGTH (INCHES)

BAR SIZE	STANDARD		TOP	
	f'c = 3 ksi	f'c = 4 ksi	f'c = 3 ksi	f'c = 4 ksi
#3	23"	20"	29"	25"
#4	29"	25"	38"	33"
#5	37"	32"	47"	41'
#6	43"	38"	56"	49"
#7	63"	55"	82"	71"
#8	72"	63"	94"	81"
#9	81"	71"	106"	91"
#10	91"	80"	119"	103"

- TOP REINFORCING IS HORIZONTAL REINFORCING SO PLACED THAT MORE THAN 12" OF FRESH CONCRETE IS CAST IN THE MEMBER BELOW THE BAR.
- THE ABOVE VALUES ARE BASED ON A MINIMUM COVER OF AT LEAST ONE BAR DIAMETER AND A MINIMUM BAR SPACING OF TWO BAR DIAMETERS.

5. REINFORCEMENT SHALL BE ACCURATELY PLACED AND ADEQUATELY SECURED IN POSITION. THE FOLLOWING PROTECTION FOR REINFORCEMENT SHALL BE PROVIDED, UNLESS OTHERWISE SHOWN OR NOTED ON THE DRAWINGS.

   COVER (INCHES):
   CAST AGAINST AND PERMANENTLY EXPOSED TO EARTH 3"

   EXPOSED TO EARTH OR WEATHER
   #6 THROUGH #18 2"
   #5 AND SMALLER 1 1/2"

   NOT EXPOSED TO WEATHER OR IN CONTACT WITH GROUND
   SLABS AND WALLS 3/4"
   BEAMS AND COLUMNS 1 1/2"

   (ALL COVER DIMENSIONS GIVEN ABOVE SHALL BE USED UNLESS THE REQUIREMENT FOR LAP SPLICE ABOVE CONTROLS)

6. SLAB REINFORCEMENT SHALL BE SECURED IN PLACE PRIOR TO CONCRETE PLACEMENT. WWR SHALL BE SET ON CHAIRS OR CONCRETE BRICK AND SHALL NOT BE PLACED BY "WALKING IN" OR PULLING UP INTO PLACE.
7. CONTRACTOR'S OPTION TO SUBSTITUTE CONSTRUCTION JOINTS FOR CONTROL JOINTS (CJ) AS REQUIRED (SEE DETAILS). MAXIMUM ASPECT RATIO IS 1:1.5. SUBMIT JOINT PLAN FOR REVIEW TO ENGINEER OF RECORD.
8. FOUNDATION DESIGN WAS DONE IN ACCORDANCE WITH THE GEOTECHNICAL ENGINEERING REPORT PREPARED BY ENGINEERING SURVEYS AND SERVICES, DATED AUGUST 28, 1985, NOVEMBER 17, 2009 AND JUNE 27, 2019, AND THE 2018 INTERNATIONAL BUILDING CODE. A REGISTERED GEOTECHNICAL ENGINEER SHALL VERIFY THAT THE FILL, BACKFILL AND/OR COMPACTION BENEATH ALL FOUNDATIONS AND SLABS ON GRADE CONFORMS WITH THE BEARING REQUIREMENTS STATED IN THE GEOTECHNICAL REPORT ALONG WITH THE DRAWINGS PRIOR TO THE PLACEMENT OF REINFORCING STEEL. FOR EXACT SOILS CLASSIFICATIONS, SEE BORING LOGS IN THE GEOTECHNICAL REPORT.
9. PROVIDE 3/4" CHAMFER AT ALL EXPOSED EDGES.
10. "ROUGHEN SURFACE" WHERE REFERRED TO ON CONCRETE SECTIONS AND DETAILS, INDICATES CONTRACTOR TO ROUGHEN SURFACE TO A FULL AMPLITUDE OF 1/4" (TYP).

FOUNDATION/CONCRETE NOTES CONTD:

11. THE CONCRETE CONTRACTOR IS TO PROVIDE AND INSTALL ALL ANCHOR RODS PER THE ANCHOR ROD LAYOUT SHOWN ON THESE DRAWINGS. A SURVEY (BY THE CONCRETE CONTRACTOR) IS REQUIRED TO VERIFY PROPER LOCATION OF ANCHOR RODS. SURVEY RESULTS SHALL BE GIVEN TO THE OWNER'S REPRESENTATIVE PRIOR TO PLACING OF ANY CONCRETE.
12. ALL UNDERGROUND PLUMBING & ELECTRICAL, INCLUDING ANY ATTACHMENTS TO REINFORCING STEEL, TO BE IN PLACE PRIOR TO CONCRETE PLACEMENT ABOVE IT - SEE MECHANICAL & ELECTRICAL DRAWINGS FOR LOCATIONS.
13. THE CONTRACTOR SHALL VERIFY ALL EXISTING CONDITIONS AND LOCATE ALL EXISTING UNDERGROUND UTILITIES AS NEEDED BEFORE COMMENCING CONSTRUCTION.
14. ALL EXISTING FOUNDATION INFORMATION (SIZE, ELEVATIONS AND LOCATIONS) SHOWN ON THESE DRAWINGS WAS TAKEN FROM EXISTING DRAWINGS. ANY DISCREPANCIES FROM THE ACTUAL LOCATIONS FOUND IN THE FIELD THAT CAUSE CONFLICTS WITH NEW FOUNDATIONS SHALL BE BROUGHT TO THE ATTENTION OF THE ENGINEER OF RECORD IMMEDIATELY FOR RESOLUTION PRIOR TO EXCAVATION & PLACING CONCRETE.
15. USE SIKA GROUT 212 OR APPROVED EQUAL FOR GROUTING UNDER COLUMN BASE PLATES, EQUIPMENT BASE PLATES AND BEARING PLATES, UNLESS NOTED OTHERWISE ON DRAWINGS.

STRUCTURAL STEEL NOTES:

DESIGN STANDARDS
1. ALL STRUCTURAL STEEL DESIGN, DETAILING, FABRICATION AND ERECTION SHALL CONFORM TO THE FOLLOWING STANDARDS UNLESS NOTED:
   A. AISC SPECIFICATION FOR STRUCTURAL STEEL BUILDINGS (AISC 360-16)
   B. AISC CODE OF STANDARD PRACTICE FOR STEEL BUILDINGS AND BRIDGES (AISC 303-16)
   C. RCSC SPECIFICATION FOR STRUCTURAL JOINTS USING ASTM A325 OR A490 BOLTS

MATERIALS
1. WIDE FLANGES: ASTM A992 (F_y = 50 KSI)
2. PLATES, CHANNELS, S SHAPES AND ANGLES: ASTM A36 (F_y = 36 KSI)
3. PIPE: ASTM A53, TYPE E, GRADE B (F_y = 35 KSI)
4. STRUCTURAL TUBING : ASTM A500, GRADE B (ROUND: F_y = 42 KSI; SQUARE OR RECTANGULAR: F_y = 46 KSI)
5. ANCHOR RODS: ASTM F1554, GR 36 (F_y = 36 KSI) GALVANIZED
6. GRATING: ANSI/NAAMM MBG 531 (BEARING BARS PER ASTM A1011), GALVANIZED, ATTACHED TO EACH SUPPORT MEMBER WITH SADDLE CLIPS OR APPROVED EQUAL (MIN 4 ATTACHMENTS PER PIECE)
7. CHECKERED PLATE: ASTM A786, STEEL FLOOR PLATE WITH RAISED PATTERN (SIZE AND ATTACHMENT PER DRAWINGS)

FINISH
1. ALL STEEL SHALL BE CLEANED OF LOOSE RUST, LOOSE MILL SCALE, DIRT AND OIL. PREPARE STRUCTURAL COMPONENT SURFACES TO BE COATED IN ACCORDANCE WITH SSPC SP 6, COMMERCIAL BLAST CLEANING.
2. ALL STEEL SHALL BE PAINTED AS PER BELOW OR APPROVED EQUAL:
   PRIMER: ONE COAT OF CARBOLINE CARBOZINC 11 PRIMER AT A DFT OF 2 TO 3 MILS.
   MID-COAT: ONE COAT OF CARBOLINE CARBOGAURD 635 AT A DFT OF 4 TO 6 MILS
   TOP COAT: ONE COAT OF CARBOLINE CARBOTHANE 134 AT A DFT OF 1 TO 2 MILS.

CONNECTIONS
1. SHOP CONNECTIONS TO BE BOLTED OR WELDED, FIELD CONNECTIONS TO BE BOLTED UNLESS NOTED OTHERWISE ON DRAWINGS. ALL HOLES ARE STANDARD SIZE UNO.
2. ALL HIGH STRENGTH BOLTED CONNECTIONS TO BE GALVANIZED 7/8"∅ A325 BOLTS UNO, (X-TYPE CONNECTIONS WHEN PLY NEAREST NUT IS GREATER THAN 3/8" THICK; N-TYPE CONNECTIONS OTHERWISE).
3. ALL "COMMON" BOLTED CONNECTIONS TO BE GALVANIZED 5/8"∅ ASTM A307. ("COMMON" BOLTS: BOLTS FOR SECONDARY MEMBERS, SUCH AS RAILINGS, STAIRS, LADDERS AND GIRTS).
4. ALL BOLTS AT BEAM TO COLUMN, HORIZ BRACING, VERT BRACING, BEAMS WITH CLIP ANGLES, MONORAIL SUPPORTS, UNDER HUNG BEAMS, TRUSS TO COLUMN, AND COLUMN SPLICE CONNECTIONS TO BE FULLY TENSIONED UNO. FINGER-TIGHTEN ALL BOLTS IN LONG-SLOTTED HOLES AND TACK WELD NUTS. ALL OTHER CONNECTIONS SHALL BE SNUG-TIGHTENED.
5. ALL CONNECTIONS SHALL HAVE A MINIMUM OF TWO BOLTS.
6. FOR STANDARD FRAMING CONNECTION DETAILS (TO NEW & EXIST STEEL), SEE DWG S-702.
7. ALL BEAM TO BEAM AND BEAM TO COLUMN CONNECTIONS SHALL FOLLOW THE DETAILS AND SCHEDULE SHOWN ON DWG S-702, (BEAM TO NEW BEAM CONNECTIONS TO BE TYPE 1 UNO ON PLANS, ALL BEAM TO EXISTING BEAM CONNECTIONS TO BE TYPE 1 UNO ON PLANS, ALL BEAM TO COLUMN CONNECTIONS TO BE TYPE 2 UNO ON PLANS.
8. IF WELD SIZE IS NOT SPECIFICALLY DEFINED, IT SHALL BE THE MINIMUM SIZE REQUIRED BY AISC SPECIFICATION BUT NOT LESS THAN 3/16" UNO. WELD SIZE SHOWN AT SKEWED CONNECTIONS INDICATE EFFECTIVE THROAT. ADJUST LEG SIZE AS REQUIRED TO ACHIEVE THROAT SIZE INDICATED.
9. WELDED CONNECTIONS SHALL CONFORM TO THE AMERICAN WELDING SOCIETY STANDARDS FOR PRE-QUALIFIED JOINTS USING APPROPRIATE ELECTRODES. ALL WELDING ELECTRODES SHALL BE E70XX FOR NEW STEEL TO NEW STEEL CONNECTIONS. WELDING ELECTRODES FOR NEW STEEL TO EXISTING STEEL SHALL BE COMPATIBLE WITH THE EXISTING STEEL.
10. ALL WELDING SHALL BE DONE BY CERTIFIED WELDERS PER AWS D1.1.
11. WHEN REINFORCING MATERIAL IS ADDED TO ANY HORIZONTAL SURFACE EXPOSED TO WEATHER BY INTERMITTENT WELDS, A MINIMUM 1/8" SEAL WELD OR APPROVED JOINT SEALANT SHALL BE PROVIDED BETWEEN THE STRUCTURAL WELDS TO PREVENT THE INTRUSION OF WATER.
12. FOR ALL WIDE FLANGE SECTIONS WITH WEB HORIZONTAL, PROVIDE (1) 1/2" DIA DRAIN HOLE AT 5'-0" OC MAX AND BETWEEN ANY STIFFENER PLATES WELDED TO THE FLANGES.

LEGEND:

- EXISTING FRAMING, EQUIPMENT, ETC
- EXISTING RAILING/TOE PLATE
- STEEL CHECKERED PLATE. EDGE OF CHECKERED PLATE (EOCP) TO BE AT EDGE OF BEAM FLANGE UNO.
- STEEL GRATING TO BE 1 1/4"x3/16" GALVANIZED W/BEARING BARS @ 1 3/16" C/C & CROSS RODS @ 4" C/C. EDGE OF GRATING (EOG) TO BE AT EDGE OF BEAM FLANGE UNO. ALL EDGES OF GRATING TO BE BANDED AT OPENINGS.
- RAILING/TOE PLATE LOCATION, SIDE MOUNTED UNO ON PLANS (SEE DETAILS ON DWG S-705)
- BEAM / BEAM — ALL FRAMING MEMBER NOT INDICATED ON PLANS TO BE HORIZONTAL BRACING L3X3X1/4 (-0'-3" FROM T/STEEL, UNO ON PLANS). FOR ALL HORIZ BRACING CONNECTIONS TO BEAMS (INCLUDING WT's), SEE DETAILS ON DWG S-702
- STEP-THRU LADDER UNO ON PLANS. CAGE REQUIRED ONLY WHERE INDICATED ON PLANS (FOR DETAILS, SEE DWG S-704)
- STAIRS (SEE TYPICAL STAIR DETAILS ON DWG S-704)
- KB — KNEE BRACE (FOR TYP KNEE BRACE DETAIL SEE DWG S-703.)
- EQUIPMENT OR OTHER PENETRATION THROUGH PLAN OR ELEVATION. ORIENT CHANNELS TO OUTSIDE OF OPENING.
- SECTION OR DETAIL NUMBER / SHOWN/CUT FROM
- SECTION DESIGNATION
- OPENING — GIRT AND JAMB ORIENTATION AT OPENINGS, TYP UNO
- FLOOR/ROOF DECK. EDGE OF DECK (EOD) TO BE AT EDGE OF BEAM FLANGE UNO.
- MOMENT CONNECTION
- DIRECTION OF DECK SPAN, EDGE OF DECKING TO BE AT GIRT LINE UNO ON PLAN.

STEEL DECK NOTES:

DESIGN STANDARDS
1. STEEL DECK SHALL BE DESIGNED, FURNISHED, FABRICATED AND ERECTED IN ACCORDANCE WITH ANSI/SDI-RD STANDARD FOR STEEL ROOF DECK AND ANSI/SDI-C STANDARD FOR CONPOSITE STEEL FLOOR).
2. ALL STEEL DECK SHALL CONFORM TO THE FOLLOWING STANDARDS UNLESS NOTED:
   A. AMERICAN IRON AND STEEL INSTITUTE (AISI) SPECIFICATION FOR DESIGN OF COLD FORMED STEEL STRUCTURAL MEMBERS, LATEST EDITION.
   B. AMERICAN WELDING SOCIETY (AWS) D1.3, STRUCTURAL WELDING CODE/SHEET STEEL.
   C. STEEL DECK INSTITUTE (SDI) DESIGN MANUAL, LATEST EDITION.

MATERIALS
1. ROOF DECK: VULCRAFT TYPE 1.5B ROOF DECK (OR APPROVED EQUAL), 22 GA, GALVANIZED (F_y = 33 KSI)
2. FLOOR DECK: VULCRAFT TYPE 1.5VL CONFORM COMPOSITE DECK (OR APPROVED EQUAL), 22 GA, GALVANIZED (F_y = 50 KSI)

INSTALLATION
1. END LAPS SHALL OCCUR OVER A SUPPORTING BEAM OR JOIST. THEY SHALL BE CENTERED OVER BEAM.
2. FASTENERS AT ROOF DECK:
   A. AT SUPPORTS - 5/8"∅ PUDDLE WELDS AT A MAXIMUM OF 1'-0" OC ALONG THE WIDTH OF THE SHEET (EQUIVALENT TO 36/4 PATTERN).
   B. SIDE LAPS - #10 TEK SCREWS @ MID SPAN.
3. FASTENERS AT FLOOR DECK:
   A. AT SUPPORTS - 5/8"∅ PUDDLE WELDS AT A MAXIMUM OF 1'-0" OC ALONG THE WIDTH OF THE SHEET (EQUIVALENT TO 36/4 PATTERN).
   B. SIDE LAPS - #10 TEK SCREWS @ MID SPAN.

ERECTION
1. ALL OPENINGS FOR VENTS, MECHANICAL EQUIPMENT OR FOR OTHER REQUIREMENTS SHOWN ON THE DESIGN DRAWINGS SHALL BE FIELD CUT.
2. LEAVE DECK AND OTHER WORK FREE FROM DIRT, WELD SPATTER, GREASE & OIL.
3. DECK SHALL BE INSTALLED IN A 3-SPAN (MIN) CONDITION WHERE POSSIBLE.

POST-INSTALLED ANCHOR NOTES:

1. POST-INSTALLED ANCHORS SHALL ONLY BE USED WHERE SPECIFIED ON THE CONSTRUCTION DOCUMENTS. THE CONTRACTOR SHALL OBTAIN APPROVAL FROM THE ENGINEER OF RECORD PRIOR TO INSTALLING POST-INSTALLED ANCHORS IN PLACE OF MISSING OR MISPLACED CAST-IN-PLACE ANCHORS.
2. CARE SHALL BE TAKEN IN PLACING POST-INSTALLED ANCHORS TO AVOID CONFLICTS WITH EXISTING REBAR. HOLES SHALL BE DRILLED AND CLEANED IN ACCORDANCE WITH THE MANUFACTURER'S WRITTEN INSTRUCTION, AS INCLUDED IN THE ANCHOR PACKAGING.
3. ANCHOR CAPACITY USED IN DESIGN SHALL BE BASED ON THE TECHNICAL DATA PUBLISHED BY THE ANCHOR BOLT MANUFACTURER OR SUCH OTHER METHOD AS APPROVED BY THE STRUCTURAL ENGINEER OF RECORD. SUBSTITUTION REQUESTS FOR ALTERNATE PRODUCTS MUST BE APPROVED IN WRITING BY THE STRUCTURAL ENGINEER OF RECORD PRIOR TO USE. CONTRACTOR SHALL PROVIDE CALCULATIONS DEMONSTRATING THAT THE SUBSTITUTED PRODUCT IS CAPABLE OF ACHIEVING THE PERFORMANCE VALUES OF THE SPECIFIED PRODUCT. SUBSTITUTIONS WILL BE EVALUATED BY THEIR HAVING AN ICC ESR SHOWING COMPLIANCE WITH THE RELEVANT BUILDING CODE FOR SEISMIC USES, LOAD RESISTANCE, INSTALLATION CATEGORY, AND AVAILABILITY OF COMPREHENSIVE INSTALLATION INSTRUCTIONS. ADHESIVE ANCHOR EVALUATION WILL ALSO CONSIDER CREEP, IN-SERVICE TEMPERATURE AND INSTALLATION TEMPERATURE.
4. THE CONTRACTOR SHALL ARRANGE AN ANCHOR MANUFACTURER'S REPRESENTATIVE TO PROVIDE ONSITE INSTALLATION TRAINING FOR ALL OF THEIR ANCHORING PRODUCTS SPECIFIED. THE STRUCTURAL ENGINEER OF RECORD MUST RECEIVE DOCUMENTED CONFIRMATION THAT ALL OF THE CONTRACTOR'S PERSONNEL WHO INSTALL ANCHORS ARE TRAINED PRIOR TO THE COMMENCEMENT OF INSTALLING ANCHORS.
5. ANCHOR CAPACITY IS DEPENDANT UPON SPACING BETWEEN ADJACENT ANCHORS AND PROXIMITY OF ANCHORS TO EDGE OF CONCRETE. INSTALL ANCHORS IN ACCORDANCE WITH SPACING AND EDGE CLEARANCES INDICATED ON THE DRAWINGS.

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	HF

SECURITY
PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

STRUCTURAL DESIGN CRITERIA, GENERAL NOTES AND LEGEND

DATE	DRAWN	CHK'D.
08/03/20	AWB	HF
SCALE: As indicated		APPROVED: JWO

S-001

SCHEDULE OF SPECIAL INSPECTION SERVICES

THE OWNER SHALL EMPLOY ONE OR MORE SPECIAL INSPECTORS TO PROVIDE INSPECTIONS DURING CONSTRUCTION ON THE TYPES OF WORK LISTED UNDER IBC SECTION 1704. THE SPECIAL INSPECTOR SHALL BE A QUALIFIED PERSON WHO SHALL DEMONSTRATE COMPETENCE FOR INSPECTION OF THE PARTICULAR TYPE OF CONSTRUCTION REQUIRING INSPECTION. THE INSPECTOR SHALL FURNISH A COPY OF ALL INSPECTION REPORTS TO THE OWNER, STRUCTURAL ENGINEER AND BUILDING OFFICIAL FOR THE WORK INSPECTED.

REQUIRED VERIFICATIONS AND INSPECTIONS OF SOILS

VERIFICATIONS AND INSPECTIONS	FREQUENCY	REFERENCE
1. VERIFY MATERIALS BELOW FOOTINGS ARE ADEQUATE TO ACHIEVE THE DESIGN BEARING CAPACITY	PERIODIC	-
2. VERIFY EXCAVATIONS ARE EXTENDED TO PROPER DEPTH AND HAVE REACHED PROPER MATERIAL	PERIODIC	-
3. PERFORM CLASSIFICATION AND TESTING OF COMPACTED FILL MATERIALS	PERIODIC	-
4. VERIFY USE OF PROPER MATERIALS, DENSITIES AND LIFT THICKNESSES DURING PLACEMENT AND COMPACTION OF COMPACTED FILL	CONTINUOUS	-
5. PRIOR TO PLACEMENT OF COMPACTED FILL, OBSERVE SUBGRADE AND VERIFY SITE HAS BEEN PROPERLY PREPARED	PERIODIC	-

REQUIRED VERIFICATIONS AND INSPECTIONS OF CONCRETE CONSTRUCTION

VERIFICATIONS AND INSPECTIONS	FREQUENCY	REFERENCE
1. INSPECT REINFORCING STEEL, INCLUDING PLACEMENT	PERIODIC	ACI 318: CHAPTER 20, 25.2, 25.3, 26.6.1-26.6.3
2. INSPECT ANCHORS CAST IN CONCRETE	PERIODIC	ACI 318: 17.8.2
3. INSPECT ANCHORS INSTALLED IN HARDENED CONCRETE	PERIODIC (SEE NOTE 1)	ACI 318: 17.8.2, 17.8.2.4
4. VERIFY USE OF REQUIRED MIX DESIGN	PERIODIC	ACI 318: CHAPTER 19, 26.4.3, 26.4.4
5. PRIOR TO CONCRETE PLACEMENT, FABRICATE SPECIMENS FOR STRENGTH TESTS, PERFORM SLUMP AND AIR CONTENT TESTS AND DETERMINE THE TEMPERATURE OF THE CONCRETE.	CONTINUOUS	ACI 318; 26.5, 26.12 ASTM C 172, C 31
6. INSPECT CONCRETE PLACEMENT FOR PROPER APPLICATION TECHNIQUES	CONTINUOUS	ACI 318; 26.5
7. VERIFY MAINTENANCE OF SPECIFIED CURING TEMPERATURES AND TECHNIQUES	PERIODIC	ACI 318; 26.5.3-26.5.5
8. ERECTION OF PRECAST CONCRETE MEMBERS	PERIODIC	ACI 318; 26.9
9. VERIFY IN-SITU CONCRETE STRENGTH, PRIOR TO REMOVAL OF SHORES AND FORMS FROM BEAMS AND STRUCTURAL SLABS	PERIODIC	ACI 318; 26.11.2
10. INSPECT FORMWORK FOR SHAPE, LOCATION AND DIMENSION OF THE CONCRETE MEMBER BEING FORMED	PERIODIC	ACI 318; 26.11.1.2(b)

NOTES:

1. ADHESIVE ANCHORS INSTALLED IN HORIZONTALLY OR UPWARD INCLINED OR SITUATION THAT RESISTS SUSTANED TENSION LOADS TO BE INSPECTED CONTINUOUSLY.

REQUIRED VERIFICATIONS AND INSPECTIONS OF STEEL CONSTRUCTION

VERIFICATIONS AND INSPECTIONS	FREQUENCY	REFERENCE
1. FABRICATOR SHALL BE PRE-QUALIFIED TO PERFORM WORK WITHOUT SPECIAL INSPECTION:	-	-
A. AT COMPLETION OF WORK, FABRICATOR SHALL SUBMIT A CERTIFICATE OF COMPLIANCE STATING THAT THE WORK WAS PERFORMED IN ACCORDANCE WITH THE DESIGN DRAWINGS	-	IBC SECTION 1704.2.5.1

ABBREVIATIONS:

ARCH =	ARCHITECTURAL
B/ =	BOTTOM OF
B/B =	BACK TO BACK
BOD =	BOTTOM OF DECK
BOT =	BOTTOM
CANT =	CANTILEVERED FRAMING
CJ =	CONTROL OR CONSTRUCTION JOINT
CLR =	CLEAR
COL =	COLUMN
CONC =	CONCRETE
CONN =	CONNECTION
CONT =	CONTINUOUS
CTO =	CABLE TRAY OPENING
DO =	DOOR OPENING
DWL =	DOWEL
EA =	EACH
EL =	ELEVATION
EOB =	END OF BEAM
EOCP =	EDGE OF CHECKERED PLATE
EOD =	EDGE OF DECK
EOG =	EDGE OF GRATING
EOM =	END OF MONORAIL
EOR =	END OF RAIL
EOS =	EDGE OF SLAB
EQ =	EQUAL
EQUIP =	EQUIPMENT
EW =	EACH WAY
FND =	FOUNDATION
FTG =	FOOTING
FO =	FAN OPENING
FS =	FAR SIDE
GL =	GIRT LINE
HB =	HORIZONTAL BRACING
HORIZ =	HORIZONTAL
HP =	HIGH POINT
IFOB =	INSIDE FACE OF BLOCK
IFOCW =	INSIDE FACE OF CONCRETE WALL
KB =	KNEE BRACE
LG =	LONG
LLH =	LONG LEG HORIZONTAL
LLV =	LONG LEG VERTICAL
LO =	LOUVER OPENING
LP =	LOW POINT
MAX =	MAXIMUM
MECH =	MECHANICAL
MIN =	MINIMUM
NS =	NEAR SIDE
NSFC =	NOT SHOWN FOR CLARITY
NTS =	NOT TO SCALE
OC =	ON CENTER
OFOB =	OUTSIDE FACE OF BLOCK
OFOCW=	OUTSIDE FACE OF CONCRETE WALL
OPNG =	OPENING
OSL =	OUTSTANDING LEG
PLATF =	PLATFORM
PO =	PIPE OPENING
REINF =	REINFORCEMENT
SCHED =	SCHEDULE
SIM =	SIMILAR
SLRS =	SEISMIC LOAD RESISTING SYSTEM
SPA =	SPACES
SQ =	SQUARE
STD =	STANDARD
STIFF =	STIFFENER
STL =	STEEL
T/ =	TOP OF
T&B =	TOP AND BOTTOM
TOC =	TOP OF CONCRETE
TOS =	TOP OF STEEL
TYP =	TYPICAL
UN =	UNLESS NOTED
UNO =	UNLESS NOTED OTHERWISE
VB =	VERTICAL BRACE
VERT =	VERTICAL
WO =	WINDOW OPENING
WP =	WORK POINT

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	HF

SECURITY

PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

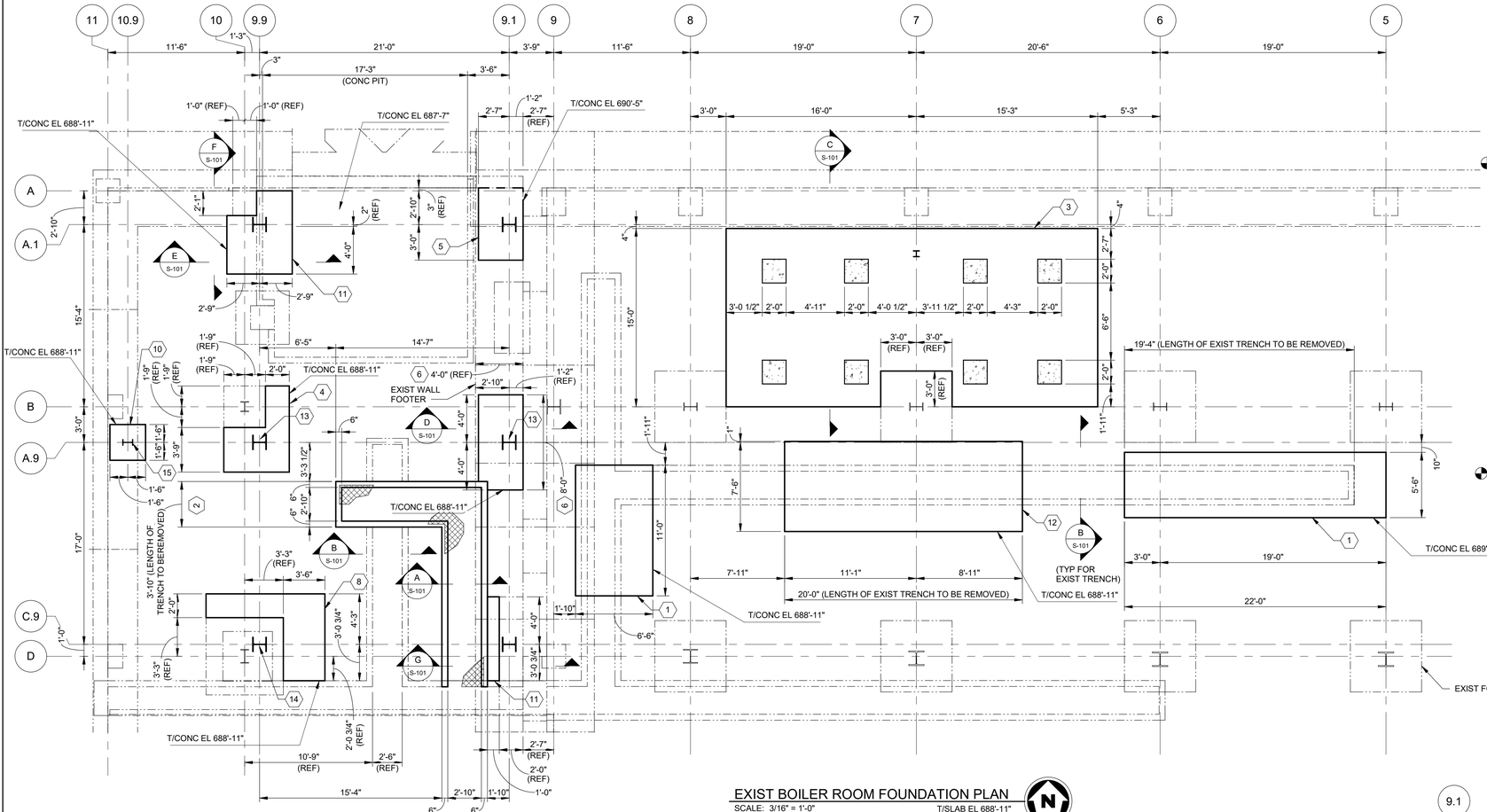
2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

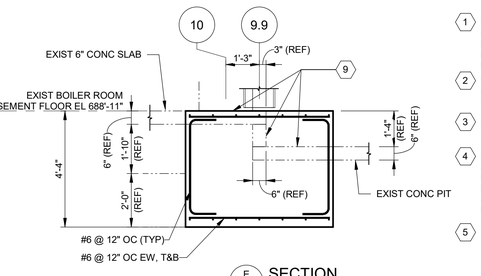
STRUCTURAL SCHEDULE OF SPECIAL INSPECTIONS

DATE	DRAWN	CHK'D.
08/03/20	AWB	HF
SCALE: As indicated		APPROVED: JWO

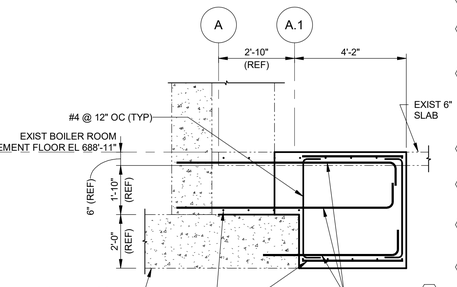
S-002



EXIST BOILER ROOM FOUNDATION PLAN
SCALE: 3/16" = 1'-0" T/SLAB EL 688'-11"



E S-101 SECTION
SCALE: 3/8" = 1'-0"



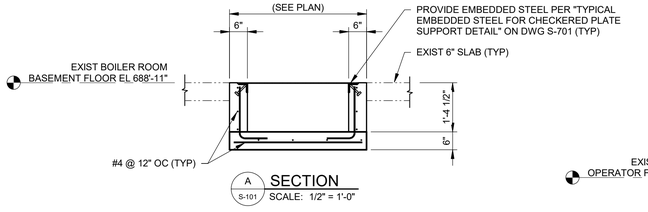
F S-101 SECTION
SCALE: 3/8" = 1'-0"

NOTES

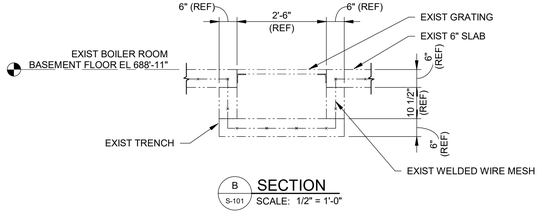
1. FOR GENERAL NOTES, DESIGN CRITERIA AND LEGEND, SEE DWG S-001 & S-002.

KEYNOTES

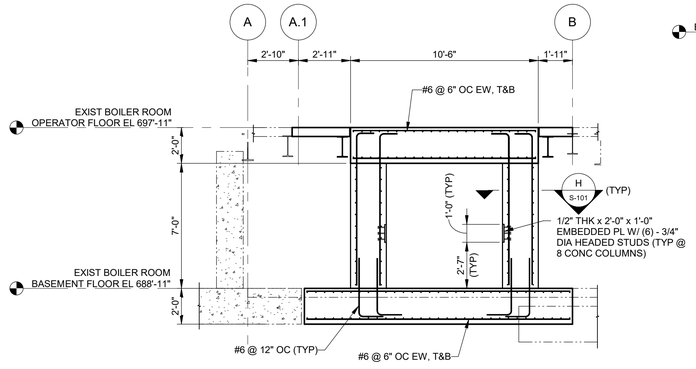
1. SAWCUT AND REMOVE EXIST 6" SLAB AND CONCRETE TRENCH FOR NEW 3'-0" THICK EQUIPMENT MAT, SEE "TYPICAL EQUIPMENT PAD DETAIL (TYPE 2)" ON DWG S-701 WITH #6 @ 6" OC EW, T&B.
2. SAWCUT AND REMOVE EXIST 6" SLAB AND CONCRETE TRENCH FOR NEW TRENCH, SEE SECTION B ON THIS DWG FOR EXIST TRENCH.
3. SAWCUT AND REMOVE EXIST 6" SLAB FOR NEW 2'-0" THICK MAT, TOC EL 688'-11".
4. SAWCUT AND REMOVE EXIST 6" SLAB FOR NEW 2'-6" THICK FOOTER WITH #6 @ 1'-0" OC, EW, T&B. ROUGHEN SURFACE OF CONCRETE AND DOWEL REBAR INTO EXIST FOUNDATION W/ HILTI HY-200 ADHESIVE ANCHORING SYSTEM OR APPROVED EQUAL AND 1'-6" EMBED.
5. 2'-0" THICK COL FOOTER WITH #6 @ 1'-0" OC, EW, T&B. DOWEL INTO EXIST FLOOR AND WALL W/ #6 @ 1'-0" OC, 1'-6" EMBED W/ HILTI HY-200 ADHESIVE ANCHORING SYSTEM OR APPROVED EQUAL ROUGHEN EXIST FLOOR FOR NEW FOUNDATION, TOC EL 690'-11".
6. SAWCUT AND REMOVE EXIST 6" SLAB AND WALL FOOTER FOR NEW COL FOOTER.
7. DOWEL WITH 1'-6" EMBED INTO EXIST WALL AND FOOTER, PROVIDE HILTI HY200 ADHESIVE ANCHORING SYSTEM OR APPROVED EQUAL.
8. SAWCUT AND REMOVE EXIST 6" SLAB FOR NEW 3'-0" THICK FOOTER WITH #6 @ 1'-0" OC, EW, T&B. ROUGHEN SURFACE OF CONCRETE AND DOWEL REBAR INTO EXIST FOUNDATION W/ HILTI HY-200 ADHESIVE ANCHORING SYSTEM OR APPROVED EQUAL AND 1'-6" EMBED.
9. DEMO EXIST PIT FLOOR/WALL AND EXIST 6" CONC SLAB FOR NEW FOUNDATION.
10. SAWCUT & REMOVE EXIST 6" SLAB FOR NEW 1'-6" THK COL FOOTER WITH #6 @ 1'-0" OC, EW, T&B, TOC EL 688'-11".
11. SAWCUT AND REMOVE EXIST 6" SLAB FOR NEW FOOTER WITH #6 @ 1'-0" OC, EW, T&B. ROUGHEN SURFACE OF CONCRETE.
12. SAWCUT AND REMOVE EXIST 6" SLAB AND CONCRETE TRENCH FOR NEW 2'-0" THK EQUIPMENT MAT, SEE "TYPICAL EQUIPMENT PAD DETAILS (TYPE 2)' ON DWG S-701 W/ #6 @ 8" OC EW, T&B.
13. PROVIDE SHEAR KEY PER "TYPICAL SHEAR KEYWAY DETAIL" ON DWG S-701.
14. SAWCUT TOP OF EXIST FOUNDATION AND PROVIDE SHEAR KEY SIM TO "TYPICAL SHEAR KEYWAY DETAIL" ON DWG S-701.
15. W10X22 COLUMN FROM TOS EL 737'-4 1/2" DN TO T/ EXIST CONC EL 689'-0 1/2", PROVIDE BASE PLATE PER "FIRE HEATER COLUMN BASE PLATE DETAIL" ON DWG S-702.



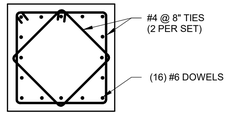
A S-101 SECTION
SCALE: 1/2" = 1'-0"



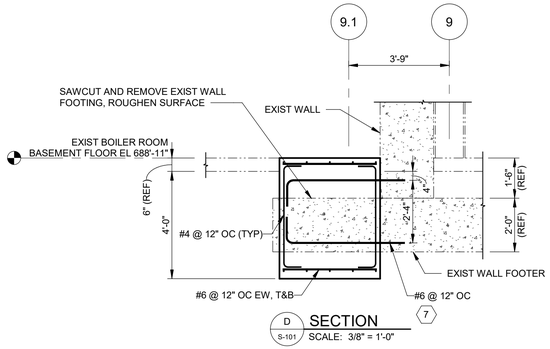
B S-101 SECTION
SCALE: 1/2" = 1'-0"



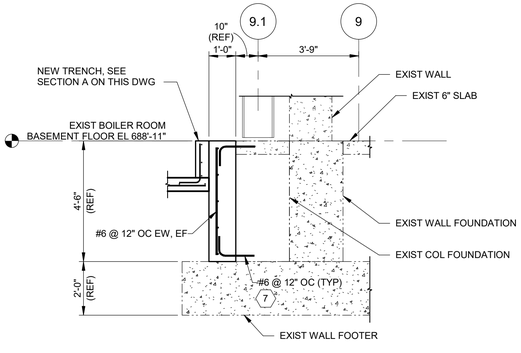
C S-101 SECTION
SCALE: 1/4" = 1'-0"



H S-101 SECTION
SCALE: 3/4" = 1'-0"



D S-101 SECTION
SCALE: 3/8" = 1'-0"



G S-101 SECTION
SCALE: 3/8" = 1'-0"

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	HF

SECURITY
PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

STRUCTURAL
EXIST BOILER ROOM FOUNDATION PLAN & SECTIONS

DATE	DRAWN	CHK'D.
08/03/20	AWB	HF
SCALE: As indicated		APPROVED: JWO

S-101

NOTES

1. FOR GENERAL NOTES, DESIGN CRITERIA AND LEGEND, SEE DWG S-001 & S-002.

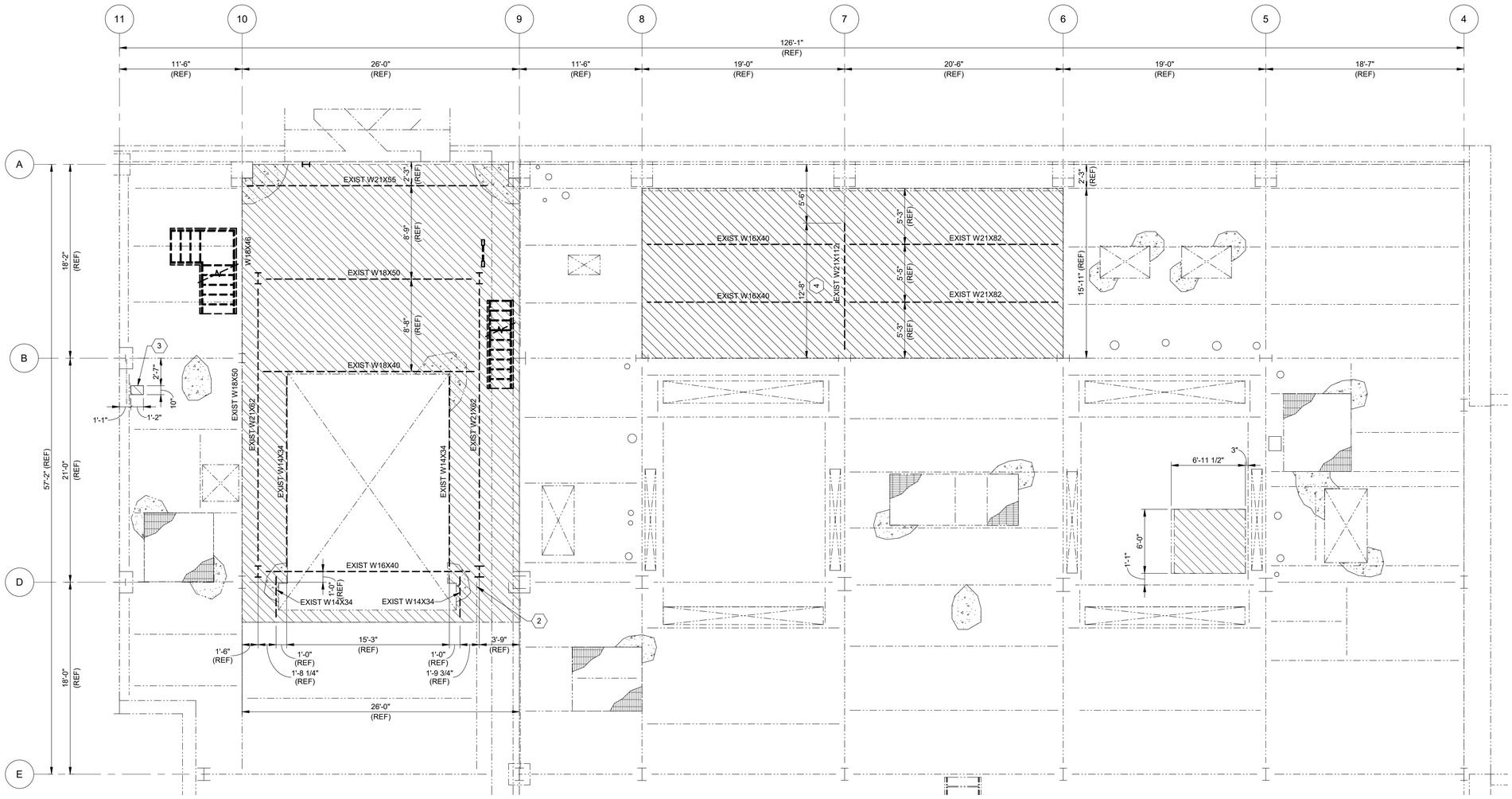
KEYNOTES

1. L4X4X5/16 POST DN TO TOC EL 697'-11", PROVIDE BASE PLATE PER "TYPICAL ANGLE POST BASE PLATE DETAIL" ON DWG S-702, BOT/BASE PLATE EL 698'-0 1/2" (GROUT AS REQD), FIELD WELD TOP OF POST TO EXIST CHANNEL W/ 3/16" FILLET WELDS ON 2 SIDES.
2. BEAM TO BE TEMPORILY SHORED UNTIL EXIST COLUMN IS REMOVED, NEW COLUMN INSTALLED AND EXIST BEAM CONNECTED TO NEW COLUMN.
3. SAWCUT AND REMOVE EXIST 6" CONC ELEVATED SLAB FOR NEW COLUMN.
4. PORTION OF EXIST W21 TO BE REMOVED, INSTALL NEW POST PER PLAN ON DWG S-103 PRIOR TO CUTTING/REMOVING EXIST W21.

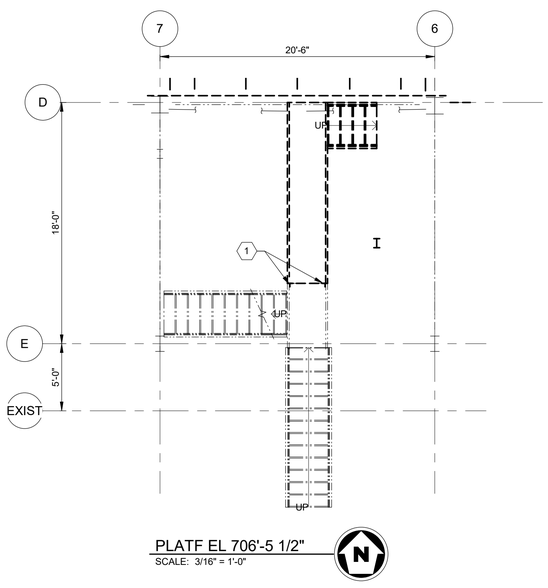
LEGEND:

EXISTING FRAMING TO BE REMOVED

EXISTING 6" CONCRETE ELEVATED SLAB TO BE REMOVED



OPERATOR FLOOR DEMOLITION PLAN @ EL 697'-11"
SCALE: 3/16" = 1'-0"



PLATF EL 706'-5 1/2"
SCALE: 3/16" = 1'-0"

1
S-204

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	HF

SECURITY

PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

STRUCTURAL
OPERATOR FLOOR DEMOLITION PLAN @ EL 697'-11"

DATE	DRAWN	CHK'D.
08/03/20	AWB	HF
SCALE: As indicated		APPROVED: JWO

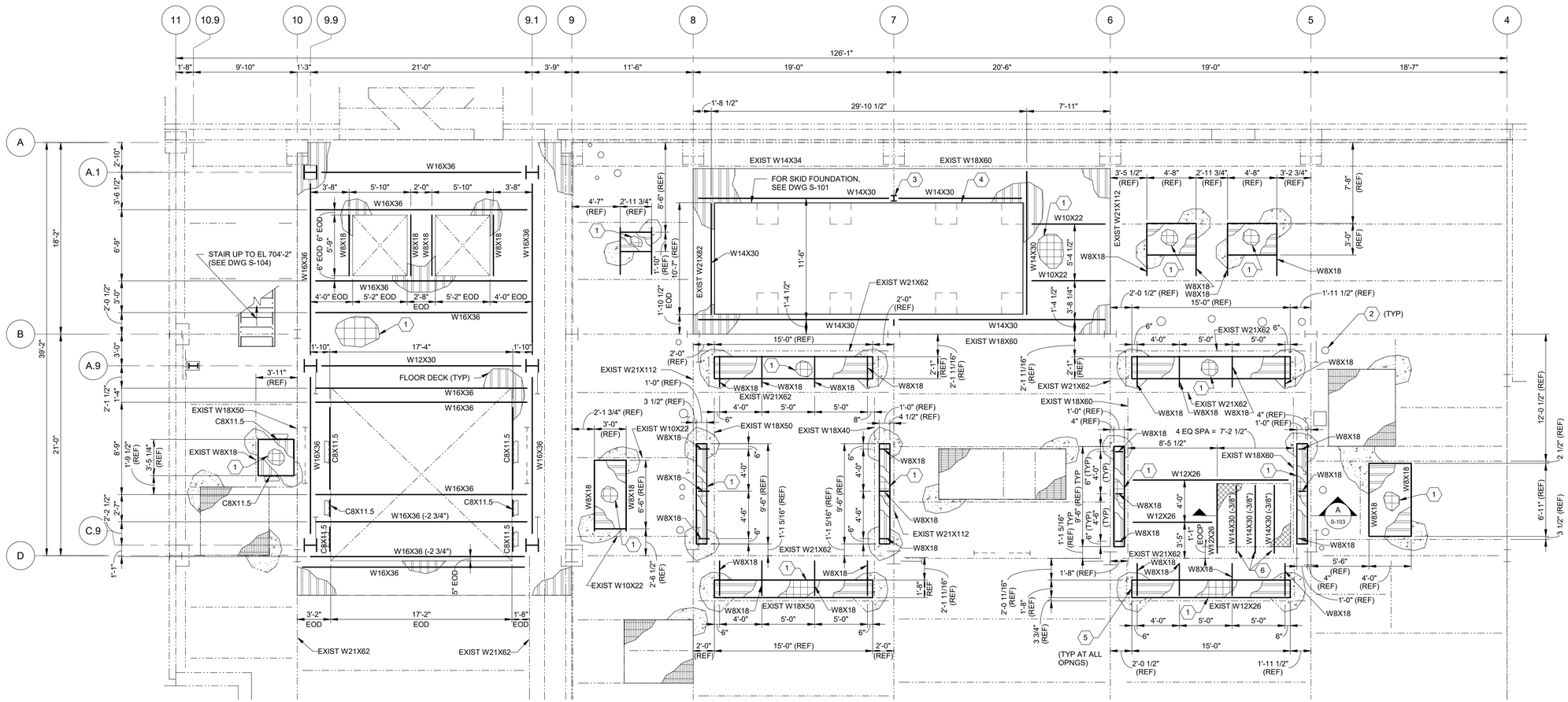
S-102

NOTES

1. FOR GENERAL NOTES, DESIGN CRITERIA AND LEGEND, SEE DWG S-001 & S-002.

KEYNOTES

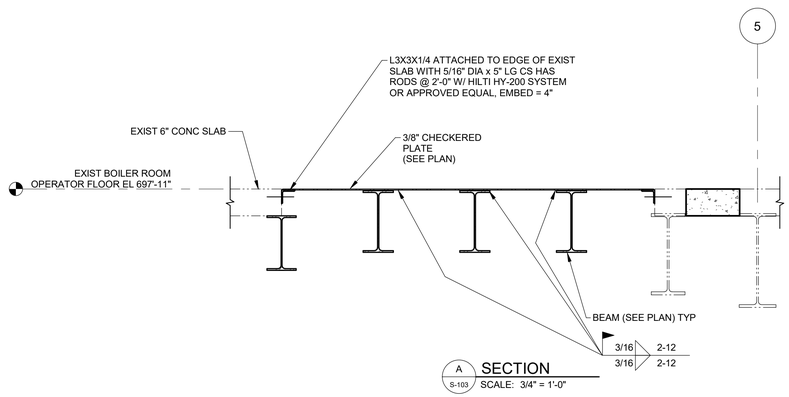
1. 6" ELEVATED CONC SLAB W/ 4X4-W4.0XW4.0 WWF REINFORCING, TOP OF SLAB EL TO BE 697'-11", PLACE REINFORCING -3 1/4" FROM TOP OF CONCRETE.
2. EXIST PIPE PENETRATION IN 6" CONC SLAB TO BE FILLED IN W/ 6" THICK CONC, PROVIDE 1/4"x1'-0"x1'-0" PLATE ATTACHED TO UNDERSIDE OF SLAB AND CENTERED ON OPENING W/ 1/2" DIA HILTI KWIK HUS EZ BOLT (OR APPROVED EQUAL) IN EACH CORNER.
3. W6X20 POST FROM BOT/EXIST W21 @ TOS EL 697'-5 1/2" DN TO EXIST TOC EL 688'-11", FIELD WELD FLANGES AND WEB OF POST TO EXIST BEAM W/ 3/16" FILLET WELD ON BOTH SIDES, PROVIDE A 1/2" x 1'-0" x 1'-0" BASE PLATE AND CONNECT BOT OF POST TO NEW CONC FOUNDATION WITH (4) - 3/4" DIA x 9" LG CS HAS RODS WITH HILTI HY-200 ADHESIVE ANCHORING SYSTEM OR APPROVED EQUAL, EMBED = 6".
4. PROVIDE 1" GAP WITH BACKER ROD AND CAULK AROUND PERIMETER OF SLAB.
5. PROVIDE L4X3X1/4 AT THE EDGE OF EXIST OPENING ANCHORED INTO FLOOR SLAB W/ 5/16" DIA X 5" LG CS HAS RODS @ 2'-0" WITH HILTI HY-200 SYSTEM OR APPROVED EQUAL, EMBED = 4".
6. COPE W14 AS REQD TO CLEAR EXIST SLAB BY 1/2" (TYP BOTH ENDS OF W14).



OPERATOR FLOOR FRAMING PLAN @ EL 697'-11"

SCALE: 3/16" = 1'-0"

(EXIST FRAMING -5 1/2" UNO)
(TOS EL NEW FRAMING -6" UNO)



A S-103 SECTION

SCALE: 3/4" = 1'-0"

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	HF

SECURITY

PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

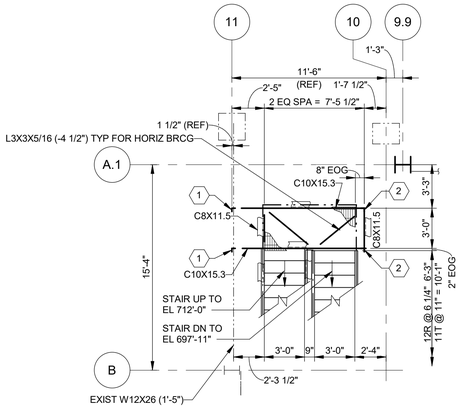
2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

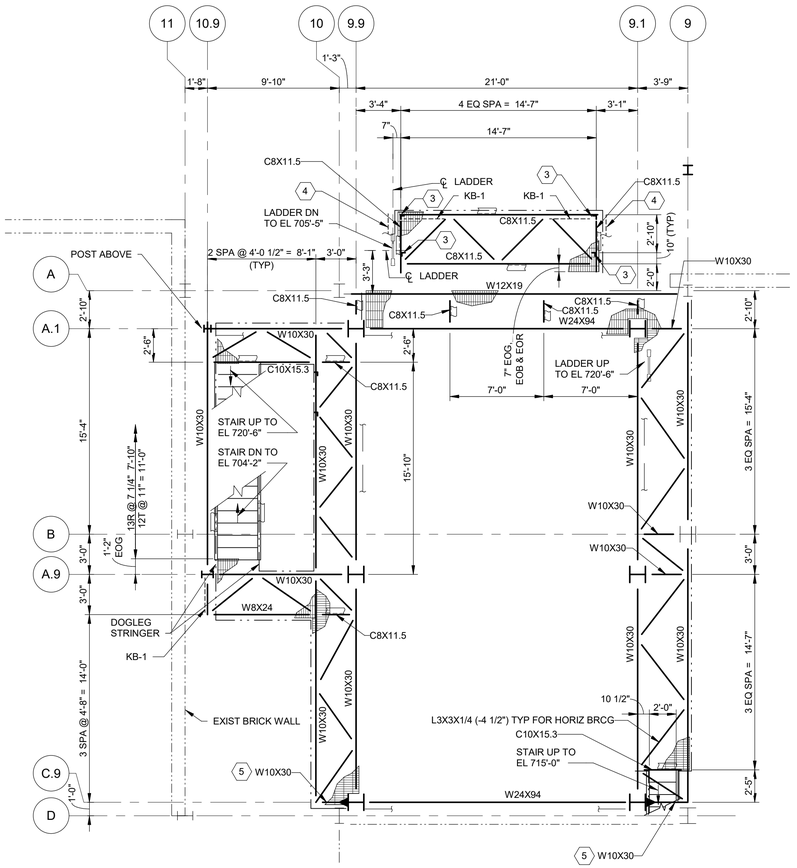
STRUCTURAL
OPERATOR FLOOR FRAMING PLAN @ EL 697'-11"

DATE	DRAWN	CHK'D.
08/03/20	AWB	HF
SCALE: As indicated		APPROVED: JWO

S-103



FRAMING PLAN @ EL 704'-2"
SCALE: 3/16" = 1'-0" (TOS EL -1 1/4" UNO)



FRAMING PLAN @ EL 712'-0"
SCALE: 3/16" = 1'-0" (TOS EL -1 1/4" UNO)

NOTES

1. FOR GENERAL NOTES, DESIGN CRITERIA AND LEGEND, SEE DWG S-001 & S-002.
2. FOR KNEE BRACE DETAILS AND SCHEDULE, SEE DWG S-703.

KEYNOTES

1. L4X4X1/4 HANGER UP TO BOT/EXIST W12X26 (REF) @ TOS EL 705'-7 1/2", PROVIDE CONNECTION TO BOT/EXIST BEAM SIM TO "TYPICAL HANGER CONNECTION DETAIL" ON DWG S-702 WITH FIELD WELD TO EXIST BEAM, CONNECT BOTTOM OF HANGER TO CHANNEL W/ (2) 7/8" A325 BOLTS SPACED @ 3" CENTERED VERTICALLY ON CHANNEL @ GAGE OF ANGLE.
2. L3X3X5/16" HANGER UP TO BOT/BEAM @ TOS EL 711'-10 1/2", PROVIDE CONNECTION TO BOT/ BEAM PER "TYPICAL HANGER CONNECTION DETAIL" ON DWG S-702, CONNECT BOTTOM OF HANGER TO CHANNEL W/ (2) 7/8" A325 BOLTS SPACED @ 3" CENTERED VERTICALLY ON CHANNEL @ GAGE OF ANGLE.
3. L4X4X3/4 POST FROM TOS 711'-10 1/2" DN TO EXIST CONC FDN EL 705'-5" (REF), CONNECT TOP OF POST TO CHANNEL W/ (2) - 7/8" A325 BOLTS SPACED @ 3" CENTERED VERTICALLY ON CHANNEL @ GAGE OF ANGLE, PROVIDE BASE PLATE PER "TYPICAL ANGLE POST BASE PLATE DETAIL" ON DWG S-702 W/ 3/4" DIA HAS-CS ROD, 9" LONG W/ HILTI HY-200 ADHESIVE SYSTEM OR APPROVED EQUAL , BOT/BASE PLATE EL 705'-6 1/2", GROUT AS REQD.
4. PROVIDE (2) - L3X3X5/16 VERTICAL BRACES EQUALLY SPACED W/ 3/8" THK GUSSET WELDED TO POSTS WITH 3/16" FILLET WELD ON 2 SIDES AND 2 BOLT CONNECTION @ GAGE OF ANGLE.
5. SHOP WELD BEAM TO COL W/ 1/4" FILLET WELD ON BOTH SIDES OF FLANGES AND WEB.

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	HF

SECURITY
PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

STRUCTURAL
FRAMING PLANS @ EL 704'-2" & 712'-0"

DATE	DRAWN	CHK'D.
08/03/20	AWB	HF
SCALE 3/16" = 1'-0"		APPROVED JWO

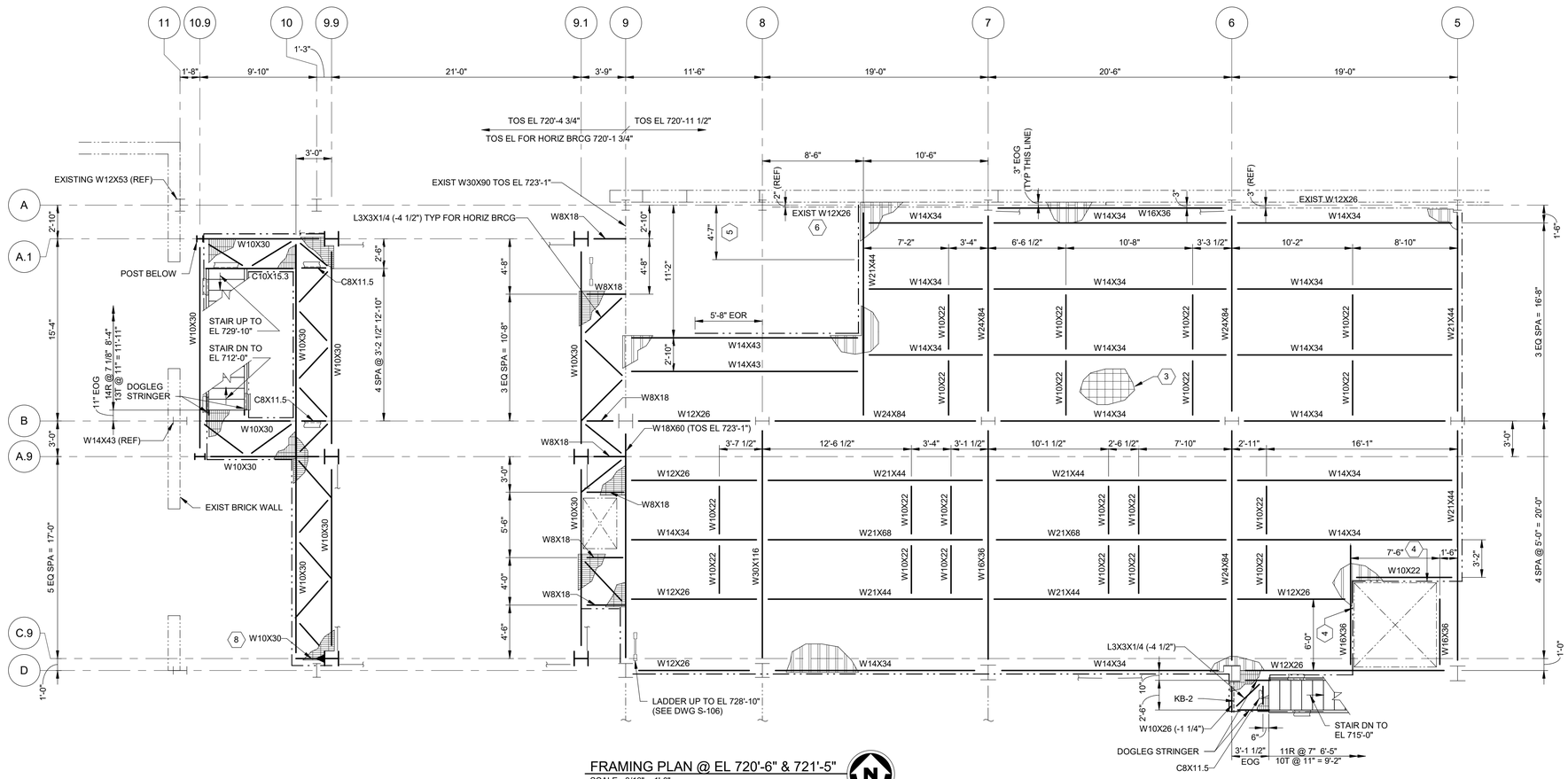
S-104

NOTES

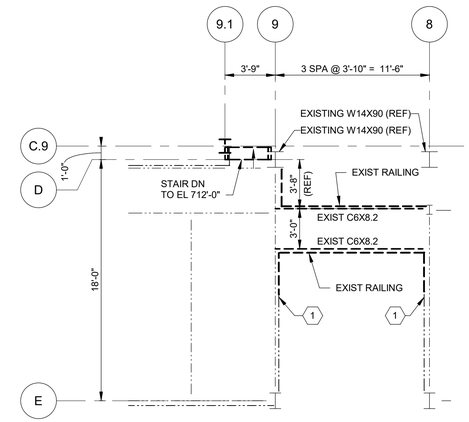
1. FOR GENERAL NOTES, DESIGN CRITERIA AND LEGEND, SEE DWG S-001 & S-002.

KEYNOTES

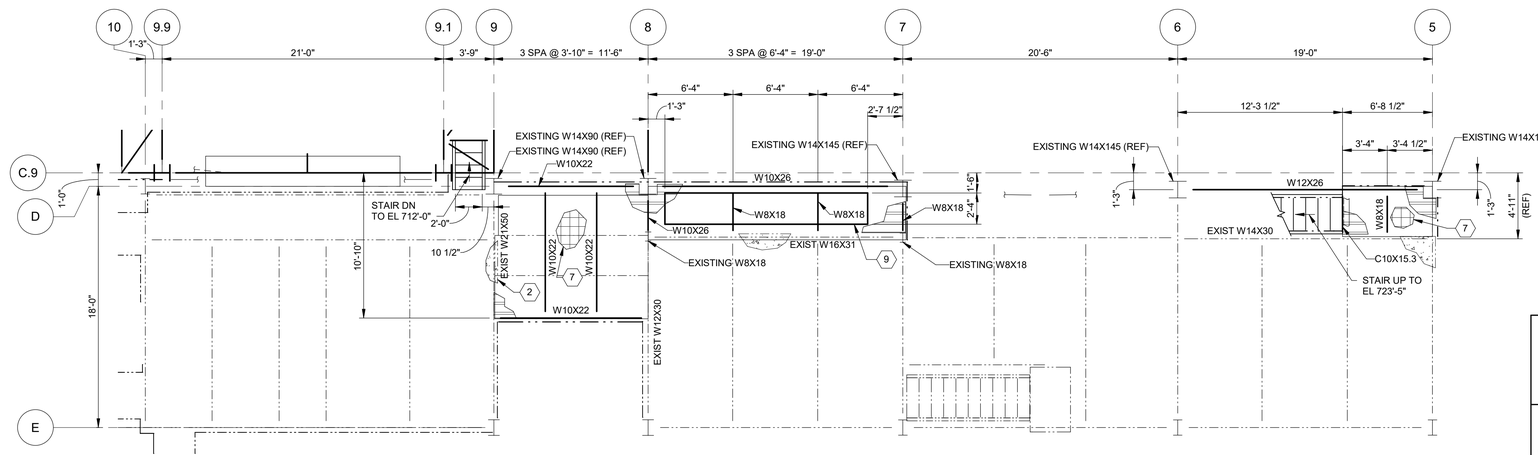
1. MODIFY EXIST RAILING AS REQD FOR NEW RAILING.
2. SAWCUT AND REMOVE EXIST ELEVATED SLAB TO CENTERLINE OF EXIST BEAM FOR NEW FLOOR SUPPORT.
3. 5 1/2" ELEVATED CONC SLAB W/4X4-W4.0XW4.0 REINFORCING, T/SLAB EL 723'-5", PLACE REINFORCING -2 3/4" FROM TOP OF CONCRETE.
4. REMOVABLE SIDE MOUNTED RAILING.
5. OMIT TOP RAIL.
6. REMOVE EXIST W12 AND REPLACE IT WITH NEW W21X44.
7. 4" ELEVATED CONC SLAB W/4X4-W4.0XW4.0 REINFORCING, T/SLAB EL 715'-0", PLACE REINFORCING -2 3/4" FROM TOP OF CONCRETE.
8. SHOP WELD BEAM TO COL W/ 1/4" FILLET WELD ON BOTH SIDES OF FLANGES AND WEB.
9. 4" THK EQUIPMENT PAD, TOC EL 715'-4", SEE "TYPICAL EQUIPMENT PAD DETAIL (TYPE 1)" ON DWG S-701.



FRAMING PLAN @ EL 720'-6" & 721'-5"
SCALE: 3/16" = 1'-0"



DEMO PLAN @ EL 715'-0"
SCALE: 3/16" = 1'-0"



FRAMING PLAN @ EL 715'-0"
SCALE: 3/16" = 1'-0" (TOS EL -0'-4" FOR NEW AND EXIST FRAMING)

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	HF

SECURITY
PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

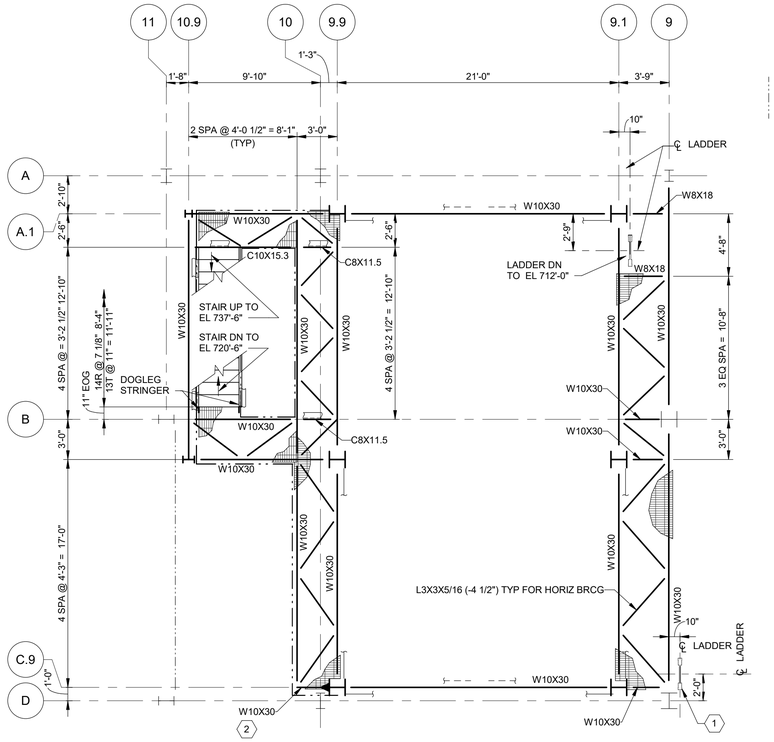
2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

STRUCTURAL FRAMING PLANS @ EL 715'-0", 720'-6" & 721'-5"

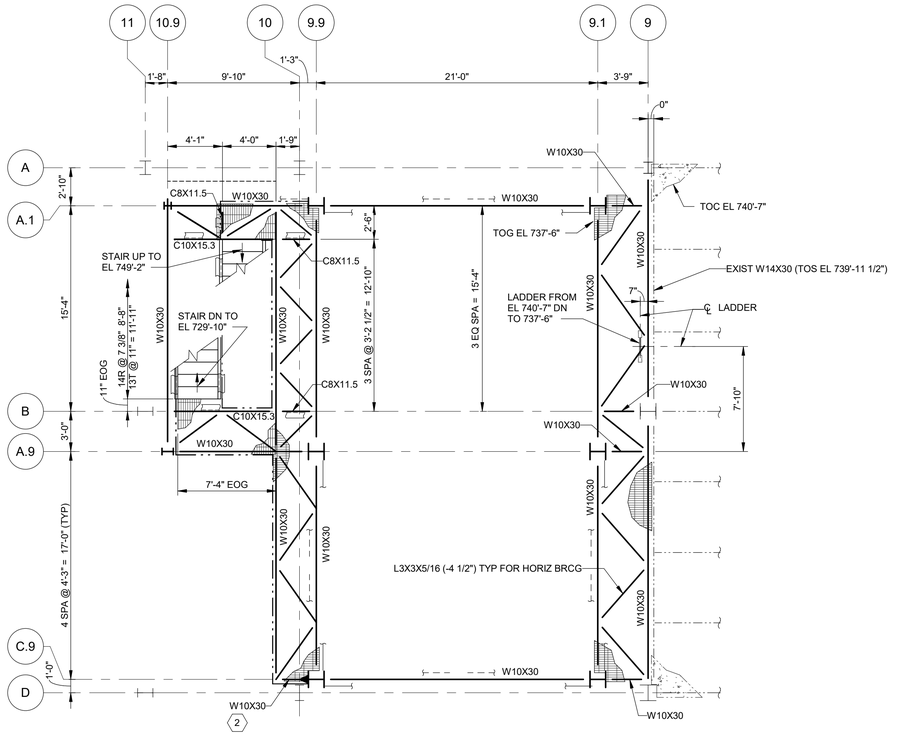
DATE	DRAWN	CHK'D.
08/03/20	AWB	HF
SCALE 3/16" = 1'-0"		APPROVED JWO

S-105



FRAMING PLAN @ EL 728'-10"

SCALE: 3/16" = 1'-0" (TOS EL -1 1/4" UNO)



FRAMING PLAN @ EL 737'-6"

SCALE: 3/16" = 1'-0" (TOS EL -1 1/4" UNO)

NOTES

1. FOR GENERAL NOTES, DESIGN CRITERIA AND LEGEND, SEE DWG S-001 & S-002.

KEYNOTES

1. LADDER DN TO TOP/NEW ELEVATED SLAB @ TOC EL 721'-5", SEE "TYPICAL STEP THRU LADDER DETAIL" ON DWG S-704.
2. SHOP WELD BEAM TO COL W/ 1/4" FILLET WELD ON BOTH SIDES OF FLANGES AND WEB.

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	HF

SECURITY

PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

STRUCTURAL
FRAMING PLANS @ EL 728'-10" & 737'-6"

DATE	DRAWN	CHK'D.
08/03/20	AWB	HF
SCALE 3/16" = 1'-0"		APPROVED JWO

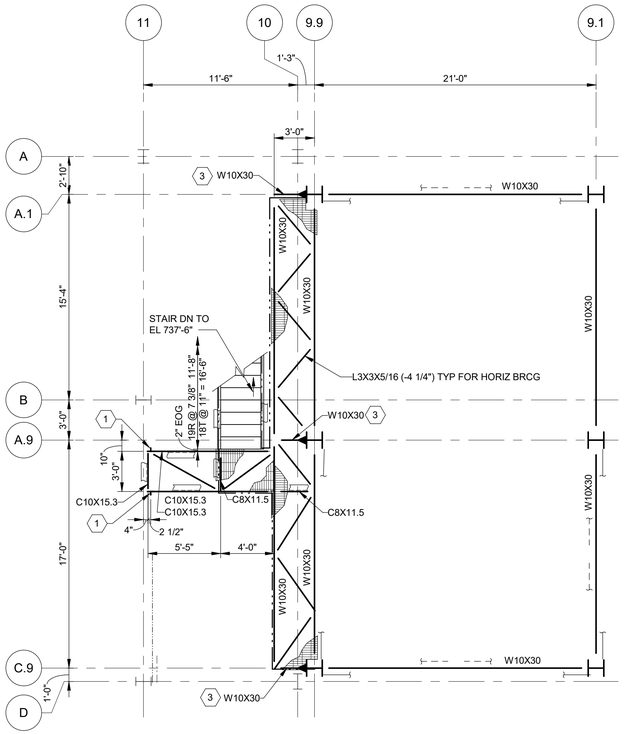
S-106

NOTES

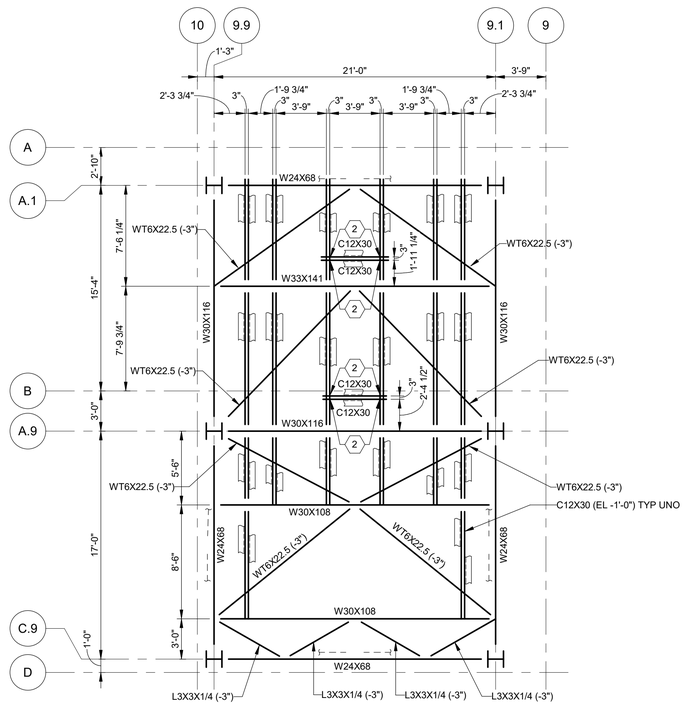
1. FOR GENERAL NOTES, DESIGN CRITERIA AND LEGEND, SEE DWG S-001 & S-002.

KEYNOTES

1. L3X3X1/4 POST FROM TOS 749'-0 1/2" DN TO T/EXIST BEAM @ TOS EL 745'-11 1/2" (REF), CONNECT TOP OF POST TO CHANNEL W/ (2) - 7/8" A325 BOLTS SPACED @ 3" CENTERED VERTICALLY ON CHANNEL @ GAGE OF ANGLE, PROVIDE BASE PLATE SIM TO "TYPICAL ANGLE POST BASE PLATE DETAIL" ON DWG S-702, FIELD WELD BASE PLATE TO TOP FLANGE OF EXIST BEAM W/ 3/16" FILLET WELD ON 4 SIDES.
2. CONNECT BOT FLANGE OF CHANNEL ABOVE TO TOP FLANGE OF CHANNELS BELOW W/ (4) - 7/8" DIA A325 BOLT @ GAGES OF CHANNELS (ONE BOLT AT EACH CHANNEL BELOW).
3. SHOP WELD BEAM/CHANNEL TO COL W/ 1/4" FILLET WELD ON BOTH SIDES OF FLANGES AND WEB.



FRAMING PLAN @ EL 749'-2"
SCALE: 3/16" = 1'-0" (TOS EL -1 1/4" UNO)



FRAMING PLAN @ EL 759'-8"
SCALE: 3/16" = 1'-0" (TOS EL -0'-0" UNO)

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	HF

SECURITY
PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

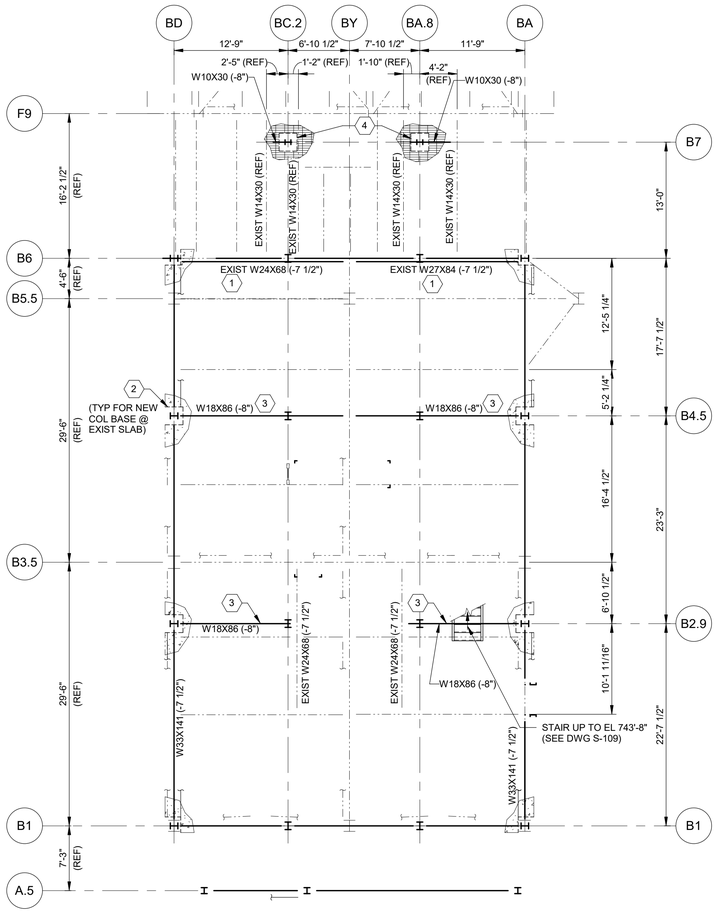
2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

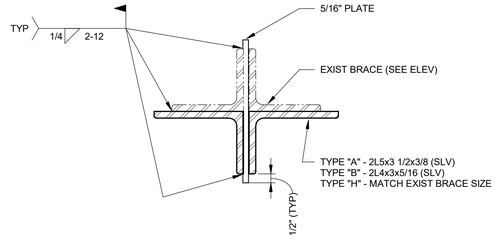
STRUCTURAL FRAMING PLANS @ EL 749'-2" & 759'-8"

DATE	DRAWN	CHK'D.
08/03/20	AWB	HF
SCALE 3/16" = 1'-0"		APPROVED JWO

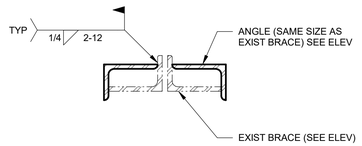
S-107



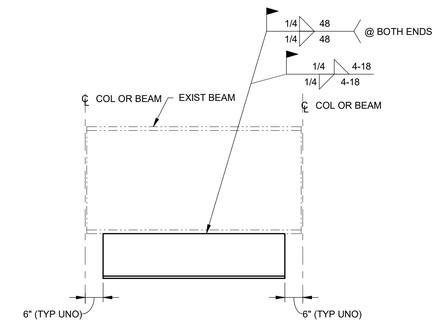
EXIST BAGHOUSE FLOOR @ TOC EL 736'-0"
SCALE: 1/8" = 1'-0" (TOS EL -0'-8" UNO)



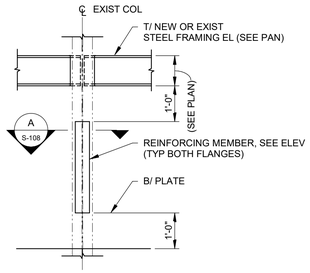
BRACE REINFORCING DETAIL TYPE "A", "B" & "H"
SCALE: 3" = 1'-0"



BRACE REINFORCING DETAIL TYPE "C"
SCALE: 3" = 1'-0"

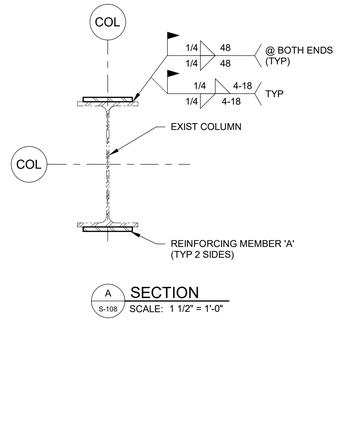


BEAM REINFORCING TYPE 'D'
SCALE: 1/2" = 1'-0"



COLUMN REINFORCING TYPE 'F'
SCALE: 1/2" = 1'-0"

BEAM REINFORCING DETAIL TYPE "E"
SCALE: 1 1/2" = 1'-0"



A S-108 SECTION
SCALE: 1 1/2" = 1'-0"

NOTES

1. FOR GENERAL NOTES, DESIGN CRITERIA AND LEGEND, SEE DWG S-001.
2. FOR KNEE BRACE DETAILS AND SCHEDULE, SEE DWG S-703.

KEYNOTES

1. PROVIDE BEAM REINFORCING PER "BEAM REINFORCING DETAIL (TYPE D)" ON THIS DWG.
2. SAWCUT AND REMOVE A 2'-0"x2'-0" SECTION OF EXIST ELEVATED CONC SLAB (8" THK (REF) FOR NEW COL BASE PLATE, OPENING TO BE CENTERED ON NEW COL, FILL WITH GROUT AFTER INSTALLATION OF NEW COL, FORM AS REQD AT EDGE OF SLAB.
3. CONNECT TOP FLANGE OF BEAM TO BOT/EXIST ELEVATED CONC SLAB W/ 5/8" DIA HILTI KWIK BOLT TZ-CS POST INSTALL BOLTS @ 3'-0" C/C FOR THE LENGTH OF THE BEAM.
4. REMOVE 2'-0"x2'-0" SECTION OF GRATING FOR NEW COLUMN BASE PLATE, PROVIDE GRATING SUPPORT AS REQD.

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	HF

SECURITY
PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

STRUCTURAL
BAGHOUSE FRAMING PLAN @ EL 736'-0"

DATE	DRAWN	CHK'D.
08/03/20	AWB	HF
SCALE: As indicated		APPROVED: JWO

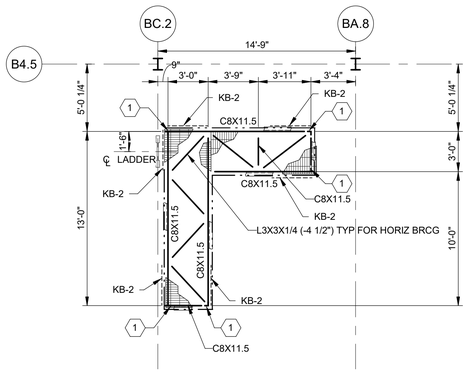
S-108

NOTES

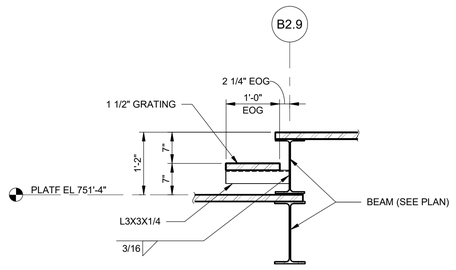
1. FOR GENERAL NOTES, DESIGN CRITERIA AND LEGEND, SEE DWG S-001 & S-002.
2. FOR KNEE BRACE DETAILS AND SCHEDULE, SEE DWG S-703.

KEYNOTES

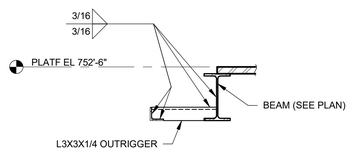
1. L4X4X1/4 POST DN TO EXIST BAGHOUSE CONCRETE FLOOR EL 736'-0"
2. W8X18 POST DN TO BEAM @ TOS EL 752'-6", PROVIDE BASE PLATE PER "TYPICAL WIDE FLANGE POST BASE PLATE AND CAP PLATE DETAIL" ON DWG S-702.
3. OUTRIGGER, SEE "TYPICAL OUTRIGGER SECTIONS" ON DWG S-706.
4. 3'-8" DIA OPENING IN GRATING, PROVIDE 1/4" TOE PLATE PER "TYPICAL TOE PLATE ATTACHMENT DETAILS" ON DWG S-705.
5. PROVIDE L3X3X1/4 WELDED TO BACK OF STRINGER FOR GRATING SUPPORT.



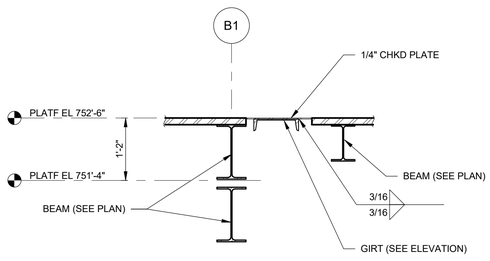
FRAMING PLAN @ EL 743'-4"
SCALE: 3/16" = 1'-0" (TOSL EL -1 1/2" UNO)



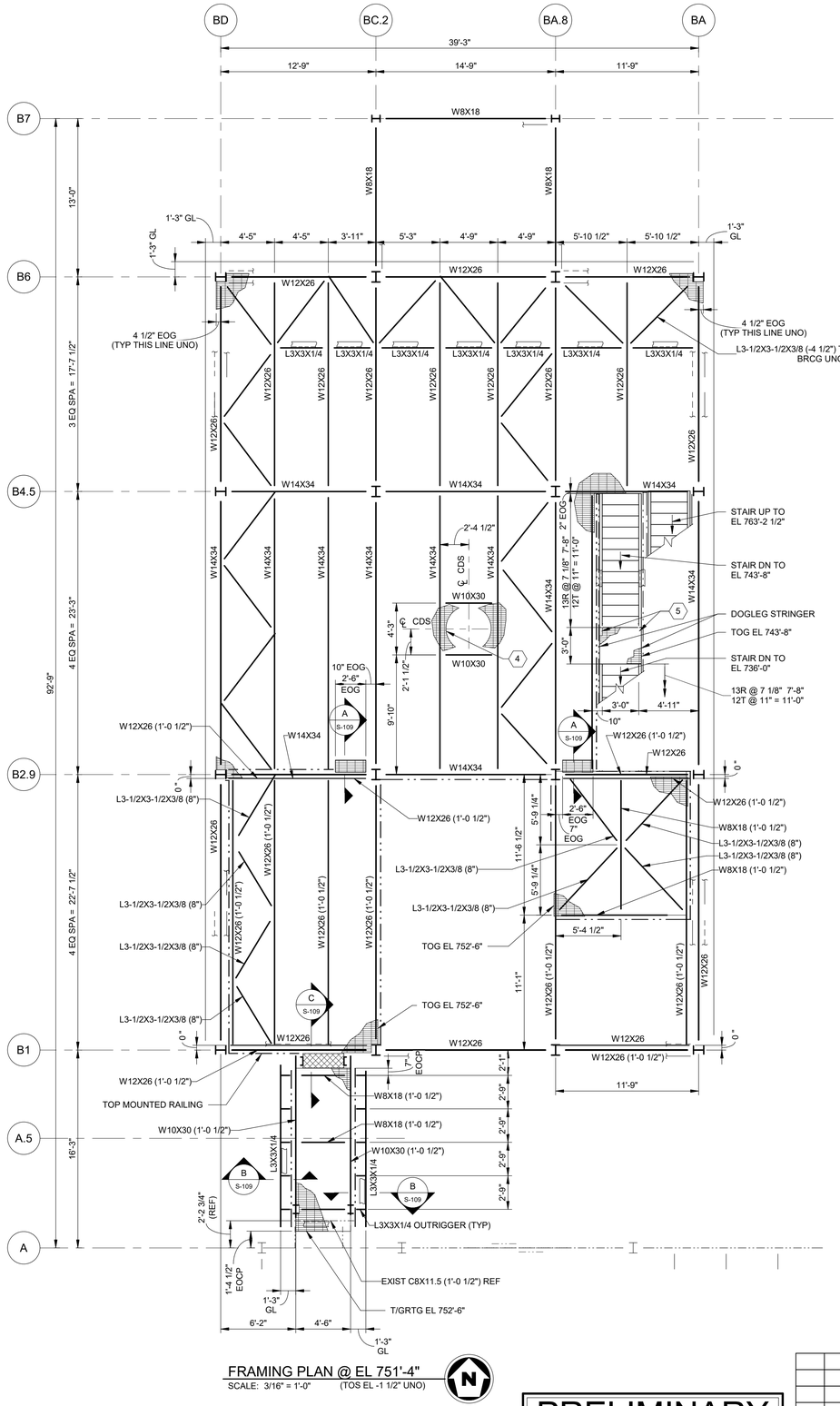
A S-109 SECTION
SCALE: 3/4" = 1'-0"



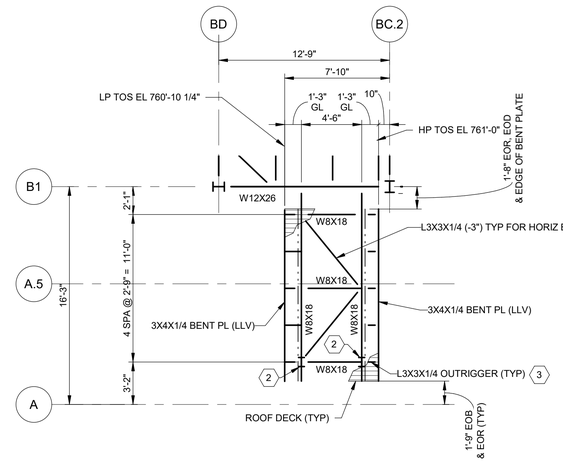
B S-109 SECTION
SCALE: 3/4" = 1'-0"



C S-109 SECTION
SCALE: 3/4" = 1'-0"



FRAMING PLAN @ EL 751'-4"
SCALE: 3/16" = 1'-0" (TOS EL -1 1/2" UNO)



ROOF FRAMING PLAN
SCALE: 3/16" = 1'-0" (TOS EL - SEE PLAN)

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	HF

SECURITY
PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

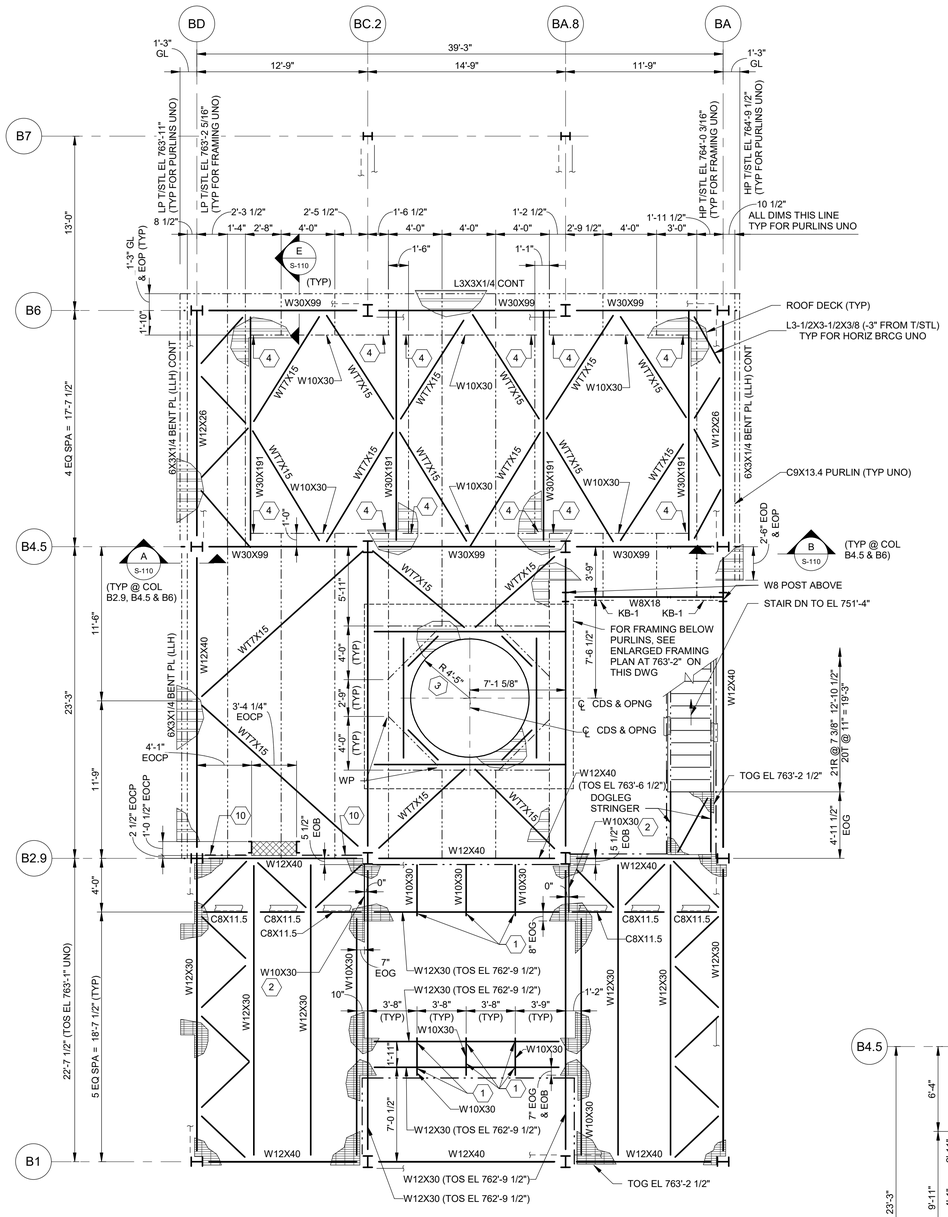
2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

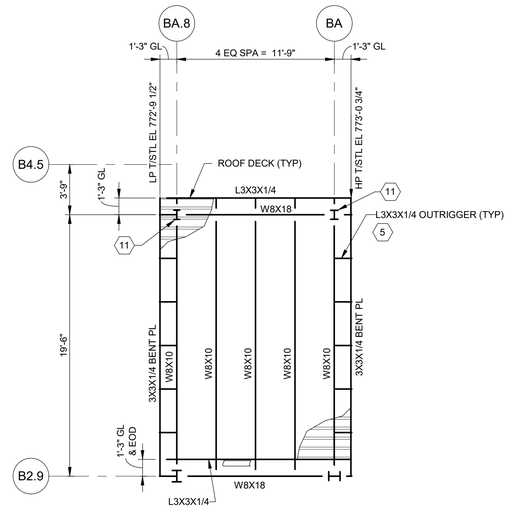
ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

STRUCTURAL
BAGHOUSE FRAMING PLANS @ EL 743'-4" & 751'-4"

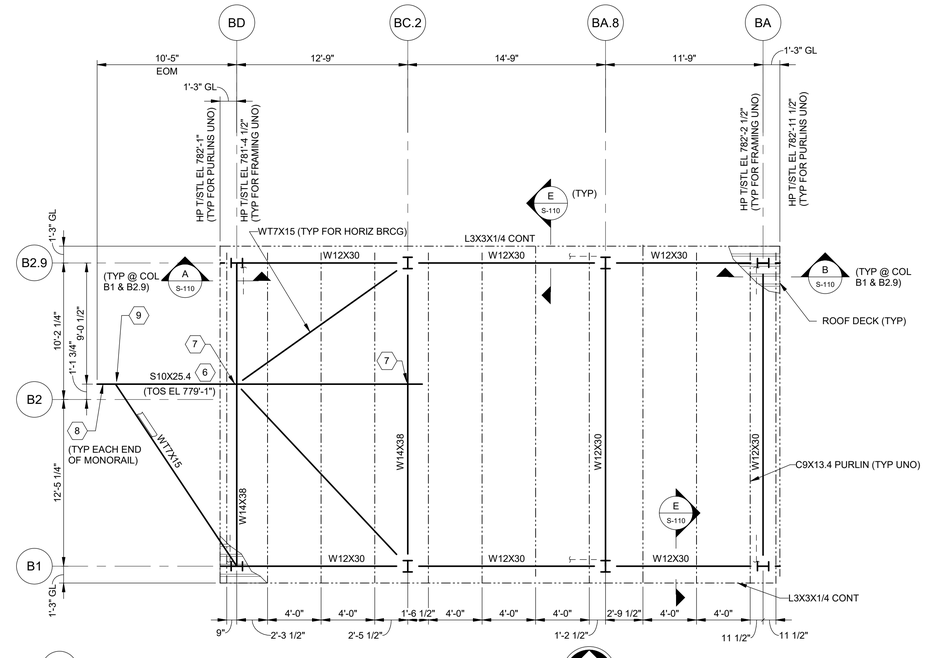
DATE	DRAWN	CHK'D.
08/03/20	AWB	HF
SCALE: As indicated		APPROVED: JWO

S-109

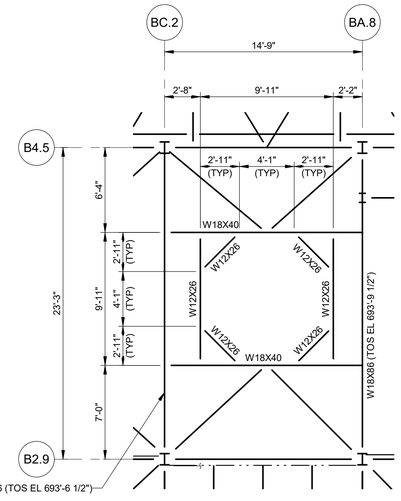




STAIR ENCLOSURE ROOF FRAMING PLAN
SCALE: 3/16" = 1'-0"



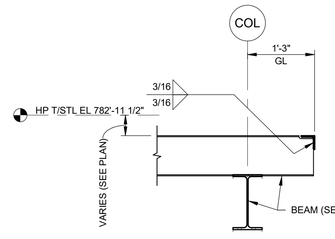
ROOF FRAMING PLAN
SCALE: 3/16" = 1'-0"



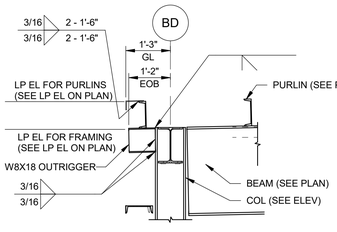
NOTE: PURLINS NOT SHOWN FOR CLARITY, SEE NORTH BAGHOUSE ENCLOSURE ROOF FRAMING PLAN ON THIS DWG.

ENLARGED FRAMING PLAN @ EL 763'-2"
SCALE: 3/16" = 1'-0" (TOS EL -0'-0")

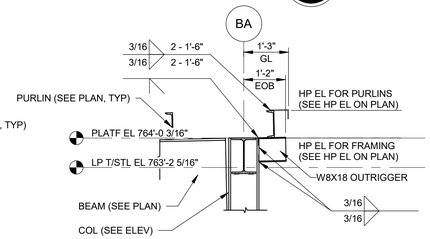
NORTH BAGHOUSE ENCLOSURE ROOF FRAMING PLAN
SCALE: 3/16" = 1'-0"



E S-110 SECTION
SCALE: 3/4" = 1'-0"



A S-110 SECTION
SCALE: 1/2" = 1'-0"



B S-110 SECTION
SCALE: 1/2" = 1'-0"

LEGEND:

PURLINS PER ELEVATION SHOWN ON PLAN (SEE HP AND LP ELEVATIONS)

FRAMING PER ELEVATION SHOWN ON PLAN (SEE HP AND LP ELEVATIONS)

NOTES

1. FOR GENERAL NOTES, DESIGN CRITERIA AND LEGEND, SEE DWG S-001.
2. FOR KNEE BRACE DETAILS AND SCHEDULE, SEE DWG S-703.

KEYNOTES

1. CONNECT BOT FLANGE OF BEAM ABOVE TO TOP FLANGE OF BEAM BELOW W/ (2) - 7/8" A3235 BOLTS @ GAGE OF BEAMS.
2. WELD BOT FLANGE OF BEAM ABOVE TO TOP FLANGE OF BEAM BELOW W/ 3/16" FILLET WELD 2" LONG SPACED @ 6" ON BOTH SIDES OF BOT FLANGE.
3. 8'-10" DIA OPENING IN ROOF DECK.
4. ATTACH BOTTOM FLANGE OF W10 TO TOP FLANGE OF BEAM BELOW W/(2) - 7/8" A325 BOLTS @ GAGE OF W10.
5. SEE "TYPICAL "OUTRIGGER SECTIONS" ON DWG S-706.
6. PROVIDE STENCILED LABEL WITH 3" HIGH LETTERS ON EACH SIDE OF MONORAIL WEB : 1 TON CAPACITY.
7. PROVIDE MONORAIL CONNECTION PER "TYPICAL MONORAIL SUPPORT (BOLTED CONNECTION)" DETAIL ON DWG S-706.
8. PROVIDE MONORAIL END STOP PER "TYPICAL MONORAIL END STOP DETAIL" ON DWG S-706.
9. CONNECT ANGLE TO TOP FLANGE OF MONORAIL WITH (2) - 7/8" A325 BOLTS @ GAGE OF MONORAIL/ANGLE.
10. TOP MOUNT RAILING.
11. W8X18 POST DN TO TOP OF BEAM , PROVIDE BASE PLATE PER "TYPICAL WIDE FLANGE POST BASE PLATE AND CAP PLATE DETAIL" ON DWG S-702.

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	HF

SECURITY
PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

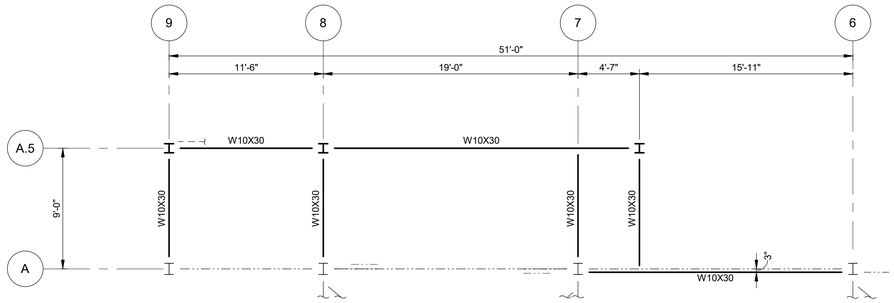
STRUCTURAL
BAGHOUSE ROOF FRAMING PLANS

DATE	DRAWN	CHK'D.
08/03/20	AWB	HF
SCALE: As indicated		APPROVED: JWO

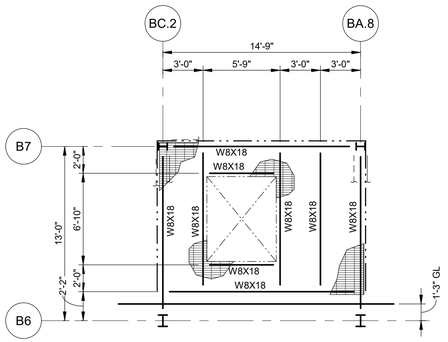
S-110

NOTES

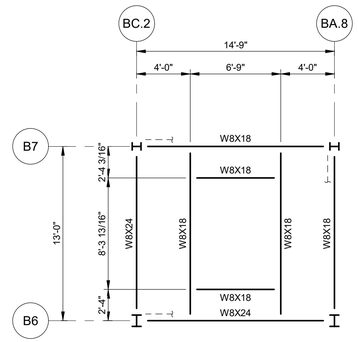
1. FOR GENERAL NOTES, DESIGN CRITERIA AND LEGEND, SEE DWG S-001.
2. FOR KNEE BRACE DETAILS AND SCHEDULE, SEE DWG S-703.



FRAMING PLAN @ EL 738'-0"
SCALE: 3/16" = 1'-0" (TOS EL -0" UNO)



FRAMING PLAN @ EL 762'-9 1/2"
SCALE: 3/16" = 1'-0" (TOS EL -1 1/2" UNO)



FRAMING PLAN @ EL 787'-4"
SCALE: 3/16" = 1'-0" (TOS EL -0" UNO)

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	HF

SECURITY

PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

STRUCTURAL
BAGHOUSE FRAMING PLANS @ EL 738'-0", 762'-9 1/2" & 787'-4"

DATE	DRAWN	CHK'D.
08/03/20	AWB	HF
SCALE 3/16" = 1'-0"		APPROVED JWO

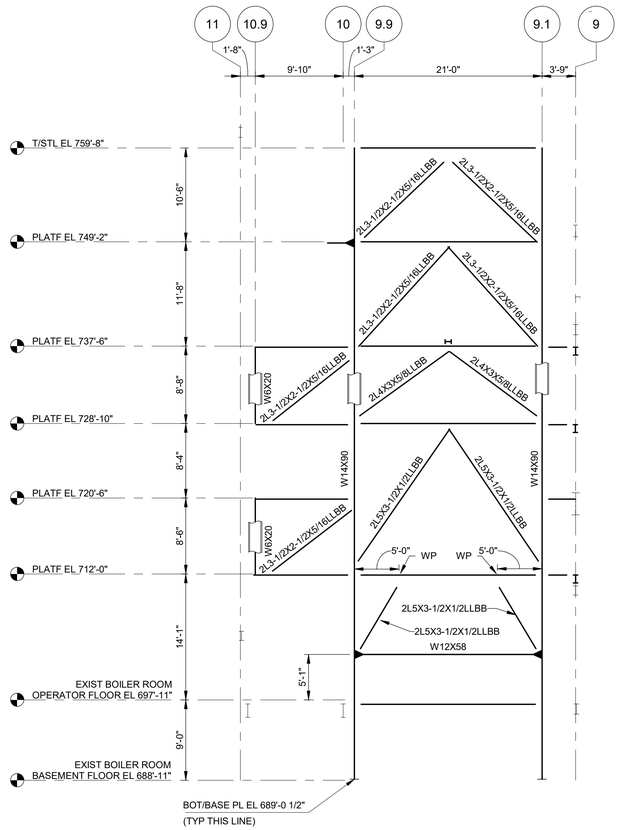
S-111

NOTES

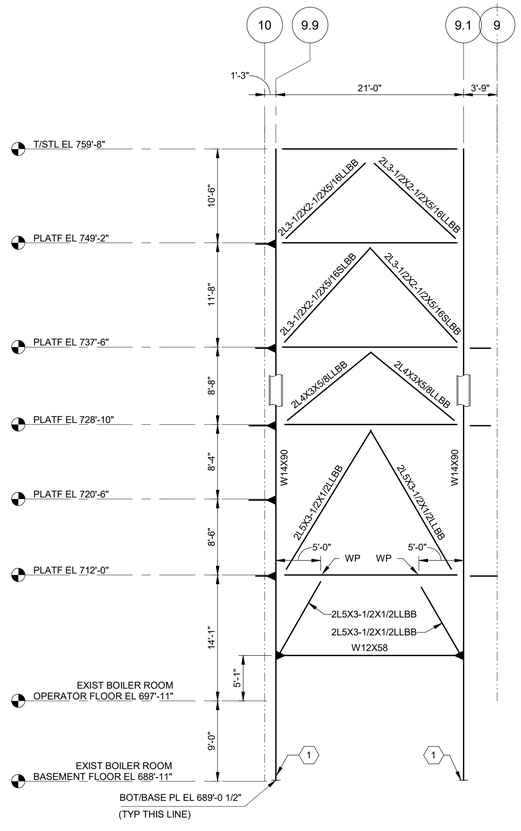
1. FOR GENERAL NOTES, DESIGN CRITERIA AND LEGEND, SEE DWG S-001.
2. SEE VERTICAL BRACE CONNECTION DETAILS ON DWG S-703.

KEYNOTES

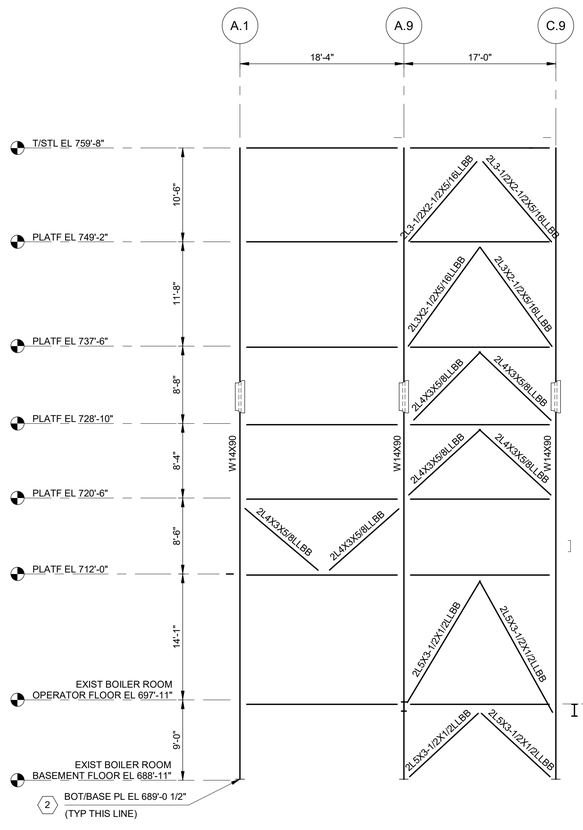
1. PROVIDE (4) 1 1/4" DIA x 2'-0" LG HAS-V-36 GALVANIZED RODS W/ HILTI HIT-HY200 SYSTEM OR APPROVED EQUAL, EMBED = 1'-6".
2. PROVIDE BASE PLATE PER "FIRE HEATER COLUMN BASE PLATE DETAIL" ON DWG S-702.



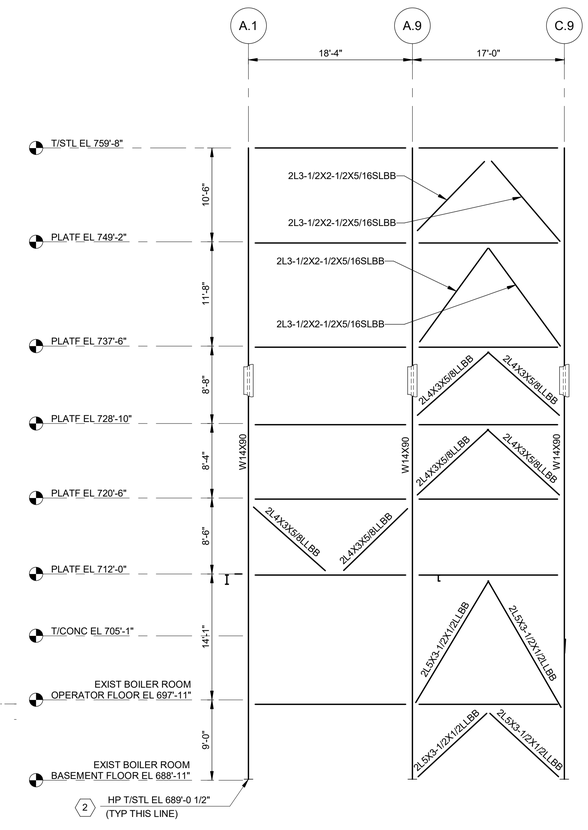
FRAMING ELEVATION @ COL LN A.1 (LOOKING NORTH)
SCALE: 1/8" = 1'-0"



FRAMING ELEVATION @ COL LN C.9 (LOOKING NORTH)
SCALE: 1/8" = 1'-0"



FRAMING ELEVATION @ COL LN 9.1 (LOOKING EAST)
SCALE: 1/8" = 1'-0"



FRAMING ELEVATION @ COL LN 9.9 (LOOKING EAST)
SCALE: 1/8" = 1'-0"

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	HF

SECURITY

PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

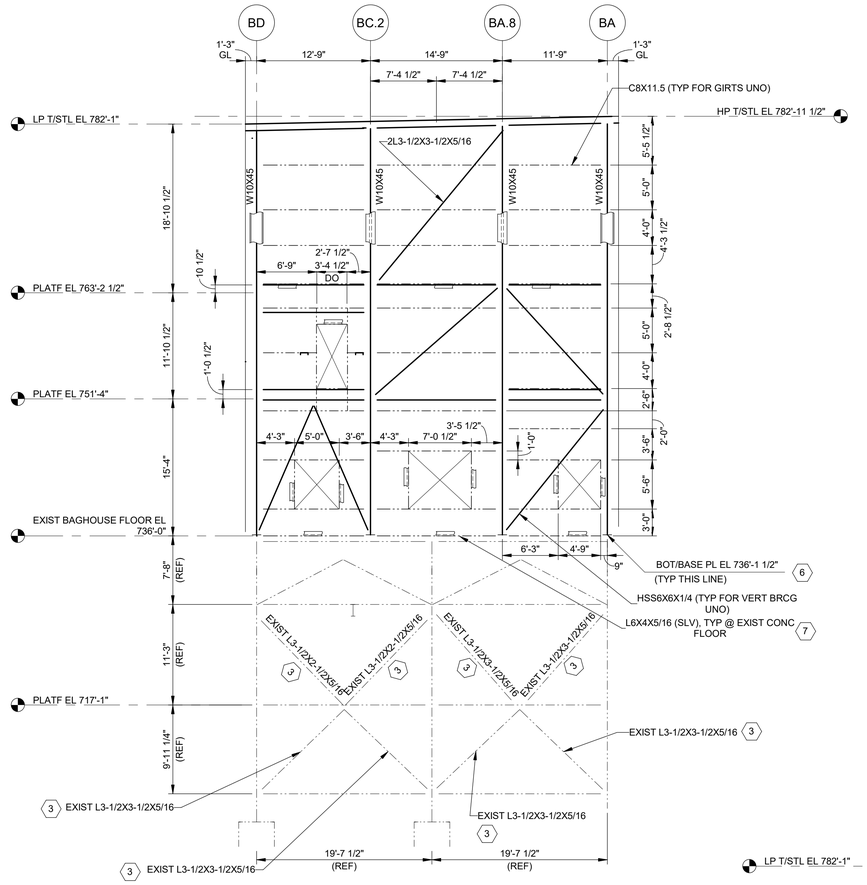
2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

STRUCTURAL
FIRE HEATER FRAMING ELEVATIONS @ COL LN A.1, C.9, 9.1 & 9.9

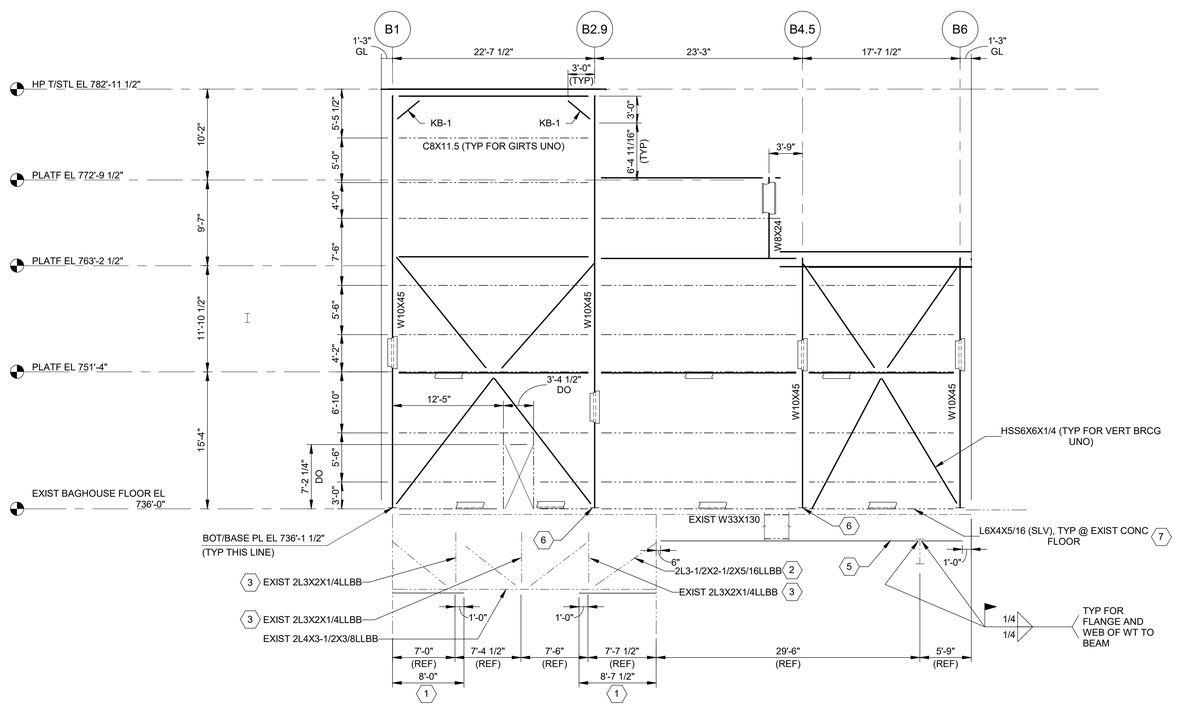
DATE	DRAWN	CHK'D.
08/03/20	AWB	HF
SCALE 1/8" = 1'-0"		APPROVED JWO

S-201



FRAMING ELEVATION @ COL LN B1 (LOOKING NORTH)

SCALE: 1/8" = 1'-0"



FRAMING ELEVATION @ COL LN BA (LOOKING WEST)

SCALE: 1/8" = 1'-0"

NOTES

1. FOR GENERAL NOTES, DESIGN CRITERIA AND LEGEND, SEE DWG S-001.
2. ALL GIRTS ARE TOED AWAY FROM OPENING AND TOED DOWN UNLESS NOTED OTHERWISE. FOR SAG RODS, SEE "TYPICAL SAG ROD DETAILS ON DWG S-706. FOR GIRT CONNECTION AND ORIENTATION, SEE DETAILS ON DWG S-706.
3. SEE VERTICAL BRACE CONNECTION DETAILS ON DWG S-703.

KEYNOTES

1. PROVIDE BEAM REINFORCING PER "BEAM REINFORCING DETAIL (TYPE A)" DWG S-108.
2. PROVIDE BRACE REINFORCING PER "BRACE REINFORCING DETAIL (TYPE B)" ON DWG S-108, BRACE TO BE REINFORCED FOR THE ENTIRE LENGTH.
3. PROVIDE BEAM REINFORCING PER "BEAM REINFORCING DETAIL (TYPE C)" ON DWG S-108, BRACE TO BE REINFORCED FOR THE ENTIRE LENGTH.
4. PROVIDE COLUMN REINFORCING PER "COLUMN REINFORCING DETAIL (TYPE F)" ON DWG S-108.
5. PROVIDE BEAM REINFORCING PER "BEAM REINFORCING (TYPE D)" DETAIL ON DWG S-108.
6. PROVIDE BASE PLATE PER "BAGHOUSE ENCLOSURE BASE PLATE DETAIL" ON DWG S-702.
7. SILL ANGLE ATTACHED TO TOP OF EXIST 8" CONC ELEVATED SLAB, SEE "TYPICAL JAMB & SILL CONNECTION TO CONCRETE" DETAIL ON DWG S-701.

LEGEND:

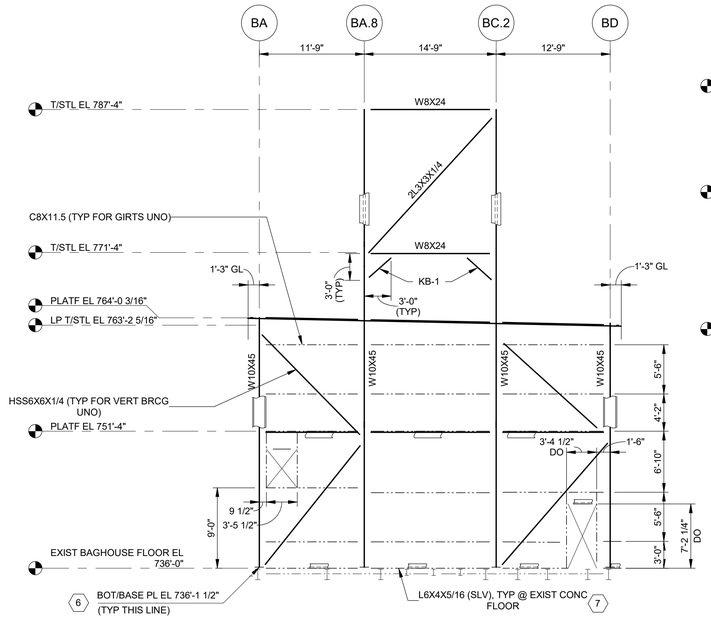
GIRTS (SEE ELEVATIONS)

FRAMING ELEVATION @ COL LN BD (LOOKING EAST)

SCALE: 1/8" = 1'-0"

PARTIAL ELEVATION @ COL LN B2.9 (LOOKING NORTH)

SCALE: 1/8" = 1'-0"



FRAMING ELEVATION @ COL LN B6 (LOOKING SOUTH)

SCALE: 1/8" = 1'-0"

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	HF

SECURITY

PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

STRUCTURAL
BAGHOUSE FRAMING ELEVATIONS SHT 1

DATE	DRAWN	CHK'D.
08/03/20	AWB	HF
SCALE: As indicated		APPROVED: JWO

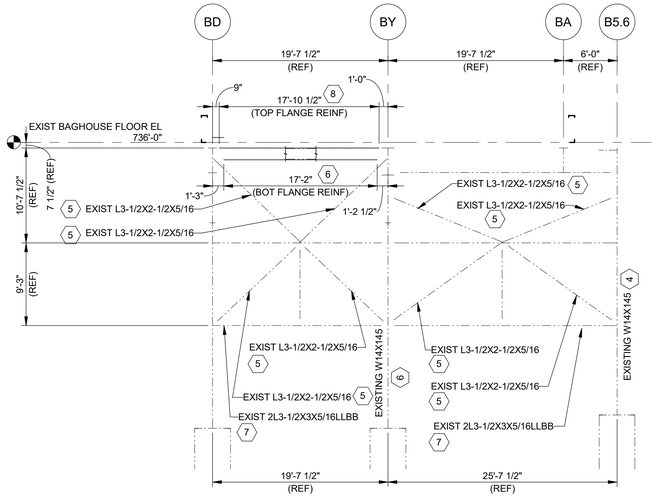
S-202

NOTES

1. FOR GENERAL NOTES, DESIGN CRITERIA AND LEGEND, SEE DWG S-001.
2. SEE VERTICAL BRACE CONNECTION DETAILS ON DWG S-703.

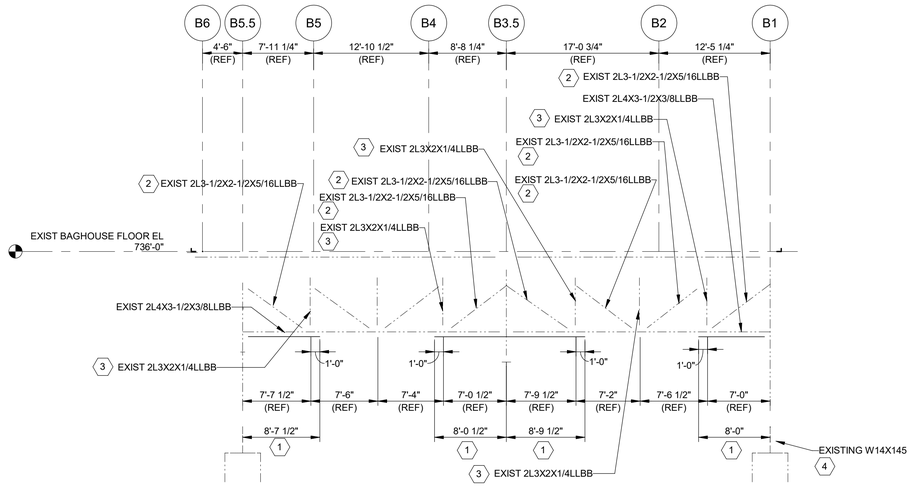
KEYNOTES

1. PROVIDE BRACE REINFORCING PER "BRACE REINFORCING DETAIL (TYPE A)" DWG S-109.
2. PROVIDE BRACE REINFORCING PER "BRACE REINFORCING DETAIL (TYPE B)" ON DWG S-109, BRACE TO BE REINFORCED FOR THE ENTIRE LENGTH.
3. PROVIDE BRACE REINFORCING PER "BRACE REINFORCING DETAIL (TYPE C)" ON DWG S-109, BRACE TO BE REINFORCED FOR THE ENTIRE LENGTH.
4. PROVIDE 3/4"x16" PLATE COLUMN REINFORCING PER "COLUMN REINFORCING DETAIL (TYPE F)" ON DWG S-109.
5. PROVIDE BRACE REINFORCING PER "BRACE REINFORCING DETAIL (TYPE C)" ON DWG S-109, BRACE TO BE REINFORCED FOR THE ENTIRE LENGTH.
6. PROVIDE BEAM REINFORCING PER "BEAM REINFORCING DETAIL (TYPE E)" DWG S-109.
7. PROVIDE BRACE REINFORCING PER "BRACE REINFORCING DETAIL (TYPE H)" DWG S-109.



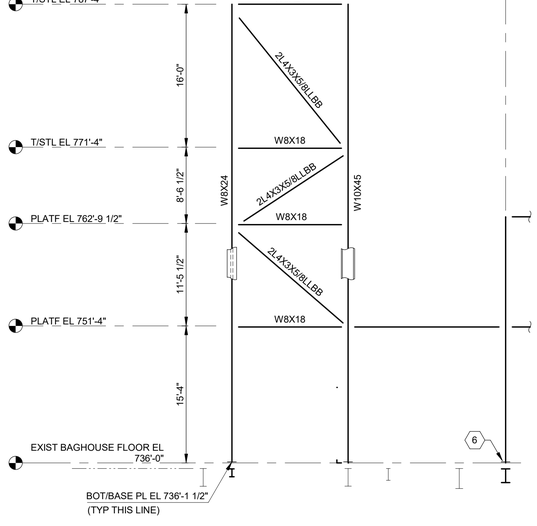
EXIST FRAMING ELEVATION @ COL LN B5.5 (LOOKING NORTH)

SCALE: 1/8" = 1'-0"



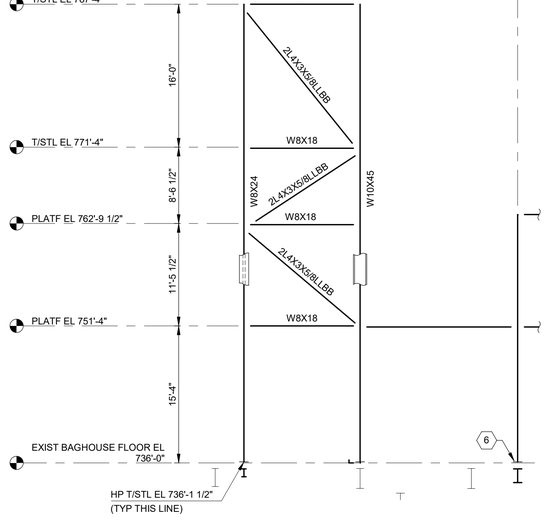
EXIST FRAMING ELEVATION @ COL LN BY (LOOKING EAST)

SCALE: 1/8" = 1'-0"



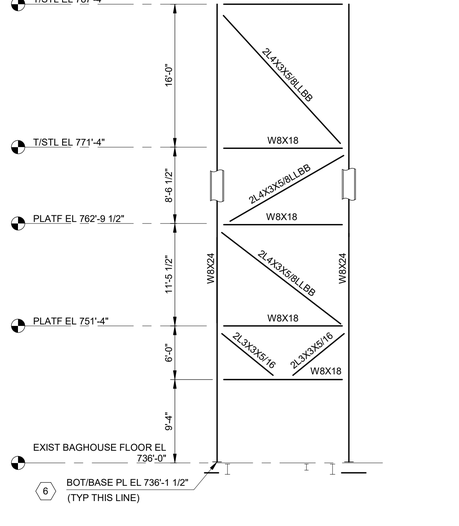
FRAMING ELEVATION @ COL LN BC.2 (LOOKING EAST)

SCALE: 1/8" = 1'-0"



FRAMING ELEVATION @ COL LN BA.8 (LOOKING EAST)

SCALE: 1/8" = 1'-0"



FRAMING ELEVATION @ COL LN B7 (LOOKING NORTH)

SCALE: 1/8" = 1'-0"

FRAMING ELEVATION @ COL LN A.5

SCALE: 1/8" = 1'-0"

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	HF

SECURITY

PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

STRUCTURAL
BAGHOUSE FRAMING ELEVATIONS SHT 2

DATE	DRAWN	CHK'D.
08/03/20	AWB	HF
SCALE 1/8" = 1'-0"		APPROVED JWO

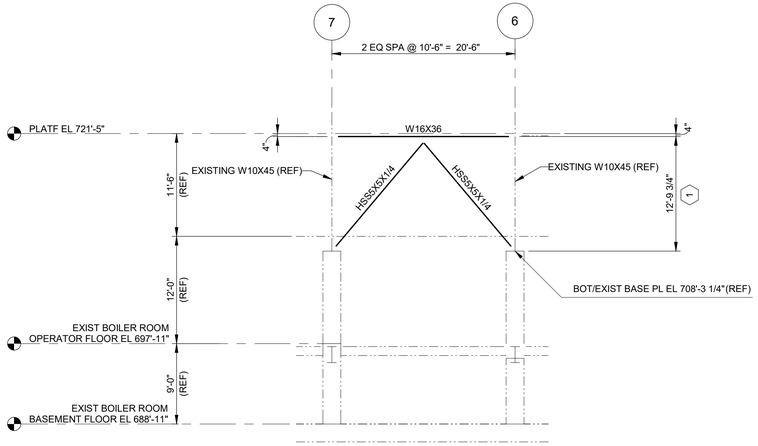
S-203

NOTES

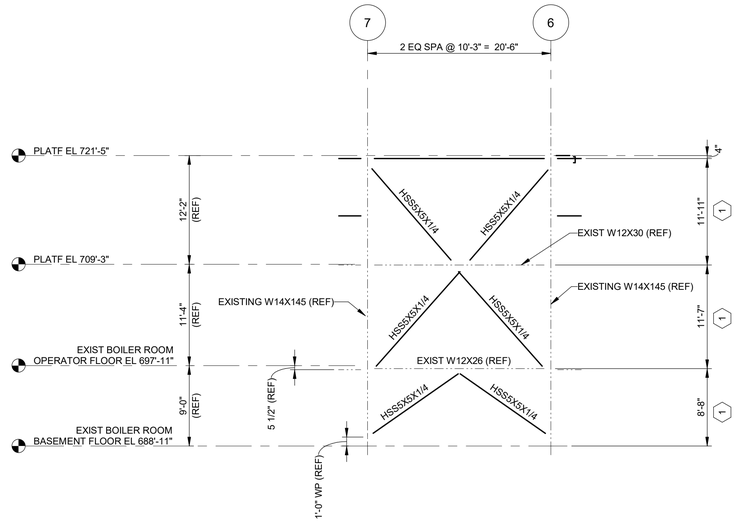
1. FOR GENERAL NOTES, DESIGN CRITERIA AND LEGEND, SEE DWG S-001

KEYNOTES

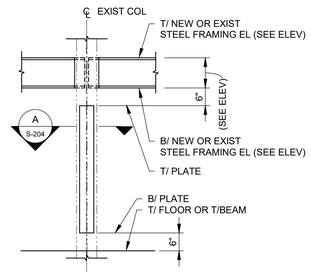
1 PROVIDE COLUMN REINFORCING PER "COLUMN REINFORCING TYPE 'A'" DETAIL ON THIS DWG.



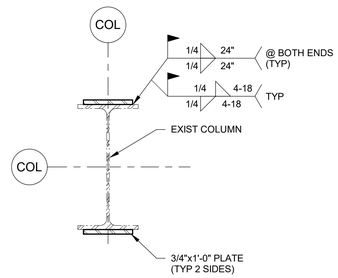
PARTIAL EXIST FRAMING ELEVATION @ COL LN A (LOOKING NORTH)
SCALE: 1/8" = 1'-0"



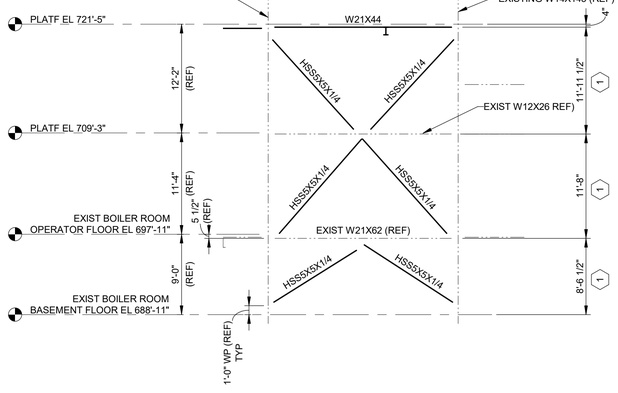
PARTIAL EXIST FRAMING ELEVATION @ COL LN D (LOOKING NORTH)
SCALE: 1/8" = 1'-0"



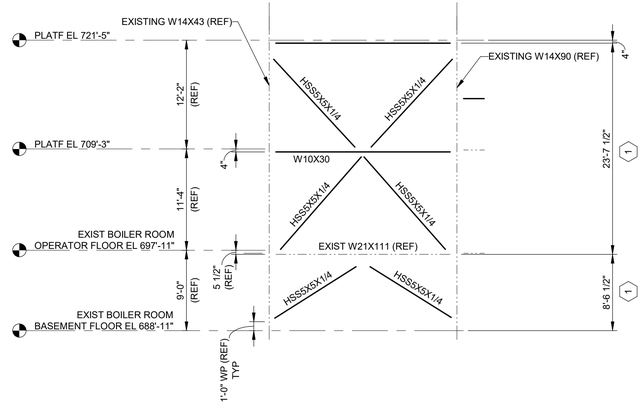
COLUMN REINFORCING TYPE 'A'
SCALE: 1/2" = 1'-0"



A S-204 SECTION
SCALE: 1 1/2" = 1'-0"



PARTIAL EXIST FRAMING ELEVATION @ COL LN 5 (LOOKING EAST)
SCALE: 1/8" = 1'-0"



PARTIAL EXIST FRAMING ELEVATION @ COL LN 8 (LOOKING EAST)
SCALE: 1/8" = 1'-0"

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	HF

SECURITY
PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

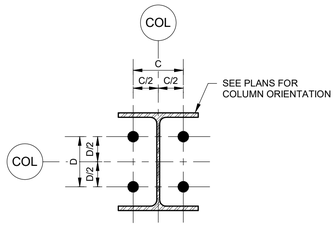
STRUCTURAL
EXIST BOILER BLDG FRAMING ELEVATIONS

DATE	DRAWN	CHK'D.
08/03/20	AWB	HF
SCALE: As indicated		APPROVED: JWO

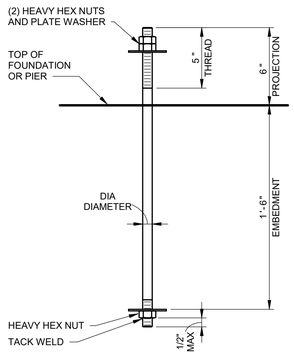
S-204

NOTES

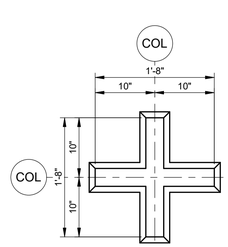
1. FOR GENERAL NOTES, DESIGN CRITERIA AND LEGEND, SEE DWG S-001 & S-002.



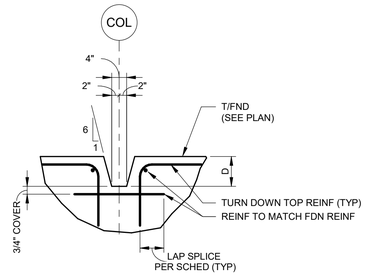
TYPICAL ANCHOR ROD ARRANGEMENT DETAIL
SCALE: 1 1/2" = 1'-0"



TYPICAL ANCHOR ROD DETAIL
SCALE: 3" = 1'-0"



PLAN



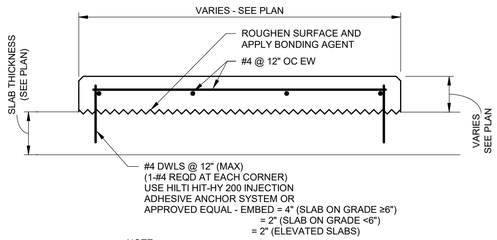
SECTION

TYPICAL SHEAR KEYWAY DETAIL
SCALE: 1" = 1'-0"

PLATE WASHER SCHEDULE	
ANCHOR ROD DIA	WASHER SIZE
1 1/4"	3"x3"x1/2" W/ 1 5/16" DIA HOLE

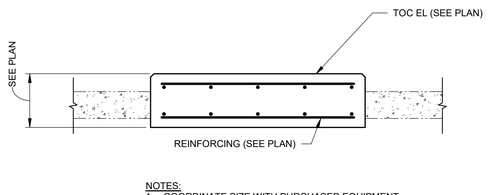
SCHEDULE NOTES:
1. ALL HOLES TO BE CENTERED ON PLATE WASHER.

2. ALL PLATE WASHERS TO BE ASTM A36 PLATE.



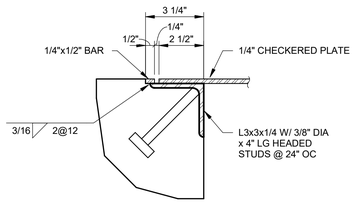
NOTE:
FOR TOP OF EQUIPMENT PAD, SIZE AND LOCATIONS, SEE ARCHITECTURAL, MECHANICAL AND ELECTRICAL DRAWINGS.

TYPICAL EQUIPMENT PAD DETAIL (TYPE 1)
SCALE: 1" = 1'-0"

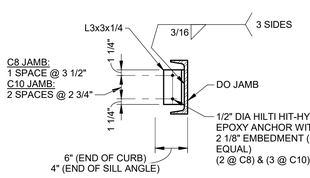


NOTES:
1. COORDINATE SIZE WITH PURCHASED EQUIPMENT AND APPROPRIATE CONTRACTOR.

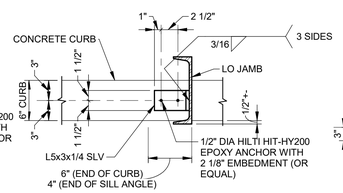
TYPICAL EQUIP PAD DETAIL (TYPE 2)
SCALE: 3/4" = 1'-0"



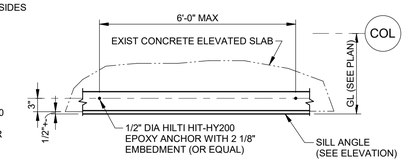
TYPICAL EMBEDDED STEEL FOR CHECKERED PLATE SUPPORT DETAIL
SCALE: 3" = 1'-0"



PLAN AT DOOR OPENING (DO) JAMB



PLAN AT LOUVER OPENING (LO) JAMB



PLAN AT SILL ANGLE

TYPICAL JAMB & SILL CONNECTIONS TO CONCRETE
SCALE: 3/4" = 1'-0"

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	HF

SECURITY
PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

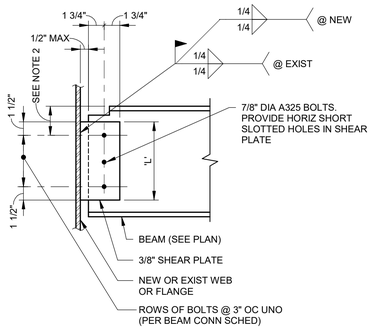
STRUCTURAL FOUNDATION DETAILS

DATE	DRAWN	CHK'D.
08/03/20	AWB	HF
SCALE: As indicated		APPROVED: JWO

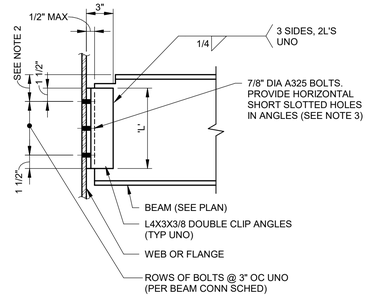
S-701

NOTES

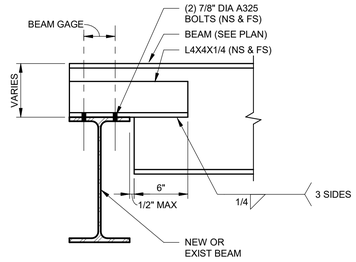
1. FOR GENERAL NOTES, DESIGN CRITERIA AND LEGEND, SEE DWG S-001 & S-002.



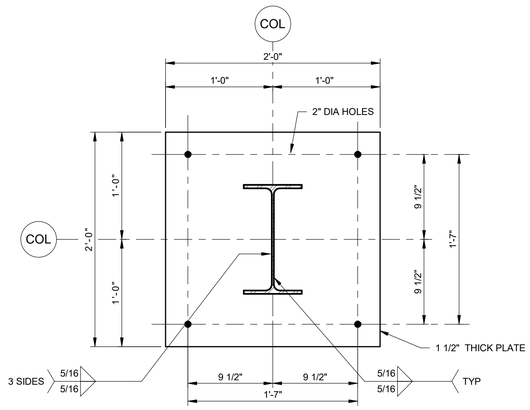
TYPE 1 (SHEAR PLATE)
SCALE: 1 1/2" = 1'-0"



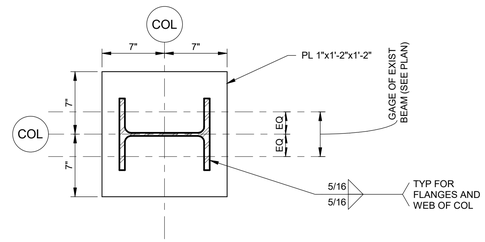
TYPE 2 (CLIP ANGLES - NEW TO NEW)
SCALE: 1 1/2" = 1'-0"



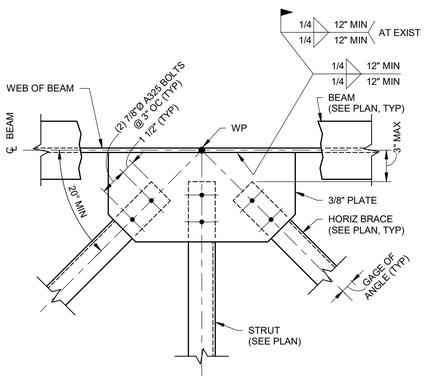
TYPE 3 (SEATED CONNECTION)
SCALE: 1 1/2" = 1'-0"



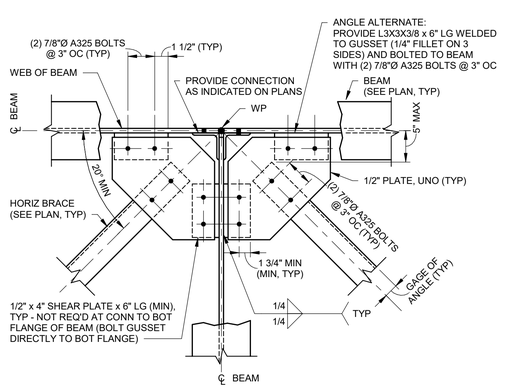
FIRE HEATER COLUMN BASE PLATE DETAIL
SCALE: 1 1/2" = 1'-0"



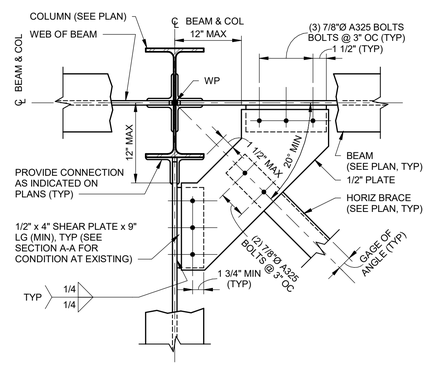
BAGHOUSE ENCLOSURE BASE PLATE DETAIL
SCALE: 1 1/2" = 1'-0"



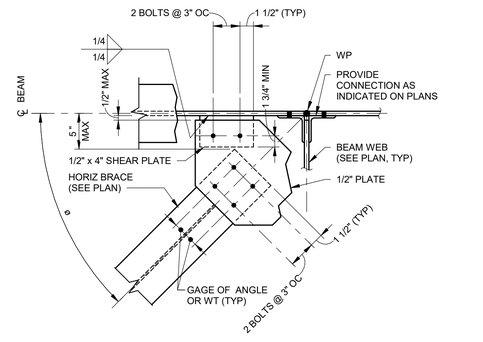
TYPICAL HORIZONTAL BRACING DETAIL TO BEAM WEB (SINGLE ANGLE)
SCALE: 1 1/2" = 1'-0"



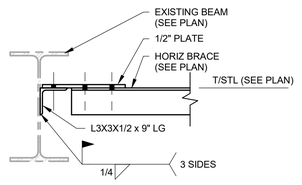
TYPICAL HORIZONTAL BRACING DETAIL TO (2) BEAMS (AT WEB, SINGLE ANGLE)
SCALE: 1 1/2" = 1'-0"



TYPICAL HORIZONTAL BRACING DETAIL AT COLUMNS (SINGLE ANGLE)
SCALE: 1 1/2" = 1'-0"

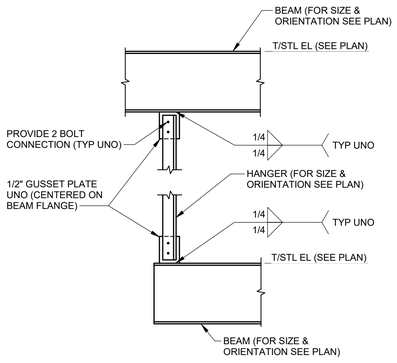


TYPICAL HORIZONTAL BRACING DETAIL TO BEAM WEB (WT OR DOUBLE ANGLE)
SCALE: 1 1/2" = 1'-0"

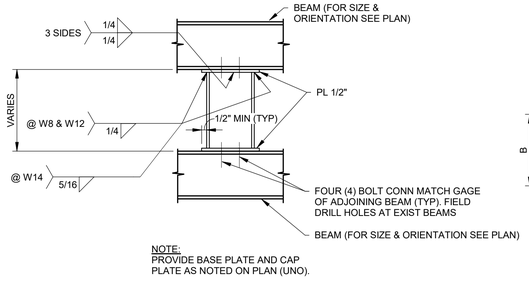


AT EXISTING

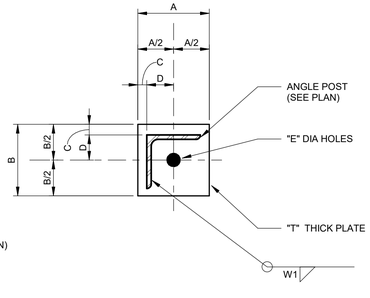
A SECTION
SCALE: 1 1/2" = 1'-0"



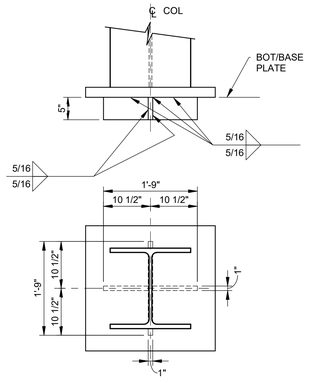
TYPICAL HANGER CONNECTION DETAIL
SCALE: 3/4" = 1'-0"



TYPICAL WIDE FLANGE POST BASE PLATE & CAP PLATE DETAIL
SCALE: 1" = 1'-0"



TYPICAL POST BASE PLATE DETAIL ONE ANCHOR BOLT (ANGLE POST)
SCALE: 3" = 1'-0"



TYPICAL SHEAR LUG DETAILS
SCALE: 3/4" = 1'-0"

SECURITY

PUBLIC	☒
ECHOGEN BUSINESS CONFIDENTIAL	☐
TOP SECRET	☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

STRUCTURAL BEAM AND HORIZONTAL BRACE CONNECTION DETAILS

DATE	DRAWN	CHK'D.
08/03/20	AWB	HF
SCALE: As indicated		APPROVED: JWO

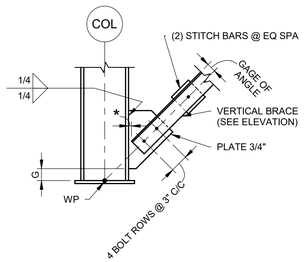
S-702

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	HF

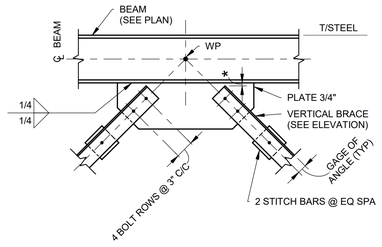
NOTES

1. FOR GENERAL NOTES, DESIGN CRITERIA AND LEGEND, SEE DWG S-001 & S-002.



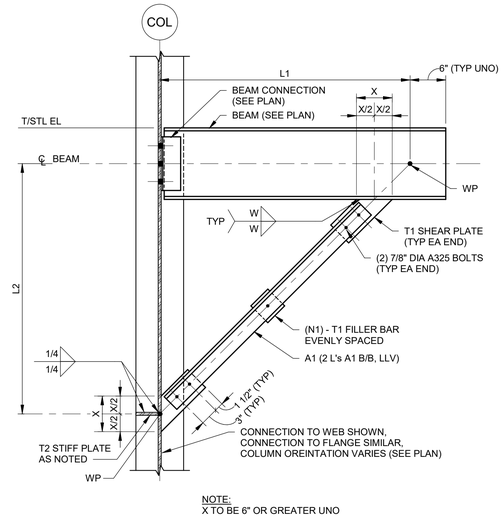
TYPICAL DOUBLE ANGLE VERTICAL BRACING TO COL FLANGE/BASE PLATE

SCALE: 1" = 1'-0"



TYPICAL DOUBLE ANGLE VERTICAL BRACING TO BEAM INTERMITTENT POINT

SCALE: 1" = 1'-0"



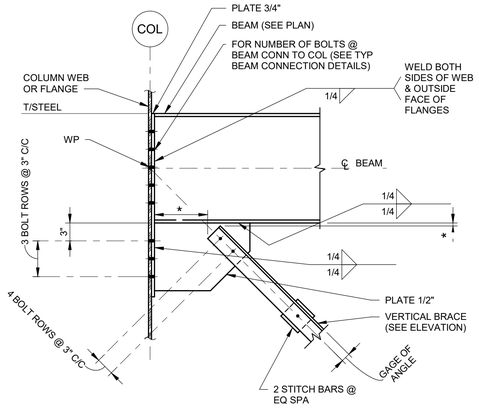
NOTE:
X TO BE 6" OR GREATER UNO

TYPICAL KNEE BRACE DETAIL TO COLUMN/BEAM - TYPE 1

SCALE: 1" = 1'-0"

KNEE BRACE SCHEDULE											
MARK	REF DWG NO	TYPE	L1	L2	L3	A1	N1	T1	T2	W	REMARKS
KB-1	S-104	1	2'-6"	2'-6"	-	L3X3X1/4	-	-	-	3/16	-
KB-2	S-105	1	2'-0"	2'-0"	-	L3X3X1/4	-	-	-	3/16	-

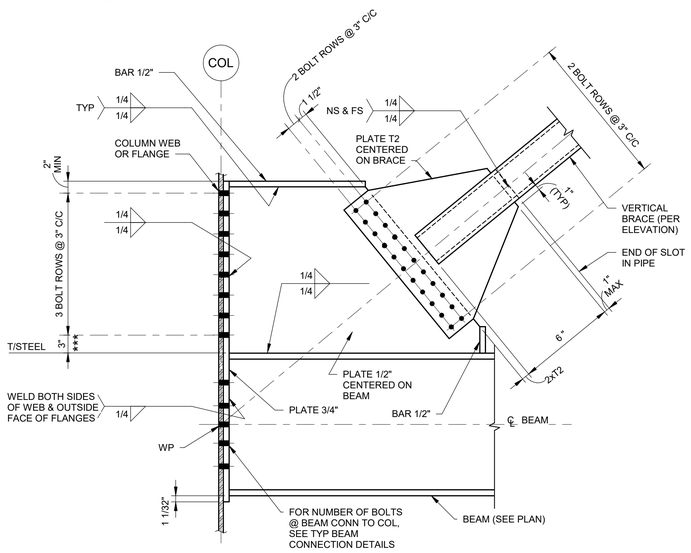
NOTE:
AT EXISTING COLUMN PROVIDE PIECE OF WT9x23 WITH (4) STANDARD HOLES IN FLANGE & (2) OVERSIZE HOLES FOR A325-SC BOLTS IN WEB. FIELD DRILL FOR BOLTS THROUGH FLANGE.



TYPE 3

TYPICAL DOUBLE ANGLE VERTICAL BRACING TO COL WITH END PLATE

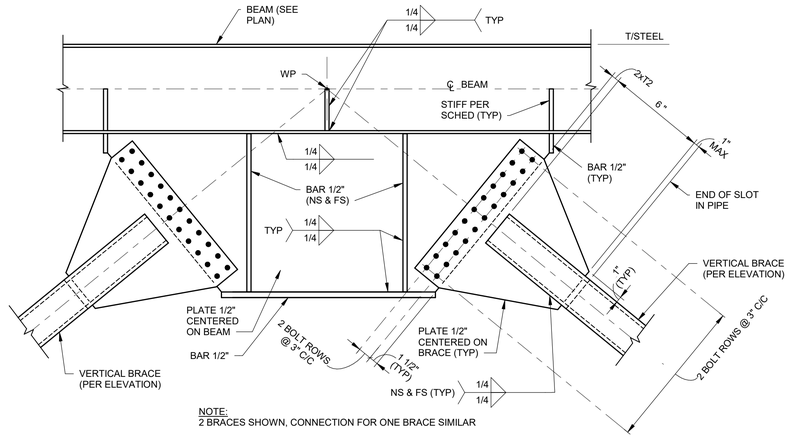
SCALE: 1" = 1'-0"



TYPE 1

TYPICAL HSS VERTICAL BRACING DETAIL TO COLUMN WITH END PLATE

SCALE: 1" = 1'-0"

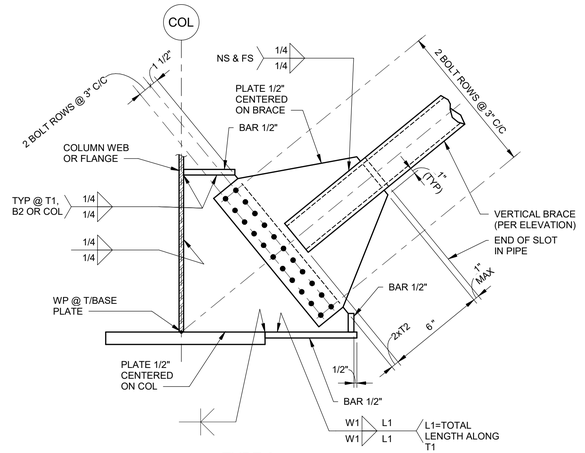


NOTE:
2 BRACES SHOWN, CONNECTION FOR ONE BRACE SIMILAR

TYPE 2

TYPICAL HSS VERTICAL BRACING DETAIL AT BEAM INTERMITTENT POINT

SCALE: 1" = 1'-0"



TYPE 3

TYPICAL HSS VERTICAL BRACING DETAIL TO COLUMN AT BASE PLATE

SCALE: 1" = 1'-0"

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	HF

SECURITY

PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

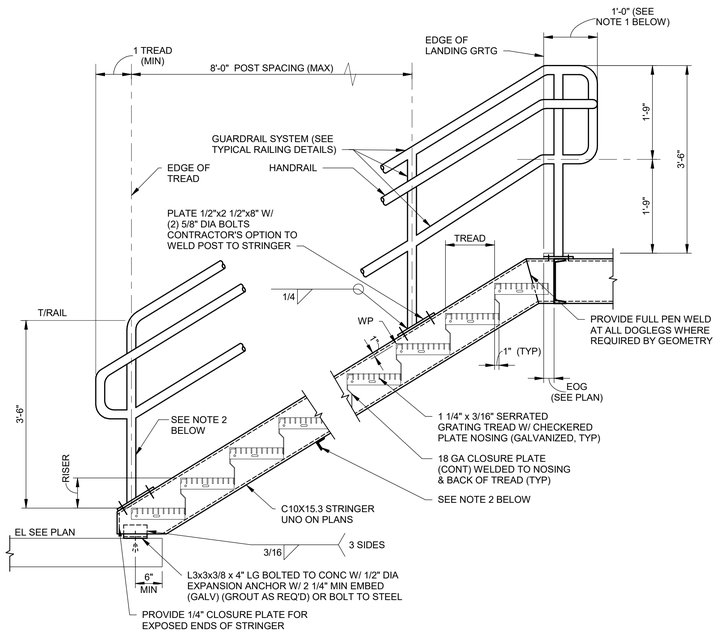
VERTICAL AND KNEE BRACE DETAILS

DATE	DRAWN	CHK'D.
08/03/20	AWB	HF
SCALE 1" = 1'-0"		APPROVED JWO

S-703

NOTES

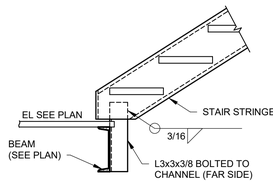
1. FOR GENERAL NOTES, DESIGN CRITERIA AND LEGEND, SEE DWG S-001.

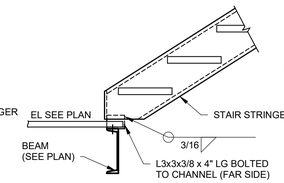


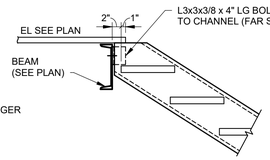
NOTES:
1. PROVIDE 1'-0" HANDRAIL EXTENSION AT TOP OF ALL STAIRS.
2. STAIR STRINGERS OVER 6'-0" LG SHALL BE LACED WITH L2x2x1/4 @ 45°. PROVIDE (1)-5/8" DIA BOLT AT EACH END OR EQUIVALENT WELD.

TYPICAL STAIR DETAIL WITH GRATING TREADS AND GUARDRAIL/HANDRAIL

SCALE: 3/4" = 1'-0"

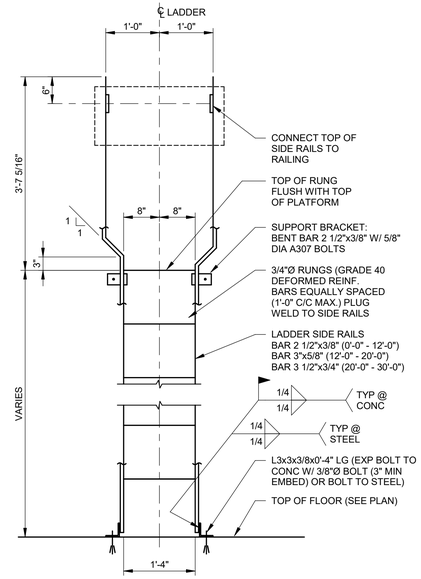






TYPICAL STAIR STRINGER CONNECTION DETAILS

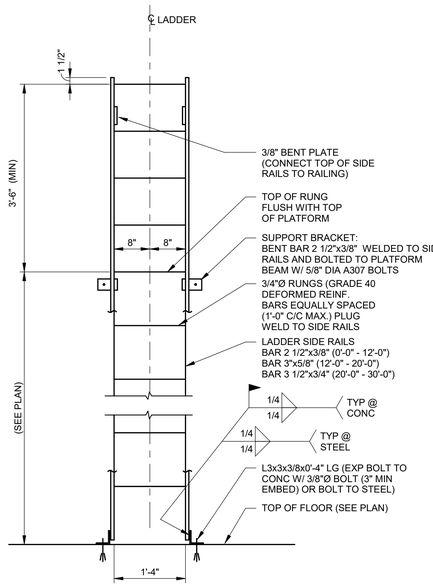
SCALE: 3/4" = 1'-0"



NOTES:
1. FOR LADDERS OVER 4'-0" TALL (T/PLATF TO T/PLATF), PROVIDE A SELF CLOSING SAFETY GATE AS MANUFACTURED BY "FABENCO, INC" (OR APPROVED EQUAL), ATTACH GATE TO RAILING POST (PLATFORM SIDE) PER MANUFACTURER'S REQUIREMENTS.
2. LADDERS EXTENDED MORE THAN 24'-0" ABOVE LOWER LEVEL SHALL BE EQUIPPED WITH APPROVED PERSONAL FALL ARREST SYSTEM OR LADDER SAFETY SYSTEM.

TYPICAL STEP-THRU LADDER DETAIL

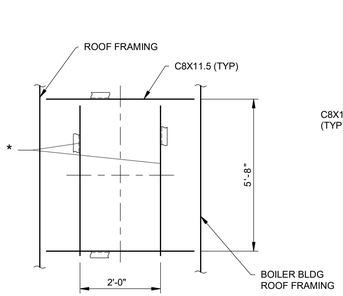
SCALE: 3/4" = 1'-0"



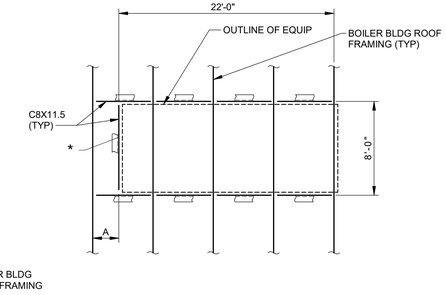
NOTES:
1. FOR LADDERS OVER 4'-0" TALL (T/PLATF TO T/PLATF), PROVIDE A SELF CLOSING SAFETY GATE AS MANUFACTURED BY "FABENCO, INC" (OR APPROVED EQUAL), ATTACH GATE TO RAILING POST (PLATFORM SIDE) PER MANUFACTURER'S REQUIREMENTS.
2. LADDERS EXTENDED MORE THAN 24'-0" ABOVE LOWER LEVEL SHALL BE EQUIPPED WITH APPROVED PERSONAL FALL ARREST SYSTEM OR LADDER SAFETY SYSTEM.

TYPICAL SIDE STEP LADDER DETAIL

SCALE: 3/4" = 1'-0"



ROOF OPENING FRAMING PLAN

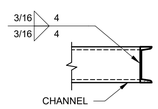


ROOF MOUNTED HVAC EQUIP SUPPORT FRAMING PLANS

NOTES:
1. CONTRACTOR TO FINALIZE EXACT FRAMING REQUIREMENTS & OPENING LOCATIONS & SIZES (X & Y DIMENSIONS). ROOF OPENING AND HVAC EQUIPMENT ARE SHOWN ON ARCHITECTURAL & MECHANICAL DRAWINGS.
2. ← OMIT THIS CHANNEL WHEN DIMENSION 'A' IS 6" OR LESS FROM C ;NTERLINE OF JOIST OR ROOF BEAM.
3. CHANNELS ARE TO BE C6X8.2.
4. CONTRACTOR'S OPTION TO USE 'QUICK FRAMES' AS ALTERNATIVE.

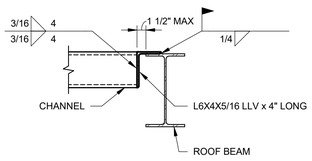
TYPICAL ROOF OPENING & ROOF EQUIPMENT SUPPORT FRAMING

SCALE: 3/8" = 1'-0"



ROOF FRAME CHANNEL TO CHANNEL CONNECTION

SCALE: 1" = 1'-0"



ROOF FRAME TO JOIST, TRUSS OR BEAM CONNECTION

SCALE: 1" = 1'-0"

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	HF

SECURITY
PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

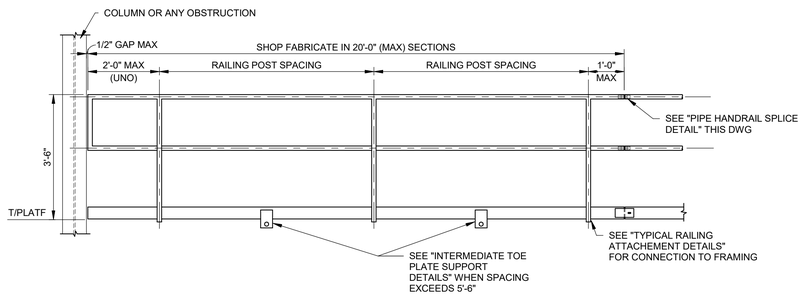
STRUCTURAL
STAIR AND ROOF FRAMING DETAILS

DATE	DRAWN	CHK'D.
08/03/20	AWB	HF
SCALE: As indicated		APPROVED: JWO

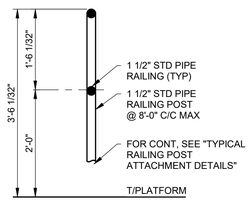
S-704

NOTES

1. FOR GENERAL NOTES, DESIGN CRITERIA AND LEGEND, SEE DWG S-001

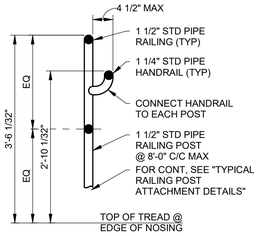


TYPICAL SHOP FABRICATED RAILING SECTION
SCALE: 1/2" = 1'-0"

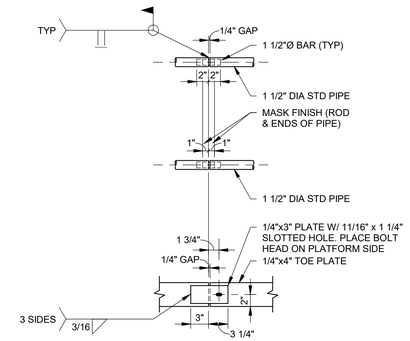


(2 RAILS)

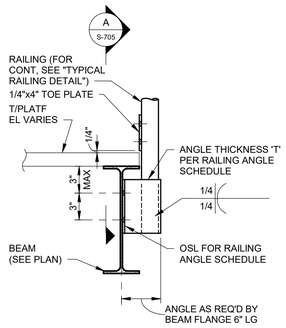
TYPICAL RAILING DETAIL
SCALE: 3/4" = 1'-0"



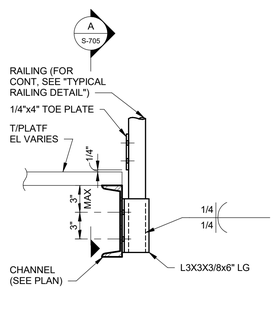
TYPICAL STAIR RAILING/HANDRAIL DETAIL
SCALE: 3/4" = 1'-0"



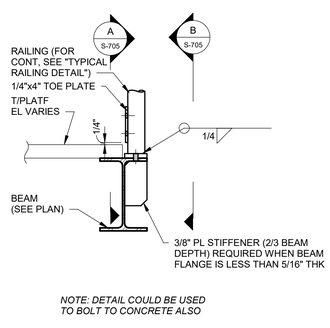
PIPE HANDRAIL SPLICE DETAIL
SCALE: 1" = 1'-0"



SIDE MOUNT (BOLTED - WIDE FLANGE)
SCALE: 1 1/2" = 1'-0"

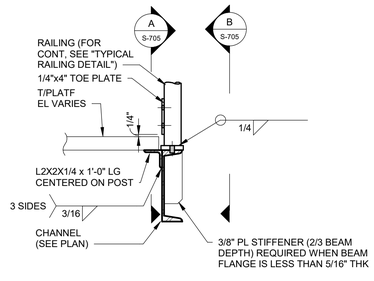


SIDE MOUNT (BOLTED - CHANNEL)
SCALE: 1 1/2" = 1'-0"

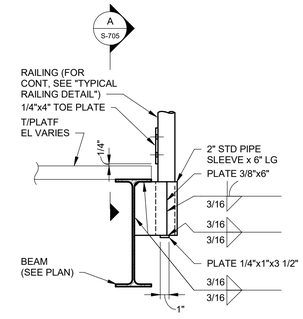


NOTE: DETAIL COULD BE USED TO BOLT TO CONCRETE ALSO

TOP MOUNT (BOLTED - WIDE FLANGE)
SCALE: 1 1/2" = 1'-0"

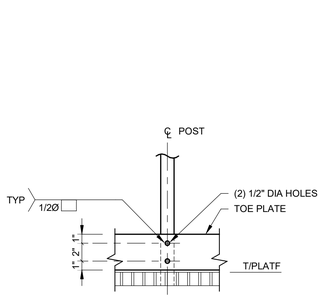


TOP MOUNT (BOLTED - CHANNEL)
SCALE: 1 1/2" = 1'-0"

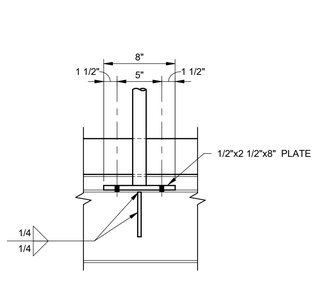


(10'-0" SECTIONS, MAX)

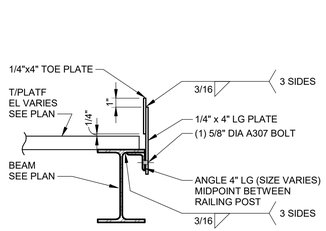
REMOVABLE (SIDE MOUNT - WELDED)
SCALE: 1 1/2" = 1'-0"



A S-705 SECTION
SCALE: 1 1/2" = 1'-0"

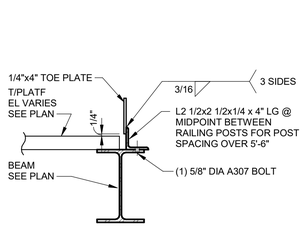


B S-705 SECTION
SCALE: 1 1/2" = 1'-0"



NOTE:
PROVIDE THIS DETAIL FOR SIDE MOUNT RAILING WHERE RAILING POST SPACING EXCEEDS 5'-6"

SIDE MOUNT RAILING

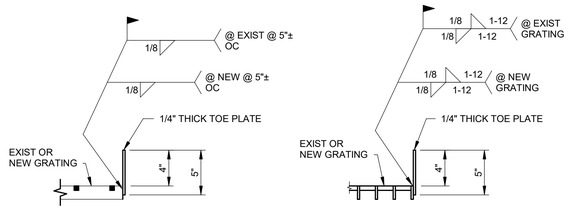


NOTE:
PROVIDE THIS DETAIL FOR SIDE MOUNT RAILING WHERE RAILING POST SPACING EXCEEDS 5'-6"

TOP MOUNT RAILING

INTERMEDIATE TOE PLATE SUPPORT DETAILS
SCALE: 1 1/2" = 1'-0"

RAILING ANGLE SCHEDULE		
OSL	BOLT GA ON OSL	T
3"	1 3/4"	3/8"
3 1/2"	2"	1/2"
4"	2 1/2"	1/2"
5"	3"	5/8"



TOE PLATE PERPENDICULAR TO BEARING BARS

TOE PLATE PARALLEL TO BEARING BARS

TYPICAL TOE PLATE ATTACHMENT DETAILS
SCALE: 1 1/2" = 1'-0"

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	HF

SECURITY
PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

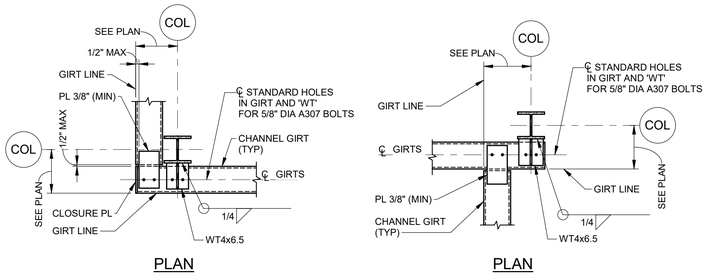
STRUCTURAL RAILING DETAILS

DATE	DRAWN	CHK'D.
08/03/20	AWB	HF
SCALE: As indicated		APPROVED: JWO

S-705

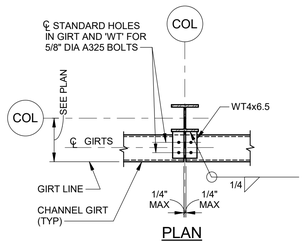
NOTES

1. FOR GENERAL NOTES, DESIGN CRITERIA AND LEGEND, SEE DWG S-001 & S-002.

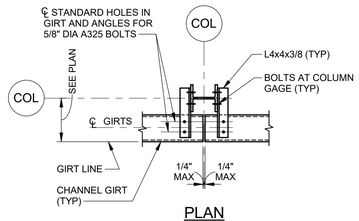


PLAN

PLAN



PLAN

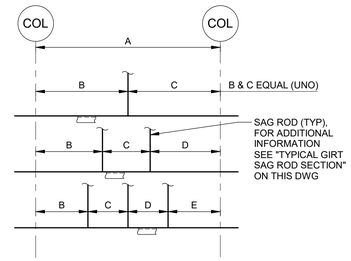


PLAN

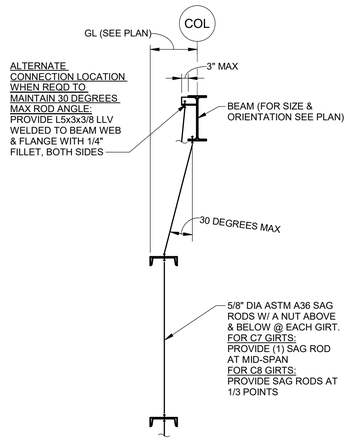
TYPICAL GIRT TO COLUMN CONNECTION DETAILS
SCALE: 3/4" = 1'-0"

SAG ROD SPACING SCHEDULE				
A	B	C	D	E
0'-0" TO 12'-0"	EQUAL	EQUAL	-	-
12'-0" TO 27'-0"	EQUAL	4'-6"	EQUAL	-

NOTE:
WORK THIS SCHEDULE WITH "TYPICAL GIRT SAG ROD SECTION" ON THIS DWG.

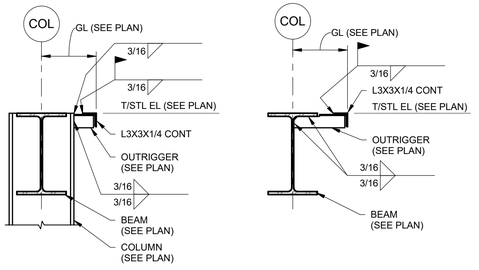


TYPICAL SAG ROD ELEVATION AND SCHEDULE
SCALE: 3/4" = 1'-0"

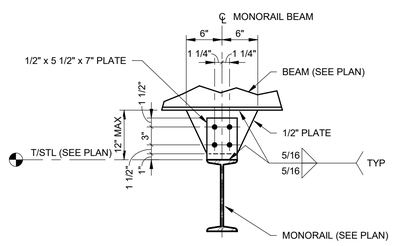


NOTES:
1. CONNECT GIRT @ HIGHEST FRAMING ELEVATION POSSIBLE (TO BOTTOM OF BEAM).
2. BEAMS ARE TO CARRY A MAXIMUM OF (5) GIRTS.

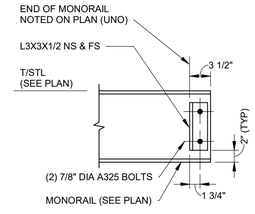
TYPICAL GIRT SAG ROD SECTION FOR GIRTS C7, C8 & C9
SCALE: 3/4" = 1'-0"



TYPICAL OUTRIGGER SECTIONS
SCALE: 3/4" = 1'-0"



TYPICAL MONORAIL SUPPORT (BOLTED CONNECTION)
SCALE: 1" = 1'-0"



TYPICAL MONORAIL END STOP DETAIL
SCALE: 1" = 1'-0"

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	HF

SECURITY
PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

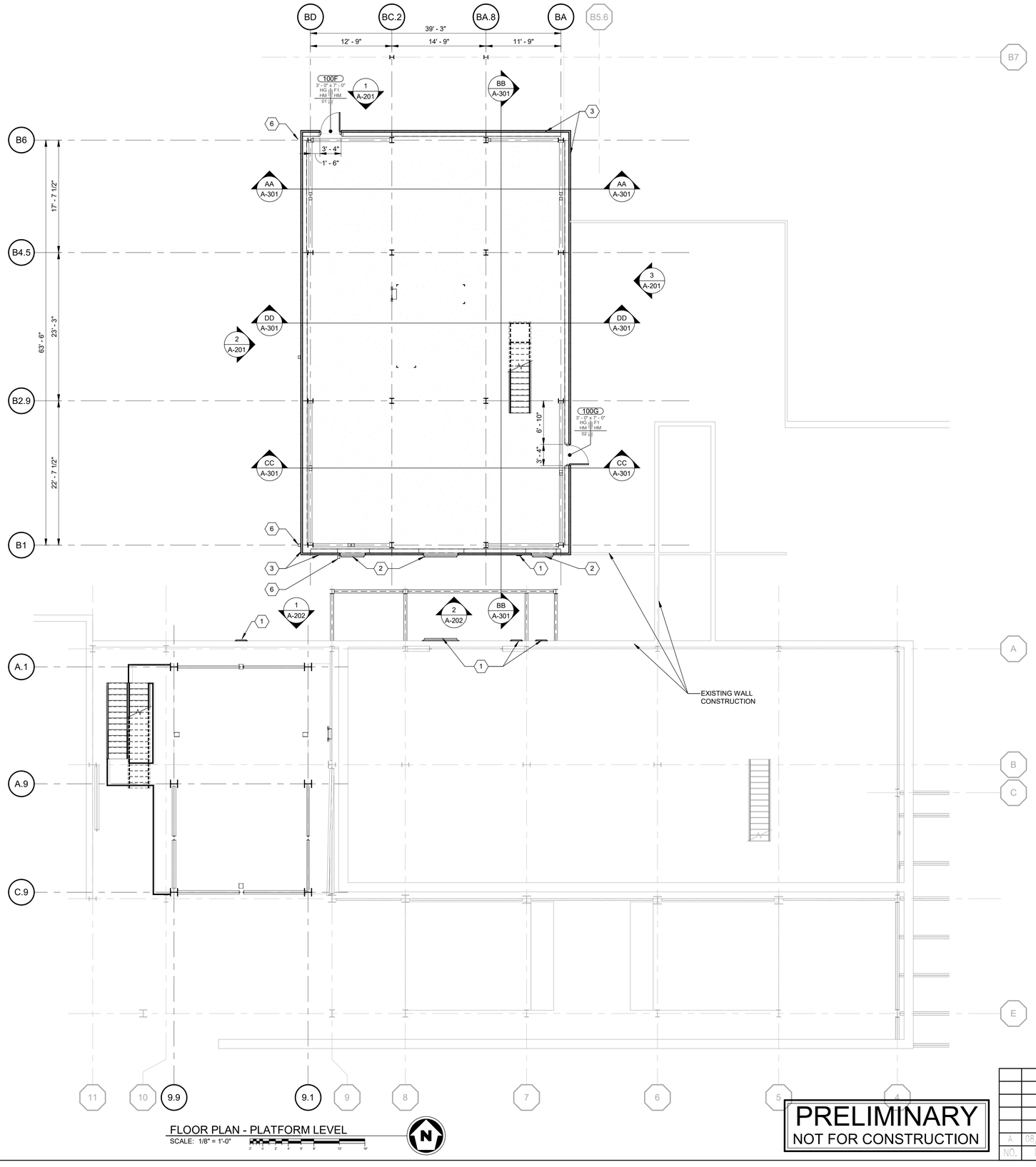
2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

STRUCTURAL
GIRT, OUTRIGGER AND MONORAIL DETAILS

DATE	DRAWN	CHK'D.
08/03/20	AWB	HF
SCALE: As indicated		APPROVED: JWO

S-706



FLOOR PLAN - PLATFORM LEVEL

SCALE: 1/8" = 1'-0"

GENERAL NOTES

1. NOT ALL KEY NOTES MAY APPLY TO THIS SHEET
2. SEE A-701 FOR DOOR HARDWARE SETS INDICATED IN DOOR TAG, ALONG WITH DOOR OPENING DETAILS
3. ALL WALL PENETRATIONS TO BE COORDINATED W/ LATEST EQUIPMENT LAYOUT, INCLUDING PIPING, DUCTWORK, AND EQUIPMENT ACCESS DOOR OPENINGS
4. EQUIPMENT, PIPING, & DUCTWORK NOT SHOWN FOR CLARITY
5. SEE STRUCTURAL DRAWINGS FOR FRAMED ROOF/WALL OPENING SIZES/LOCATIONS AND STAIRS LOCATIONS/DETAILS

KEY NOTES

1. WALL PENETRATION - CHEMLINK E-CURB PENETRATION SYSTEM, SEE DETAIL 7 ON A-701. COORDINATE W/ MECHANICAL DRAWINGS FOR SIZE AND LOCATIONS
2. DUCT PENETRATION - SHEET METAL TRIM WEATHERPROOF CLOSURES, MATCH PANEL COLOR
3. INSULATED METAL WALL PANEL W/ MFR STANDARD BASE FLASHING, CORNER TRIM, OPENING TRIM, AND CONNECTIONS TO EXISTING WALLS
4. SINGLE-PLY MEMBRANE ROOF SYSTEM W/ MFR STANDARD POLYISO INSULATION AND MFR STANDARD FASCIA
5. INFILL EXISTING OPENING W/ INSULATED METAL WALL PANEL, UTILIZE MFR STANDARD CHANNELS AND TRIM TO PROVIDE WEATHERPROOF INSTALLATION
6. 6"x6" GUTTER AND 5"x4" DOWNSPOUT
7. PROVIDE ROOF CURB AND MEMBRANE FLASHING AT EQUIPMENT ENCLOSURE BY EQUIPMENT SUPPLIER
8. PROVIDE MEMBRANE FLASHING FROM EXISTING ROOF TO NEW INSULATED METAL WALL PANEL
9. ROOF PENETRATION - SEE DETAILS 6/7 ON A-701
10. EQUIPMENT MONORAIL - SEE STRUCTURAL DRAWINGS
11. PORTABLE GUARDRAIL (SAFETYRAIL 2000, BLUEWATER MANUF OR APPROVED EQUAL) INCLUDING RAILS AND BASE WEIGHTS
12. PROVIDE ROOF MEMBRANE MANFACTURER'S STANDARD 5'x5' WALKWAY PAD AT DOOR
13. ROOF MANUFACTURER'S STANDARD LAP JOINT AT EXISTING ROOF SYSTEM TO NEW SINGLE-PLY MEMBRANE ROOF SYSTEM
14. PROVIDE MEMBRANE FLASHING FROM NEW SINGLE-PLY MEMBRANE ROOF SYSTEM TO EXISTING WALL CONSTRUCTION

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	MLB

SECURITY

PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

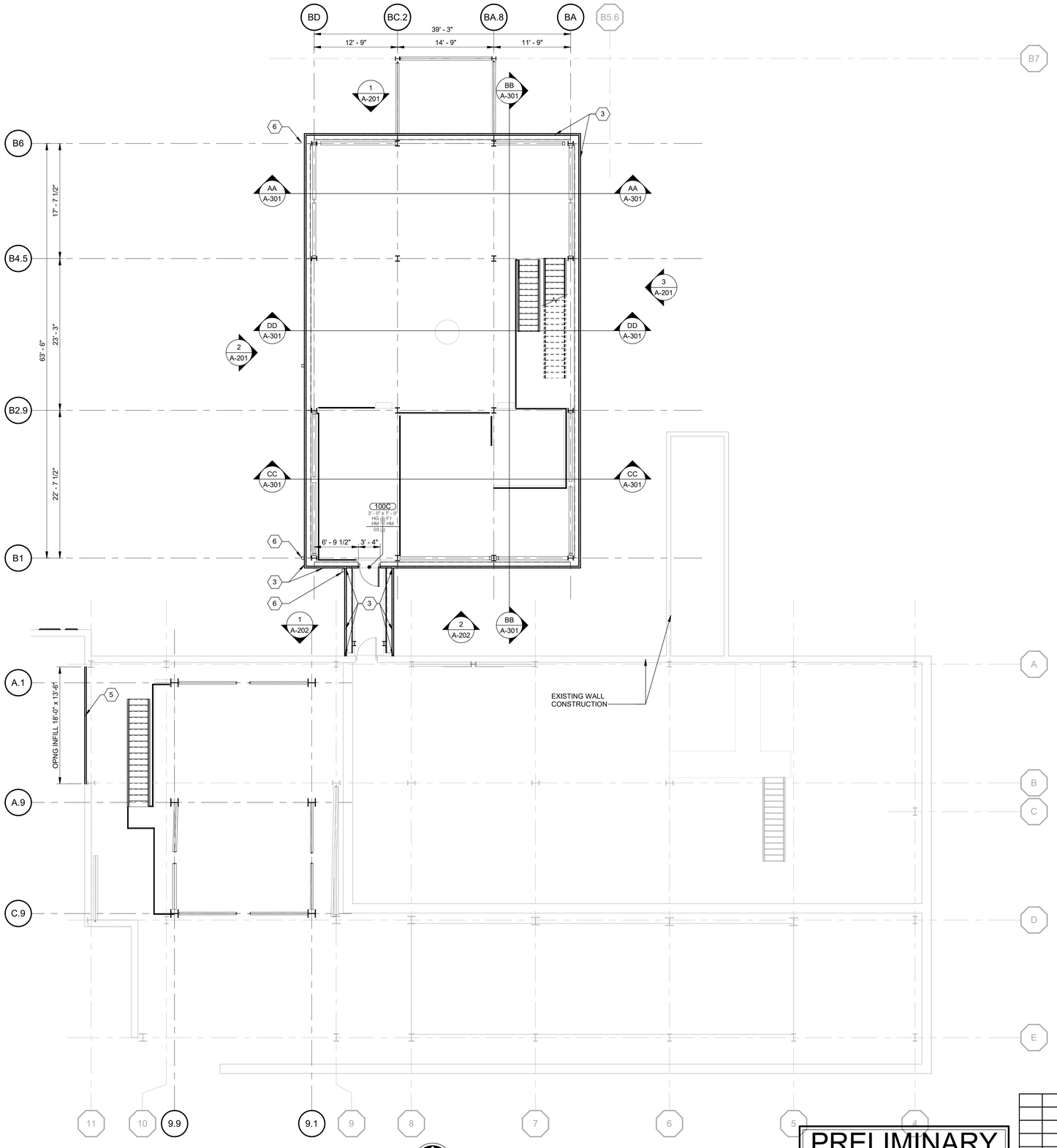
2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

ARCHITECTURAL
FLOOR PLAN – EXISTING BAGHOUSE LEVEL

DATE	DRAWN	CHK'D.
08/03/20	Author	Checker
SCALE: As indicated		APPROVED: Approver

A–115



FLOOR PLAN - PLATFORM LEVEL
SCALE: 1/8" = 1'-0"

GENERAL NOTES

1. NOT ALL KEY NOTES MAY APPLY TO THIS SHEET
2. SEE A-701 FOR DOOR HARDWARE SETS INDICATED IN DOOR TAG, ALONG WITH DOOR OPENING DETAILS
3. ALL WALL PENETRATIONS TO BE COORDINATED W/ LATEST EQUIPMENT LAYOUT, INCLUDING PIPING, DUCTWORK, AND EQUIPMENT ACCESS DOOR OPENINGS
4. EQUIPMENT, PIPING, & DUCTWORK NOT SHOWN FOR CLARITY
5. SEE STRUCTURAL DRAWINGS FOR FRAMED ROOF/WALL OPENING SIZES/LOCATIONS AND STAIRS LOCATIONS/DETAILS

KEY NOTES

1. WALL PENETRATION - CHEMLINK E-CURB PENETRATION SYSTEM, SEE DETAIL 7 ON A-701. COORDINATE W/ MECHANICAL DRAWINGS FOR SIZE AND LOCATIONS
2. DUCT PENETRATION - SHEET METAL TRIM WEATHERPROOF CLOSURES, MATCH PANEL COLOR
3. INSULATED METAL WALL PANEL W/ MFR STANDARD BASE FLASHING, CORNER TRIM, OPENING TRIM, AND CONNECTIONS TO EXISTING WALLS
4. SINGLE-PLY MEMBRANE ROOF SYSTEM W/ MFR STANDARD POLYISO INSULATION AND MFR STANDARD FASCIA
5. INFILL EXISTING OPENING W/ INSULATED METAL WALL PANEL, UTILIZE MFR STANDARD CHANNELS AND TRIM TO PROVIDE WEATHERPROOF INSTALLATION
6. 6"x6" GUTTER AND 5"x4" DOWNSPOUT
7. PROVIDE ROOF CURB AND MEMBRANE FLASHING AT EQUIPMENT ENCLOSURE BY EQUIPMENT SUPPLIER
8. PROVIDE MEMBRANE FLASHING FROM EXISTING ROOF TO NEW INSULATED METAL WALL PANEL
9. ROOF PENETRATION - SEE DETAILS 6/7 ON A-701
10. EQUIPMENT MONORAIL - SEE STRUCTURAL DRAWINGS
11. PORTABLE GUARDRAIL (SAFETYRAIL 2000, BLUEWATER MANUF OR APPROVED EQUAL) INCLUDING RAILS AND BASE WEIGHTS
12. PROVIDE ROOF MEMBRANE MANFACTURER'S STANDARD 5'x5' WALKWAY PAD AT DOOR
13. ROOF MANUFACTURER'S STANDARD LAP JOINT AT EXISTING ROOF SYSTEM TO NEW SINGLE-PLY MEMBRANE ROOF SYSTEM
14. PROVIDE MEMBRANE FLASHING FROM NEW SINGLE-PLY MEMBRANE ROOF SYSTEM TO EXISTING WALL CONSTRUCTION

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	MLB

SECURITY
PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

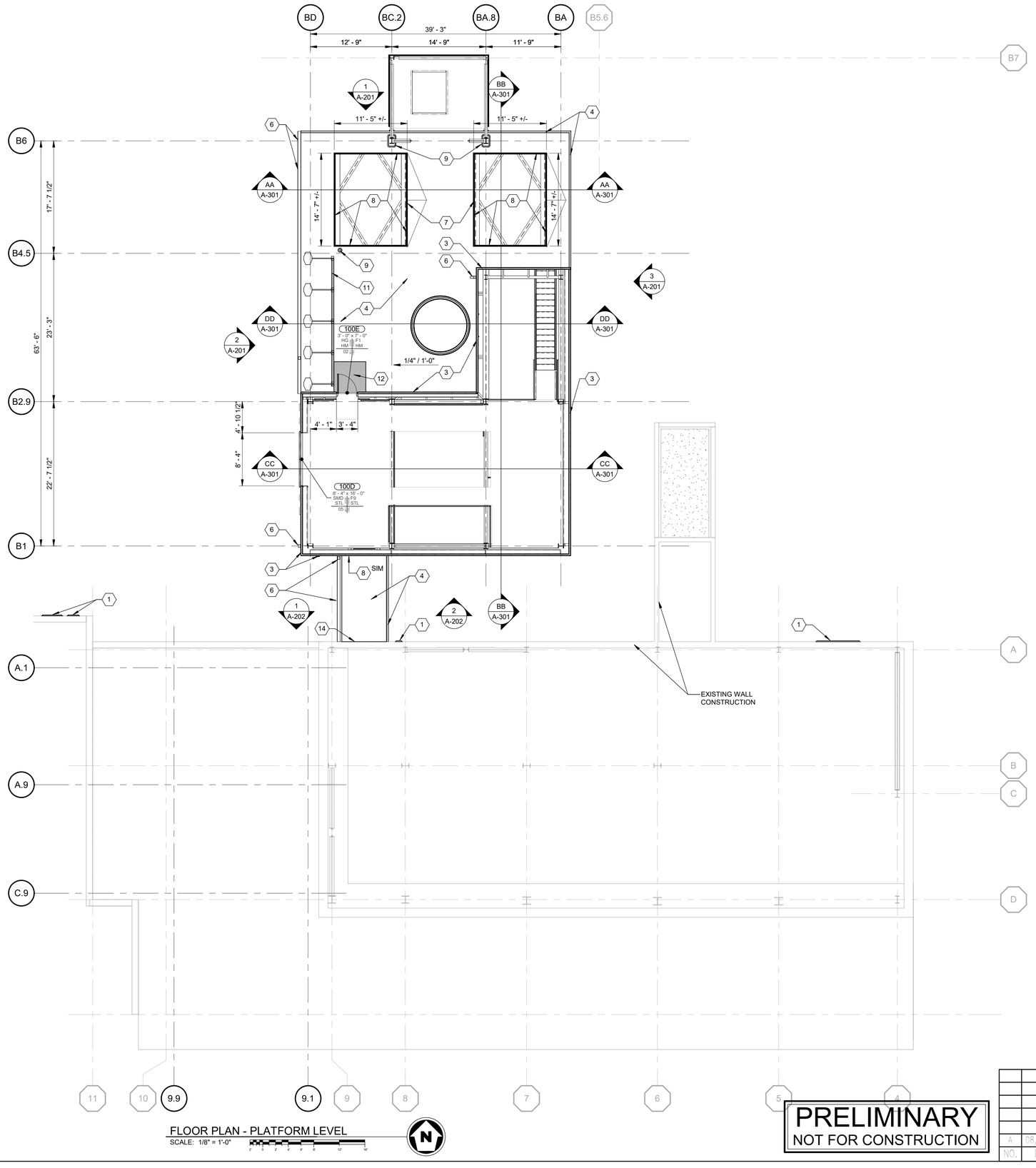
2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

ARCHITECTURAL
FLOOR PLAN – PLATFORM LEVEL 752'–6"

DATE	DRAWN	CHK'D.
08/03/20	Author	Checker
SCALE: As indicated		APPROVED: Approver

A–117



FLOOR PLAN - PLATFORM LEVEL

SCALE: 1/8" = 1'-0"

PRELIMINARY
NOT FOR CONSTRUCTION

GENERAL NOTES

1. NOT ALL KEY NOTES MAY APPLY TO THIS SHEET
2. SEE A-701 FOR DOOR HARDWARE SETS INDICATED IN DOOR TAG, ALONG WITH DOOR OPENING DETAILS
3. ALL WALL PENETRATIONS TO BE COORDINATED W/ LATEST EQUIPMENT LAYOUT, INCLUDING PIPING, DUCTWORK, AND EQUIPMENT ACCESS DOOR OPENINGS
4. EQUIPMENT, PIPING, & DUCTWORK NOT SHOWN FOR CLARITY
5. SEE STRUCTURAL DRAWINGS FOR FRAMED ROOF/WALL OPENING SIZES/LOCATIONS AND STAIRS LOCATIONS/DETAILS

KEY NOTES

1. WALL PENETRATION - CHEMLINK E-CURB PENETRATION SYSTEM, SEE DETAIL 7 ON A-701. COORDINATE W/ MECHANICAL DRAWINGS FOR SIZE AND LOCATIONS
2. DUCT PENETRATION - SHEET METAL TRIM WEATHERPROOF CLOSURES, MATCH PANEL COLOR
3. INSULATED METAL WALL PANEL W/ MFR STANDARD BASE FLASHING, CORNER TRIM, OPENING TRIM, AND CONNECTIONS TO EXISTING WALLS
4. SINGLE-PLY MEMBRANE ROOF SYSTEM W/ MFR STANDARD POLYISO INSULATION AND MFR STANDARD FASCIA
5. INFILL EXISTING OPENING W/ INSULATED METAL WALL PANEL, UTILIZE MFR STANDARD CHANNELS AND TRIM TO PROVIDE WEATHERPROOF INSTALLATION
6. 6"x6" GUTTER AND 5"x4" DOWNSPOUT
7. PROVIDE ROOF CURB AND MEMBRANE FLASHING AT EQUIPMENT ENCLOSURE BY EQUIPMENT SUPPLIER
8. PROVIDE MEMBRANE FLASHING FROM EXISTING ROOF TO NEW INSULATED METAL WALL PANEL
9. ROOF PENETRATION - SEE DETAILS 6/7 ON A-701
10. EQUIPMENT MONORAIL - SEE STRUCTURAL DRAWINGS
11. PORTABLE GUARDRAIL (SAFETYRAIL 2000, BLUEWATER MANUF OR APPROVED EQUAL) INCLUDING RAILS AND BASE WEIGHTS
12. PROVIDE ROOF MEMBRANE MANFACTURER'S STANDARD 5'x5' WALKWAY PAD AT DOOR
13. ROOF MANUFACTURER'S STANDARD LAP JOINT AT EXISTING ROOF SYSTEM TO NEW SINGLE-PLY MEMBRANE ROOF SYSTEM
14. PROVIDE MEMBRANE FLASHING FROM NEW SINGLE-PLY MEMBRANE ROOF SYSTEM TO EXISTING WALL CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	MLB

SECURITY

PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

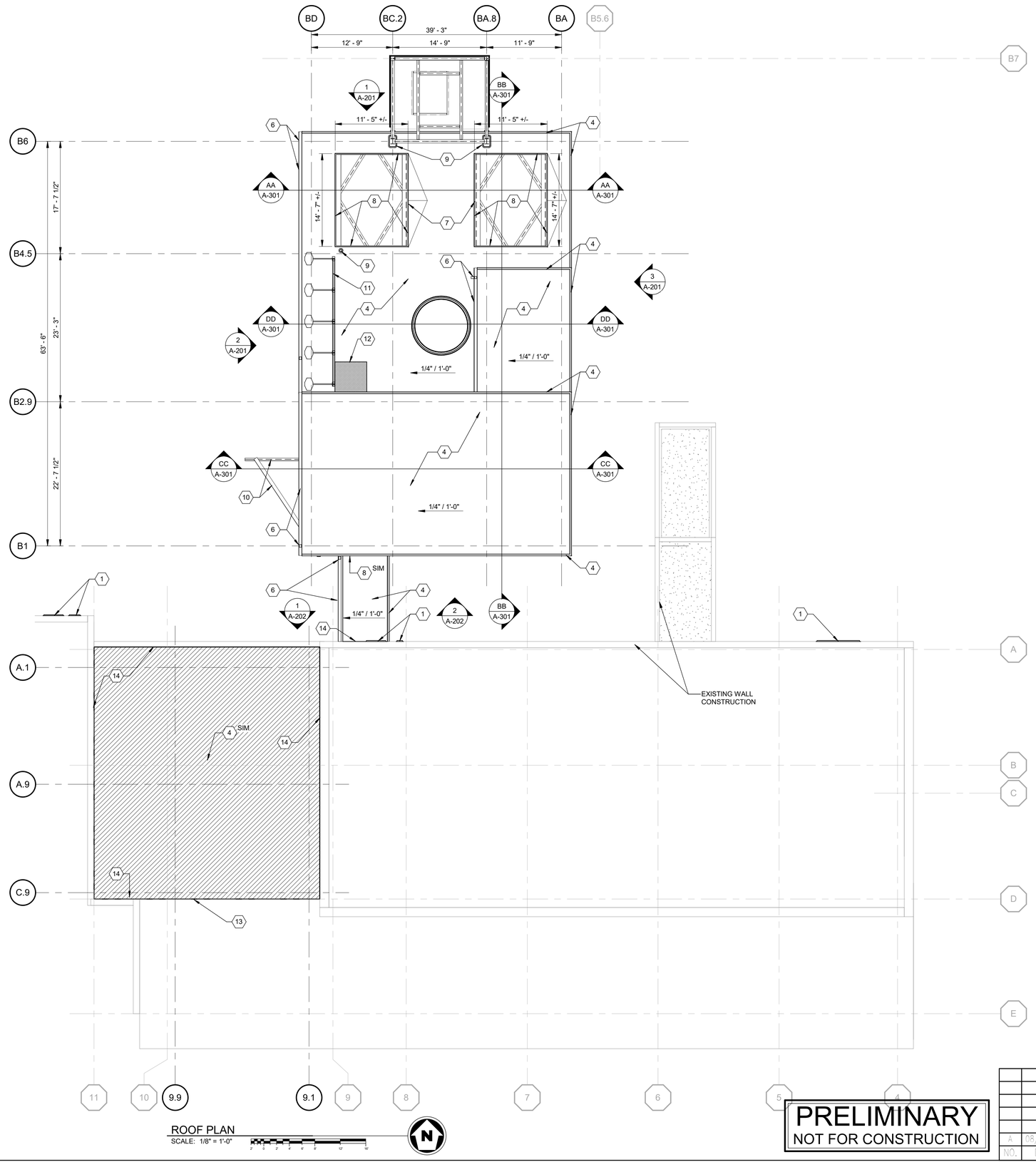
2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

ARCHITECTURAL
FLOOR PLAN – PLATFORM LEVEL
763'–2 1/2"

DATE	DRAWN	CHK'D.
08/03/20	Author	Checker
SCALE: As indicated		APPROVED: Approver

A–118



ROOF PLAN
SCALE: 1/8" = 1'-0"

GENERAL NOTES

1. NOT ALL KEY NOTES MAY APPLY TO THIS SHEET
2. SEE A-701 FOR DOOR HARDWARE SETS INDICATED IN DOOR TAG, ALONG WITH DOOR OPENING DETAILS
3. ALL WALL PENETRATIONS TO BE COORDINATED W/ LATEST EQUIPMENT LAYOUT, INCLUDING PIPING, DUCTWORK, AND EQUIPMENT ACCESS DOOR OPENINGS
4. EQUIPMENT, PIPING, & DUCTWORK NOT SHOWN FOR CLARITY
5. SEE STRUCTURAL DRAWINGS FOR FRAMED ROOF/WALL OPENING SIZES/LOCATIONS AND STAIRS LOCATIONS/DETAILS

KEY NOTES

1. WALL PENETRATION - CHEMLINK E-CURB PENETRATION SYSTEM, SEE DETAIL 7 ON A-701. COORDINATE W/ MECHANICAL DRAWINGS FOR SIZE AND LOCATIONS
2. DUCT PENETRATION - SHEET METAL TRIM WEATHERPROOF CLOSURES, MATCH PANEL COLOR
3. INSULATED METAL WALL PANEL W/ MFR STANDARD BASE FLASHING, CORNER TRIM, OPENING TRIM, AND CONNECTIONS TO EXISTING WALLS
4. SINGLE-PLY MEMBRANE ROOF SYSTEM W/ MFR STANDARD POLYISO INSULATION AND MFR STANDARD FASCIA
5. INFILL EXISTING OPENING W/ INSULATED METAL WALL PANEL, UTILIZE MFR STANDARD CHANNELS AND TRIM TO PROVIDE WEATHERPROOF INSTALLATION
6. 6"x6" GUTTER AND 5"x4" DOWNSPOUT
7. PROVIDE ROOF CURB AND MEMBRANE FLASHING AT EQUIPMENT ENCLOSURE BY EQUIPMENT SUPPLIER
8. PROVIDE MEMBRANE FLASHING FROM EXISTING ROOF TO NEW INSULATED METAL WALL PANEL
9. ROOF PENETRATION - SEE DETAILS 6/7 ON A-701
10. EQUIPMENT MONORAIL - SEE STRUCTURAL DRAWINGS
11. PORTABLE GUARDRAIL (SAFETYRAIL 2000, BLUEWATER MANUF OR APPROVED EQUAL) INCLUDING RAILS AND BASE WEIGHTS
12. PROVIDE ROOF MEMBRANE MANFACTURER'S STANDARD 5'x5' WALKWAY PAD AT DOOR
13. ROOF MANUFACTURER'S STANDARD LAP JOINT AT EXISTING ROOF SYSTEM TO NEW SINGLE-PLY MEMBRANE ROOF SYSTEM
14. PROVIDE MEMBRANE FLASHING FROM NEW SINGLE-PLY MEMBRANE ROOF SYSTEM TO EXISTING WALL CONSTRUCTION

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	MLR

SECURITY
PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

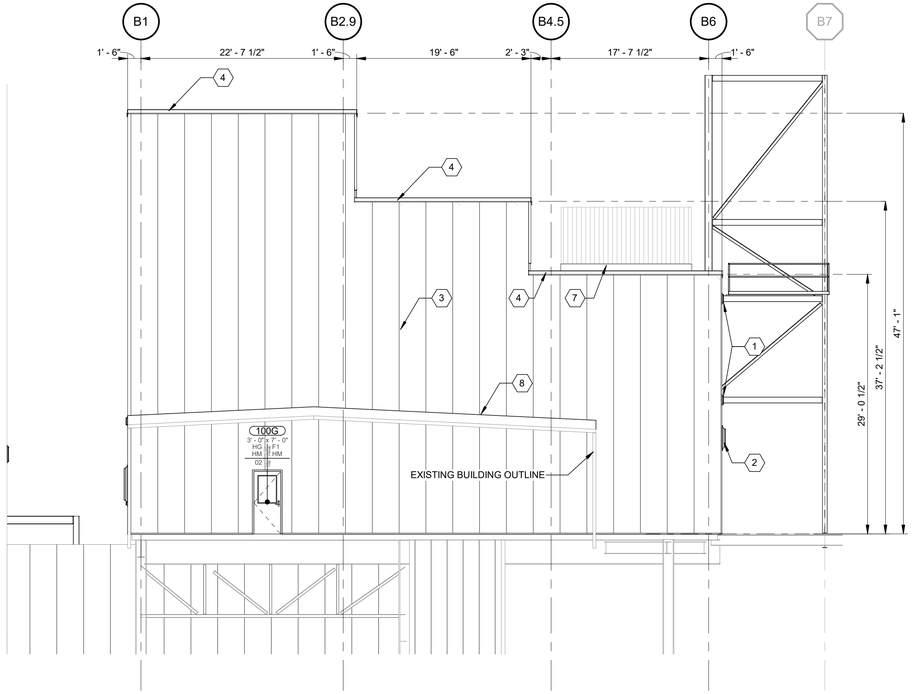
2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

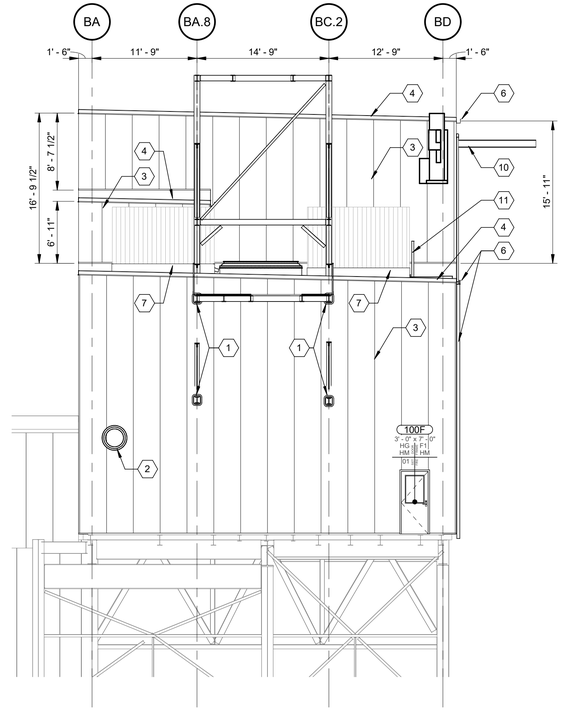
ARCHITECTURAL ROOF PLAN

DATE	DRAWN	CHK'D.
08/03/20	Author	Checker
SCALE: As indicated		APPROVED: Approver

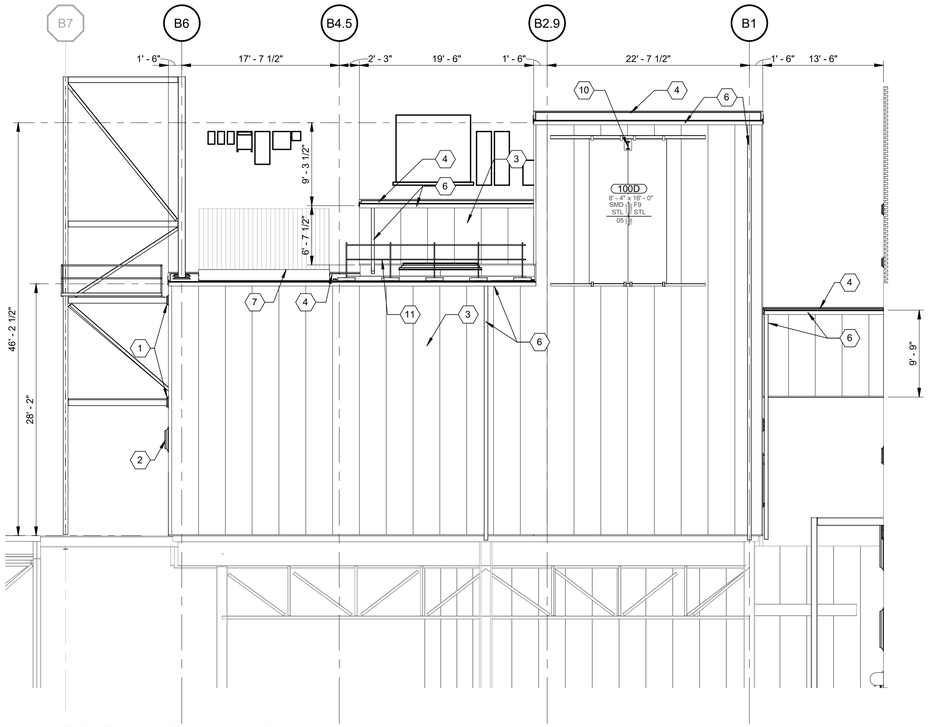
A–119



3 A-110 EXTERIOR ELEVATION - EAST
NEW ADDITION
SCALE: 1/8" = 1'-0"



1 A-110 EXTERIOR ELEVATION - NORTH
NEW ADDITION
SCALE: 1/8" = 1'-0"



2 A-110 EXTERIOR ELEVATION - WEST
NEW ADDITION
SCALE: 1/8" = 1'-0"

GENERAL NOTES

1. NOT ALL KEY NOTES MAY APPLY TO THIS SHEET
2. SEE A-701 FOR DOOR HARDWARE SETS INDICATED IN DOOR TAG, ALONG WITH DOOR OPENING DETAILS
3. ALL WALL PENETRATIONS TO BE COORDINATED W/ LATEST EQUIPMENT LAYOUT, INCLUDING PIPING, DUCTWORK, AND EQUIPMENT ACCESS DOOR OPENINGS
4. EQUIPMENT, PIPING, & DUCTWORK NOT SHOWN FOR CLARITY
5. SEE STRUCTURAL DRAWINGS FOR FRAMED ROOF/WALL OPENING SIZES/LOCATIONS AND STAIRS LOCATIONS/DETAILS

KEY NOTES

1. WALL PENETRATION - CHEMLINK E-CURB PENETRATION SYSTEM, SEE DETAIL 7 ON A-701. COORDINATE W/ MECHANICAL DRAWINGS FOR SIZE AND LOCATIONS
2. DUCT PENETRATION - SHEET METAL TRIM WEATHERPROOF CLOSURES, MATCH PANEL COLOR
3. INSULATED METAL WALL PANEL W/ MFR STANDARD BASE FLASHING, CORNER TRIM, OPENING TRIM, AND CONNECTIONS TO EXISTING WALLS
4. SINGLE-PLY MEMBRANE ROOF SYSTEM W/ MFR STANDARD POLYISO INSULATION AND MFR STANDARD FASCIA
5. INFILL EXISTING OPENING W/ INSULATED METAL WALL PANEL, UTILIZE MFR STANDARD CHANNELS AND TRIM TO PROVIDE WEATHERPROOF INSTALLATION
6. 6"x6" GUTTER AND 5"x4" DOWNSPOUT
7. PROVIDE ROOF CURB AND MEMBRANE FLASHING AT EQUIPMENT ENCLOSURE BY EQUIPMENT SUPPLIER
8. PROVIDE MEMBRANE FLASHING FROM EXISTING ROOF TO NEW INSULATED METAL WALL PANEL
9. ROOF PENETRATION - SEE DETAILS 6/7 ON A-701
10. EQUIPMENT MONORAIL - SEE STRUCTURAL DRAWINGS
11. PORTABLE GUARDRAIL (SAFETYRAIL 2000, BLUEWATER MANUF OR APPROVED EQUAL) INCLUDING RAILS AND BASE WEIGHTS
12. PROVIDE ROOF MEMBRANE MANFACTURER'S STANDARD 5'x5' WALKWAY PAD AT DOOR
13. ROOF MANUFACTURER'S STANDARD LAP JOINT AT EXISTING ROOF SYSTEM TO NEW SINGLE-PLY MEMBRANE ROOF SYSTEM
14. PROVIDE MEMBRANE FLASHING FROM NEW SINGLE-PLY MEMBRANE ROOF SYSTEM TO EXISTING WALL CONSTRUCTION

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	MLB

SECURITY
PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

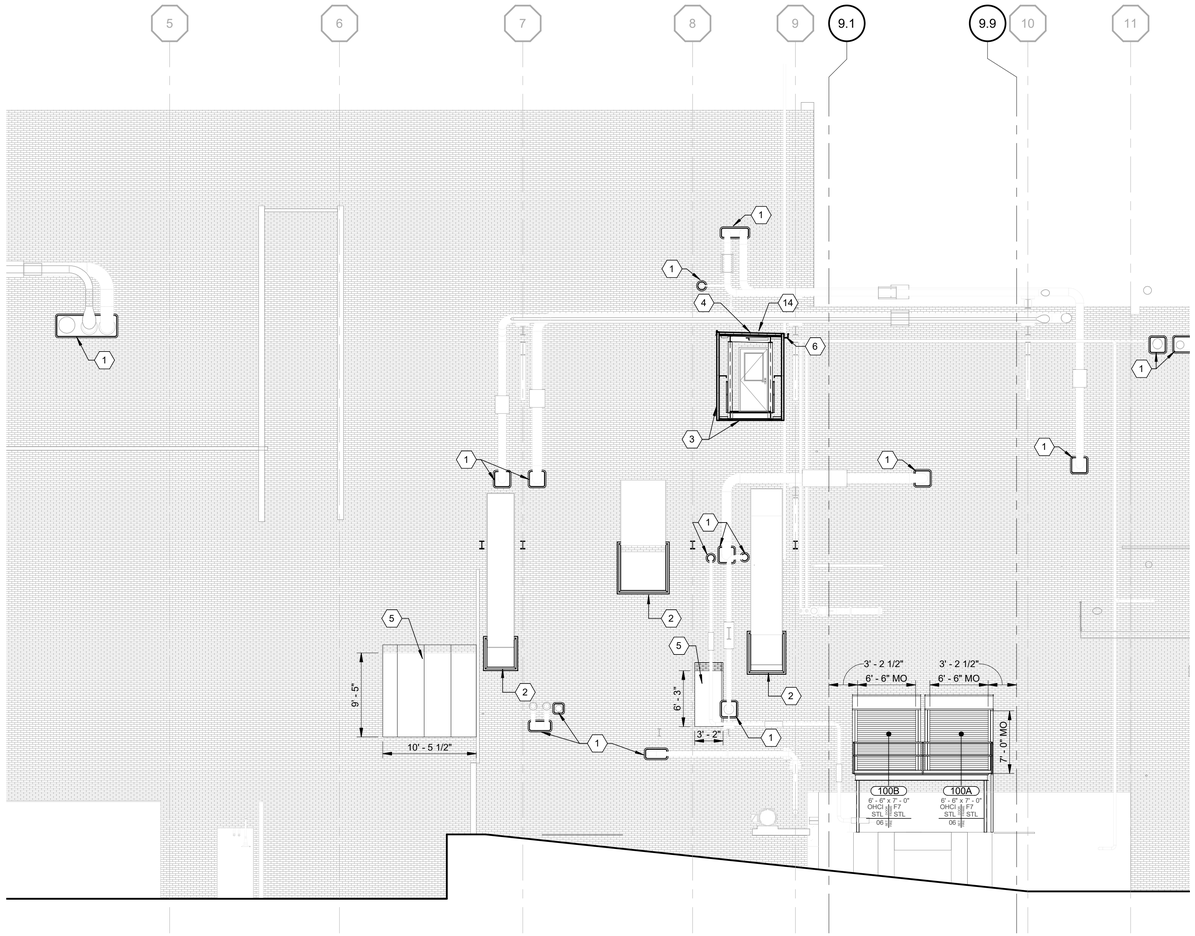
2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

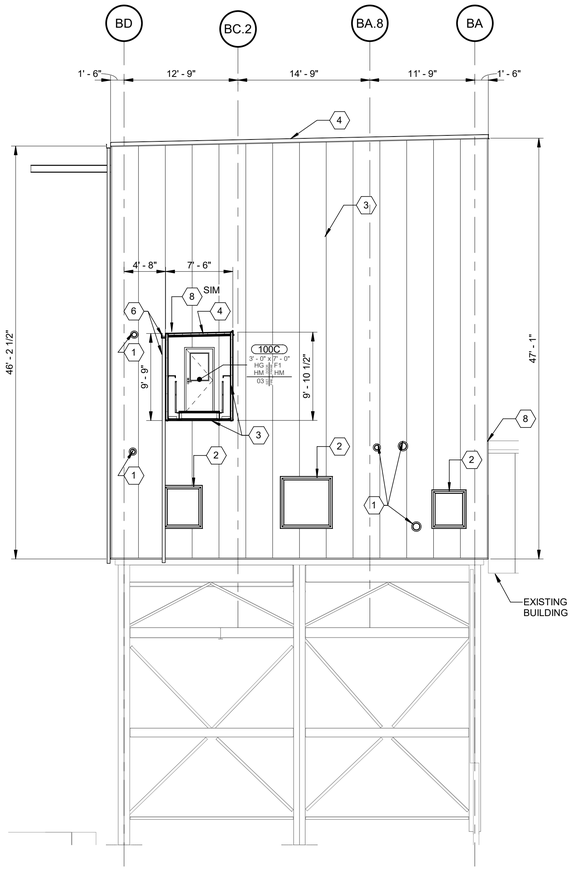
ARCHITECTURAL EXTERIOR ELEVATIONS

DATE	DRAWN	CHK'D.
08/03/20	Author	Checker
SCALE: As indicated		APPROVED: Approver

A–201



1 A-110 EXTERIOR ELEVATION - NORTH
EXISTING BUILDING
SCALE: 1/8" = 1'-0"



2 A-111 EXTERIOR ELEVATION - SOUTH
NEW ADDITION
SCALE: 1/8" = 1'-0"

GENERAL NOTES

1. NOT ALL KEY NOTES MAY APPLY TO THIS SHEET
2. SEE A-701 FOR DOOR HARDWARE SETS INDICATED IN DOOR TAG, ALONG WITH DOOR OPENING DETAILS
3. ALL WALL PENETRATIONS TO BE COORDINATED W/ LATEST EQUIPMENT LAYOUT, INCLUDING PIPING, DUCTWORK, AND EQUIPMENT ACCESS DOOR OPENINGS
4. EQUIPMENT, PIPING, & DUCTWORK NOT SHOWN FOR CLARITY
5. SEE STRUCTURAL DRAWINGS FOR FRAMED ROOF/WALL OPENING SIZES/LOCATIONS AND STAIRS LOCATIONS/DETAILS

KEY NOTES

1. WALL PENETRATION - CHEMLINK E-CURB PENETRATION SYSTEM, SEE DETAIL 7 ON A-701. COORDINATE W/ MECHANICAL DRAWINGS FOR SIZE AND LOCATIONS
2. DUCT PENETRATION - SHEET METAL TRIM WEATHERPROOF CLOSURES, MATCH PANEL COLOR
3. INSULATED METAL WALL PANEL W/ MFR STANDARD BASE FLASHING, CORNER TRIM, OPENING TRIM, AND CONNECTIONS TO EXISTING WALLS
4. SINGLE-PLY MEMBRANE ROOF SYSTEM W/ MFR STANDARD POLYISO INSULATION AND MFR STANDARD FASCIA
5. INFILL EXISTING OPENING W/ INSULATED METAL WALL PANEL, UTILIZE MFR STANDARD CHANNELS AND TRIM TO PROVIDE WEATHERPROOF INSTALLATION
6. 6"x6" GUTTER AND 5"x4" DOWNSPOUT
7. PROVIDE ROOF CURB AND MEMBRANE FLASHING AT EQUIPMENT ENCLOSURE BY EQUIPMENT SUPPLIER
8. PROVIDE MEMBRANE FLASHING FROM EXISTING ROOF TO NEW INSULATED METAL WALL PANEL
9. ROOF PENETRATION - SEE DETAILS 6/7 ON A-701
10. EQUIPMENT MONORAIL - SEE STRUCTURAL DRAWINGS
11. PORTABLE GUARDRAIL (SAFETYRAIL 2000, BLUEWATER MANUF OR APPROVED EQUAL) INCLUDING RAILS AND BASE WEIGHTS
12. PROVIDE ROOF MEMBRANE MANFACTURER'S STANDARD 5'x5' WALKWAY PAD AT DOOR
13. ROOF MANUFACTURER'S STANDARD LAP JOINT AT EXISTING ROOF SYSTEM TO NEW SINGLE-PLY MEMBRANE ROOF SYSTEM
14. PROVIDE MEMBRANE FLASHING FROM NEW SINGLE-PLY MEMBRANE ROOF SYSTEM TO EXISTING WALL CONSTRUCTION

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	MLB

SECURITY
PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

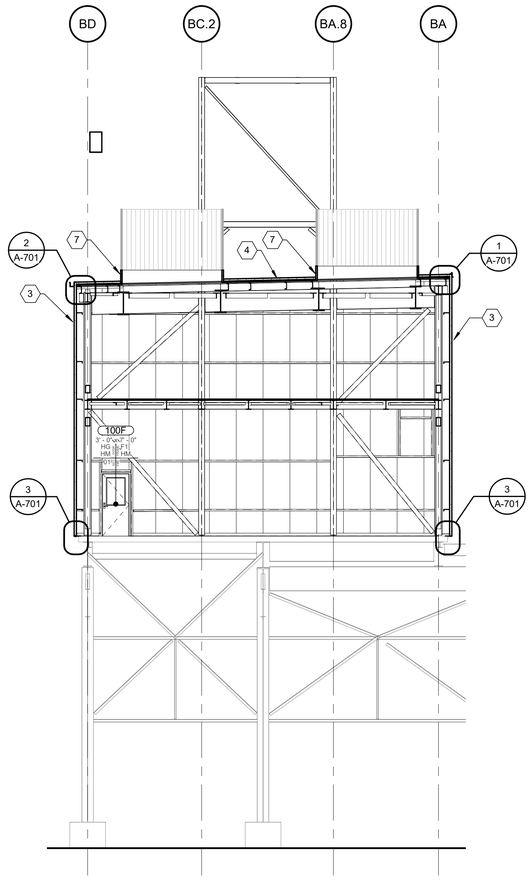
2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

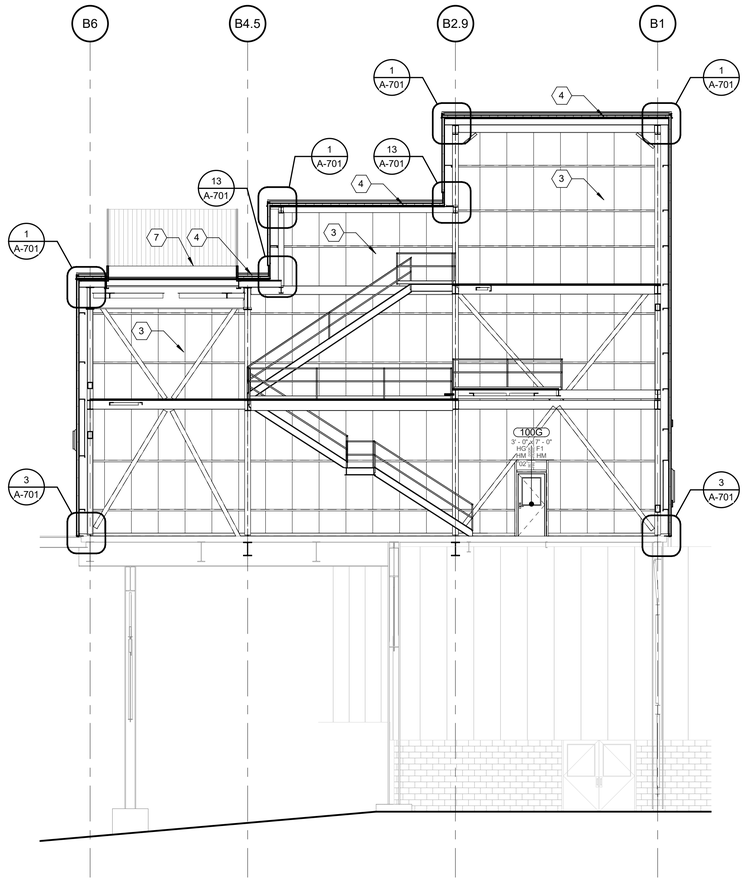
ARCHITECTURAL
EXTERIOR ELEVATIONS

DATE	DRAWN	CHK'D.
08/03/20	Author	Checker
SCALE: As indicated		APPROVED: Approver

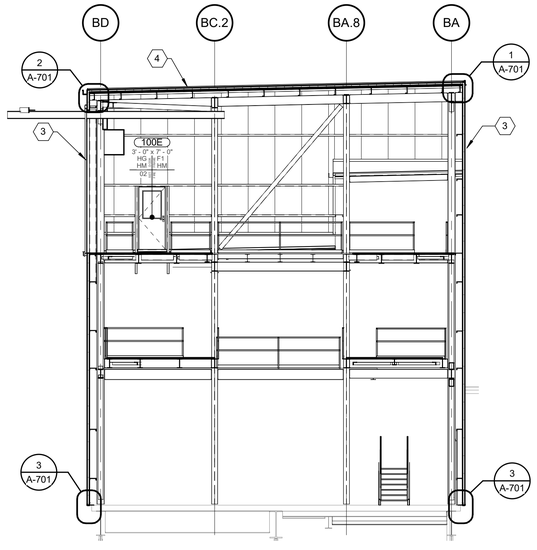
A–202



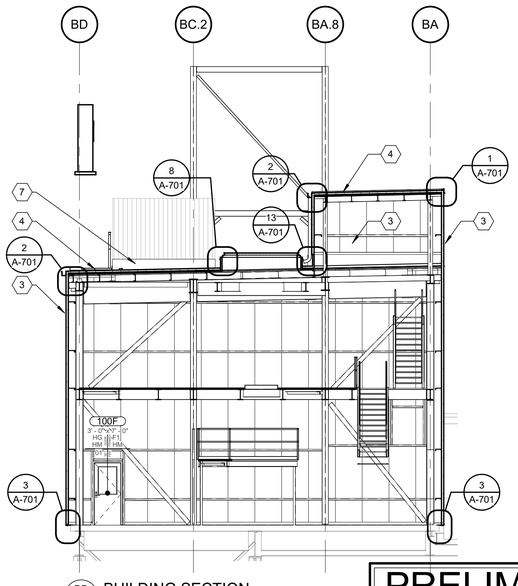
AA A-110 BUILDING SECTION
SCALE: 1/8" = 1'-0"



BB A-111 BUILDING SECTION
SCALE: 1/8" = 1'-0"



CC A-114 BUILDING SECTION
SCALE: 1/8" = 1'-0"



DD A-114 BUILDING SECTION
SCALE: 1/8" = 1'-0"

GENERAL NOTES

1. NOT ALL KEY NOTES MAY APPLY TO THIS SHEET
2. SEE A-701 FOR DOOR HARDWARE SETS INDICATED IN DOOR TAG, ALONG WITH DOOR OPENING DETAILS
3. ALL WALL PENETRATIONS TO BE COORDINATED W/ LATEST EQUIPMENT LAYOUT, INCLUDING PIPING, DUCTWORK, AND EQUIPMENT ACCESS DOOR OPENINGS
4. EQUIPMENT, PIPING, & DUCTWORK NOT SHOWN FOR CLARITY
5. SEE STRUCTURAL DRAWINGS FOR FRAMED ROOF/WALL OPENING SIZES/LOCATIONS AND STAIRS LOCATIONS/DETAILS

KEY NOTES

1. WALL PENETRATION - CHEMLINK E-CURB PENETRATION SYSTEM, SEE DETAIL 7 ON A-701. COORDINATE W/ MECHANICAL DRAWINGS FOR SIZE AND LOCATIONS
2. DUCT PENETRATION - SHEET METAL TRIM WEATHERPROOF CLOSURES, MATCH PANEL COLOR
3. INSULATED METAL WALL PANEL W/ MFR STANDARD BASE FLASHING, CORNER TRIM, OPENING TRIM, AND CONNECTIONS TO EXISTING WALLS
4. SINGLE-PLY MEMBRANE ROOF SYSTEM W/ MFR STANDARD POLYISO INSULATION AND MFR STANDARD FASCIA
5. INFILL EXISTING OPENING W/ INSULATED METAL WALL PANEL, UTILIZE MFR STANDARD CHANNELS AND TRIM TO PROVIDE WEATHERPROOF INSTALLATION
6. 6"x6" GUTTER AND 5"x4" DOWNSPOUT
7. PROVIDE ROOF CURB AND MEMBRANE FLASHING AT EQUIPMENT ENCLOSURE BY EQUIPMENT SUPPLIER
8. PROVIDE MEMBRANE FLASHING FROM EXISTING ROOF TO NEW INSULATED METAL WALL PANEL
9. ROOF PENETRATION - SEE DETAILS 6/7 ON A-701
10. EQUIPMENT MONORAIL - SEE STRUCTURAL DRAWINGS
11. PORTABLE GUARDRAIL (SAFETYRAIL 2000, BLUEWATER MANUF OR APPROVED EQUAL) INCLUDING RAILS AND BASE WEIGHTS
12. PROVIDE ROOF MEMBRANE MANFACTURER'S STANDARD 5'x5' WALKWAY PAD AT DOOR
13. ROOF MANUFACTURER'S STANDARD LAP JOINT AT EXISTING ROOF SYSTEM TO NEW SINGLE-PLY MEMBRANE ROOF SYSTEM
14. PROVIDE MEMBRANE FLASHING FROM NEW SINGLE-PLY MEMBRANE ROOF SYSTEM TO EXISTING WALL CONSTRUCTION

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	MLB

SECURITY
PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

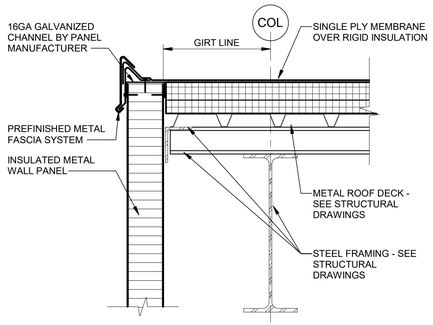
2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

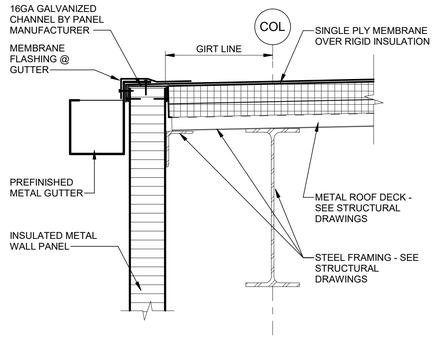
ARCHITECTURAL BUILDING SECTIONS

DATE	DRAWN	CHK'D.
08/03/20	Author	Checker
SCALE: As indicated		APPROVED: Approver

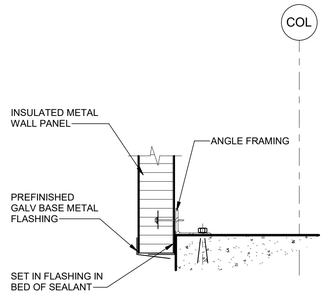
A-301



1 A-301 EAVE DETAIL
SCALE: 1 1/2" = 1'-0"



2 A-301 GUTTER DETAIL
SCALE: 1 1/2" = 1'-0"



3 A-301 BASE DETAIL
SCALE: 1 1/2" = 1'-0"

HARDWARE MANUFACTURERS

C	CLOSER (OVERHEAD DOOR CLOSER)
C1	PARALLEL ARM PUSH SIDE DOOR MOUNTED CLOSER (PREFERRED) A. "DORMA" 8916 SPA8 B. "LCN" 4111 SERIES C. "NORTON" 7500

H	HINGES
H3	EXTERIOR HINGE (NRP) 4 1/2" x 4 1/2" 32D A. "HAGER" BB1191 NRP B. "McKINNEY" TA2314 NRP C. "STANLEY" FBB191

PK	KICK PLATE - COUNTERSUNK HOLES 3 SIDES BEVELED
PK1	10" HIGH x DOOR WIDTH - 2" x 0.050 A. "HAGER" 193 S B3E 32D B. "IVES" 8400 32D C. "ROCKWOOD" K1050

ML	MORTISE LATCHSET - LEVER TRIM
ML3	PASSAGE FUNCTION - 26D A. "SCHLAGE" L9010-07 B. "SARGENT" 8215 C. "DORMA" ML9010 D. "CORBIN RUSSWIN" ML2010-AS E. "YALE" PB8801
ML6	ENTRANCE FUNCTION - 32D A. "SCHLAGE" L9453-07 B. "SARGENT" 8216 C. "DORMA" ML9953 D. "CORBIN RUSSWIN" ML2067-AS E. "YALE" PB8807

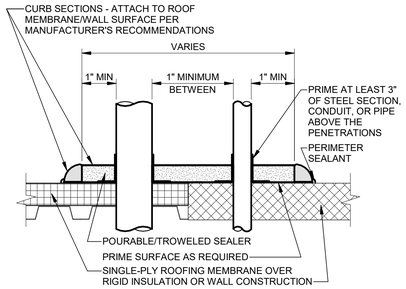
RD	RAIN DRIP
RD1	40" DRIP FOR SINGLE DOOR (2 1/2" PROTECTION) A. "NATIONAL GUARD" 16A B. "PEMKO" 346C C. "REESE" R201

SW	SWEEP WEATHER STRIP
SW1	36" SWEEP A. "NATIONAL GUARD" 200NA B. "PEMKO" 315CN C. "REESE" 323A

T	THRESHOLD
T1	4" x 1/2" ADA ACCEPTABLE, SINGLE 36" A. "NATIONAL GUARD" 424 B. "PEMKO" 170A

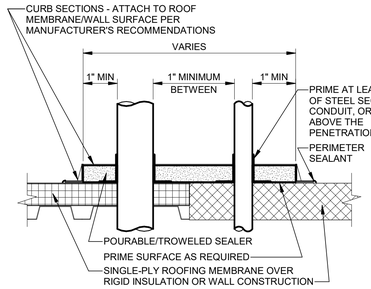
WS	WEATHERSTRIP
WS1	SILICONE PERIMETER GASKET (SINGLE) A. "NATIONAL GUARD" 700ES B. "PEMKO" 290AS C. "REESE" 855C

BASIS OF DESIGN: PROVIDE CHEMLINK CHEMCURB PENETRATION SEAL SYSTEM OR APPROVED EQUAL, FOLLOW MANUFACTURER'S INSTALLATION RECOMMENDATIONS - APPLICABLE TO CONDUITS, VENT PIPES, STRUCTURAL STEEL, AND SIMILAR ROOF PENETRATIONS

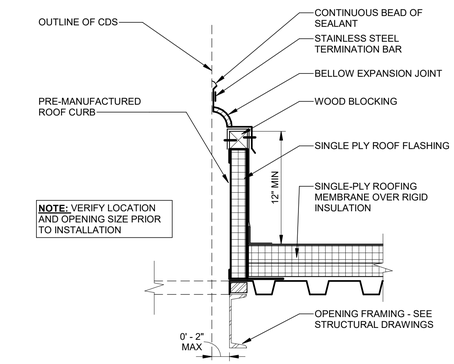


PIPE PENETRATION DETAIL
SCALE: 1 1/2" = 1'-0"

BASIS OF DESIGN: PROVIDE CHEMLINK E-CURB PENETRATION SEAL SYSTEM OR APPROVED EQUAL, FOLLOW MANUFACTURER'S INSTALLATION RECOMMENDATIONS - APPLICABLE TO CONDUITS, VENT PIPES, STRUCTURAL STEEL, AND SIMILAR ROOF PENETRATIONS



PIPE PENETRATION DETAIL
SCALE: 1 1/2" = 1'-0"



8 A-301 CDS ROOF PENETRATION DETAIL
SCALE: 1 1/2" = 1'-0"

SEALANT TYPE LEGEND

TYPE	JOINT LOCATIONS
S-1	**SILICONE** INTERIOR SEALANT FOR USE IN MANUFACTURING AREAS • CONTROL JOINTS ON EXPOSED INTERIOR SURFACES OF EXTERIOR WALLS • INTERIOR DOORS, WINDOWS, AND ENTRANCES • LABORATORIES • PROCESS AND MANUFACTURING AREAS • OTHER JOINTS AS INDICATED ON DRAWINGS
S-2	**POLYURETHANE-RUBBER BASED** EXTERIOR SEALANT FOR GENERAL CAULKING AND SEALING • CONSTRUCTION JOINTS IN CAST-IN-PLACE CONCRETE • JOINTS BETWEEN PLANT-PRECAST ARCHITECTURAL CONCRETE UNITS • JOINTS IN DIMENSION STONE CLADDING • JOINTS IN GLASS UNIT MASONRY ASSEMBLIES • JOINTS IN EXTERIOR INSULATION AND FINISH SYSTEMS • JOINTS BETWEEN METAL PANELS • JOINTS BETWEEN DIFFERENT MATERIALS LISTED ABOVE • PERIMETER JOINTS BETWEEN MATERIALS LISTED ABOVE AND FRAMES OF DOORS, WINDOWS, AND LOUVERS • OTHER JOINTS AS INDICATED ON DRAWINGS
S-3	**ELASTOMERIC** ELASTOMERIC SEALANT FOR DYNAMIC JOINTS • CONTROL AND EXPANSION JOINTS IN CAST-IN-PLACE CONCRETE • CONTROL AND EXPANSION JOINTS IN PRECAST ARCHITECTURAL CONCRETE UNITS • CONTROL AND EXPANSION JOINTS IN UNIT MASONRY • CONTROL AND EXPANSION JOINTS IN DIMENSION STONE CLADDING • CONTROL AND EXPANSION JOINTS IN GLASS UNIT MASONRY ASSEMBLIES • CONTROL AND EXPANSION JOINTS IN EXTERIOR INSULATION AND FINISH SYSTEMS • CONTROL AND EXPANSION JOINTS BETWEEN METAL PANELS • CONTROL AND EXPANSION JOINTS IN CEILINGS AND OTHER OVERHEAD SURFACES • OTHER JOINTS AS INDICATED ON DRAWINGS
S-4	**POLYURETHANE** EXTERIOR SEALANT FOR HORIZONTAL JOINTS IN CONCRETE WALKS AND PAVEMENT • ISOLATION AND CONTRACTION JOINTS IN CAST-IN-PLACE CONCRETE SLABS • ISOLATION AND CONTRACTION JOINTS IN CAST-IN-PLACE CONCRETE STEPS • OTHER JOINTS AS INDICATED ON DRAWINGS
S-5	**SILICONE-MILDEW RESISTANT** INTERIOR SEALANT FOR USE IN NON-MANUFACTURING WET AREAS • JOINTS BETWEEN PLUMBING FIXTURES • TILE CONTROL AND EXPANSION JOINTS WHERE INDICATED • ADJOINING WALLS AND FLOORS • COUNTER TOPS AND CABINETS • OTHER JOINTS AS INDICATED ON DRAWINGS
S-6	**BUTYL-RUBBER BASED** SEALANT FOR USE IN CONCEALED AREAS • ALUMINUM THRESHOLDS • SILL PLATES • ROOF FLASHING • OTHER JOINTS AS INDICATED ON DRAWINGS
S-7	**ACRYLIC LATEX** SEALANT FOR USE IN CONCEALED AREAS • CONTROL JOINTS ON EXPOSED INTERIOR SURFACES OF EXTERIOR WALLS • PERIMETER JOINTS BETWEEN INTERIOR WALL SURFACES AND FRAMES OF INTERIOR DOORS, WINDOWS, AND ELEVATOR ENTRANCES • CORRIDORS AND OFFICE AREAS • WAREHOUSE AND NON-MANUFACTURING AREAS • OTHER JOINTS AS INDICATED ON DRAWINGS
S-8	**POLYUREA** SEALANT FOR USE IN FLOOR JOINTS WITHIN FREEZER OR REFRIGERATED AREAS • CONTROL AND EXPANSION JOINTS IN BRICK PAVERS • CONTROL AND EXPANSION JOINTS IN CAST-IN-PLACE CONCRETE SLABS • CONTROL AND EXPANSION JOINTS IN TILE • CONTROL AND EXPANSION JOINTS IN EPOXY • JOINTS BETWEEN DIFFERENT MATERIALS LISTED ABOVE • OTHER JOINTS AS INDICATED ON DRAWINGS

HARDWARE SETS

HW SET #01

C1	CLOSER
H3	1 1/2 PAIR BUTT HINGES
ML6	MORTISE LATCH - ENTRANCE
PK1	KICK PLATE
RD1	RAIN DRIP
SW1	SWEEP WEATHER STRIP
T1	THRESHOLD
WS1	WEATHER STRIP

HW SET #02 S-HM-EX-HF-NR-PAML

C1	CLOSER
H3	1 1/2 PAIR BUTT HINGES
ML6	MORTISE LATCH - PASSAGE
PK1	KICK PLATE
RD1	RAIN DRIP
SW1	SWEEP WEATHER STRIP
T1	THRESHOLD
WS1	WEATHER STRIP

HW SET #03 S-HM-IN-HF-NR-PAML

C1	CLOSER
H3	1 1/2 PAIR BUTT HINGES
ML3	MORTISE LATCH - PASSAGE
PK1	KICK PLATE

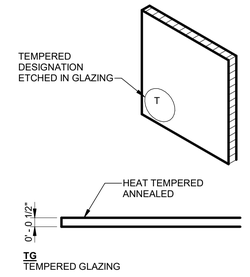
HW SET #05

BI-PARTING SLIDING MONORAIL DOOR: MANUFACTURER'S STANDARD HARDWARE - BASIS OF DESIGN: PS ACCESS SOLUTIONS

HW SET #06

MANUAL OVERHEAD COILING DOOR: MANUFACTURER'S STANDARD HARDWARE

GLAZING TYPES

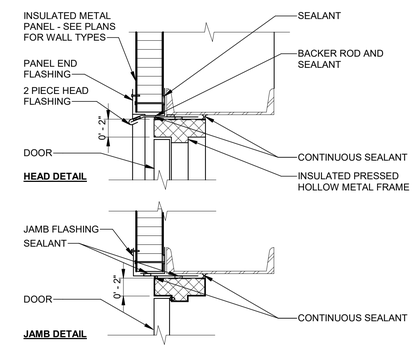


TG
TEMPERED GLAZING

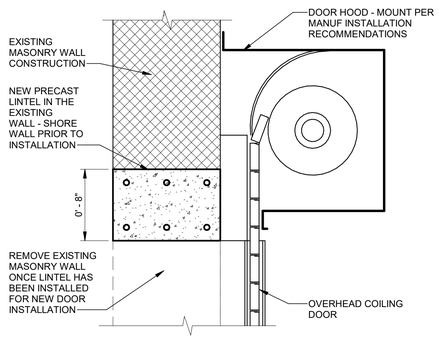
LOCATION
MAN DOOR LITES

SEALANT NOTES

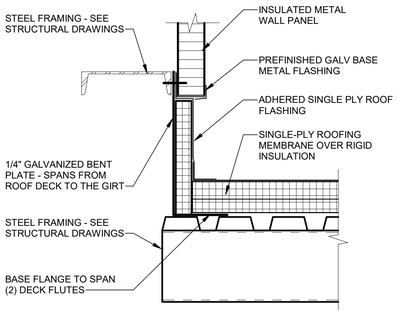
1. NOT ALL SEALANTS LISTED ARE USED ON THIS PROJECT. SEE DETAILS, SCHEDULES, DRAWINGS, NOTES, & SPECIFICATIONS FOR LOCATIONS AND TYPES.
2. NOT ALL LOCATIONS SHOWN ARE APPLICABLE TO THIS PROJECT. SEE DETAILS, SCHEDULES, DRAWINGS, NOTES, & SPECIFICATIONS FOR LOCATIONS AND TYPES.
3. SEALANT TYPE LEGEND CONTAINS LOCATIONS FOR SEALANT TO BE USED THAT ARE NOT SHOWN BELOW. SEE DETAILS, SCHEDULES, DRAWINGS, NOTES, & SPECIFICATIONS FOR LOCATIONS.



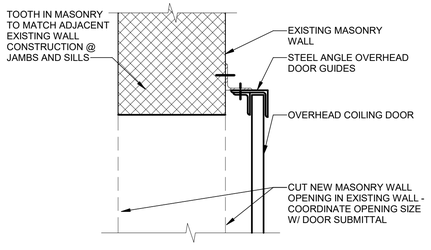
MAN DOOR HEAD/JAMB DETAILS
SCALE: 1 1/2" = 1'-0"



OVERHEAD COILING DOOR HEAD DETAIL
SCALE: 1 1/2" = 1'-0"



13 A-301 CDS ROOF PENETRATION DETAIL
SCALE: 1 1/2" = 1'-0"



OVERHEAD COILING DOOR JAMB DETAIL
SCALE: 1 1/2" = 1'-0"

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	MLB

SECURITY
PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

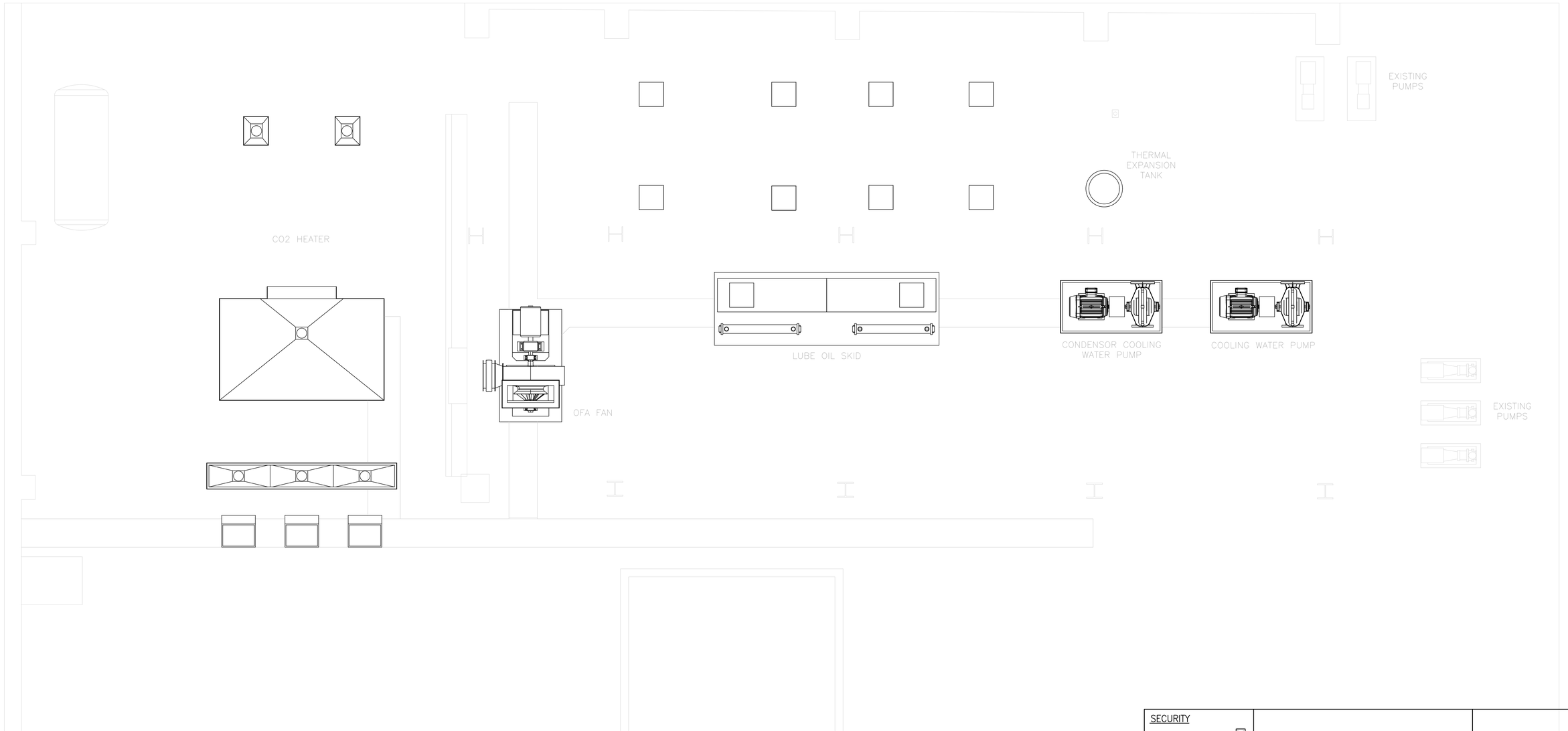
2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

ARCHITECTURAL MISCELLANEOUS DETAILS / SCHEDULES

DATE	DRAWN	CHK'D.
08/03/20	Author	Checker
SCALE: As indicated		APPROVED: Approver

A-701



BASEMENT AREA

PLAN VIEW

1/4" = 1'-0"

NO.	DATE	REVISION	BY
.	.	.	.
.	.	.	.
.	.	.	.
A	08/03/20	ISSUED FOR BIDS	CDMS

SECURITY

PUBLIC ☒

ECHOGEN BUSINESS CONFIDENTIAL ☐

TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

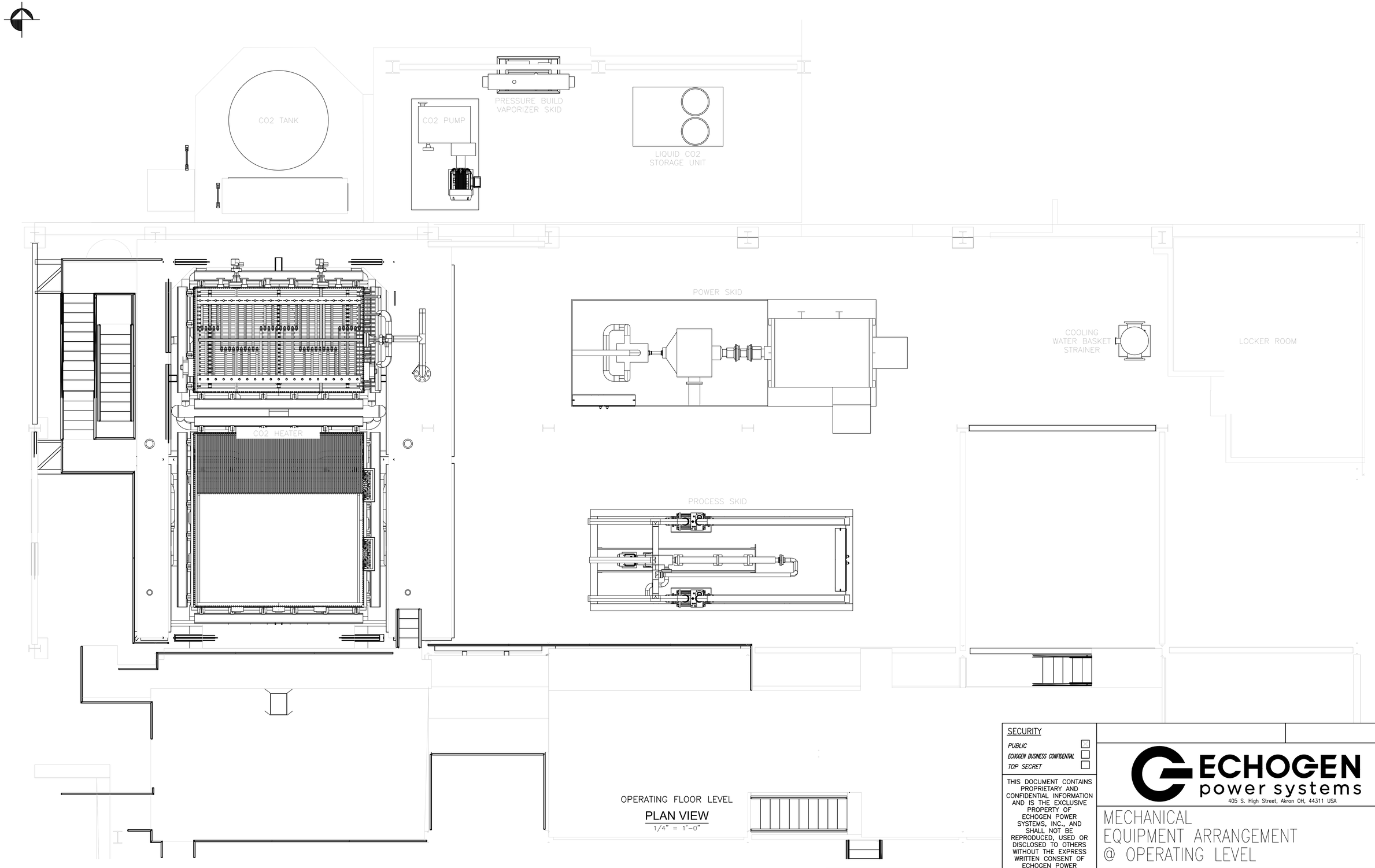
2011 ALL RIGHTS RESERVED
ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

MECHANICAL EQUIPMENT ARRANGEMENT @ BASEMENT LEVEL

DATE	DRAWN	CHK'D.
05/22/2020	BB	KJR
SCALE 1/4"=1'-0"		APPROVED .

M-100



PLAN VIEW

1/4" = 1'-0"

NO.	DATE	REVISION	BY
.	.	.	.
.	.	.	.
.	.	.	.
A	08/03/20	ISSUED FOR BIDS	CDMS

SECURITY

PUBLIC [X]
ECHOGEN BUSINESS CONFIDENTIAL [ ]
TOP SECRET [ ]

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

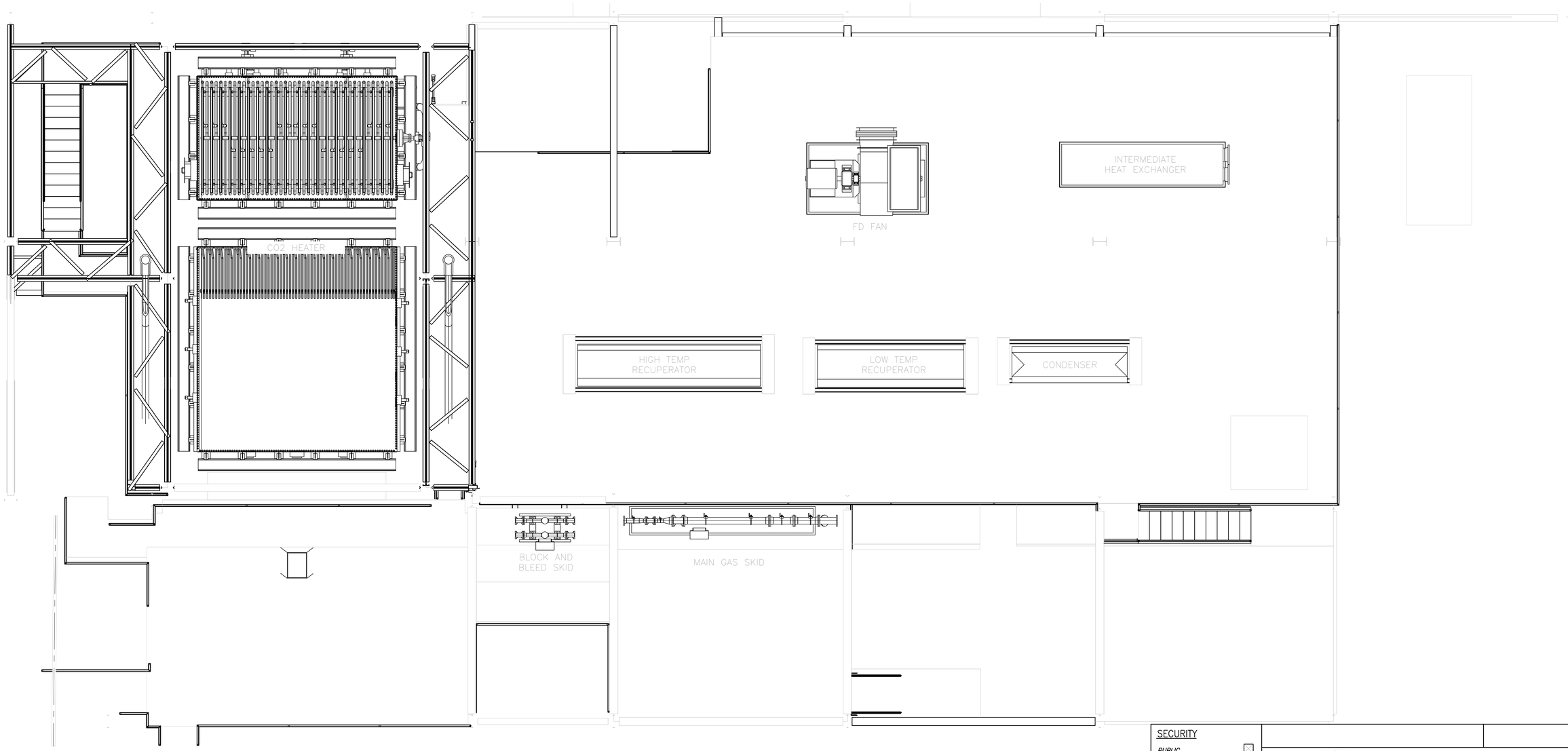
2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

MECHANICAL EQUIPMENT ARRANGEMENT @ OPERATING LEVEL

DATE	DRAWN	CHK'D.
05/22/2020	BB	KJR
SCALE 1/4"=1'-0"		APPROVED .

M-101



MEZZANINE LEVEL

PLAN VIEW

1/4" = 1'-0"

NO.	DATE	REVISION	BY
.	.	.	.
.	.	.	.
.	.	.	.
A	08/03/20	ISSUED FOR BIDS	CDMS

SECURITY

PUBLIC ☐
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

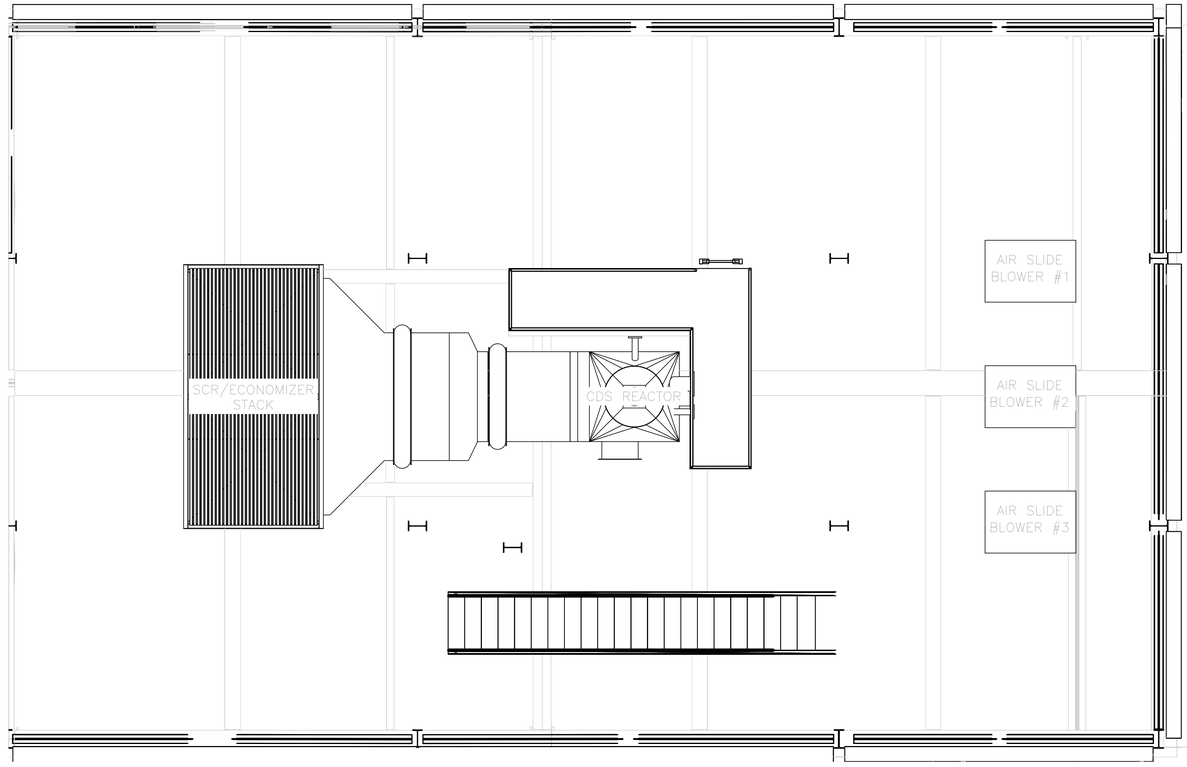
2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

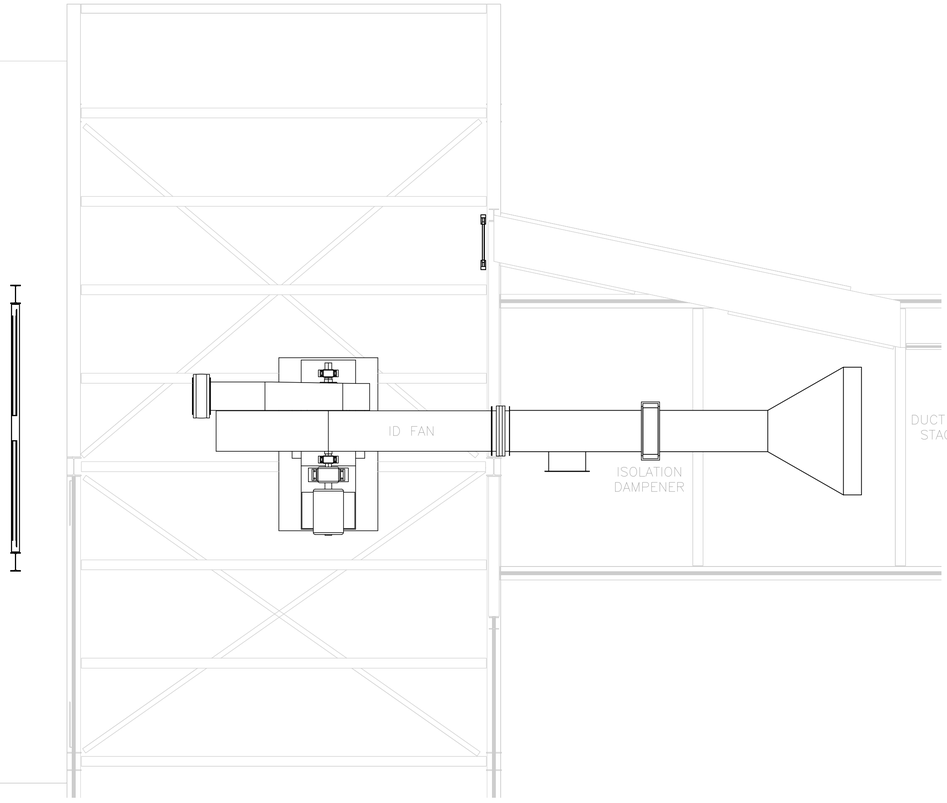
ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

MECHANICAL EQUIPMENT ARRANGEMENT @ MEZZANINE LEVEL

DATE	DRAWN	CHK'D.
05/22/2020	BB	KJR
SCALE 1/4"=1'-0"		APPROVED .

M-102





OUTSIDE PLATFORM MAIN LEVEL

PLAN VIEW

1/4" = 1'-0"

NO.	DATE	REVISION	BY
.	.	.	.
.	.	.	.
.	.	.	.
A	08/03/20	ISSUED FOR BIDS	CDMS

SECURITY

PUBLIC [X]
ECHOGEN BUSINESS CONFIDENTIAL [ ]
TOP SECRET [ ]

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

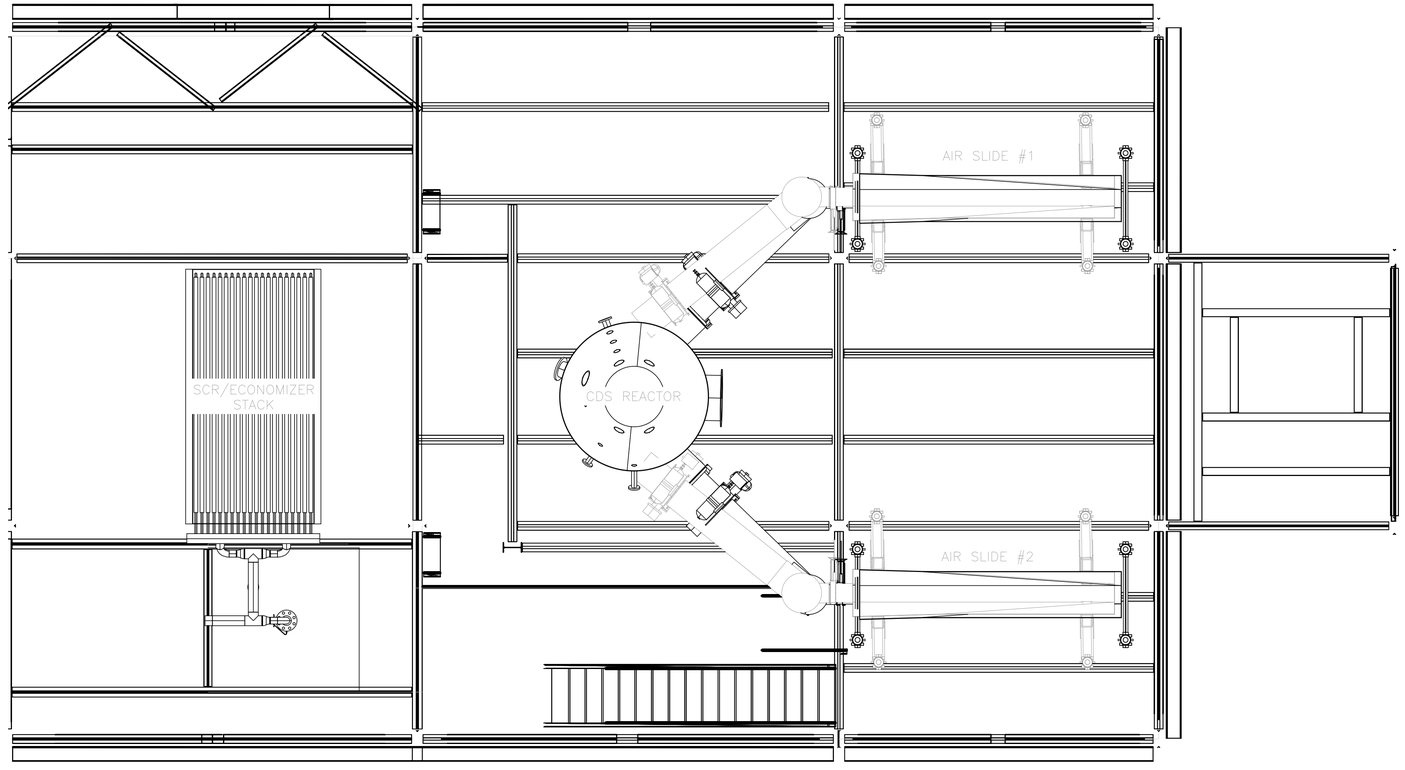
2011 ALL RIGHTS RESERVED
ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

MECHANICAL EQUIPMENT ARRANGEMENT @ OUTSIDE PLATFORM MAIN LEVEL

DATE	DRAWN	CHK'D.
05/22/2020	BB	KJR
SCALE 1/4"=1'-0"		APPROVED .

M-103



OUTSIDE PLATFORM INTERMEDIATE LEVEL

PLAN VIEW

1/4" = 1'-0"

NO.	DATE	REVISION	BY
.	.	.	.
.	.	.	.
.	.	.	.
A	08/03/20	ISSUED FOR BIDS	CDMS

SECURITY

PUBLIC [x]

ECHOGEN BUSINESS CONFIDENTIAL [ ]

TOP SECRET [ ]

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

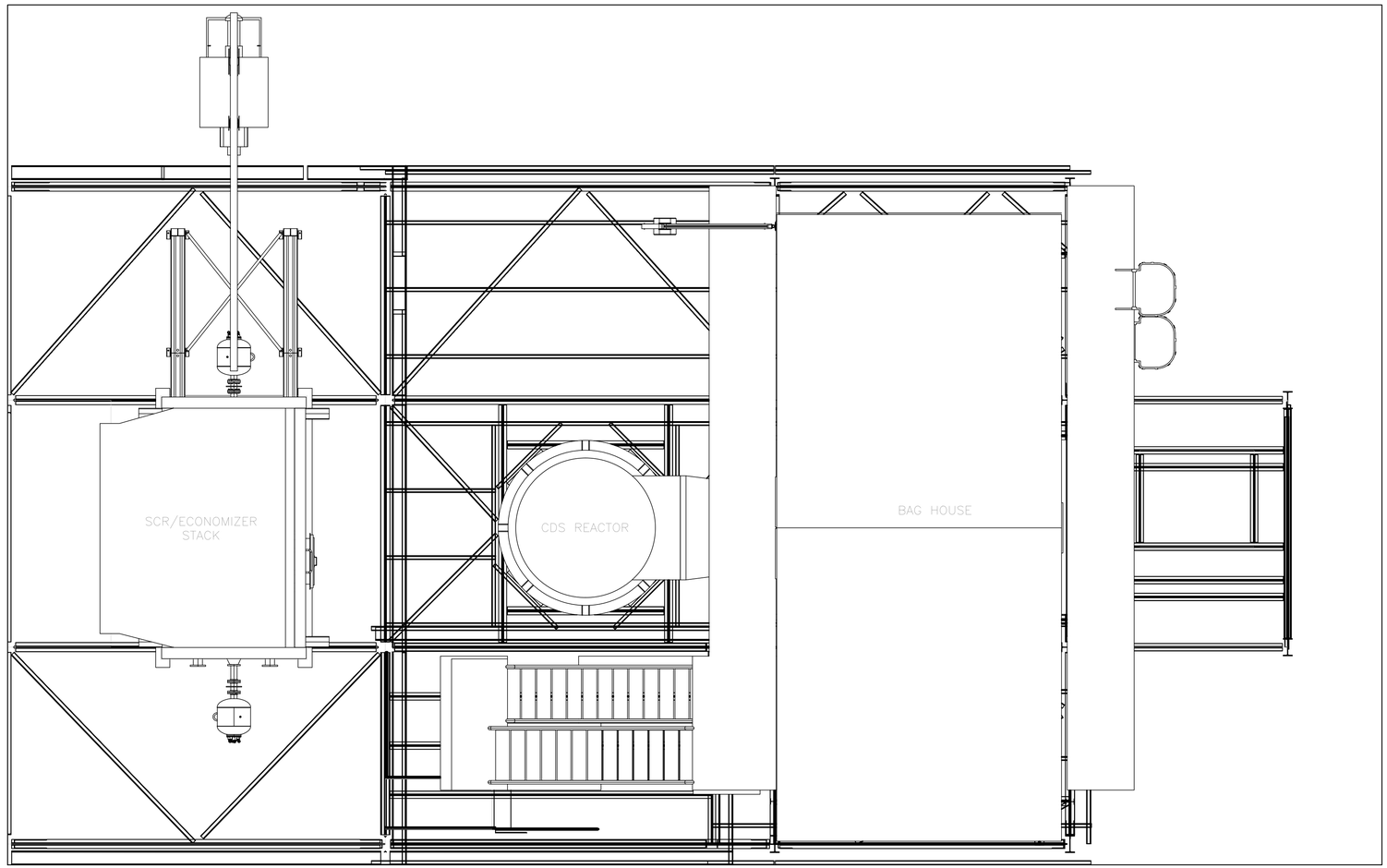
2011 ALL RIGHTS RESERVED
ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

MECHANICAL EQUIPMENT ARRANGEMENT @ OUTSIDE PLATFORM INTERM LEVEL

DATE	DRAWN	CHK'D.
05/22/2020	BB	KJR
SCALE 1/4"=1'-0"		APPROVED .

M-104



OUTSIDE PLATFORM UPPER LEVEL

PLAN VIEW

1/4" = 1'-0"

NO.	DATE	REVISION	BY
.	.	.	.
.	.	.	.
.	.	.	.
A	08/03/20	ISSUED FOR BIDS	CDMS

SECURITY

PUBLIC ☒

ECHOGEN BUSINESS CONFIDENTIAL ☐

TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

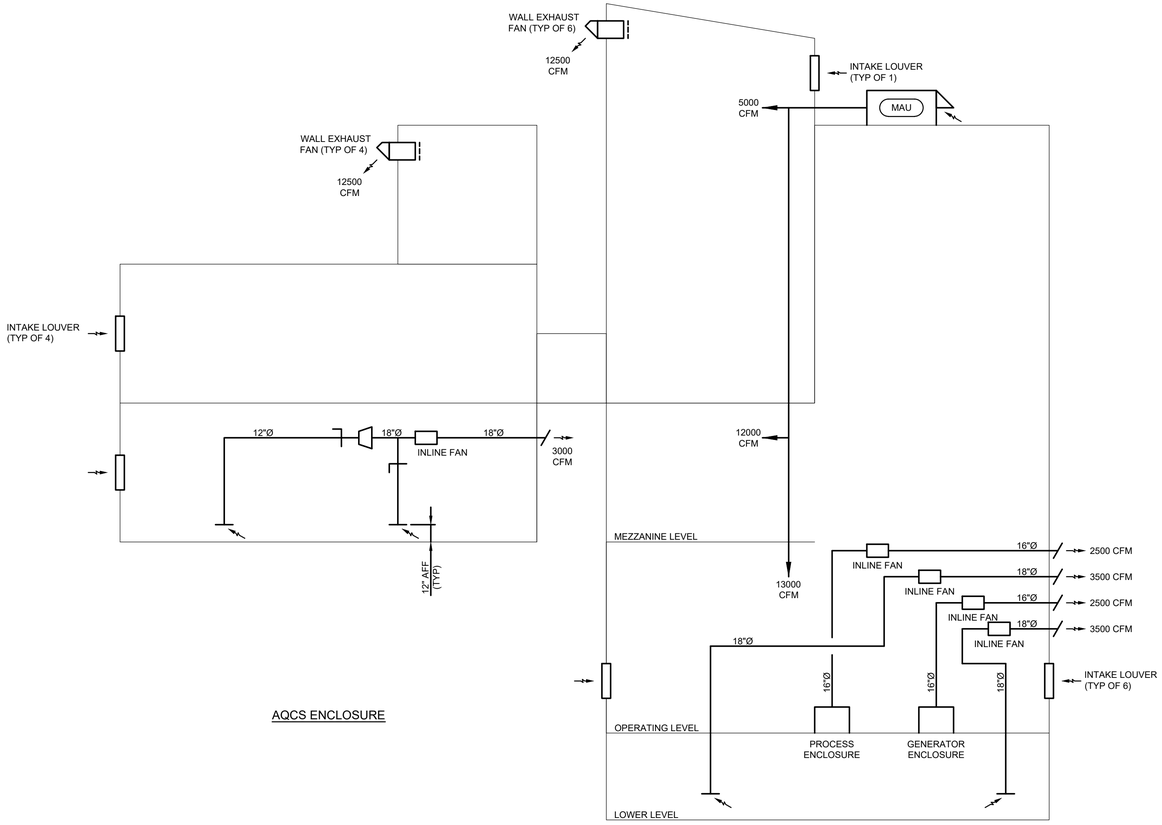
2011 ALL RIGHTS RESERVED
ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

MECHANICAL EQUIPMENT ARRANGEMENT @ OUTSIDE PLATFORM UPPER LEVEL

DATE	DRAWN	CHK'D.
05/22/2020	BB	KJR
SCALE 1/4"=1'-0"		APPROVED .

M-105



AQCS ENCLOSURE

CO2 HEATER ENCLOSURE

AIRFLOW DIAGRAM

SCALE: NONE

H&V EQUIPMENT LIST

ITEM NO	DESCRIPTION	SIZE	QUANTITY	LOCATION
1	ELECTRIC UNIT HEATER	15 KW, BUILT-IN CONTROLS, WALL BRACKET	20	CO2 HEATER ENCLOSURE
2	WALL EXHAUST FAN	12500 CFM, 2 HP, RAIN HOOD, OSHA GUARD AND WALL BOX	6	CO2 HEATER ENCLOSURE
3	INLINE FAN	3500 CFM, 2 HP	2	CO2 HEATER ENCLOSURE
4	MAKEUP AIR UNIT	30000 CFM, 15 HP 2 MMBH STEAM HTG COIL, ROOF CURB	1	CO2 HEATER ENCLOSURE
5	INLINE FAN	2500 CFM, 1 HP	2	CO2 HEATER ENCLOSURE
6	WALL LOUVER	40 SF COMBINATION TYPE WITH CHAIN OPERATOR	6	CO2 HEATER ENCLOSURE
7	ELECTRIC UNIT HEATER	12.5 KW, BUILT-IN CONTROLS, WALL BRACKET	10	AQCS ENCLOSURE
8	WALL EXHAUST FAN	12500 CFM, 2 HP, RAIN HOOD, OSHA GUARD AND WALL BOX	4	AQCS ENCLOSURE
9	INLINE FAN	3000 CFM, 3/4 HP	1	AQCS ENCLOSURE
10	WALL LOUVER	40 SF COMBINATION TYPE WITH CHAIN OPERATOR	4	AQCS ENCLOSURE

NO.	DATE	REVISION	BY
A	08/03/20	ISSUED FOR BIDS	KJR

SECURITY

PUBLIC ☒

ECHOGEN BUSINESS CONFIDENTIAL ☐

TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

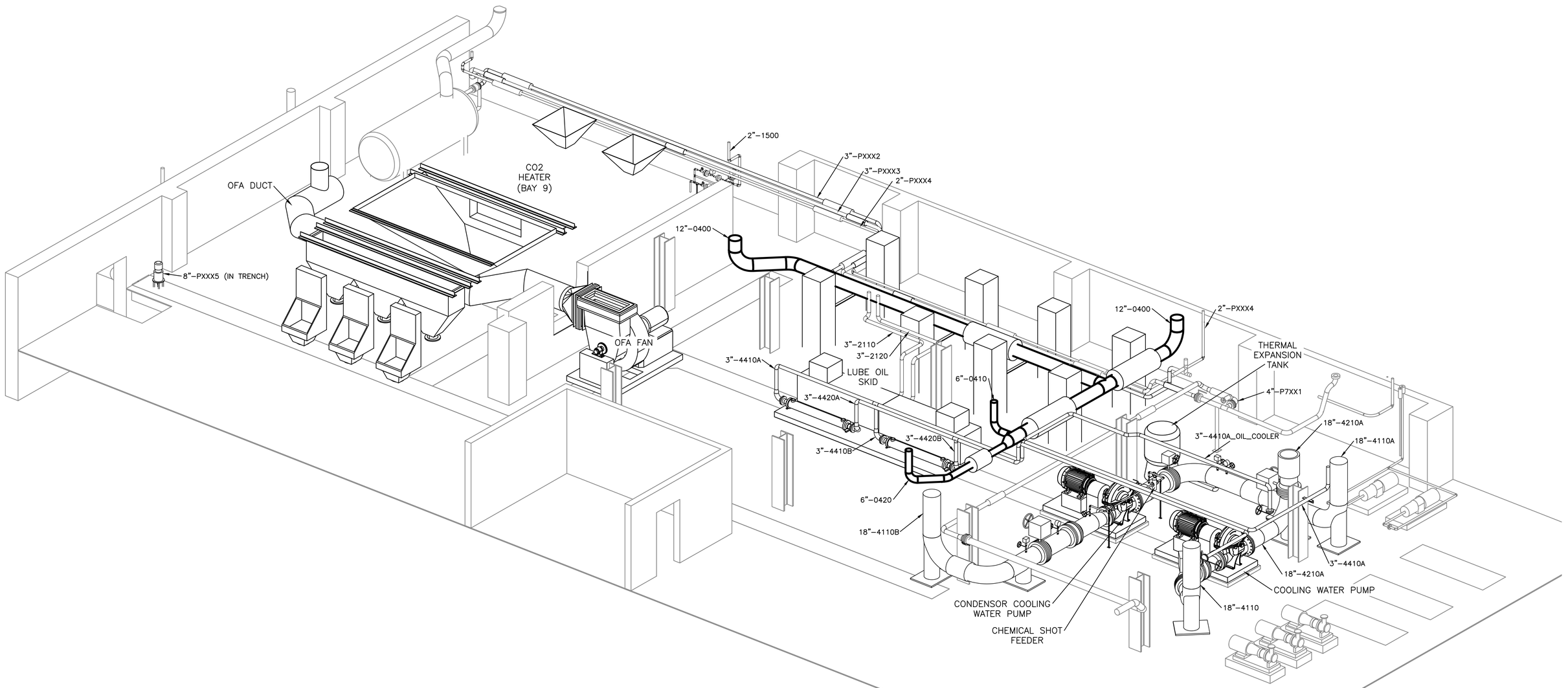
2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

MECHANICAL
AIRFLOW DIAGRAM

DATE	DRAWN	CHK'D.
05/28/20	JAB	KJR
SCALE: AS NOTED		APPROVED: KLM

M-201



BASEMENT AREA LOOKING NW

3D VIEW

1/4" = 1'–0"

NO.	DATE	REVISION	BY
.	.	.	.
.	.	.	.
.	.	.	.
A	08/03/20	ISSUED FOR BID	BB

SECURITY

PUBLIC ☒

ECHOGEN BUSINESS CONFIDENTIAL ☐

TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

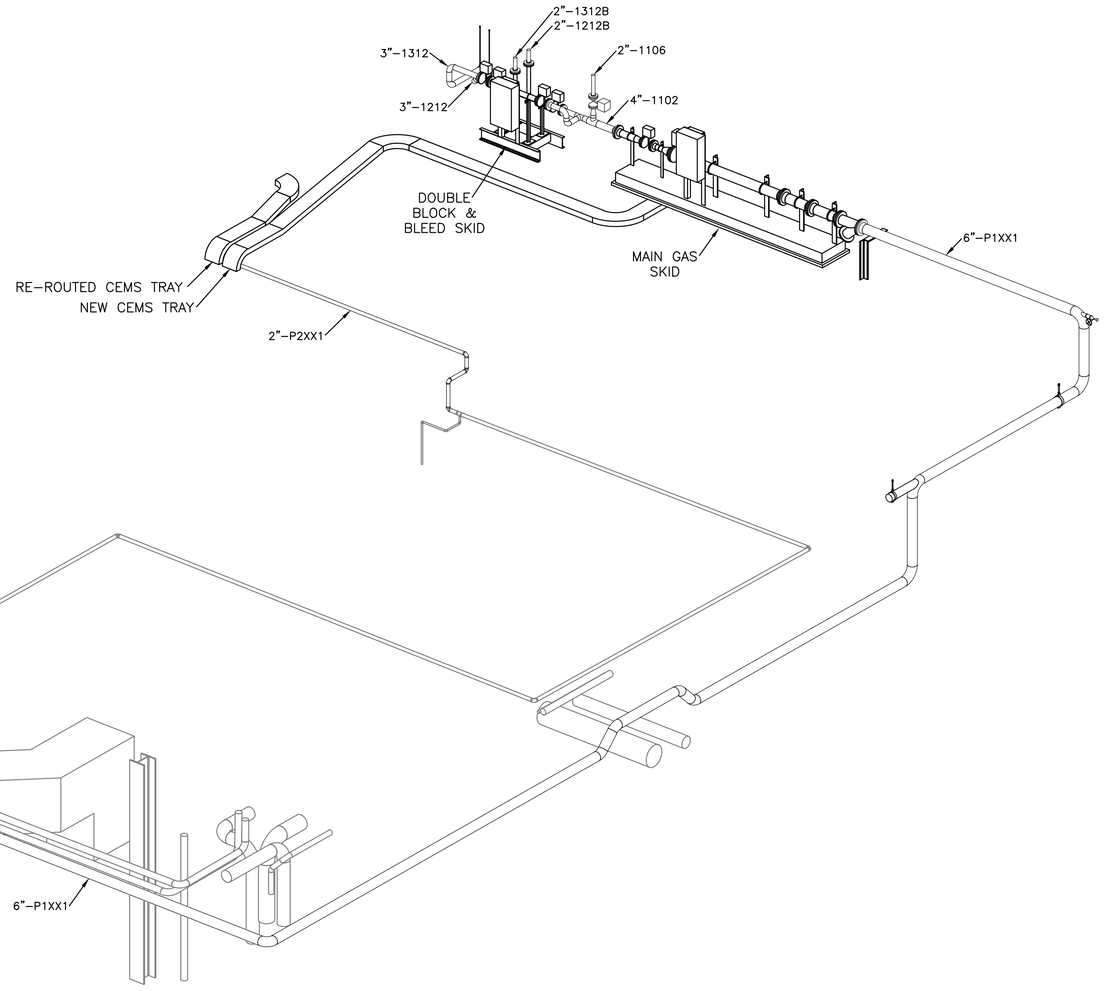
2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

PIPING
PIPING 3D VIEW @ BASEMENT LEVEL

DATE	DRAWN	CHK'D.
05/26/2020	BB	SMK
SCALE 1/4"=1'–0"		APPROVED .

P–100



OPERATING LEVEL LOOKING NW

3D VIEW

1/4" = 1'–0"

NO.	DATE	REVISION	BY
.	.	.	.
.	.	.	.
.	.	.	.
A	08/03/20	ISSUED FOR BID	BB

SECURITY

PUBLIC ☒

ECHOGEN BUSINESS CONFIDENTIAL ☐

TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2011 ALL RIGHTS RESERVED
ECHOGEN POWER SYSTEMS, INC.

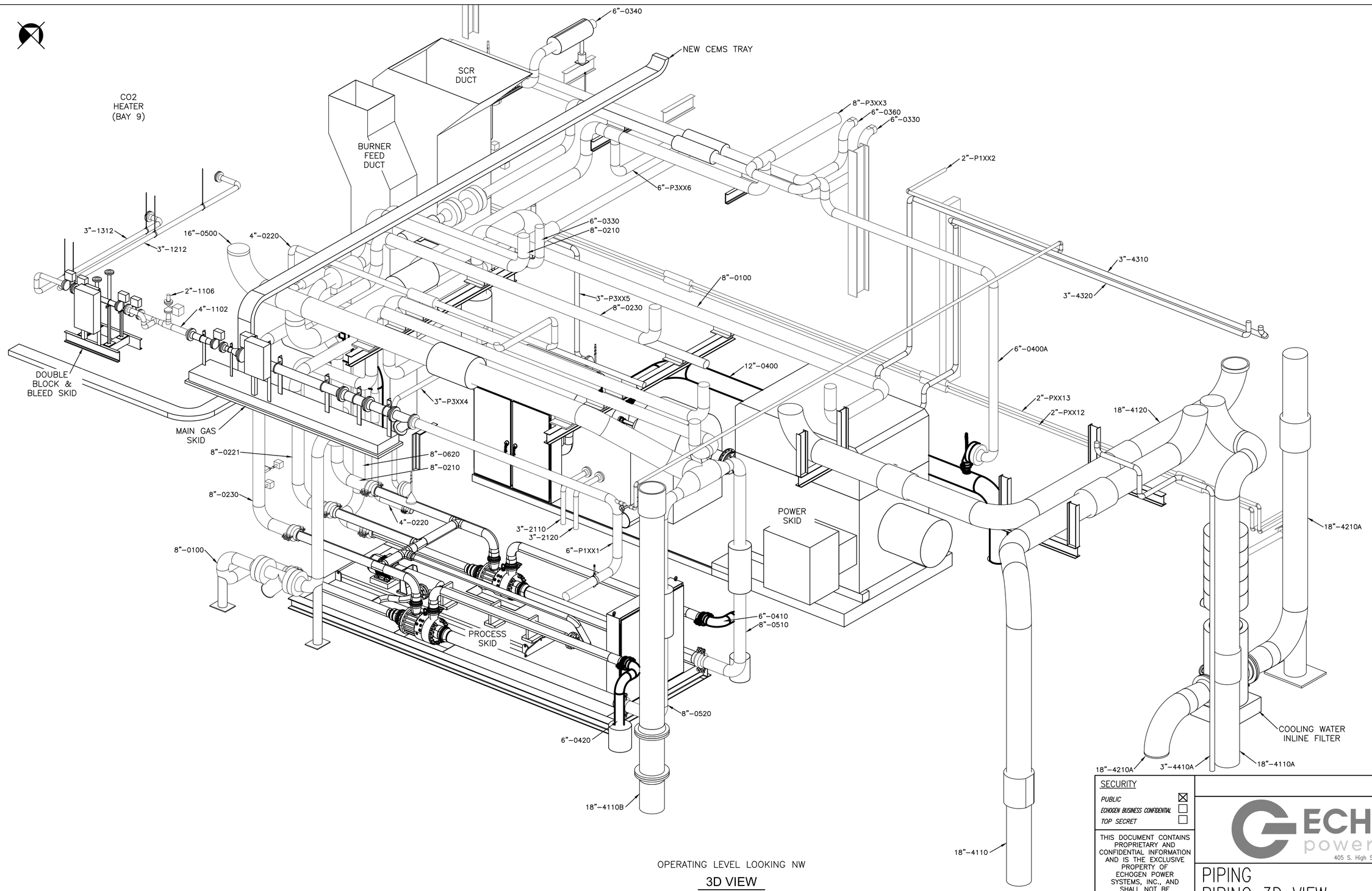
ECHOGEN power systems

405 S. High Street, Akron OH, 44311 USA

PIPING
PIPING 3D VIEW @ OPERATING LEVEL (GAS SUPPLY)

DATE	DRAWN	CHK'D.
05/26/2020	BB	SMK
SCALE 1/4"=1'–0"		APPROVED .

P–101



OPERATING LEVEL LOOKING NW

3D VIEW

3/8" = 1'–0"

NO.	DATE	REVISION	BY
.	.	.	.
.	.	.	.
.	.	.	.
A	08/03/20	ISSUED FOR BID	BB

SECURITY

PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

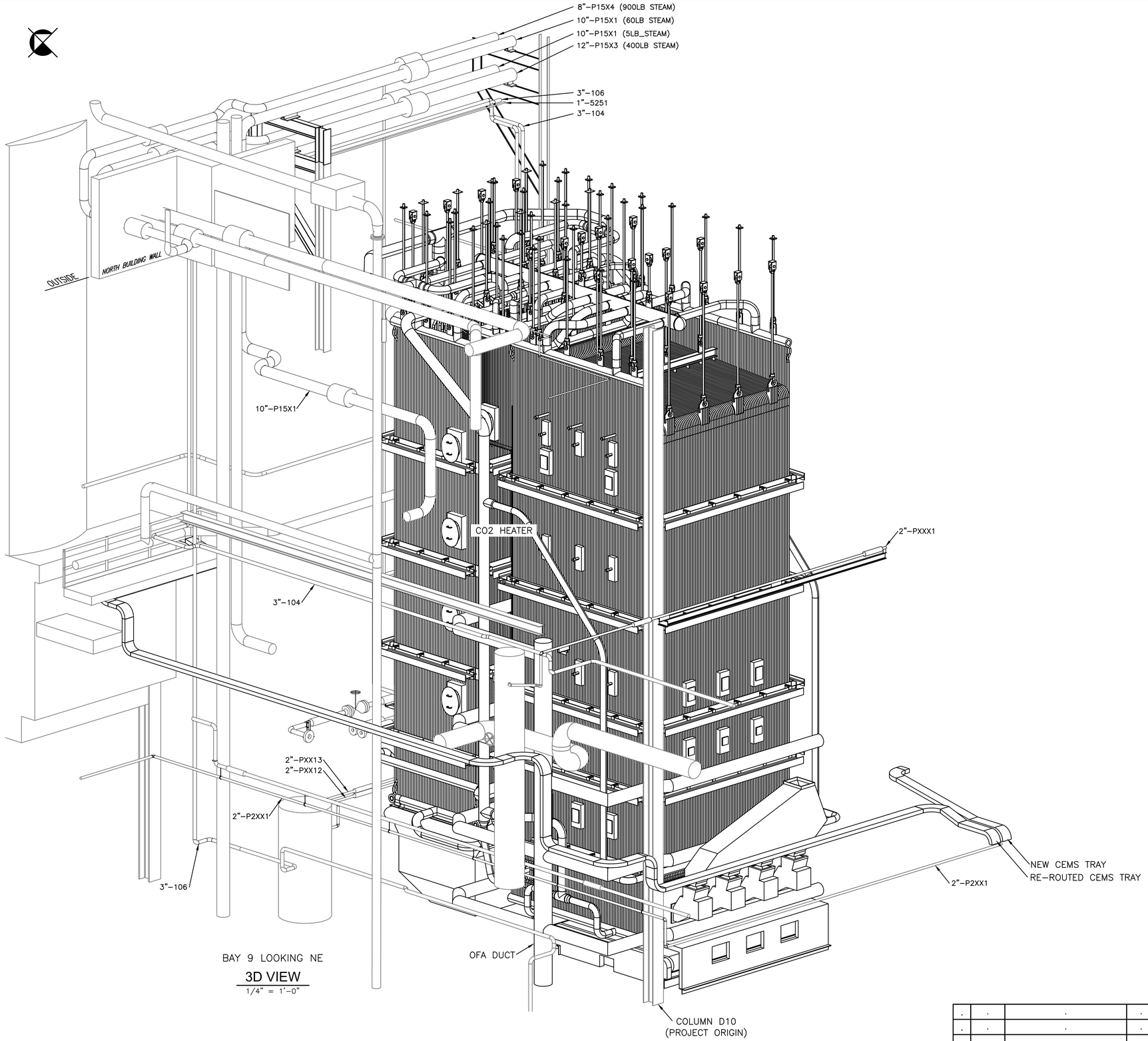
2011 ALL RIGHTS RESERVED
ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

PIPING
PIPING 3D VIEW @ OPERATING LEVEL

DATE	DRAWN	CHK'D.
05/26/2020	BB	SMK
SCALE 3/8"=1'–0"		APPROVED .

P–102



BAY 9 LOOKING NE

3D VIEW

1/4" = 1'–0"

NO.	DATE	REVISION	BY
.	.	.	.
.	.	.	.
.	.	.	.
A	08/03/20	ISSUED FOR BID	BB

SECURITY

PUBLIC ☒

ECHOGEN BUSINESS CONFIDENTIAL ☐

TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

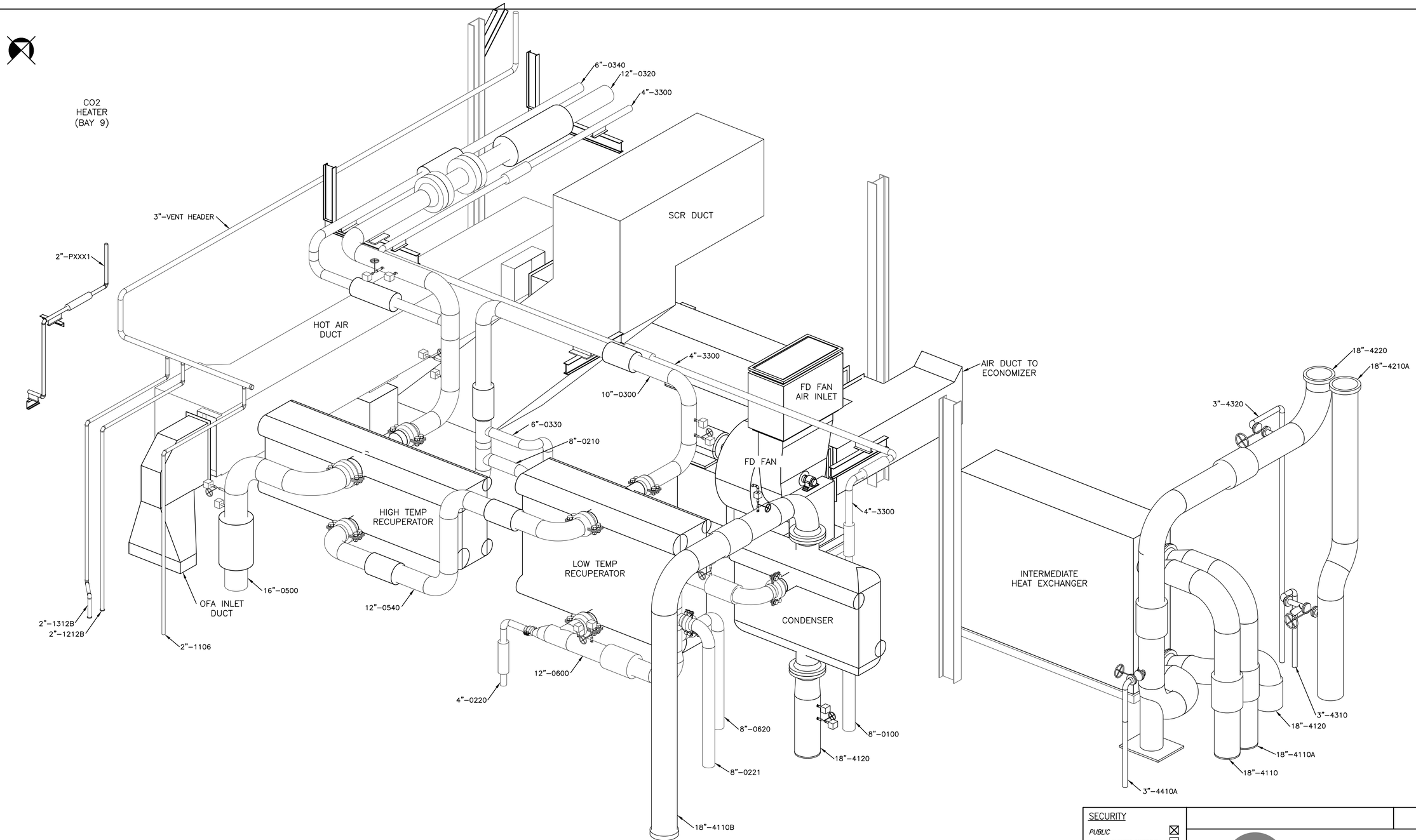
2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

PIPING
PIPING 3D VIEW @ BAY 9

DATE	DRAWN	CHK'D.
05/26/2020	BB	SMK
SCALE 1/4"=1'–0"		APPROVED .

P–103



MEZZININE LEVEL LOOKING NW

3D VIEW

3/8" = 1'–0"

NO.	DATE	REVISION	BY
.	.	.	.
.	.	.	.
.	.	.	.
A	08/03/20	ISSUED FOR BID	BB

SECURITY

PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

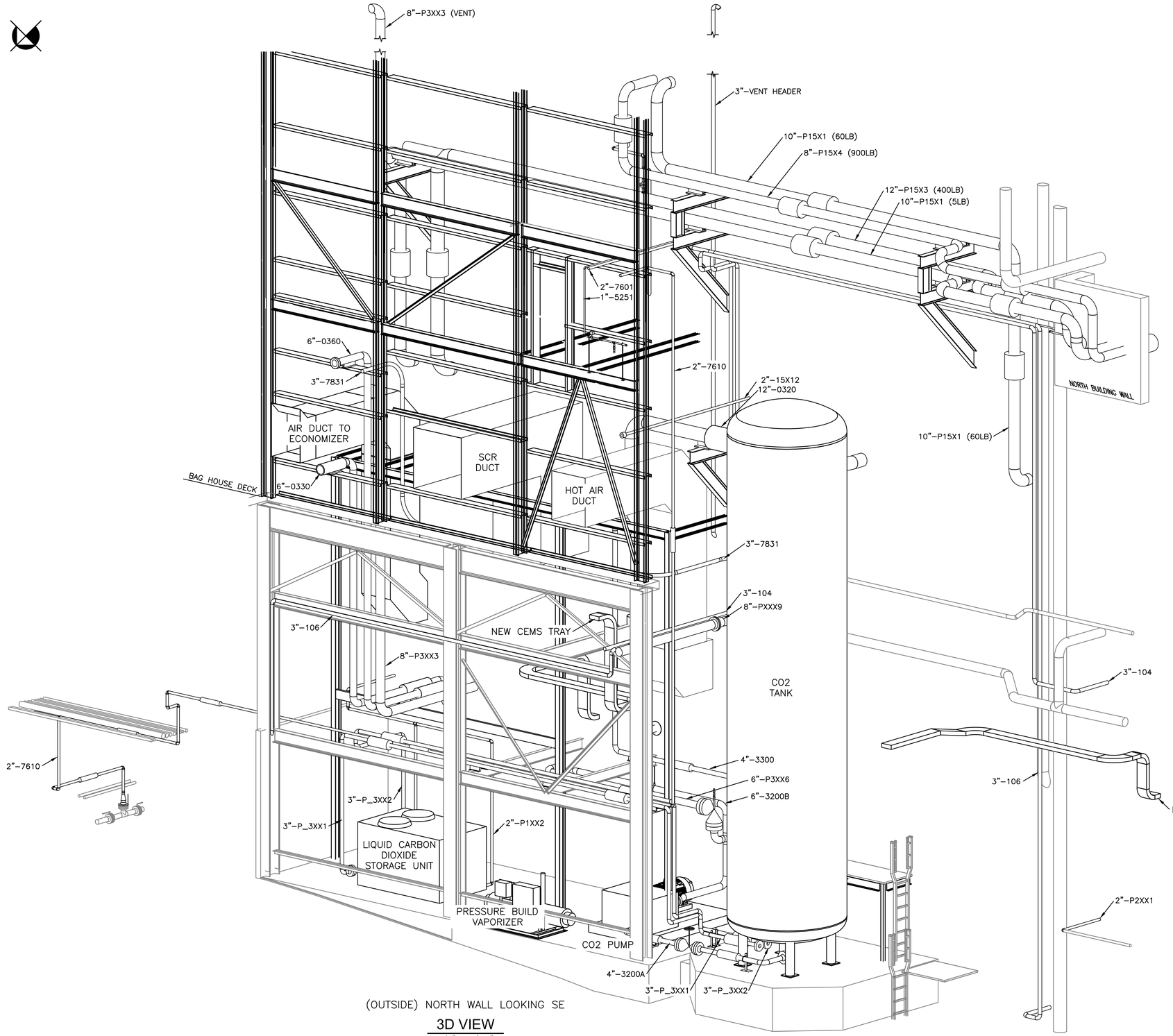
2011 ALL RIGHTS RESERVED
ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

PIPING
PIPING 3D VIEW @ MEZZININE LEVEL

DATE	DRAWN	CHK'D.
05/26/2020	BB	SMK
SCALE 3/8"=1'–0"		APPROVED .

P–104



(OUTSIDE) NORTH WALL LOOKING SE

3D VIEW

1/4" = 1'–0"

NO.	DATE	REVISION	BY
.	.	.	.
.	.	.	.
.	.	.	.
A	08/03/20	ISSUED FOR BID	BB

SECURITY

PUBLIC ☒

ECHOGEN BUSINESS CONFIDENTIAL ☐

TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

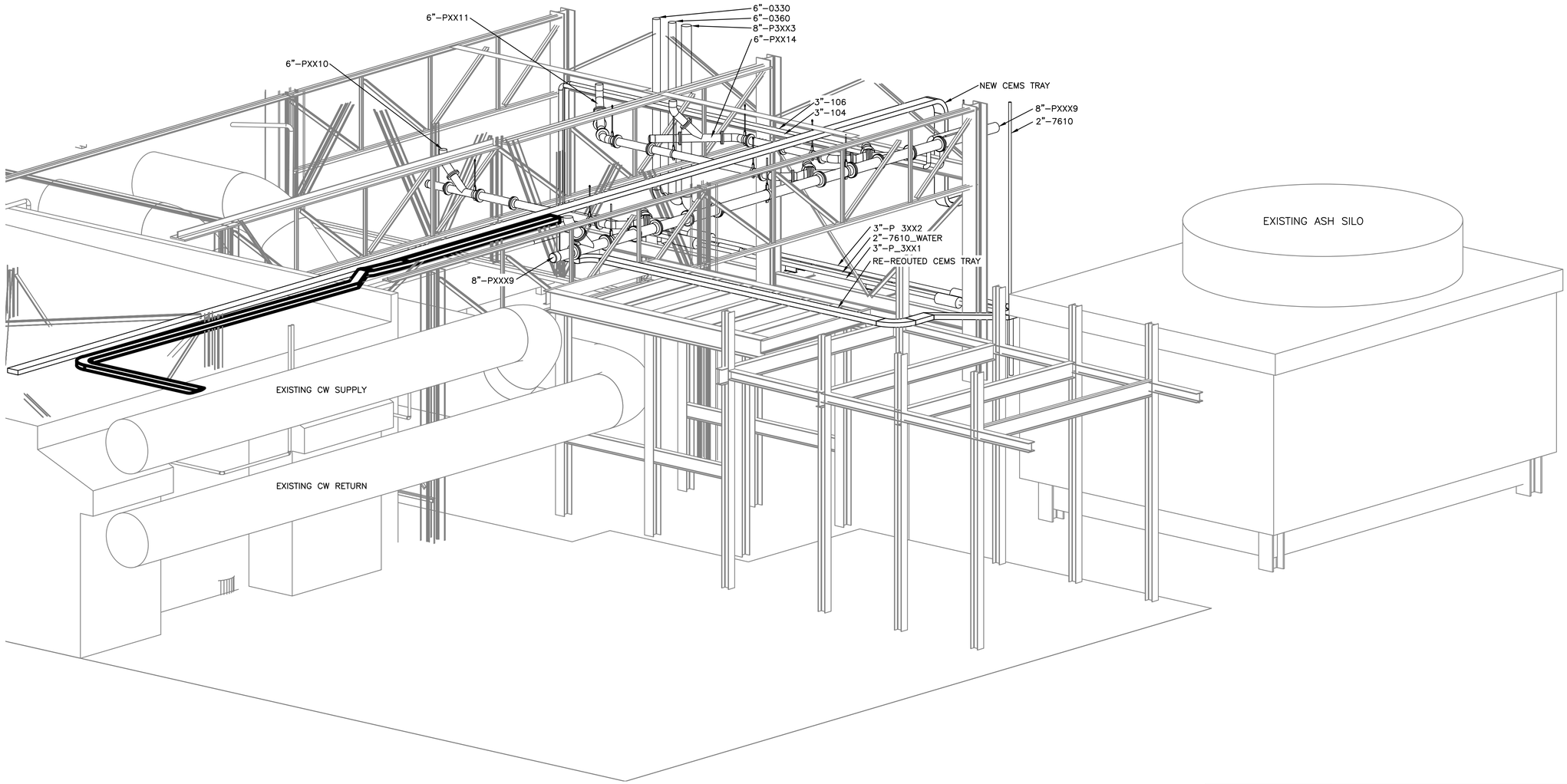
2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

PIPING
PIPING 3D VIEW @ OUTSIDE NORTH WALL

DATE	DRAWN	CHK'D.
05/26/2020	BB	SMK
SCALE 1/4"=1'–0"		APPROVED .

P–105



(OUTSIDE) BELOW BAGHOUSE DECK

3D VIEW

1/4" = 1'–0"

NO.	DATE	REVISION	BY
.	.	.	.
.	.	.	.
.	.	.	.
A	08/03/20	ISSUED FOR BID	BB

SECURITY

PUBLIC ☒

ECHOGEN BUSINESS CONFIDENTIAL ☐

TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

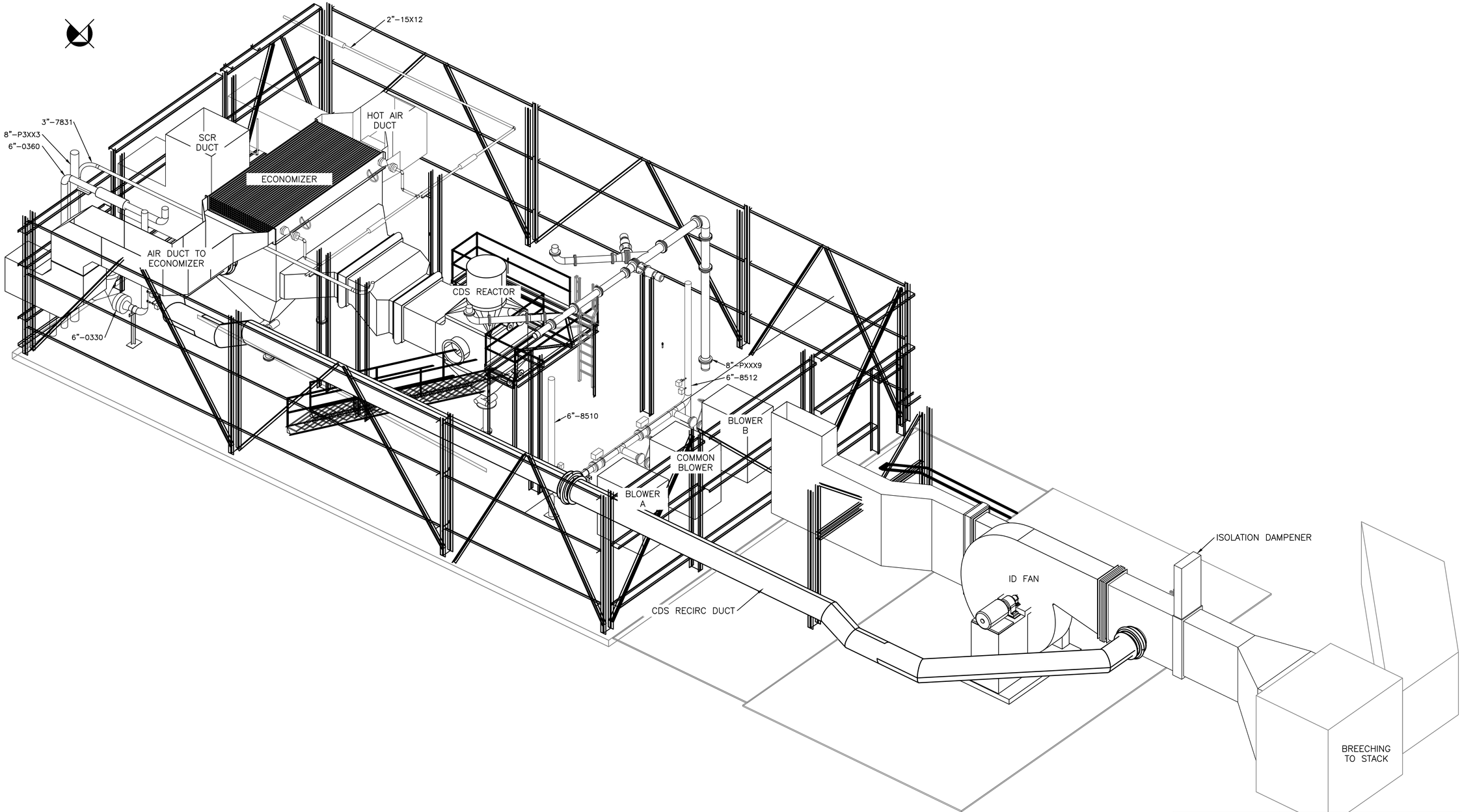
ECHOGEN power systems

405 S. High Street, Akron OH, 44311 USA

PIPING
PIPING 3D VIEW
@ OUTSIDE BELOW BAG HOUSE DECK

DATE	DRAWN	CHK'D.
05/26/2020	BB	SMK
SCALE 1/4"=1'–0"		APPROVED .

P–106



BAGHOUSE DECK MAIN LEVEL

3D VIEW

1/4" = 1'–0"

NO.	DATE	REVISION	BY
.	.	.	.
.	.	.	.
.	.	.	.
A	08/03/20	ISSUED FOR BID	BB

SECURITY

PUBLIC ☒

ECHOGEN BUSINESS CONFIDENTIAL ☐

TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

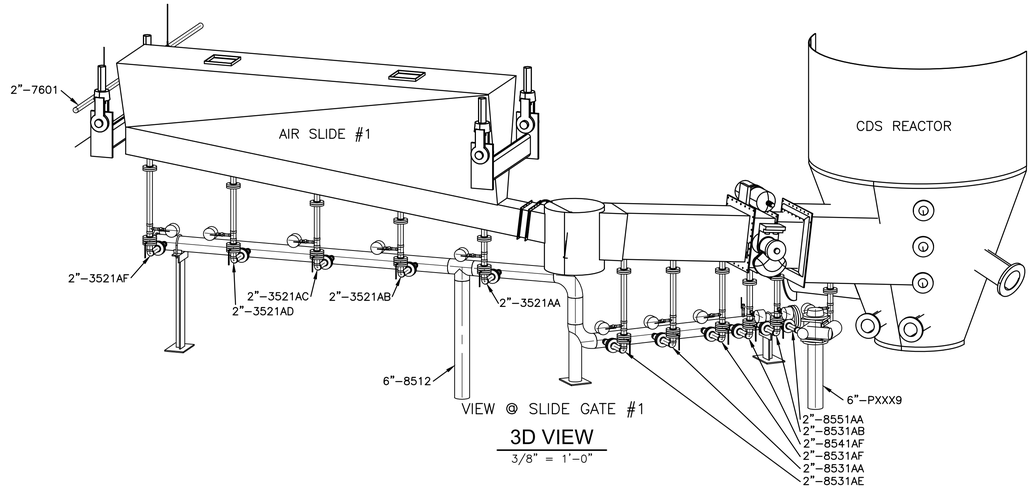
2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

PIPING
PIPING 3D VIEW @ BAG HOUSE DECK MAIN LEVEL

DATE	DRAWN	CHK'D.
05/26/2020	BB	SMK
SCALE 1/4"=1'–0"		APPROVED .

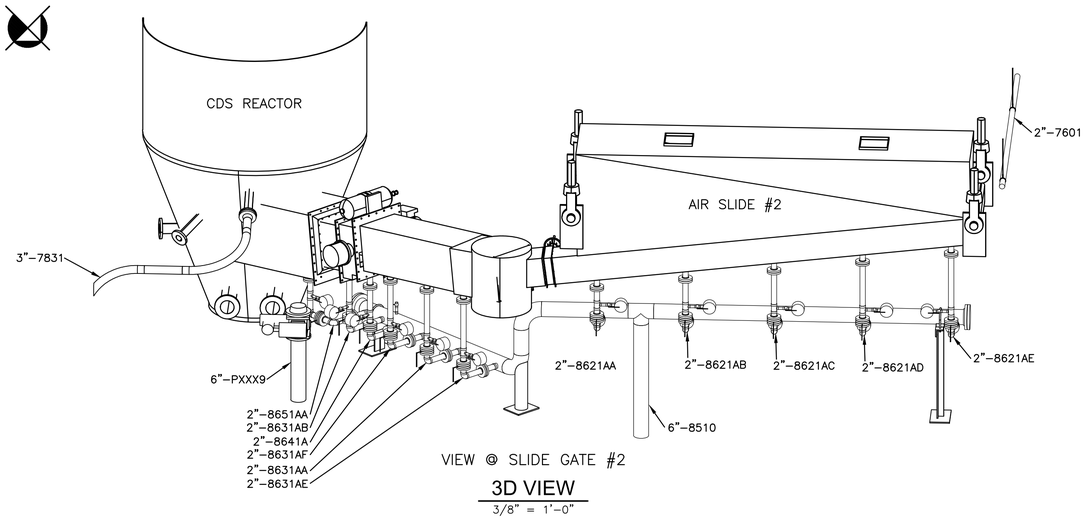
P–107



VIEW @ SLIDE GATE #1

3D VIEW

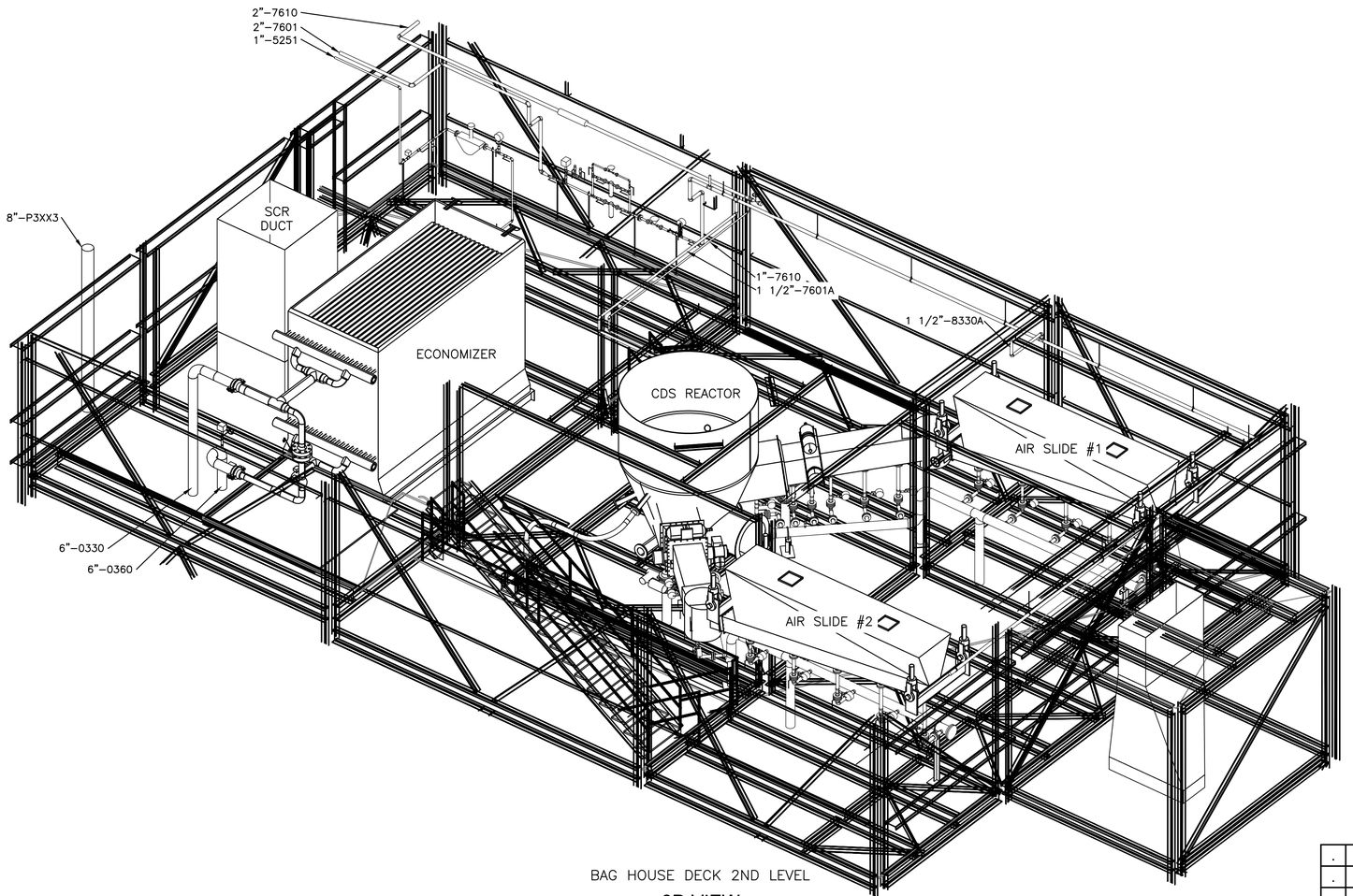
3/8" = 1'–0"



VIEW @ SLIDE GATE #2

3D VIEW

3/8" = 1'–0"



BAG HOUSE DECK 2ND LEVEL

3D VIEW

1/4" = 1'–0"

NO.	DATE	REVISION	BY
.	.	.	.
.	.	.	.
.	.	.	.
A	08/03/20	ISSUED FOR BID	BB

SECURITY

PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

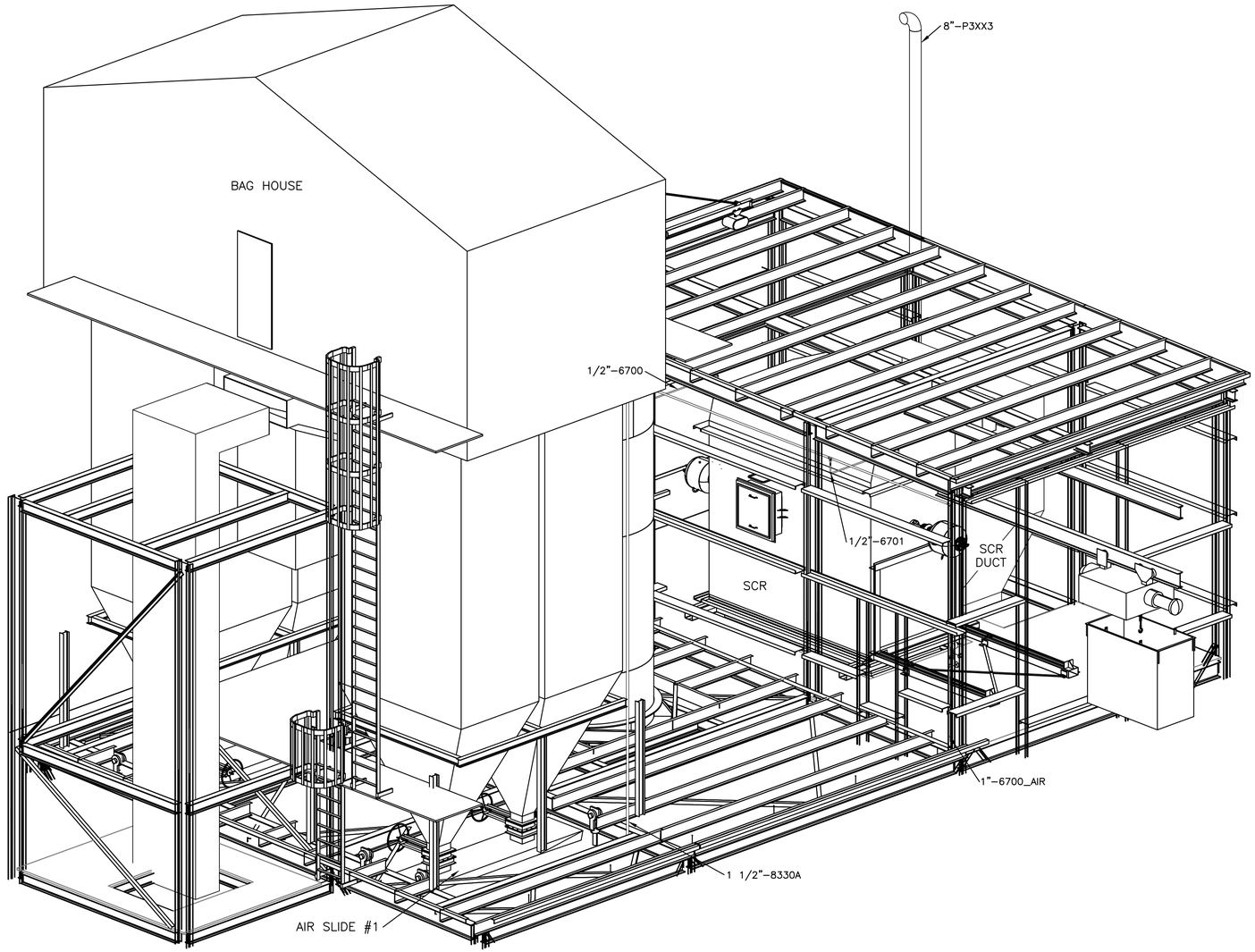
2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

PIPING
PIPING 3D VIEW
@ BAG HOUSE DECK SECOND LEVEL

DATE	DRAWN	CHK'D.
05/26/2020	BB	SMK
SCALE 1/4"=1'–0"		APPROVED .

P–108



BAG HOUSE DECK UPPER LEVEL

3D VIEW

1/4" = 1'-0"

NO.	DATE	REVISION	BY
.	.	.	.
.	.	.	.
.	.	.	.
A	08/03/20	ISSUED FOR BID	BB

SECURITY

PUBLIC ☒

ECHOGEN BUSINESS CONFIDENTIAL ☐

TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

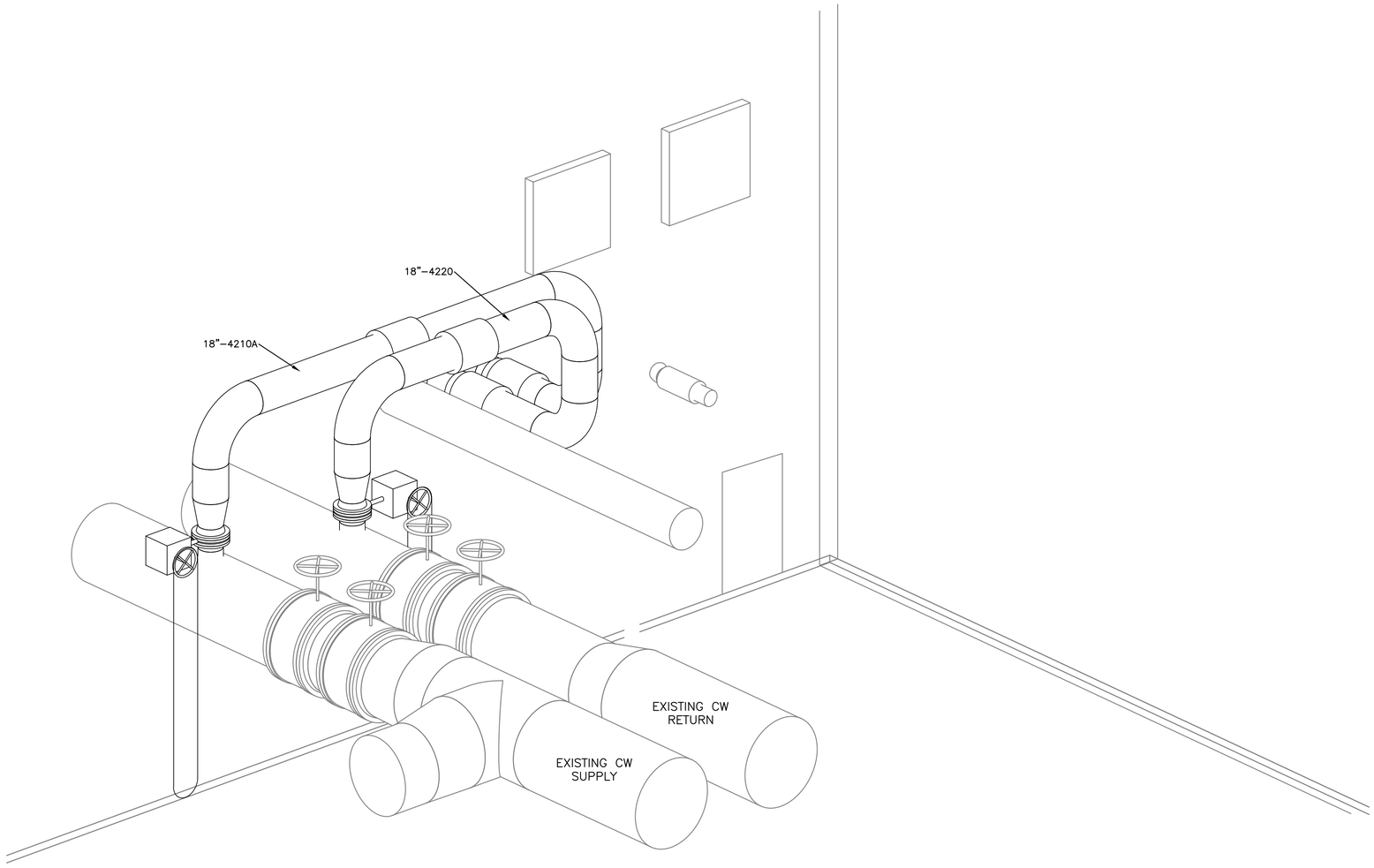
PIPING

PIPING 3D VIEW

@ BAG HOUSE DECK UPPER LEVEL

DATE	DRAWN	CHK'D.
05/26/2020	BB	SMK
SCALE 1/4"=1'-0"		APPROVED .

P-109



(OUTSIDE) NORTHEAST WALL LOOKING SW

3D VIEW

1/4" = 1'–0"

NO.	DATE	REVISION	BY
.	.	.	.
.	.	.	.
.	.	.	.
A	08/03/20	ISSUED FOR BID	BB

SECURITY

PUBLIC ☒

ECHOGEN BUSINESS CONFIDENTIAL ☐

TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

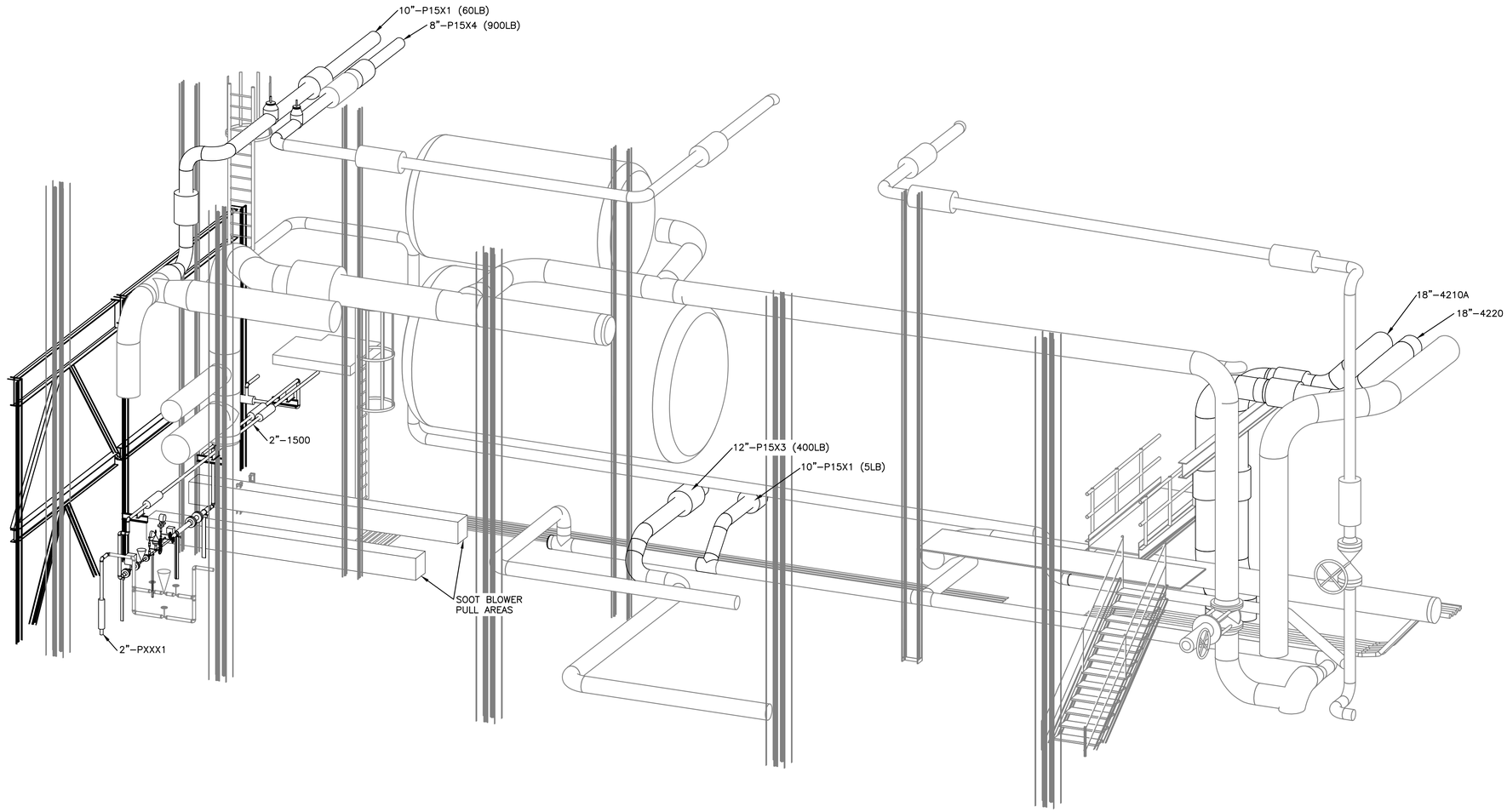
2011 ALL RIGHTS RESERVED
ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

PIPING
PIPING 3D VIEW @ OUTSIDE NORTHEAST WALL

DATE	DRAWN	CHK'D.
05/26/2020	BB	SMK
SCALE 3/8"=1'–0"		APPROVED .

P–110



NORTH DEARATOR

3D VIEW

1/4" = 1'-0"

NO.	DATE	REVISION	BY
.	.	.	.
.	.	.	.
.	.	.	.
A	08/03/20	ISSUED FOR BID	BB

SECURITY

PUBLIC ☒

ECHOGEN BUSINESS CONFIDENTIAL ☐

TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

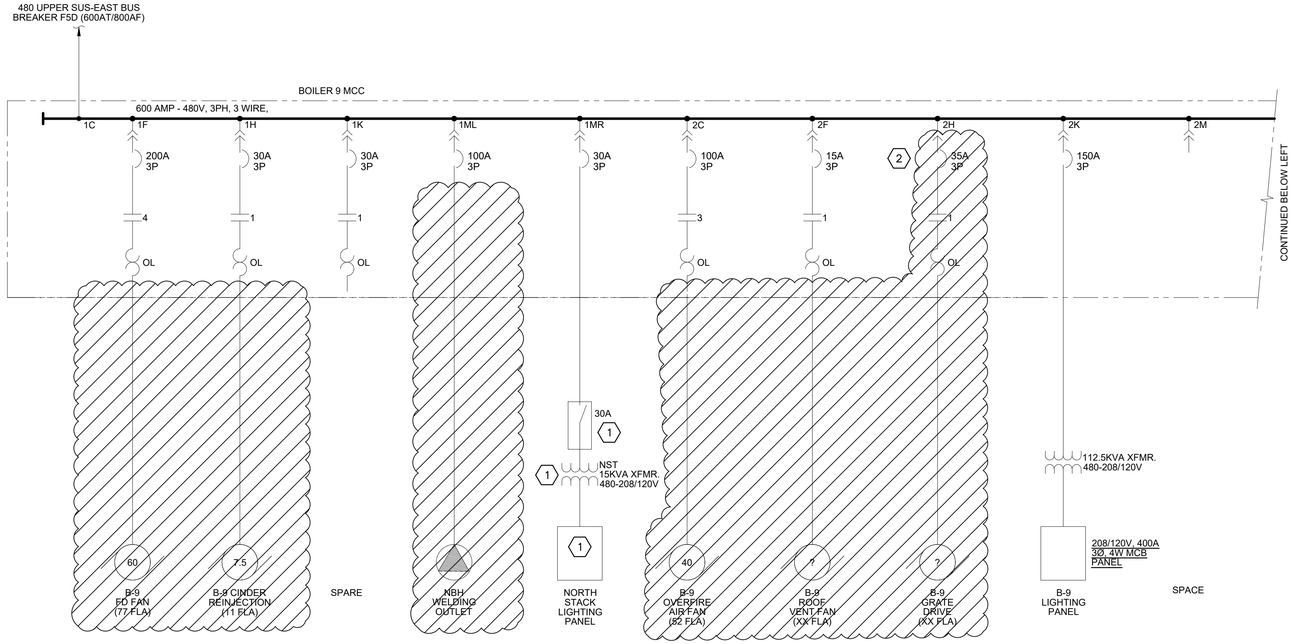
2011 ALL RIGHTS RESERVED
ECHOGEN POWER SYSTEMS, INC.

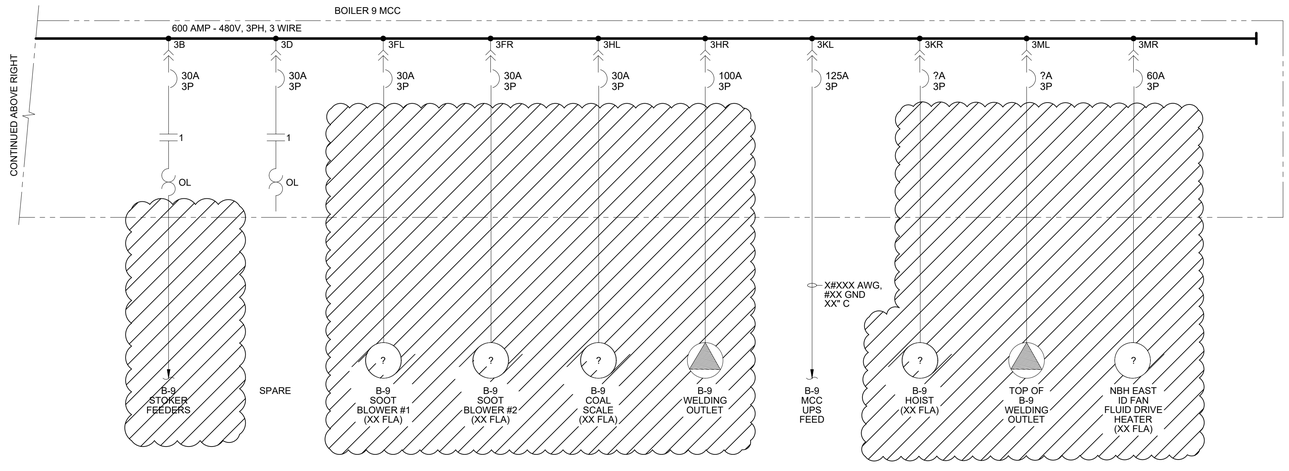
ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

PIPING
PIPING 3D VIEW @ NORTH DEARATOR

DATE	DRAWN	CHK'D.
05/26/2020	BB	SMK
SCALE 1/4"=1'-0"		APPROVED .

P-111





NOTES:

1. EC SHALL DE-ENERGIZE, LOTO, DISCONNECT CONDUCTORS AT EQUIPMENT, AT MCC AND REMOVE ALL CONDUCTORS, ASSOCIATED RACEWAYS, FITTINGS AND SUPPORTS. EC SHALL USE HOFFMAN GASKETED KNOCK OUT SEALS TO CLOSE ANY OPEN PUNCHED HOLES FROM DEMO, TYPE HOL-SEALERS OR APPROVED EQUAL.
2. AT THE TIME OF DESIGN EXACT SIZES OF STARTERS, HP AND OCPD'S IN SOME INSTANCES WERE NOT KNOWN AND SHOP DRAWINGS WERE NOT AVAILABLE. IF THE STARTER SIZE OR OCPD'S WAS NOT AVAILABLE ON THE UNIVERSITY OF MISSOURI ONELINES IT WAS SIZED PER HP, NEMA STANDARDS AND NEC. IN ADDITION, WIRE SIZES AND CONDUIT SIZES WERE NOT AVAILABLE ON UNIVERSITY OF MISSOURI ONELINES AND ARE NOT ILLUSTRATED ON THIS ONE-LINE DIAGRAM. IN SOME INSTANCES INFORMATION WAS NOT KNOWN AND COULD NOT BE ASCERTAINED. THESE ITEMS ARE LEFT BLANK OR W/ A QUESTION MARK.

KEY NOTES:

1. ELECTRICAL CONTRACTOR TO RELOCATE PANEL NSLP, 15 KVA TRANSFORMER NST AND 30A DISCONNECT. REWORK AND RESUPPLY AS REQUIRED. REFER TO DRAWING E-404 FOR ADDITIONAL INFORMATION.
2. ELECTRICAL CONTRACTOR SHALL REMOVE EXISTING SIZE 1 STARTER AND RETURN TO UNIVERSITY OF MISSOURI FOR RECLAMATION.

LEGEND:

DENOTES AREA OF DEMOLITION.

PRELIMINARY
NOT FOR CONSTRUCTION

SECURITY
PUBLIC ☐
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

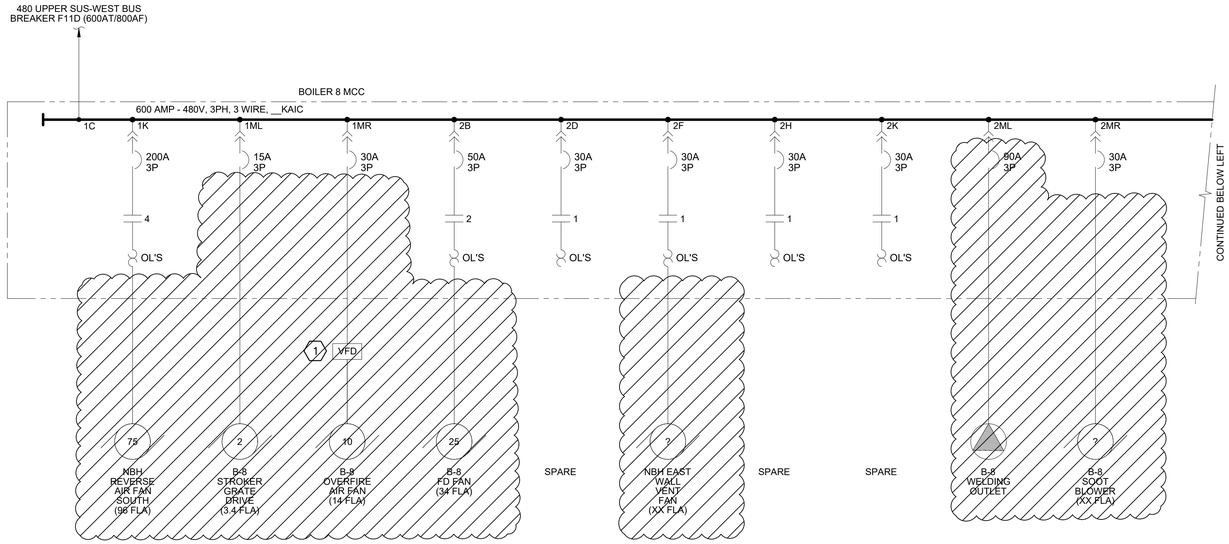
NO.	DATE	REVISION	BY
A	08/10/20	ISSUED FOR BID	KLM

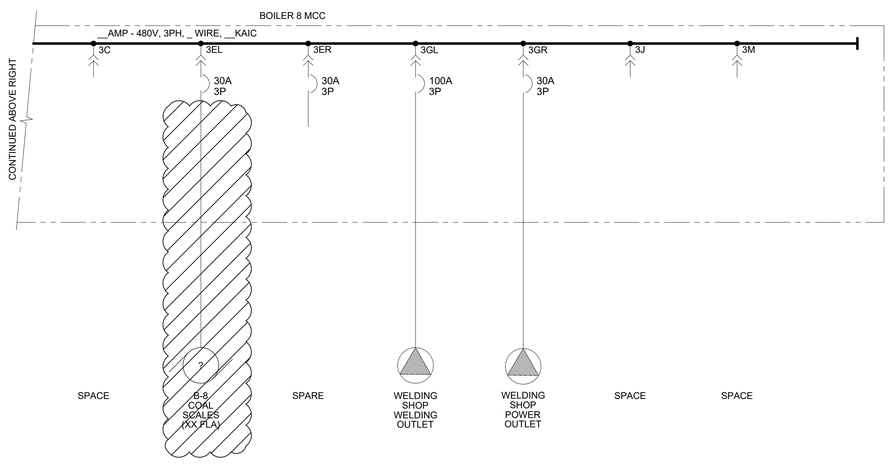
ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

ELECTRICAL
BOILER 9 MCC DEMOLITION
SINGLE LINE DIAGRAM

DATE	DRAWN	CHK'D.
01/03/20	BLP	SDS
SCALE		APPROVED
NONE		MET

E-101-DEMO





NOTES:

1. EC SHALL DE-ENERGIZE, LOTO, DISCONNECT CONDUCTORS AT EQUIPMENT, AT MCC AND REMOVE ALL CONDUCTORS, ASSOCIATED RACEWAYS, FITTINGS AND SUPPORTS. EC SHALL USE HOFFMAN GASKETED KNOCK OUT SEALS TO CLOSE ANY OPEN PUNCHED HOLES FROM DEMO, TYPE HOL-SEALERS OR APPROVED EQUAL.
2. AT THE TIME OF DESIGN EXACT SIZES OF STARTERS, HP AND OCPD'S IN SOME INSTANCES WERE NOT KNOWN AND SHOP DRAWINGS WERE NOT AVAILABLE. IF THE STARTER SIZE OR OCPD'S WAS NOT AVAILABLE ON THE UNIVERSITY OF MISSOURI ONELINES IT WAS SIZED PER HP, NEMA STANDARDS AND NEC. IN ADDITION, WIRE SIZES AND CONDUIT SIZES WERE NOT AVAILABLE ON UNIVERSITY OF MISSOURI ONELINES AND ARE NOT ILLUSTRATED ON THIS ONE-LINE DIAGRAM. IN SOME INSTANCES INFORMATION WAS NOT KNOWN AND COULD NOT BE ASCERTAINED. THESE ITEMS ARE LEFT BLANK OR W/ A QUESTION MARK.

KEY NOTES:

1. EC SHALL RETURN VFD TO UNIVERSITY OF MISSOURI FOR RECLAMATION.

LEGEND:

DENOTES AREA OF DEMOLITION.

PRELIMINARY
NOT FOR CONSTRUCTION

SECURITY
PUBLIC ☐
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

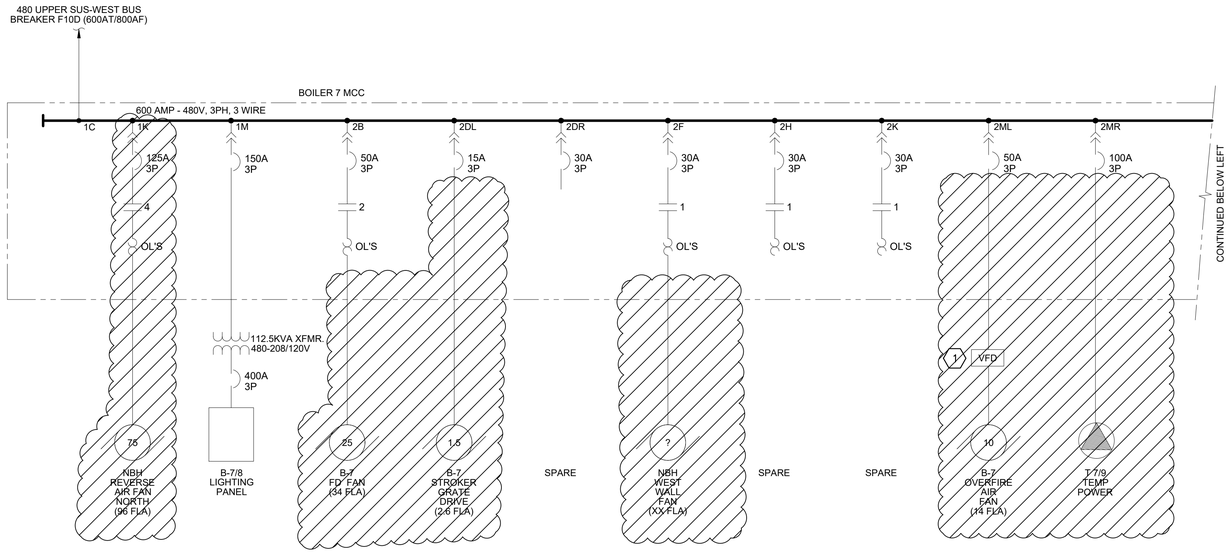
NO.	DATE	REVISION	BY
A	08/10/20	ISSUED FOR BID	KLM

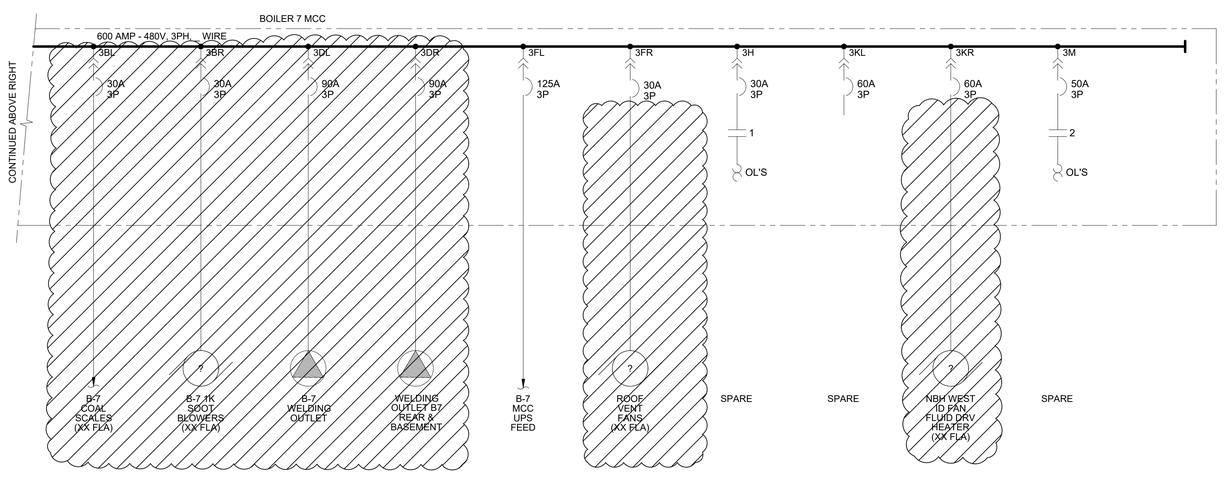
ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

ELECTRICAL
BOILER 8 MCC DEMOLITION
SINGLE LINE DIAGRAM

DATE	DRAWN	CHK'D.
01/06/20	BLP	SDS
SCALE		APPROVED
NONE		MET

E-102-DEMO





NOTES:

1. EC SHALL DE-ENERGIZE, LOTO, DISCONNECT CONDUCTORS AT EQUIPMENT, AT MCC AND REMOVE ALL CONDUCTORS, ASSOCIATED RACEWAYS, FITTINGS AND SUPPORTS. EC SHALL USE HOFFMAN GASKETED KNOCK OUT SEALS TO CLOSE ANY OPEN PUNCHED HOLES FROM DEMO, TYPE HOL-SEALERS OR APPROVED EQUAL.
2. AT THE TIME OF DESIGN EXACT SIZES OF STARTERS, HP AND OCPD'S IN SOME INSTANCES WERE NOT KNOWN AND SHOP DRAWINGS WERE NOT AVAILABLE. IF THE STARTER SIZE OR OCPD'S WAS NOT AVAILABLE ON THE UNIVERSITY OF MISSOURI ONELINES IT WAS SIZED PER HP, NEMA STANDARDS AND NEC. IN ADDITION, WIRE SIZES AND CONDUIT SIZES WERE NOT AVAILABLE ON UNIVERSITY OF MISSOURI ONELINES AND ARE NOT ILLUSTRATED ON THIS ONE-LINE DIAGRAM. IN SOME INSTANCES INFORMATION WAS NOT KNOWN AND COULD NOT BE ASCERTAINED. THESE ITEMS ARE LEFT BLANK OR W/ A QUESTION MARK.

KEY NOTES:

1. EC SHALL RETURN VFD TO UNIVERSITY OF MISSOURI FOR RECLAMATION.

LEGEND:

DENOTES AREA OF DEMOLITION.

PRELIMINARY
NOT FOR CONSTRUCTION

SECURITY

PUBLIC ☐
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

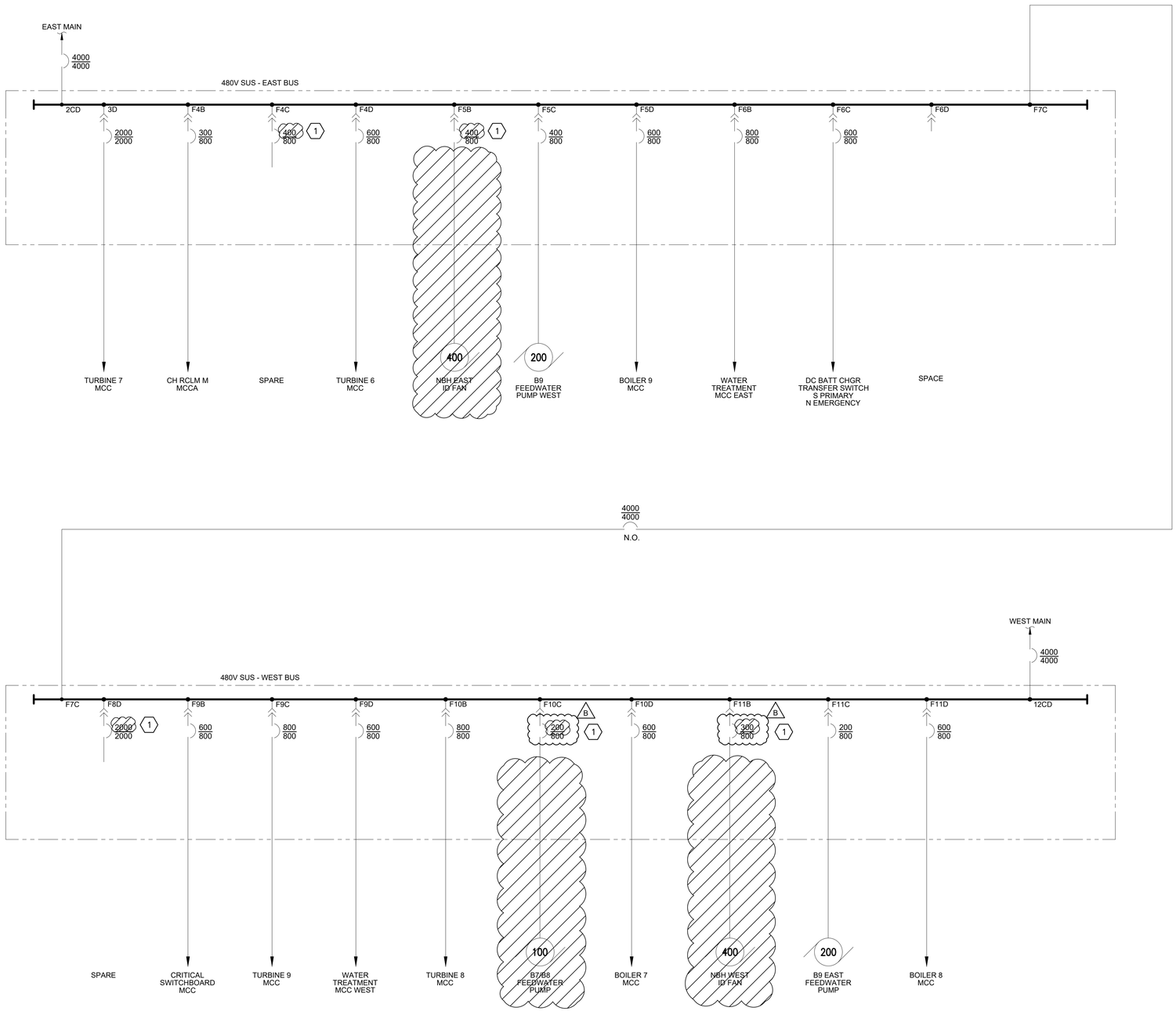
NO.	DATE	REVISION	BY
A	08/10/20	ISSUED FOR BID	KLM

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

ELECTRICAL
BOILER 7 MCC DEMOLITION
SINGLE LINE DIAGRAM

DATE	DRAWN	CHK'D.
01/06/20	BLP	SDS
SCALE: NONE		APPROVED: MET

E-103-DEMO



NOTES:

1. EC SHALL DE-ENERGIZE, LOTO, DISCONNECT CONDUCTORS AT EQUIPMENT, AT SWGR AND REMOVE ALL CONDUCTORS, ASSOCIATED RACEWAYS, FITTINGS AND SUPPORTS. EC SHALL USE HOFFMAN GASKETED KNOCK OUT SEALS TO CLOSE ANY OPEN PUNCHED HOLES FROM DEMO, TYPE HOL-SEALERS OR APPROVED EQUAL.
2. AT THE TIME OF DESIGN EXACT SIZES OF TRIP UNITS, BREAKER FRAMES, HP AND IN SOME INSTANCES WERE NOT KNOWN AND SHOP DRAWINGS WERE NOT AVAILABLE. IN ADDITION, WIRE SIZES AND CONDUIT SIZES WERE NOT AVAILABLE ON UNIVERSITY OF MISSOURI ONELINES AND ARE NOT ILLUSTRATED ON THIS ONE-LINE DIAGRAM. IN SOME INSTANCES PERTINENT INFORMATION WAS NOT KNOWN AND COULD NOT BE ASCERTAINED. THESE ITEMS ARE LEFT BLANK.

KEY NOTES:

1. REMOVE AND REPLACE TRIP UNITS PER E-106 AND RETURN TO UNIVERSITY OF MISSOURI FOR RECLAMATION.

B

LEGEND:

DENOTES AREA OF DEMOLITION.

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
B	08/26/20	ADDENDUM 2	KLM
A	08/10/20	ISSUED FOR BID	KLM

SECURITY

PUBLIC ☐
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

480V UPPER SUS EAST & WEST BUS DEMOLITION SINGLE LINE DIAGRAM

DATE	DRAWN	CHK'D.
02/25/20	BLP	SDS
SCALE: NONE		APPROVED: MET

E-106-DEMO

PANEL: UPS INVERTER PANEL 2

LOCATION: **BOILER 7, 8 & 9 MCC ROOM** VOLTAGE: **240/120V, 1Ø, 3W, 10 KAIC** REMARKS: **DEMO SCHEDULE**

MOUNTING: **SURFACE MTD.** BUS RATING: **100A**

DWG NO: OCP: **MLO**

CKT	PANEL NOTES	DESCRIPTION	BRKR	DIV %	LOAD KVA		LOAD KVA	DIV %	BRKR	DESCRIPTION	PANEL NOTES	CKT
1		SPARE		100%	0.0	A	0.1	100%		BOILER CONT. RM S. RECEPT		2
3		SPARE	30A	100%	0.0	B	0.0	100%	30A	SPARE		4
5		E315 TG-7 GOV.SLC		100%	0.2	A	0.1	100%		PLC S. BAGHOUSE BOILER 10		6
7		E318 TG-7 CONTROL PNL PNLVIA		100%	0.1	B	0.0	100%		SPARE		8
9		E319 TG-7 VOLTAGE REG. PNL.		100%	0.1	A	0.0	100%		NORTH BAGHOUSE ID FAN		10
11		SPARE		100%	0.0	B	0.0	100%	20A	CONTROL PANEL PLC		12
13		BOILER #9 CBU-2	20A	100%	0.0	A	0.0	100%	20A	SPARE CKT IN CONTROL PANEL		14
15		BOILER #9 CBU-1	20A	100%	0.0	B	0.0	100%	20A	BOILER #9 NEW CONTROL CABINET		16
17		BOILER CONT. RM. N. RECEPTS.	20A	100%	0.1	A	0.0	100%	20A	BOILER #8 NEW CONTROL CABINET		18
19				0%	0.0	B	0.0	100%	20A	BOILER #7 NEW CONTROL CABINET		20
21				0%	0.0	A	0.0	100%	20A	BOILER #7 NEW CONTROL CABINET		22
23				0%	0.0	B	0.0	0%				24
25				0%	0.0	A	0.0	0%				26
27				0%	0.0	B	0.0	0%				28
29				0%	0.0	A	0.0	0%				30

A PHASE CONNECTED LOAD KVA: 0.5 **A PHASE LOAD AMPS:** 4.2

B PHASE CONNECTED LOAD KVA: 0.1 **B PHASE LOAD AMPS:** 1.2

TOTAL CONNECTED LOAD KVA: 0.6 **TOTAL LOAD AMPS:** 1.5

KVA DEMAND LOAD: 0.6 **AMP DEMAND LOAD:** 1.5

NOTES:

1. EC SHALL REMOVE 20A CIRCUIT BREAKERS, BRANCH CIRCUITS, ASSOCIATED RACEWAYS AND SUPPORTS AS ILLUSTRATED ON THIS DRAWING. RETURN BREAKERS TO UNIVERSITY OF MISSOURI FOR RECLAMATION.

LEGEND:

DENOTES AREA OF DEMOLITION.

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/10/20	ISSUED FOR BID	KLM

SECURITY

PUBLIC ☐
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

BOILER 7, 8 & 9 MCC ROOM INVERTER PANEL 2 SCHEDULE DEMOLITION

DATE	DRAWN	CHK'D.
01/03/20	BLP	SDS
SCALE NONE		APPROVED MET

E-201-DEMO

GENERAL REQUIREMENTS:

1. THE WORK REQUIRED UNDER THIS SECTION SHALL CONSIST OF ALL LABOR, MATERIALS, EQUIPMENT, POWER, TRANSPORTATION, HOISTING IMPLEMENTS, ETC., NECESSARY FOR THE COMPLETE INSTALLATION, TESTING AND WARRANTY OF ALL ELECTRICAL DEVICES AND SYSTEMS OF THIS CONTRACT. EXECUTE SAME WITHOUT CHARGE OR CLAIM FOR EXTRA COMPENSATION. ELECTRICAL CONTRACTOR'S PRICE IS ASSUMED TO UNDERSTAND AND INCLUDE ANY PREMIUM COSTS INVOLVED.

2. ELECTRICAL, MECHANICAL, PIPING, STRUCTURAL AND CIVIL DRAWINGS, AS WELL AS ALL SPECIFICATIONS ARE A PART OF THE CONTRACT DOCUMENTS. THE ELECTRICAL CONTRACTOR SHALL BE RESPONSIBLE FOR COMPLETE FAMILIARITY WITH ALL PROJECT DOCUMENTS. COORDINATE WORK WITH ALL TRADES DURING CONSTRUCTION. NO ADDITIONAL COMPENSATION WILL BE ALLOWED FOR ELECTRICAL CONTRACTOR'S FAILURE TO COORDINATE DURING CONSTRUCTION.

3. THE ELECTRICAL CONTRACTOR SHALL VISIT THE WORK SITE AND BECOME FAMILIAR WITH THE CONDITIONS AFFECTING THE INSTALLATION AND SCOPE OF WORK. SUBMISSION OF A BID PROPOSAL SHALL PRESUPPOSE KNOWLEDGE OF SUCH CONDITIONS AND NO ADDITIONAL COMPENSATION SHALL BE ALLOWED WHERE EXTRA LABOR OR MATERIALS ARE REQUIRED BECAUSE OF IGNORANCE OF EXISTING CONDITIONS.

4. THE ELECTRICAL DRAWINGS ARE DIAGRAMMATIC AND SHOW THE GENERAL LOCATION, ARRANGEMENT, AND EXTENT OF WORK TO BE DONE. THE EXACT SIZES, LOCATIONS, AND ARRANGEMENTS ARE SUBJECT TO THE ACTUAL FIELD CONDITIONS.

5. DISCREPANCIES BETWEEN ELECTRICAL, MECHANICAL, PIPING, STRUCTURAL AND CIVIL CONTRACT DRAWINGS, OR SPECIFICATIONS SHALL BE BROUGHT TO THE ATTENTION OF THE ELECTRICAL ENGINEER - PRIOR TO FINAL BID SUBMITTAL.

6. THE ELECTRICAL CONTRACTOR SHALL SECURE AND PAY FOR ALL LOCAL AND STATE OFFICIAL PERMITS, LICENSES, BONDS, AND INSPECTIONS - REQUIRED BY LAWS OF THE GOVERNING BODIES FOR ELECTRICAL WORK.

7. THE ELECTRICAL CONTRACTOR SHALL COMPLY WITH THE `LIFE SAFETY CODE'-NFPA 101 AND THE 2017 EDITION OF THE `NATIONAL ELECTRICAL CODE'-NFPA 70 (N.E.C.) SHALL BE OBSERVED AS A MINIMUM REQUIREMENT FOR ALL ELECTRICAL WORK. IN ADDITION, THE ELECTRICAL CONTRACTOR SHALL COMPLY WITH ALL LOCAL AND STATE CODES AND ORDINANCES INCLUDING TENNESSEE BASIC BUILDING CODE. ALSO, ELECTRICAL CONTRACTOR SHALL COMPLY W/ LOCAL AMENDMENTS, ORDINANCES AND ARCONIC CORPORATE STANDARDS. NO EXTRA COMPENSATION WILL BE ALLOWED FOR ANY CHANGES NECESSARY FOR CODE COMPLIANCE.

8. CONTRACTOR TO PROVIDE ITEMS SPECIFIED HEREIN ON DESIGN DRAWINGS. SHOP DRAWINGS, CATALOG CUTS OR OTHER PERTINENT INFORMATION SHALL ONLY BE SUBMITTED TO "ENGINEER" FOR ANY "APPROVED EQUAL" SUBSTITUTION REQUESTS.

9. EC SHALL CHECK CIVIL, PIPING, INSTRUMENTATION AND MECHANICAL DRAWINGS AND SPECIFICATIONS FOR EQUIPMENT TO BE INSTALLED BY OTHERS. EC IS RESPONSIBLE FOR THE PROPER WIRING AND NECESSARY ELECTRICAL ADJUSTMENTS TO EQUIPMENT TO CONFORM TO MANUFACTURER SPECIFIED REQUIREMENTS OF THE EQUIPMENT.

10. THE FINAL LOCATIONS OF ALL EQUIPMENT, OUTLETS, ETC., ARE SUBJECT TO REASONABLE CHANGES BY THE ELECTRICAL ENGINEER OR OWNER BEFORE ROUGH-IN AT NO ADDITIONAL COST.

11. MATERIALS AND EQUIPMENT USED ON THIS PROJECT SHALL MEET OSHA REQUIREMENTS. RELATED TEMPORARY/PORTABLE WIRING SHALL BE PROVIDED BY THE ELECTRICAL CONTRACTOR TO OSHA REQUIREMENTS FOR THE USE OF ALL TRADES DURING CONSTRUCTION. ALL 120 VOLT, SINGLE PHASE 15 AND 20 AMPERE RECEPTACLE OUTLETS USED BY WORKMEN SHALL BE PROTECTED BY A GROUND FAULT CIRCUIT INTERRUPTER.

12. PROVIDE ALL CUTTING AND PATCHING REQUIRED FOR ELECTRICAL DEMOLITION AND NEW INSTALLATION OF ELECTRICAL WORK. SUCH CUTTING AND PATCHING SHALL BE BY SKILLED WORKMEN IN THE TRADE. REFER TO ARCHITECTURAL, STRUCTURAL, CIVIL AND MECHANICAL SPECIFICATIONS FOR CUTTING AND PATCHING REQUIREMENTS.

13. AUTHORIZED REPRESENTATIVES OF THE OWNER SHALL HAVE ACCESS TO AND PRIVILEGE OF INSPECTING ALL WORK AND MATERIALS AS WORK PROGRESSES. THESE REPRESENTATIVES SHALL HAVE AUTHORITY TO APPROVE OR REJECT WORK OR MATERIAL USING DRAWINGS, SPECIFICATIONS, CODES, AND GOOD ENGINEERING PRACTICES AS THE BASIS FOR APPROVAL OR REJECTION.

14. THE EXISTING ELECTRIC, TELEPHONE SERVICES, AND ALL OTHER COMMUNICATIONS SYSTEMS SHALL BE MAINTAINED THROUGHOUT THE CONSTRUCTION PERIOD. ANY SERVICE SHUTDOWNS THAT ARE REQUIRED TO COMPLY WITH THE CONTRACT DOCUMENTS SHALL BE SCHEDULED THROUGH OWNER AND DONE AT A TIME AS DIRECTED BY OWNER. NO ADDITIONAL COMPENSATION SHALL BE ALLOWED FOR THESE SHUTDOWN PERIODS EVEN THOUGH PREMIUM-TIME WORK MAY BE REQUIRED. PROVIDE TEMPORARY SERVICES TO EQUIPMENT OR SYSTEMS THAT CANNOT BE SHUTDOWN, AS DIRECTED BY THE OWNER.

15. BIDS SHALL BE BASED UPON THE SPECIFIED PRODUCTS WITHIN CONSTRUCTION DOCUMENTS UNLESS OTHERWISE NOTED. ELECTRICAL DESIGN IS BASED ON THESE SPECIFIED PRODUCTS TO MEET SPECIFIC DESIGN PARAMETERS. ALTERNATIVE MANUFACTURERS MAY ONLY BE USED IF EXACT ELECTRICAL SPECIFICATIONS AND PHYSICAL DIMENSIONS ARE EQUIVALENT AND GET THE APPROVAL OF THE ENGINEER. THE DRAWINGS AND SPECIFICATIONS ARE BASED ON THE PRODUCTS SPECIFIED BY AN ORDER NUMBER, TYPE, MODEL #, SIZE, AND FEATURES, AND THUS ESTABLISH A MINIMUM QUALITY LEVEL THAT SUBSTITUTES MUST MEET TO QUALIFY FOR REVIEW. VERBAL REQUESTS OR APPROVALS SHALL NOT BE BINDING ON THE ARCHITECT, ENGINEER OR OWNER. SHOULD THE ELECTRICAL CONTRACTOR PROPOSE TO FURNISH MATERIALS AND EQUIPMENT OTHER THAN THOSE SPECIFIED, HE SHALL SUBMIT A WRITTEN REQUEST FOR SUBSTITUTIONS TO THE ENGINEER AT BID OPENING. THE ELECTRICAL CONTRACTOR SHALL INDICATE ANY ADDITIONS OR REDUCTIONS TO THE CONTRACT PRICE ON THE BID FORM.

16. TEST FOR GROUNDS, SHORT CIRCUITS, AND PROPER FUNCTION OF ALL EQUIPMENT AFTER INSTALLATION IS COMPLETE. FAULTS IN THE INSTALLATION SHALL BE CORRECTED TO THE OWNER'S SATISFACTION. ALL INSULATION RESISTANCE TESTS SHALL BE MADE WITH AN APPROVED AND CALIBRATED MEGOHMMETER PER NETA STANDARDS, DOCUMENTED AND SUBMITTED TO OWNER AT END OF THE PROJECT.

17. DEMONSTRATE TO THE OWNER'S SATISFACTION THE PROPER OPERATION OF EACH OF THE SYSTEMS COMPRISING THIS CONTRACT BEFORE FINAL ACCEPTANCE.

18. A MINIMUM OF ONE SET OF RECORD DRAWINGS SHALL BE GIVEN TO THE OWNER AT COMPLETION OF THE WORK. THESE DRAWINGS SHALL SHOW EXACT EQUIPMENT, CONDUIT AND WIRING LOCATIONS, AND SHALL INDICATE THE `AS-BUILT' CONDITION. CHANGES TO THE DRAWINGS SHALL BE INDICATED IN RED. THE ELECTRICAL CONTRACTOR SHALL UPDATE THESE DRAWINGS DAILY ON SITE FOR THE OWNER'S REPRESENTATIVE TO REVIEW DURING CONSTRUCTION.

19. AT ALL TIMES KEEP PREMISES AND BUILDING(S) IN NEAT AND ORDERLY CONDITION; FOLLOW EXPLICITLY THE INSTRUCTIONS OF THE OWNER'S REPRESENTATIVE. UPON COMPLETION OF WORK, THIS ELECTRICAL CONTRACTOR SHALL THOROUGHLY CLEAN ALL APPARATUS FURNISHED BY HIM. THE BREVITY OF THIS SPECIFICATION SHALL NOT BE CONSTRUED AS RELIEVING THE ELECTRICAL CONTRACTOR OF HIS RESPONSIBILITY TO PERFORM ALL WORK IN A FIRST-CLASS WORKMANLIKE MANNER, FULLY COMPLYING WITH ALL APPLICABLE CODES AND CONTRACT DOCUMENTS. THE SITE SHALL BE CLEANED ON A DAILY BASIS WITH ALL DEBRIS REMOVED DAILY.

EXECUTION:

1. ALL ELECTRICAL MATERIALS SHALL BE NEW AND SHALL BE LABELED OR LISTED BY U.L. OR AN ACCREDITED TESTING ORGANIZATION.

2. ALL EQUIPMENT, DEVICES AND RELATED APPURTENANCES SHALL BE THE LATEST PRODUCT OF THE SPECIFIED MANUFACTURER AND SHALL CONFORM TO CONTRACT REQUIREMENTS.

3. ALL ELECTRICAL SYSTEMS, DEVICES AND RELATED ITEMS SHALL BE FULLY TESTED. REPLACE ANY AND ALL DEFECTIVE DEVICES, ITEMS, OR SYSTEMS BEFORE COMPLETION OF THE PROJECT.

4. BALANCE THE LOAD WITH AMPROBE ON ALL PANELS, SUBSEQUENT TO COMPLETION OF INSTALLATION, WITH ALL EQUIPMENT OPERATING SIMULTANEOUSLY.

5. EQUIPMENT, ITEMS, AND APPURTENANCES REQUIRING INSPECTION, MAINTENANCE, OR MANUAL OPERATION SHALL NOT BE INSTALLED IN INACCESSIBLE LOCATIONS OR LOCATIONS THAT MAY BECOME INACCESSIBLE. N.E.C. ARTICLE 110 WORKING SPACE CLEARANCE REQUIREMENTS SHALL BE STRICTLY ADHERED TO.

6. WHEN WORK UNDER THIS CONTRACT CANNOT BE PLACED WHERE SHOWN DUE TO WORK OF OTHERS OR STRUCTURAL INTERFERENCE, WORK SHALL THEN BE RELOCATED WHERE SO INSTRUCTED BY THE OWNER'S REPRESENTATIVE. ELEVATIONS GIVEN FOR OUTLETS ARE FROM FINISHED FLOOR TO CENTER LINE OF OUTLETS, UNLESS OTHERWISE NOTED.

7. THE ELECTRICAL CONTRACTOR SHALL FURNISH AND INSTALL ALL FRAMING, SUPPORTS, FITTINGS, UNISTRUT, HANGERS, ETC., NECESSARY TO SUPPORT RACEWAYS, BOXES, CABLE TRAY, LIGHTING FIXTURES, PANELBOARDS, TRANSFORMERS, AND ASSOCIATED DISTRIBUTION EQUIPMENT.

RACEWAYS:

1. ALL CONDUIT SHALL BE (RGS) RIGID GALVANIZED STEEL, 3/4" MINIMUM SIZE. THE ELECTRICAL CONTRACTOR SHALL PROVIDE JUNCTION AND/OR PULL BOXES WHERE SHOWN ON THE DRAWINGS OR AS REQUIRED, WHETHER SHOWN ON THE DRAWINGS OR NOT.

2. USE LIQUID-TIGHT FLEXIBLE METAL CONDUIT FOR FINAL CONNECTIONS TO MOTORS AND VIBRATING EQUIPMENT, 2'-0" MAXIMUM LENGTH FOR RACEWAYS THAT ARE 2" OR LESS AND 4'-0" FOR RACEWAYS 2 1/2" AND OVER.

3. NO RUN OF CONDUIT BETWEEN OUTLETS, BETWEEN FITTINGS WITH REMOVABLE COVERS, OR BETWEEN OUTLET FITTINGS SHALL CONTAIN MORE THAN THE EQUIVALENT OF FOUR (4) QUARTER 90° BENDS INCLUDING THOSE BENDS LOCATED IMMEDIATELY AT THE OUTLET OR FITTING.

4. ALL EXPOSED CONDUIT SHALL BE INSTALLED PARALLEL WITH WALLS, FLOORS AND CEILINGS. CLAMPS OR BRACKETS SHALL BE SECURED TO BRICK, MASONRY OR CONCRETE WALLS BY MEANS OF EXPANSION BOLTS AND TO WOOD WITH WOOD SCREWS. `SHOT IN PLACE' ANCHORS AND FASTENERS CAN BE USED PENDING APPROVAL BY THE STRUCTURAL ENGINEER AND OWNER. ALL SUPPORTS, HANGERS OR FRAME WORK SHALL BE GALVANIZED OR PLATED UNLESS OTHERWISE NOTED.

5. A MINIMUM OF 6 INCH SEPARATION BETWEEN CONDUIT AND HOT WATER OR STEAM LINES SHALL BE MAINTAINED.

6. FLAT STRAPS MAY NOT BE USED TO SUPPORT CONDUIT OR BOXES. NO DRILLING OF BUILDING STRUCTURAL MEMBERS, FOR SUPPORTING CONDUITS, WILL BE ALLOWED WITHOUT PRE-AUTHORIZATION BY OWNER. CONDUIT RUNS SHALL BE SUPPORTED AS REQUIRED BY THE NEC.

7. CONDUIT AND PROCESS PIPING SHALL NOT BE USED AS SUPPORT FOR ANY CONDUIT OR CONNECTED ENCLOSURES, DEVICES SUCH AS JUNCTION BOXES, CONTROL PANELS, PANELBOARDS, OTHER CONDUIT ETC. THESE ENCLOSURES AND DEVICES MUST HAVE A SEPARATE MEANS OF SUPPORT.

8. THERE SHALL BE SEPARATE CONDUIT SYSTEMS FOR THE FOLLOWING GROUPS OF WIRING.
   A. LIGHTING/GENERAL POWER BRANCH CIRCUIT WIRING
   B. MECHANICAL EQUIPMENT FEEDERS
   C. INSTRUMENTATION WIRING
   D. CONTROL WIRING

14. CONDUITS SHALL BE CONTINUOUS AND SECURED TO ALL BOXES IN SUCH A MANNER THAT EACH CONDUIT SYSTEM SHALL BE ELECTRICALLY CONTINUOUS FROM THE POINT OF SERVICE TO ALL OUTLET BOXES.

15. ALL RACEWAYS SHALL BE CAPPED UNTIL CONDUCTORS ARE INSTALLED.

16. ALL EMPTY RACEWAYS SHALL HAVE TAGGED NYLON PULL STRING/ROPE.

17. CONDUITS PENETRATING A FIREWALL SHALL BE INSTALLED PER UL APPROVED ENGINEERED DRAWINGS OF A UL LISTED FIRE STOPPING SYSTEMS EQUAL TO OR GREATER THAN THE FIRE RATING OF THE FIRE WALL BEING PENETRATED.

18. ELECTRICAL CONTRACTOR SHALL BE RESPONSIBLE FOR FURNISHING CONDUIT, WIRE AND CONNECTING TO EQUIPMENT CALLED OUT IN ELECTRICAL, MECHANICAL, INSTRUMENTATION DRAWINGS AND SPECIFICATIONS REQUIRING ELECTRICAL CONNECTIONS.

19. FIELD CUT THREADS ON RMC CONDUIT SHALL BE PROTECTED FROM CORROSION WITH AN ANTI-CORROSION COMPOUND SUCH AS THOMAS & BETTS KOPR-SHIELD OR APPROVED EQUAL. REPAIRS TO PLASTIC COATING ON CONDUITS, CONDULETS AND FITTINGS SHALL BE MADE IN ACCORDANCE W/ MANUFACTURER'S RECOMMENDATIONS.

20. ALL INDOOR CONDUIT CONNECTIONS TO PULL BOXES, JUNCTION BOXES, PANELBOARDS, MOTOR CONTROL CENTERS AND CABINETS WITHOUT THREADED CONDUIT HUBS SHALL BE MADE WITH CROUSE HINDS MYERS HUBS OR APPROVED EQUAL.

GROUNDING:

1. THE GROUNDED CIRCUIT CONDUCTORS (NEUTRAL) OF THE SYSTEM ELECTRICALLY CONTINUOUS THROUGHOUT AND GROUNDED ONLY IN THE SERVICE ENTRANCE EQUIPMENT.

2. ALL LOCKNUTS AT ENCLOSURES TO MAKE TIGHT ELECTRICAL CONTACT WITH THE ENCLOSURE. REMOVE PAINT FROM ENCLOSURES UNDER LOCKNUTS. WHERE POSITIVE ELECTRICAL CONTINUITY AT ENCLOSURES CANNOT BE OBTAINED, THEN ENTERING CONDUITS TO BE BONDED TO THE ENCLOSURE.

3. AN EQUIPMENT GROUNDING CONDUCTOR (GREEN GROUND WIRE) TO BE INSTALLED WITH ALL CIRCUITS. MINIMUM SIZE #12 GREEN GROUND. THE EQUIPMENT GROUNDING CONDUCTOR TO CONNECT TO THE METALLIC CONDUIT SYSTEM IN EVERY ENCLOSURE (PANELBOARD, JUNCTION, OUTLET, SWITCH, AND PULL BOXES, MOTOR TERMINAL BOX AND ANY OTHER METALLIC ENCLOSURE). IN ALL BOXES EQUIPMENT GROUNDING CONDUCTOR SHALL BE CONNECTED TOGETHER AND PIGTAIL CONNECTED TO THE ENCLOSURE UNDER A SEPARATE SCREW IN THREADED GROUND TAP OR SEPARATE LISTED GROUND LUG AND TO DEVICES WHERE THEY OCCUR. IN PANELBOARDS CONNECT TO GROUND BUS.

4. FLEXIBLE CONDUIT NOT TO BE CONSIDERED AS A GROUNDING PATH. ALL FLEXIBLE CONDUIT TO HAVE A GREEN GROUND WIRE INSIDE THE CONDUIT SIZED PER NEC TABLE 250-122.

5. ALL GROUNDING LUGS SHALL BE LISTED W/ UL-467 AND APPROVED FOR THE APPLICATION.

CONDUCTORS:

1. ALL 600 V CONDUCTORS SHALL BE COPPER AT 98% CONDUCTIVITY. STRANDING SHALL BE CLASS B. MINIMUM CONDUCTOR SIZE FOR CONTROL TO BE NO. 14 AWG.

2. A SEPARATE #12 AWG MINIMUM BARE OR INSULATED GREEN GROUNDING CONDUCTOR SHALL BE RUN THROUGH ALL RACEWAYS FOR GROUNDING RACEWAYS, DEVICES AND EQUIPMENT. REFER TO CONDUIT CABLE SCHEDULE AND SINGLE LINES FOR ADDITIONAL INFORMATION.

3. CONDUCTORS SHALL BE PULLED INTO CONDUIT UTILIZING IDEAL INDUSTRIES `YELLOW 77' OR EQUIVALENT, WIRE PULLING COMPOUND.

4. ALL 277/480V CONDUCTORS SHALL BE IDENTIFIED USING BROWN, ORANGE AND YELLOW. ALL 120/208V CONDUCTORS SHALL BE IDENTIFIED USING BLACK, RED AND BLUE. PHASE TAPE SHALL BE USED FOR IDENTIFICATION WHERE CONDUCTOR INSULATION IS NOT PROPERLY IDENTIFIED.

5. ALL WIRE AND CABLE SHALL BE PROPERLY TAGGED AND WELL PROTECTED AGAINST INJURY OR DAMAGE. A TAG OR LABEL SHALL BE AFFIXED WITH WIRE MARKERS AT ALL TERMINAL ENDS INDICATING CIRCUIT NUMBERS. REFER TO PANEL SCHEDULES FOR ADDITIONAL INFORMATION.

6. EACH BRANCH CIRCUIT SHALL HAVE ITS OWN NEUTRAL CONDUCTOR INSTALLED BACK TO THE PANEL THAT IS ITS SUPPLY.

7. EACH FEEDER SHALL BE GROUPED AND IDENTIFIED WITH AN IDENTIFICATION TAG IN ALL JUNCTION BOXES, PANELS, SWITCHBOARD, ETC. TAGS SHALL INDICATE FEEDER IDENTIFICATION NUMBER MATCHING CONDUIT AND CABLE SCHEDULE.

8. LEAVE AT LEAST 6 IN. FREE WIRE `PIG-TAIL' AT ALL OUTLETS FOR CONNECTION TO WIRING DEVICE OR CONTROL COMPONENT.

9. INDIVIDUAL CIRCUITS ARE SHOWN ON THE DRAWINGS FOR CLARITY. GENERAL BRANCH CIRCUITS NOT ILLUSTRATED IN THE CONDUIT AND CABLE SCHEDULE CAN BE GROUPED TOGETHER FOR "HOME RUNS" PROVIDED THE NUMBER AND AMPACITY OF CONDUCTORS IN ANY ONE CONDUIT ARE WITHIN THAT ALLOWED BY THE NATIONAL ELECTRICAL CODE. (N.E.C.) AND DE-RATING RULES IN NEC TABLE 310-15(b)(2)(a) SHALL BE FOLLOWED.

10. ALL 120V WIRING AND ABOVE SHALL BE RUN IN CONDUIT UNLESS OTHERWISE SPECIFIED. CABLE SHALL NOT BE INSTALLED IN CONDUIT UNTIL CONDUIT SYSTEM IS COMPLETE BETWEEN PULL POINTS.

11. FOR POWER AND LIGHTING CIRCUITS EACH CONDUCTOR SHALL BE CONTINUOUS WITHOUT JOINTS AND SPLICES, EXCEPT AS REQUIRED ON MULTI-OUTLET LIGHTING AND RECEPTACLE BRANCH CIRCUITS, IF AT LOCATIONS AND IN FITTINGS APPROVED FOR THAT PURPOSE.

12. ALL JOINTS AND SPLICES IN WIRE #10 OR SMALLER SHALL BE TWISTED AND MADE MECHANICALLY STRONG WITH SPRING PRESSURE TYPE CONNECTORS.

13. WIRES TERMINATED AT LUGS SHALL TERMINATE AT LUGS SPECIFICALLY APPROVED FOR THE SIZE AND 90° WIRE SPECIFIED ABOVE. IN NO CASE SHALL THE WIRE BE "DOUBLED" OR SUPPLEMENTED BY OTHER WIRE OR STRANDS OF WIRE WHEN TERMINATING A WIRE AT A LUG WHICH IS TOO LARGE FOR THE WIRE TO BE TERMINATED. IN NO CASE SHALL THE WIRE BE REDUCED IN SIZE BY THE REMOVAL OF ONE OR MORE STRANDS OF WIRE; NOR ANY SIMILAR MODIFICATION FOR THE PURPOSE OF TERMINATING A WIRE AT A LUG THAT IS TOO SMALL FOR THE WIRE.

14. NO SPLICES WILL BE PERMITTED IN CONDUIT OR WIRE RACEWAYS; MAKE SPLICES IN OUTLET OR JUNCTION BOXES. USE ENOUGH SPARE WIRE TO ENABLE TWO OR MORE SPLICES TO BE REMADE WITH WIRE IN THE EVENT OF A FAULT.

15. CABLE INSTALLED IN CABLE TRAYS SHALL COMPLY WITH NEC CABLE TYPE TC-ER REQUIREMENTS.

LIGHTING FIXTURES:

1. LIGHTING FIXTURES SHALL BE AS SPECIFIED WITHIN CONSTRUCTION DRAWING DOCUMENTS. REFER TO LIGHTING SCHEDULE AND LIGHTING PLAN FOR ADDITIONAL INFORMATION.

2. ALL FIXTURES SHALL BE CLEANED & OPERATIONAL AT THE COMPLETION OF THIS PROJECT. ANY DAMAGED OR DEFECTIVE FIXTURES TO BE REPLACED AT NO COST TO OWNER.

3. PROVIDE ALL MOUNTING STRAPS, ACCESSORIES, ETC. REQUIRED FOR A COMPLETE INSTALLATION. PROVIDE ALL FIXTURE HANGERS AND SUPPORTS.

DISTRIBUTION EQUIPMENT:

1. MCC'S, TRANSFORMERS, PANELBOARDS AND MOTOR STARTERS SHALL BE AS SPECIFIED WITHIN THE CONSTRUCTION DRAWINGS AND DOCUMENTS.

2. PROVISIONS FOR FUTURE TO BE PREPARED SPACES FOR ADDING BREAKERS COMPLETE WITH ALL DRILLINGS, CONNECTORS, HARDWARE, ETC. SUCH THAT NO ADDITIONAL ITEMS EXCEPT THE BREAKER ARE REQUIRED.

3. ELECTRICAL CONTRACTOR SHALL FURNISH AND INSTALL TYPED PANEL DIRECTORIES INDICATING PANEL DESIGNATION, CIRCUIT NUMBERS AND EQUIPMENT SERVED FOR ALL PANELS. EXISTING PANELS AFFECTED BY NEW WORK SHALL ALSO BE PROVIDED WITH NEW, UPDATED AND TYPED DIRECTORIES.

4. ALL MAIN POWER DISTRIBUTION PANELBOARDS SHALL HAVE 100% RATED BREAKERS INSTALLED.

5. NEW CIRCUIT BREAKERS OR MCPS PROVIDED FOR EXISTING MCC'S SHALL BE MEET OR EXCEED THE SHORT CIRCUIT CURRENT INTERRUPTING RATING OF EXISTING MCC CIRCUIT BREAKERS/MCPS. EC SHALL FIELD VERIFY ALL LOCATIONS PERTINENT TO THIS PROJECT AS DESCRIBED IN THESE CONSTRUCTION DOCUMENTS.

6. TOP OF PANEL/CABINETS TO BE INSTALLED AT 6'-0" ABOVE FINISHED FLOOR UNLESS OTHERWISE NOTED ON DRAWINGS.

BOXES:

1. OUTLET BOXES LOCATED OUTDOORS SHALL BE STEEL FS OR FD TYPE BOXES WITH PLASTIC COATED FINISH AND THREADED HUBS.

2. OUTDOOR PULL BOXES SHALL BE STAINLESS STEEL 316 NEMA 4X UNLESS OTHERWISE NOTED.

3. INSTALL PULL BOXES, JUNCTION BOXES, SPLICE BOXES, AND CONDUIT FITTINGS WHERE SHOWN AND AT OTHER LOCATIONS AS PER NEC. ALL INDOOR BOXES SHALL BE UL/NEMA 12 UNLESS CONDITIONS OR DRAWINGS DICTATE OTHERWISE.

WIRING DEVICES:

1. WIRING DEVICES AND COVER PLATES SHALL BE SPECIFIED WITHIN CONSTRUCTION DRAWING DOCUMENTS.

IDENTIFICATION:

1. ALL ELECTRICAL EQUIPMENT SHALL BE PERMANENTLY IDENTIFIED BY MEANS OF A PHENOLIC NAMEPLATE (1/8" MIN. LETTER SIZE) ATTACHED TO THE DEVICE COVER. NAMEPLATE SHALL BE WHITE WITH BLACK LETTERING.

2. EQUIPMENT TO BE IDENTIFIED SHALL INCLUDE , BUT NOT BE LIMITED TO: PANELBOARDS, TRANSFORMERS, DISCONNECT SWITCHES, MOTOR STARTERS AND CONTACTORS.

3. NAMEPLATES SHALL BE ATTACHED BY MEANS OF STAINLESS STEEL SCREWS TO DEVICE ENCLOSURES.

4. NAMEPLATES SHALL BE BLACK LETTERING ON A WHITE BACKGROUND FOR NORMAL POWER AND BLACK LETTERING ON A RED BACKGROUND FOR EMERGENCY POWER.

5. NAMEPLATES SHALL BE 1/16" THICK MIN. FOR SIGNS UP TO 20 SQUARE INCHES OR 8" IN LENGTH, AND 1/8" THICK MIN FOR LARGER SIZES.

QUALITY CONTROL:

1. ALL EQUIPMENT, ITEMS, DEVICES AND APPURTENANCES SHALL BE PROTECTED FROM DEBRIS AND DAMAGE WHILE STORED AT THE SITE DURING AND AFTER INSTALLATION.

2. SCARRED FACTORY FINISHED ELECTRICAL EQUIPMENT SHALL BE `TOUCHED UP' WITH FACTORY FURNISHED PAINT. RUSTED OR MARRED SURFACES OF ELECTRICAL EQUIPMENT SHALL BE CLEANED AND PRIMED BEFORE PAINTING.

3. ELECTRICAL CONTRACTOR SHALL MAINTAIN ACCURATE RECORDS OF ALL DEVIATIONS AND CHANGES FROM THE CONTRACTOR DOCUMENTS INCLUDING DIMENSIONED LOCATIONS OF BUILDING SYSTEM CHANGES, PANEL SCHEDULES, AND APPURTENANCES TO GIVE A COMPLETE RECORD OF THE INSTALLED ELECTRICAL SYSTEMS.

4. ALL WORK SHALL BE PERFORMED IN ACCORDANCE WITH THE NATIONAL ELECTRICAL CONTRACTOR ASSOCIATION (NECA) "STANDARD OF INSTALLATION".

5. COLD GALVANIZING SPRAY SHALL BE USED ON ALL FIELD CUTS OF GALVANIZED STRUT.

ELECTRICAL ABBREVIATIONS

A	AMPS, AMPERE
AF	AMPS FRAME
AFF	ABOVE FINISHED FLOOR
AFG	ABOVE FINISHED GRADE
AT	AMPS TRIP
B/	BOTTOM OF
BFF	BELOW FINISHED FLOOR
C	CONDUIT
EC	ELECTRICAL CONTRACTOR
EGC	EQUIPMENT GROUNDING CONDUCTOR
ETR	EXISTING TO REMAIN
EW	EACH WAY
GEC	GROUNDING ELECTRODE CONDUCTOR
GFCI	GROUND FAULT CIRCUIT INTERRUPTER
G/GND	GROUND
GPR	GENERAL POWER RECEPTACLE
IS	INTRINSICALLY SAFE
JB	JUNCTION BOX
KVA	KILO VOLT AMPERE
KW	KILO WATT
LTG	LIGHTING
LSI	LONG TIME DELAY, SHORT TIME DELAY, INSTANTANEOUS SETTINGS AVAILABLE
LFMC	LIQUID FLEXIBLE METALLIC CONDUIT
MC	MECHANICAL CONTRACTOR
MCB	MAIN CIRCUIT BREAKER
MCP	MOTOR CIRCUIT PROTECTOR
MISC	MISCELLANEOUS
MJB	MARSHALLING JUNCTION BOX
MLO	MAIN LUGS ONLY
NEC	NATIONAL ELECTRICAL CODE
NTS	NOT TO SCALE
OCPD	OVER CURRENT PROTECTION DEVICE
PB	PULLBOX
RECEP	RECEPTACLE
RGS	RIGID GALVANIZED STEEL
RIS	REMOTE INDICATOR STATION
SS	STAINLESS STEEL
TBD	TO BE DETERMINED
T/	TOP OF
TYP	TYPICAL
UON	UNLESS OTHERWISE NOTED
V	VOLTS, VOLTAGE
W/	WITH
W/O	WITHOUT
WP	WEATHERPROOF

MISC DEVICES & SYMBOLS LEGEND

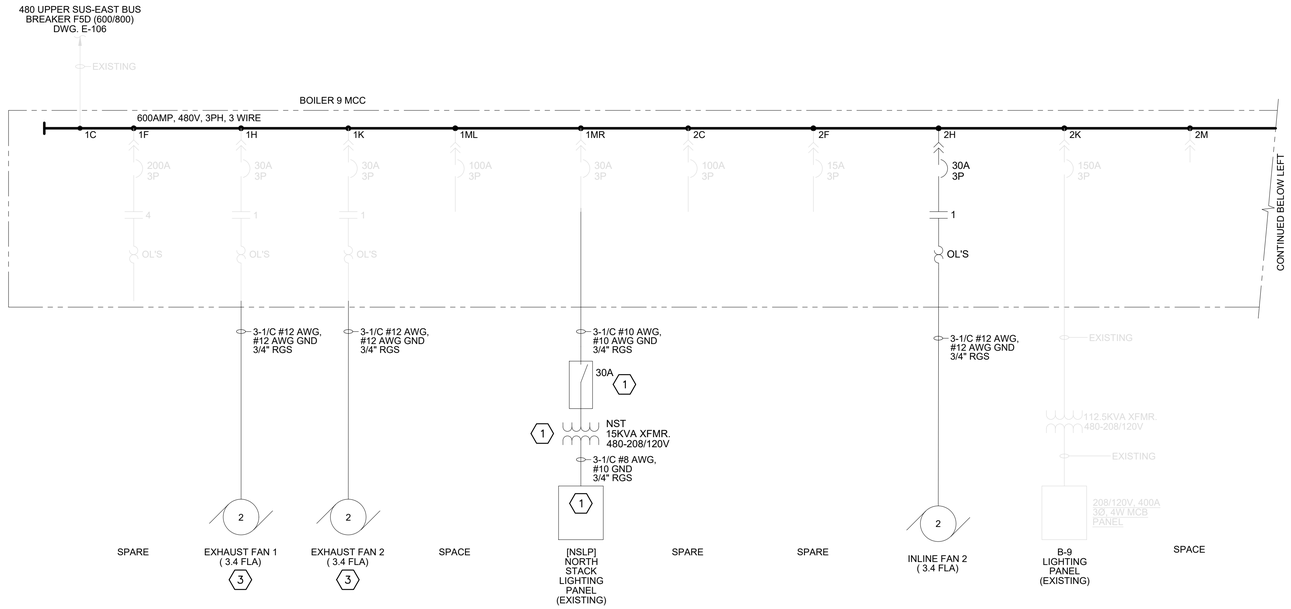
SYMBOL	DESCRIPTION
NO GE CL	AUTOMATIC TRANSFER SWITCH
1	STARTER
NFD	NON-FUSED DISC. SWITCH
CONT. PNL.	CONTROL PANEL
VFD	VARIABLE FREQUENCY DRIVE
	TRANSFORMER
	120VAC RECEPTACLE
	480VAC PIN & SLEEVE POWER RECEPTACLE
XP	120VAC HAZARDOUS AREA TWIST-LOCK RECEPTACLE
GFCI	120VAC GROUND FAULT RECEPTACLE
WR GFCI	120VAC WEATHER RESISTANT GROUND FAULT RECEPTACLE
GFCI P	DUPLEX RECEPTACLE - PROTECTED LOAD SIDE OF GFCI
$	20A - 120V SINGLE POLE TOGGLE SWITCH
$OC	20A - 120V SINGLE POLE TOGGLE SWITCH OCCUPANCY SENSOR
$D	20A - 120V SINGLE POLE TOGGLE SWITCH DIMMER
$3	20A - 120V SINGLE POLE TOGGLE SWITCH THREE WAY
$4	20A - 120V SINGLE POLE TOGGLE SWITCH FOUR WAY
	480VAC, 3Ø, 4W PANELBOARD
	208/120VAC, 1Ø, 3W PANELBOARD
	TRANSFORMER, SIZE AS SHOWN ON PLANS
	LED BEACON

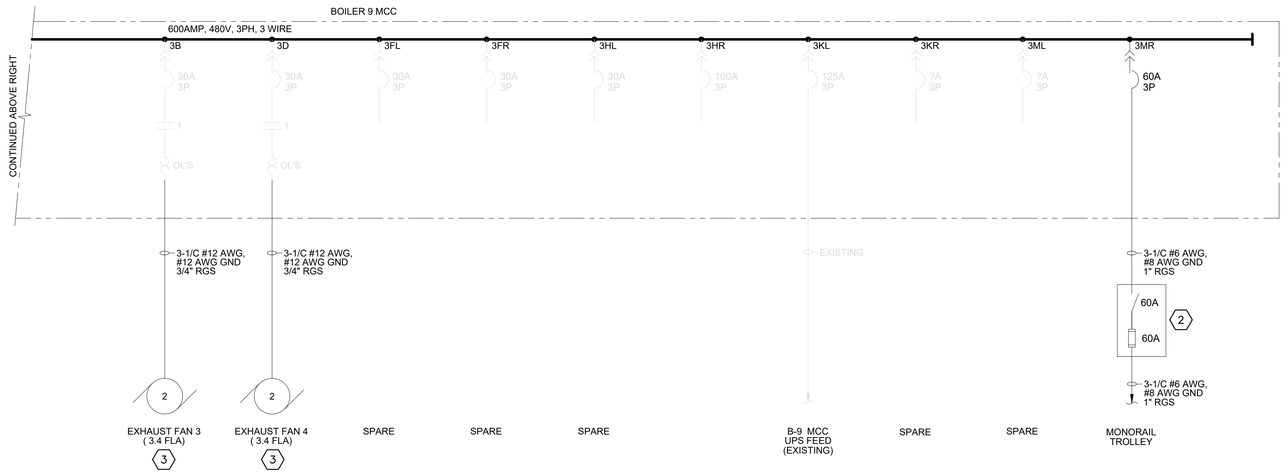
DRAWING INDEX:

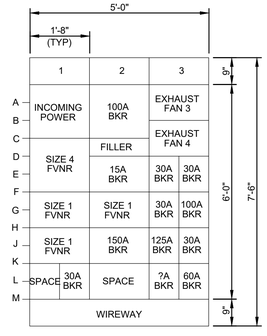
E-001	GENERAL NOTES, SYMBOL LEGEND & DRAWING INDEX
E-101	BOILER 9 MCC SINGLE LINE DIAGRAM
E-102	BOILER 8 MCC SINGLE LINE DIAGRAM
E-103	BOILER 7 MCC SINGLE LINE DIAGRAM
E-104	AQCS MCC SINGLE LINE DIAGRAM
E-105	GENERATOR 7/8 13.8KV SINGLE LINE DIAGRAM
E-106	480V SUS EAST & WEST BUS SINGLE LINE DIAGRAM
E-107	DC POWER DISTRIBUTION SYSTEM SINGLE LINE DIAGRAM
E-108	NORTH STACK LIGHTING WIRING DIAGRAMS
E-201	BOILER 7, 8 & 9 MCC ROOM INVERTER PANEL SCHEDULES
E-202	AQCS PANEL SCHEDULES
E-203	BOILERHOUSE PANEL SCHEDULES
E-401	EXISTING BOILER ROOM BASEMENT FLOOR ELECTRICAL POWER PLAN
E-402	EXISTING BOILER ROOM OPERATOR FLOOR ELECTRICAL POWER PLAN
E-403	ELEVATED PLATFORM AT TOC EL. 723'-5" ELECTRICAL PLAN
E-404	EXISTING BAGHOUSE FLOOR ELECTRICAL PLAN
E-405	ELEVATED PLATFORMS @ TOC EL. 751'-4" ELECTRICAL PLAN
E-410	ELECTRICAL BUILDING 1ST FLOOR 13.8KV ROUTING PLAN
E-411	1ST FLOOR 13.8KV ROUTING PLAN
E-412	ELECTRICAL BUILDING 2ND FLOOR SUS BUS PLAN
E-413	ELECTRICAL BUILDING 3RD FLOOR DC CABINET PLAN
E-414	BFB1 ELECTRICAL ROOM FLOOR PLAN
E-416	1ST FLOOR CRITICAL LOADS PLAN
E-501	ELECTRICAL FURNACE SECTIONS
E-502	MISC. SECTIONS

DEMOLITION DRAWINGS:

E-101-DEMO	BOILER 9 MCC DEMOLITION SINGLE LINE DIAGRAM
E-102-DEMO	BOILER 8 MCC DEMOLITION SINGLE LINE DIAGRAM
E-103-DEMO	BOILER 7 MCC DEMOLITION SINGLE LINE DIAGRAM
E-106-DEMO	480V SUS EAST & WEST BUS SINGLE LINE DIAGRAM - DEMOLITION
E-107-DEMO	DC POWER DISTRIBUTION SYSTEM SINGLE LINE DIAGRAM -







BOILER 9 MCC ELEVATION

SCALE: 1/2"=1'-0"

1/2" = 1'-0"

NOTES:

1. CONDUCTORS SHALL BE TYPE THHN/THWN-2.
2. CONDUIT AND FITTINGS SHALL BE RIGID GALVANIZED STEEL. SIZE AS NOTED.
3. AT THE TIME OF DESIGN EXACT SIZES OF STARTERS, HP AND OCPD'S IN SOME INSTANCES WERE NOT KNOWN AND SHOP DRAWINGS WERE NOT AVAILABLE. IF THE STARTER SIZE OR OCPD'S WAS NOT AVAILABLE ON THE UNIVERSITY OF MISSOURI ONELINES IT WAS SIZED PER HP, NEMA STANDARDS AND NEC. IN ADDITION, WIRE SIZES AND CONDUIT SIZES OF EXISTING BRANCH CIRCUITS AND FEEDERS WERE NOT AVAILABLE ON UNIVERSITY OF MISSOURI ONELINES AND ARE NOT ILLUSTRATED ON THIS ONE-LINE DIAGRAM. EC SHALL PRICE PROJECT PER THESE CONTRACT DRAWINGS. ANY DISCREPANCIES ON SIZES WILL BE PICKED UP IN DETAILED DESIGN AND ADJUSTED AT THAT TIME.
4. FOR PRICING PURPOSES AT THIS TIME EC SHALL USE AN AVERAGE OF 150' FOR BRANCH CIRCUITS FOR EXHAUST FANS 1-4 AND INLINE FAN 2.
5. FOR PRICING PURPOSES AT THIS TIME EC SHALL USE AN AVERAGE OF 90' FOR CONTROL CIRCUITS FOR DAMPER MOTORS CONTROLLING EXHAUST FANS 1-4 LOUVERS.
6. EC SHALL BE RESPONSIBLE FOR PROVIDING AND INSTALLING NEW STARTER(S) AS DESIGNATED ON THIS DRAWING. EC SHALL MATCH EXISTING STARTERS, KAIC RATING AND SHALL HAVE A MINIMUM OF PROPERLY SIZED MCP (MOTOR CIRCUIT PROTECTOR) 120V CONTROL TRANSFORMER, OVERLOAD RESET PUSHBUTTON, GREEN PILOT LIGHT FOR OFF INDICATION, RED PILOT LIGHT FOR ON INDICATION AND TWO SETS OF AUXILIARY NO/NC CONTACTS ON THE CONTACTOR.
7. EC SHALL BE RESPONSIBLE FOR PROVIDING AND INSTALLING FILLER PLATES AS REQUIRED FOR ANY MODIFICATIONS AS DEFINED IN THESE CONTRACT DRAWINGS.
8. EC SHALL BE RESPONSIBLE FOR ADJUSTING MCP AMPACITY RANGES AND OVERLOAD SETTINGS PER HP OF MOTOR, SERVICE FACTOR AND NEMA DESIGN RATING AS DEFINED IN NEC FOR BOTH NEW AND EXISTING MOTOR STARTERS THAT ARE BEING USED UNDER THE SCOPE OF THIS PROJECT.
9. EC SHALL FIELD VERIFY ALL MODIFICATIONS REQUIRED TO MCC PER CONTRACT DRAWINGS PRIOR TO PROCUREMENT OF ANY STARTERS OR ANCILLARY PARTS.

KEY NOTES:

1. ELECTRICAL CONTRACTOR TO RELOCATE PANEL NSLP, 15 KVA TRANSFORMER NST AND 30A DISCONNECT. REWORK AND RESUPPLY AS REQUIRED. REFER TO DRAWING E-404 FOR ADDITIONAL INFORMATION.
2. EC SHALL PROVIDE AND INSTALL 60A, 3 WIRE , FUSIBLE, NEMA 12, HEAVY DUTY FUSIBLE DISCONNECT SWITCH.
3. EXHAUST FAN DAMPER MOTORS FOR WALL LOUVERS WILL NEED TO BE CONNECTED TO MOTOR STARTER CONTACTOR AUX NO CONTACTS SO THAT WHEN THE EXHAUST FAN IS IN THE ON CONDITION THE LOUVERS OPEN. THIS CONTROL CIRCUIT IS CONTROLLED POWERED BY THE 120V CONTROL TRANSFORMER IN THE STARTER.

REFERENCE DRAWINGS:

E-101-DEMO BOILER 9 MCC DEMOLITION

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/10/20	ISSUED FOR BID	KLM

SECURITY

PUBLIC ☐
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

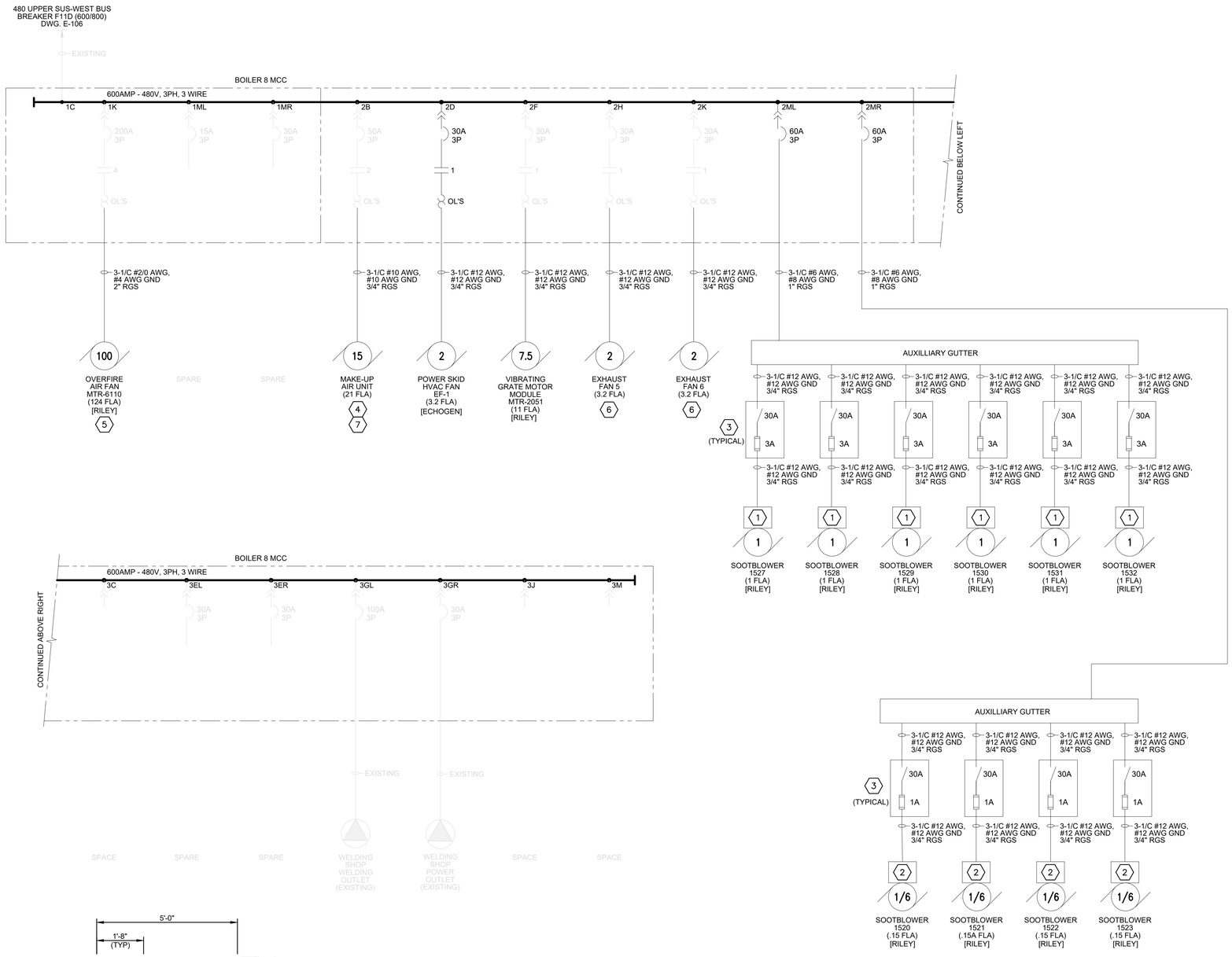
2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

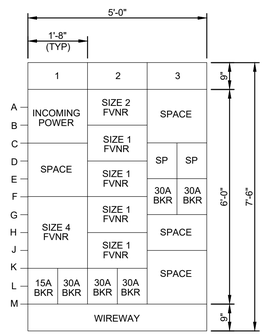
ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

ELECTRICAL
BOILER 9 MCC
SINGLE LINE DIAGRAM

DATE	DRAWN	CHK'D.
01/03/20	BLP	SDS
SCALE: NONE		APPROVED: MET

E-101





BOILER 8 MCC ELEVATION

SCALE: 1/2"=1'-0"

1/2" = 1'-0"

NOTES:

1. CABLE SHALL BE TYPE THHN/THWN-2.
2. CONDUIT AND FITTINGS SHALL BE RIGID GALVANIZED STEEL.
3. AT THE TIME OF DESIGN EXACT SIZES OF STARTERS, HP AND OCPD'S IN SOME INSTANCES WERE NOT KNOWN AND SHOP DRAWINGS WERE NOT AVAILABLE. IF THE STARTER SIZE OR OCPD'S WAS NOT AVAILABLE ON THE UNIVERSITY OF MISSOURI ONELINES IT WAS SIZED PER HP, NEMA STANDARDS AND NEC. IN ADDITION, WIRE SIZES AND CONDUIT SIZES OF EXISTING BRANCH CIRCUITS AND FEEDERS WERE NOT AVAILABLE ON UNIVERSITY OF MISSOURI ONELINES AND ARE NOT ILLUSTRATED ON THIS ONE-LINE DIAGRAM. EC SHALL PRICE PROJECT PER THESE CONTRACT DRAWINGS. ANY DISCREPANCIES ON SIZES WILL BE PICKED UP IN DETAILED DESIGN AND ADJUSTED AT THAT TIME.
4. FOR PRICING PURPOSES AT THIS TIME EC SHALL USE AN AVERAGE OF 180' FOR BRANCH CIRCUITS FOR MAKE UP AIR UNIT, EXHAUST FANS 5 AND 6.
5. FOR PRICING PURPOSES AT THIS TIME EC SHALL USE AN AVERAGE OF 90' FOR CONTROL CIRCUITS FOR DAMPER MOTORS CONTROLLING EXHAUST FANS 5-6 LOUVERS.
5. FOR PRICING PURPOSES AT THIS TIME EC SHALL USE AN AVERAGE OF 150' FOR CONTROL CIRCUITS FOR DAMPER MOTORS CONTROLLING MAKE UP AIR UNIT LOUVER.
6. EC SHALL BE RESPONSIBLE FOR PROVIDING AND INSTALLING NEW STARTER(S) AS DESIGNATED ON THIS DRAWING. EC SHALL MATCH EXISTING STARTERS, KAIC RATING AND SHALL HAVE A MINIMUM OF PROPERLY SIZED MCP (MOTOR CIRCUIT PROTECTOR) 120V CONTROL TRANSFORMER, OVERLOAD RESET PUSHBUTTON, GREEN PILOT LIGHT FOR OFF INDICATION, RED PILOT LIGHT FOR ON INDICATION AND TWO SETS OF AUXILIARY NO/NC CONTACTS ON THE CONTACTOR.
7. EC SHALL BE RESPONSIBLE FOR PROVIDING AND INSTALLING FILLER PLATES AS REQUIRED FOR ANY MODIFICATIONS AS DEFINED IN THESE CONTRACT DRAWINGS.
8. EC SHALL BE RESPONSIBLE FOR ADJUSTING MCP AMPACITY RANGES AND OVERLOAD SETTINGS PER HP OF MOTOR, SERVICE FACTOR AND NEMA DESIGN RATING AS DEFINED IN NEC FOR BOTH NEW AND EXISTING MOTOR STARTERS THAT ARE BEING USED UNDER THE SCOPE OF THIS PROJECT.
9. EC SHALL FIELD VERIFY ALL MODIFICATIONS REQUIRED TO MCC PER CONTRACT DRAWINGS PRIOR TO PROCUREMENT OF ANY STARTERS OR ANCILLARY PARTS.

KEY NOTES:

1. TYPE IK-4M RETRACTABLE SOOTBLOWERS W/ INTEGRAL MOTOR STARTERS PROVIDE BY OTHERS WIRED BY EC.
2. TYPE DIAMOND POWER G9B SOOTBLOWERS W/ INTEGRAL MOTOR STARTERS PROVIDED BY OTHERS WIRED BY EC.
3. EC SHALL PROVIDE AND INSTALL 30A, 3 WIRE , FUSIBLE, NEMA 12, HEAVY DUTY FUSIBLE DISCONNECT SWITCH.
4. MAKEUP AIR UNIT SHALL PROVIDED BY MECHANICAL CONTRACTOR SHALL HAVE INTEGRAL STARTER.
5. OVERFIRE AIR FAN WILL NEED TO HAVE HEATER IN MOTOR WINDINGS CONNECTED TO MOTOR STARTER CONTACTOR AUX NC CONTACTS SO THAT THE HEATER IS POWERED AND CONTROLLED BY 120V CONTROL TRANSFORMER. FUNCTIONALLY THE HEATER SHALL BE ENERGIZED WHEN THE MOTOR IS DE-ENERGIZED.
6. EXHAUST FAN DAMPER MOTORS FOR WALL LOUVERS WILL NEED TO BE CONNECTED TO MOTOR STARTER CONTACTOR AUX NO CONTACTS SO THAT WHEN THE EXHAUST FAN IS IN THE ON CONDITION THE LOUVERS OPEN. THIS CONTROL CIRCUIT IS CONTROLLED POWERED BY THE 120V CONTROL TRANSFORMER IN THE STARTER.
7. MAKE UP AIR UNIT DAMPER MOTOR FOR WALL LOUVER WILL NEED TO BE CONNECTED TO MOTOR STARTER CONTACTOR AUX NO CONTACTS SO THAT WHEN THE MAKE UP AIR UNIT FAN IS IN THE ON CONDITION THE LOUVERS OPEN. THIS CONTROL CIRCUIT IS CONTROLLED POWERED BY THE 120V CONTROL TRANSFORMER IN THE STARTER.

REFERENCE DRAWINGS:

E-102-DEMO BOILER 8 MCC DEMOLITION

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/10/20	ISSUED FOR BID	KLM

SECURITY

PUBLIC ☐
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

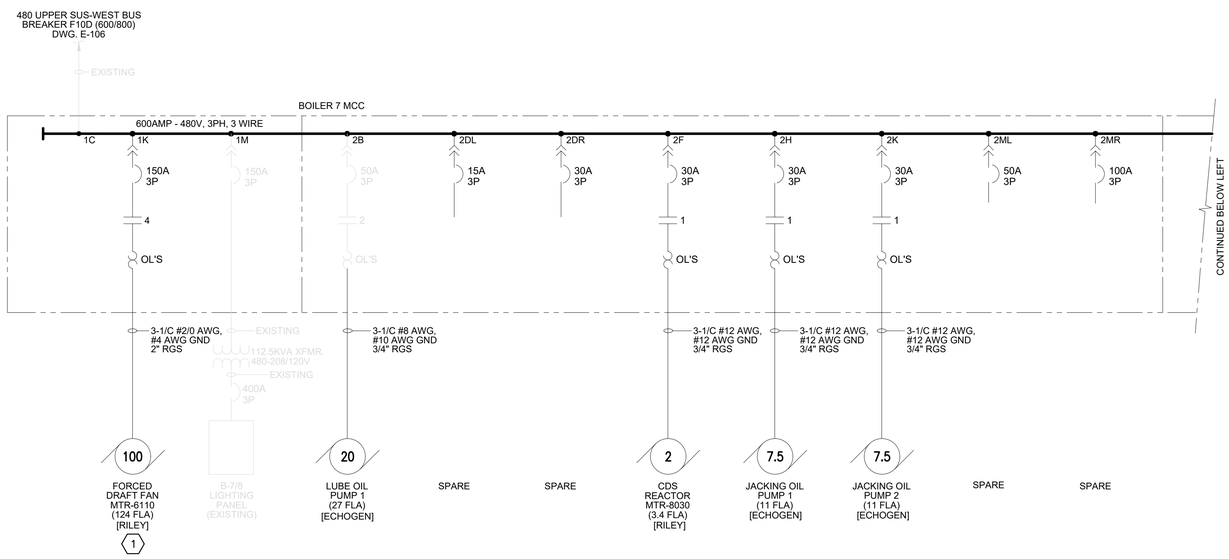
2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

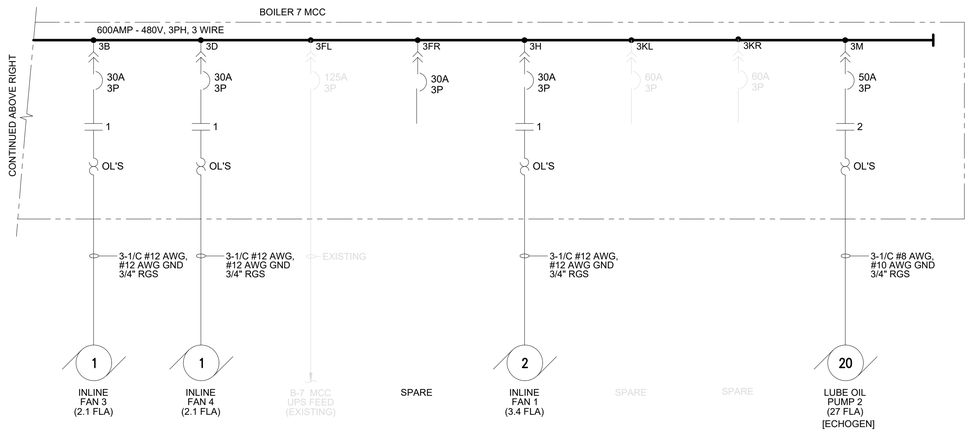
ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

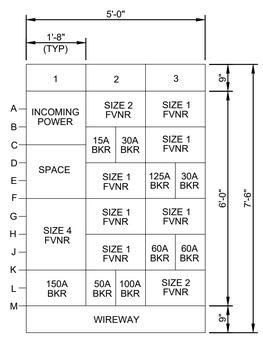
ELECTRICAL
BOILER 8 MCC
SINGLE LINE DIAGRAM

DATE	DRAWN	CHK'D.
01/06/20	BLP	SDS
SCALE: NONE		APPROVED: MET

E-102







BOILER 7 MCC ELEVATION

SCALE: 1/2"=1'-0"

NOTES:

1. CABLE SHALL BE TYPE THHN/THWN-2.
2. CONDUIT AND FITTINGS SHALL BE RIGID GALVANIZED STEEL. SIZE AS NOTED.
3. AT THE TIME OF DESIGN EXACT SIZES OF STARTERS, HP AND OCPD'S IN SOME INSTANCES WERE NOT KNOWN AND SHOP DRAWINGS WERE NOT AVAILABLE. IF THE STARTER SIZE OR OCPD'S WAS NOT AVAILABLE ON THE UNIVERSITY OF MISSOURI ONELINES IT WAS SIZED PER HP, NEMA STANDARDS AND NEC. IN ADDITION, WIRE SIZES AND CONDUIT SIZES OF EXISTING BRANCH CIRCUITS AND FEEDERS WERE NOT AVAILABLE ON UNIVERSITY OF MISSOURI ONELINES AND ARE NOT ILLUSTRATED ON THIS ONE-LINE DIAGRAM. EC SHALL PRICE PROJECT PER THESE CONTRACT DRAWINGS. ANY DISCREPANCIES ON SIZES WILL BE PICKED UP IN DETAILED DESIGN AND ADJUSTED AT THAT TIME.
4. FOR PRICING PURPOSES AT THIS TIME EC SHALL USE AN AVERAGE OF 120' FOR BRANCH CIRCUITS FOR INLINE FANS 1, 3 AND 4.
5. EC SHALL BE RESPONSIBLE FOR PROVIDING AND INSTALLING NEW STARTER(S) AS DESIGNATED ON THIS DRAWING. EC SHALL MATCH EXISTING STARTERS, KAIC RATING AND SHALL HAVE A MINIMUM OF PROPERLY SIZED MCP (MOTOR CIRCUIT PROTECTOR) 120V CONTROL TRANSFORMER, OVERLOAD RESET PUSHBUTTON, GREEN PILOT LIGHT FOR OFF INDICATION, RED PILOT LIGHT FOR ON INDICATION AND TWO SETS OF AUXILIARY NO/NC CONTACTS ON THE CONTACTOR.
6. EC SHALL BE RESPONSIBLE FOR PROVIDING AND INSTALLING FILLER PLATES AS REQUIRED FOR ANY MODIFICATIONS AS DEFINED IN THESE CONTRACT DRAWINGS.
7. EC SHALL BE RESPONSIBLE FOR ADJUSTING MCP AMPACITY RANGES AND OVERLOAD SETTINGS PER HP OF MOTOR, SERVICE FACTOR AND NEMA DESIGN RATING AS DEFINED IN NEC FOR BOTH NEW AND EXISTING MOTOR STARTERS THAT ARE BEING USED UNDER THE SCOPE OF THIS PROJECT.
8. EC SHALL FIELD VERIFY ALL MODIFICATIONS REQUIRED TO MCC PER CONTRACT DRAWINGS PRIOR TO PROCUREMENT OF ANY STARTERS OR ANCILLARY PARTS.

KEY NOTES:

1. FORCED DRAFT FAN WILL NEED TO HAVE HEATER IN MOTOR WINDINGS CONNECTED TO MOTOR STARTER CONTACTOR AUX NC CONTACTS SO THAT THE HEATER IS POWERED AND CONTROLLED BY 120V CONTROL TRANSFORMER. FUNCTIONALLY THE HEATER SHALL BE ENERGIZED WHEN THE MOTOR IS DE-ENERGIZED.

REFERENCE DRAWINGS:

E-103-DEMO BOILER 7 MCC DEMOLITION

1/2" = 1'-0"

NO.	DATE	REVISION	BY
A	08/10/20	ISSUED FOR BID	KLM

PRELIMINARY
NOT FOR CONSTRUCTION

SECURITY
PUBLIC ☐
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

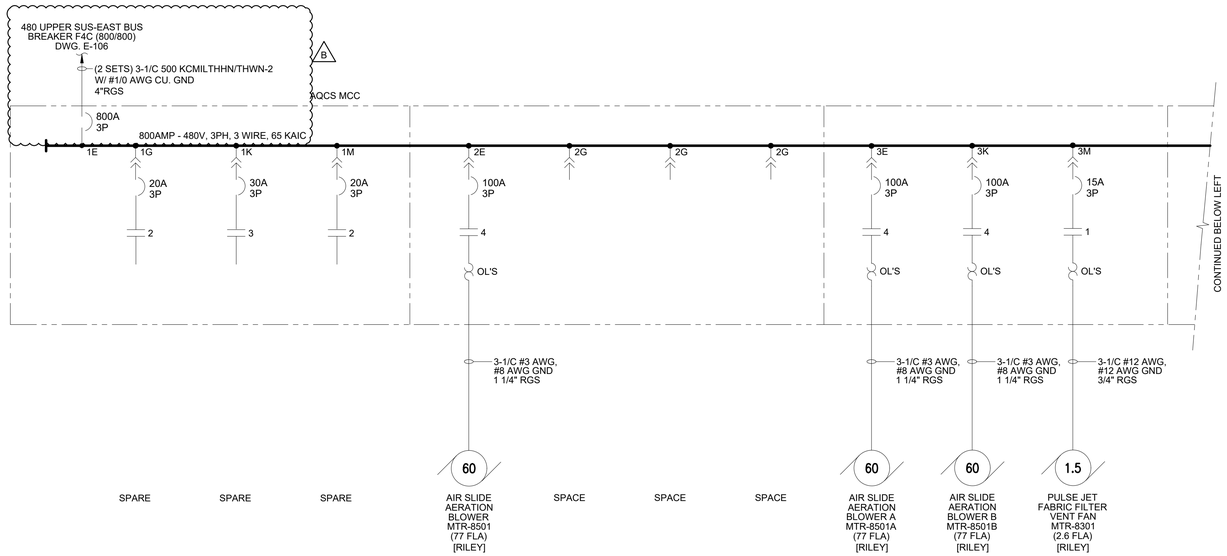
2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

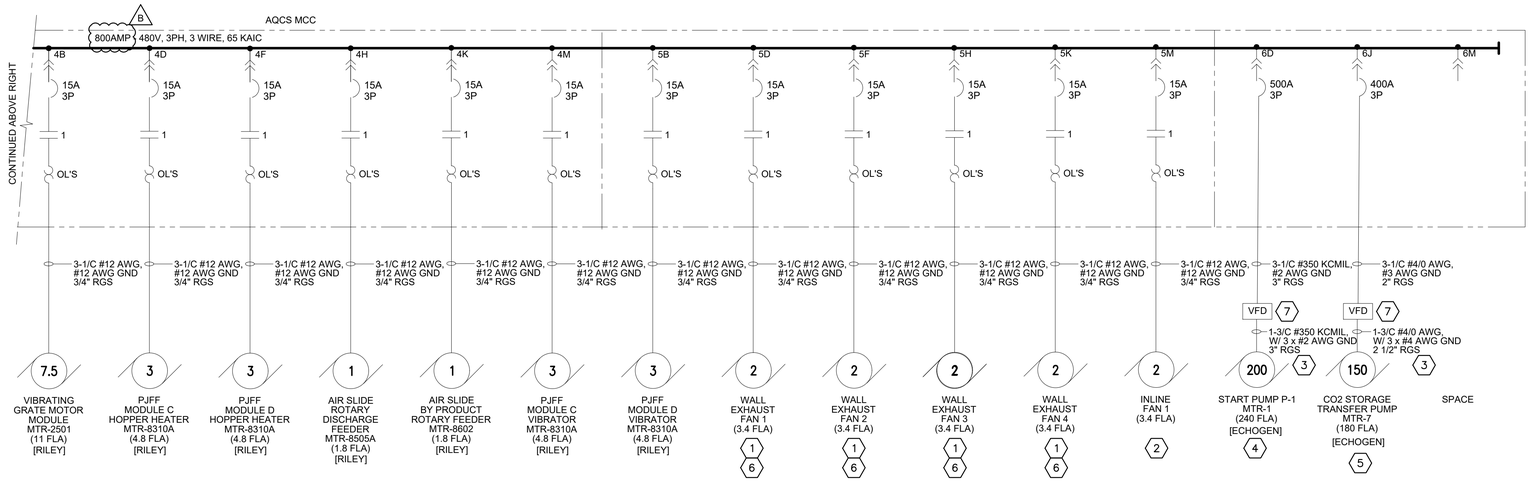
ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

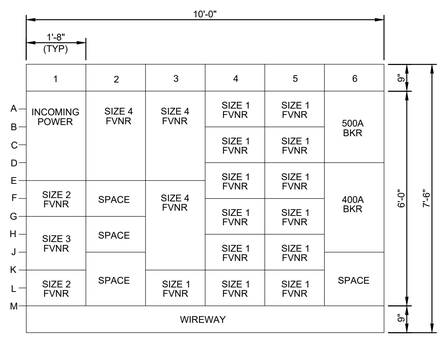
ELECTRICAL
BOILER 7 MCC
SINGLE LINE DIAGRAM

DATE	DRAWN	CHK'D.
01/06/20	BLP	SDS
SCALE: NONE		APPROVED: MET

E-103







AQCS MCC ELEVATION

SCALE: 1/2"=1'-0"

1/2" = 1'-0"

NOTES:

1. CONDUCTORS SHALL BE TYPE THHN/THWN-2 UNLESS NOTED OTHERWISE.
2. CONDUIT AND FITTINGS SHALL BE RIGID GALVANIZED STEEL. SIZE AS NOTED.
3. ELECTRICAL CONTRACTOR SHALL RECEIVE, STORE AND INSTALL NEW 1200A LSIG, 480V, W/ ARC FLASH REDUCTION, MCC PROVIDED BY OTHERS. COORDINATE AS NECESSARY WITH CONSTRUCTION MANAGEMENT AND OTHER TRADES.
4. FOR PRICING PURPOSES AT THIS TIME EC SHALL USE AN AVERAGE OF 80' FOR BRANCH CIRCUITS FOR EXHAUST FANS 1-4 AND INLINE FAN 1.
5. FOR PRICING PURPOSES AT THIS TIME EC SHALL USE AN AVERAGE OF 70' FOR CONTROL CIRCUITS FOR DAMPER MOTORS CONTROLLING EXHAUST FANS 1-4 LOUVERS.
6. ALL OCPD'S SHALL BE CONSIDERED AS MCP'S.

KEY NOTES:

1. ELECTRICAL CONTRACTOR SHALL WIRE 120V MOTORIZED DAMPER MOTORS FOR FOUR (4) WALL LOUVERS TO THROUGH "NO" AUXILIARY CONTACTS ON MOTOR STARTER SUPPLIED BY STARTER 120V CONTROL TRANSFORMER. COORDINATE W/ MECHANICAL CONTRACTOR.
2. ELECTRICAL CONTRACTOR SHALL WIRE 120V MOTORIZED DAMPER MOTOR FOR ONE (1) WALL LOUVER TO THROUGH "NO" AUXILIARY CONTACTS ON MOTOR STARTER SUPPLIED BY STARTER 120V CONTROL TRANSFORMER. COORDINATE W/ MECHANICAL CONTRACTOR.
3. XLPE/PVC, LOW VOLTAGE POWER, SHIELDED, 2000V, SEGMENTED EQUIPMENT GROUNDING CONDUCTORS, UL TYPE TC-ER, METHOD 4 COLOR CODE VFD CABLE.
4. START PUMP P-1 WILL NEED TO HAVE HEATER IN MOTOR WINDINGS CONNECTED TO VFD AUX NC CONTACTS SO THAT THE HEATER IS POWERED AND CONTROLLED BY 120V CONTROL TRANSFORMER. FUNCTIONALLY THE HEATER SHALL BE ENERGIZED WHEN THE MOTOR IS DE-ENERGIZED.
5. CO2 TRANSFER PUMP WILL NEED TO HAVE HEATER IN MOTOR WINDINGS CONNECTED TO VFD AUX NC CONTACTS SO THAT THE HEATER IS POWERED AND CONTROLLED BY 120V CONTROL TRANSFORMER. FUNCTIONALLY THE HEATER SHALL BE ENERGIZED WHEN THE MOTOR IS DE-ENERGIZED.
6. EXHAUST FAN DAMPER MOTORS FOR WALL LOUVERS WILL NEED TO BE CONNECTED TO MOTOR STARTER CONTACTOR AUX NO CONTACTS SO THAT WHEN THE EXHAUST FAN IS IN THE ON CONDITION THE LOUVERS OPEN. THIS CONTROL CIRCUIT IS CONTROLLED POWERED BY THE 120V CONTROL TRANSFORMER IN THE STARTER.
7. C02 STORAGE PUMP (150HP) VFD SHALL BE AIR COOLED, AC INPUT W/PRE-CHARGE, NEMA 1/IP20, 480VAC, 3Ø, 180A, 150HP NORMAL DUTY, FRAME 7, FILTERED, CM JUMPER INSTALLED, DOOR MTD. FULL NUMERIC LCD HIM, NO FEEDBACK, NO BYPASS, 115VAC I/O, ETHERNET, DRIVE ONLY CONTROL POWER.
   START PUMP P-1 (200HP) VFD SHALL BE AIR COOLED, AC INPUT W/PRE-CHARGE, NEMA 1/IP20, 480VAC, 3Ø, 240A, 200HP NORMAL DUTY, FRAME 7, FILTERED, CM JUMPER INSTALLED, DOOR MTD. FULL NUMERIC LCD HIM, NO FEEDBACK, NO BYPASS, 115VAC I/O, ETHERNET, DRIVE ONLY CONTROL POWER.

REFERENCE DRAWINGS:

REFER TO DWG. E-001 FOR DRAWING INDEX.
E-404 EXISTING BAGHOUSE ELECTRICAL FLOOR PLAN

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
B	08/26/20	ADDENDUM 2	KLM
A	08/10/20	ISSUED FOR BID	KLM

SECURITY
PUBLIC ☐
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

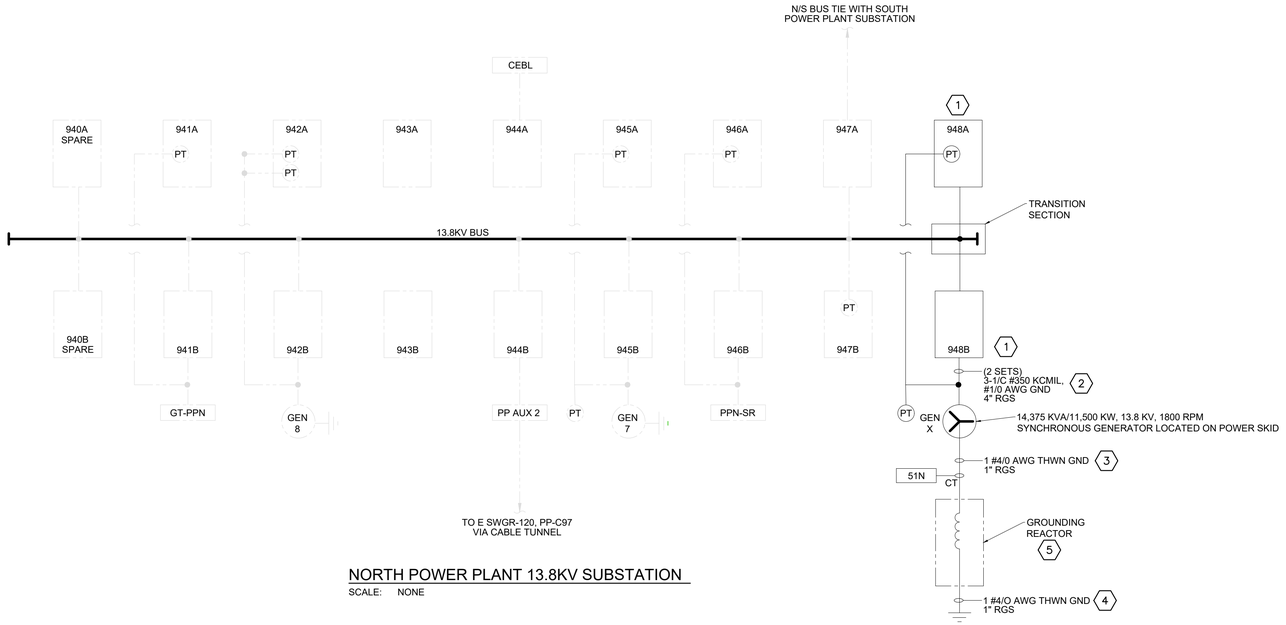
2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

ELECTRICAL
AQCS MCC
SINGLE LINE DIAGRAM

DATE	DRAWN	CHK'D.
07/20/20	BLP	SDS
SCALE		APPROVED
NONE		MET

E-104



NORTH POWER PLANT 13.8KV SUBSTATION

SCALE: NONE

NOTES:

1. CONDUIT AND FITTINGS SHALL BE RIGID GALVANIZED STEEL. SIZE AS NOTED.
2. ELECTRICAL CONTRACTOR SHALL RECEIVE, STORE AND INSTALL NEW GROUNDING REACTOR PROVIDED BY OTHERS. COORDINATE AS NECESSARY WITH CONSTRUCTION MANAGEMENT AND OTHER TRADES.
3. ELECTRICAL CONTRACTOR SHALL RECEIVE, STORE AND INSTALL NEW POWELL POWL-VAC 13.8 KV TRANSITION SECTION AND BREAKER/CONTROL SECTION PROVIDED BY OTHERS. COORDINATE AS NECESSARY WITH CONSTRUCTION MANAGEMENT AND OTHER TRADES.

KEY NOTES:

1. GENERAL ELECTRIC 13.8KV, 3000A BUS, 3Ø, 3 WIRE, 60 HZ. SWITCHGEAR. FOR LOCATION OF 13.8KV POWELL POWL-VAC TRANSITION SECTION, BREAKER/CONTROL SECTION 948A AND 948B SEE DWG. E-410.
2. 15 KV TYPE MV-105, 100% & 133% INSULATION, PVC JACKET, EPR INSULATION, 5 MIL BARE COPPER TAPE HELICALLY APPLIED W/ 25% MINIMUM OVERLAP.TYPE OKONITE OR KERITE.
3. EC SHALL BOND GEC TO BOTH SIDES OF RGS.
4. EC SHALL EXOTHEMICALLY WELD GEC TO NEAREST BUILDING STEEL COLUMN
5. AIR CORE REACTOR, SINGLE PHASE, 13.8 KV, 0.287 OHM,300A CONTINUOUS, 3650A FOR 10 SECONDS.

REFERENCE DRAWINGS:

E-103-DEMO BOILER 7 MCC DEMOLITION

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/10/20	ISSUED FOR BID	KLM

SECURITY

PUBLIC ☐
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

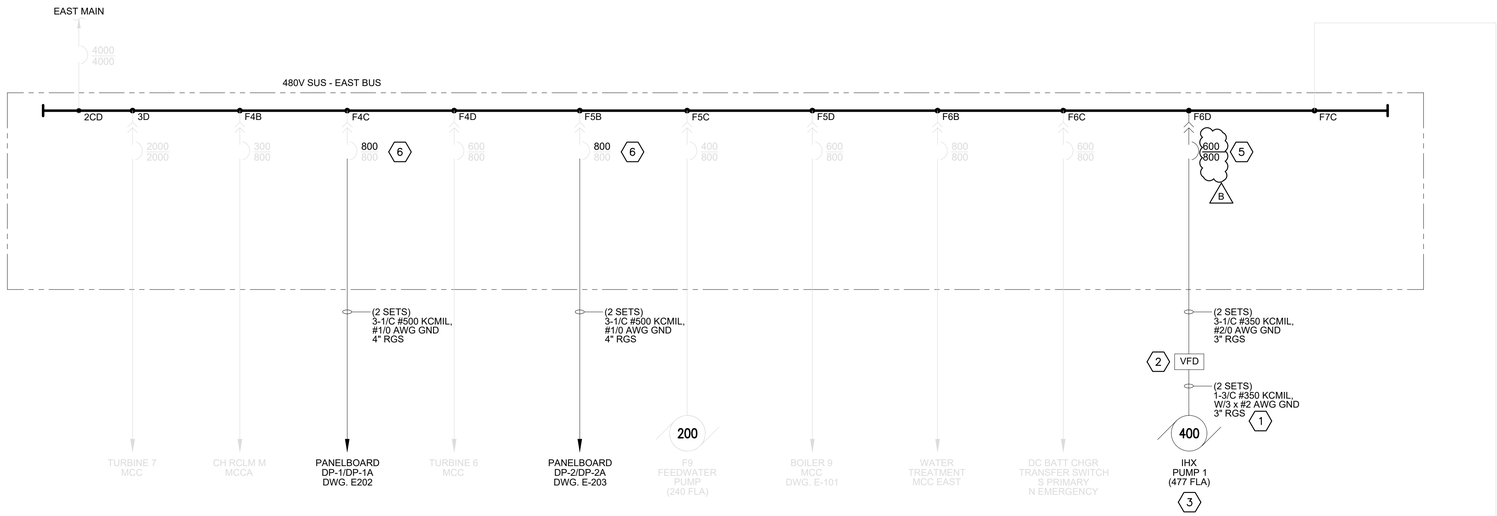
2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

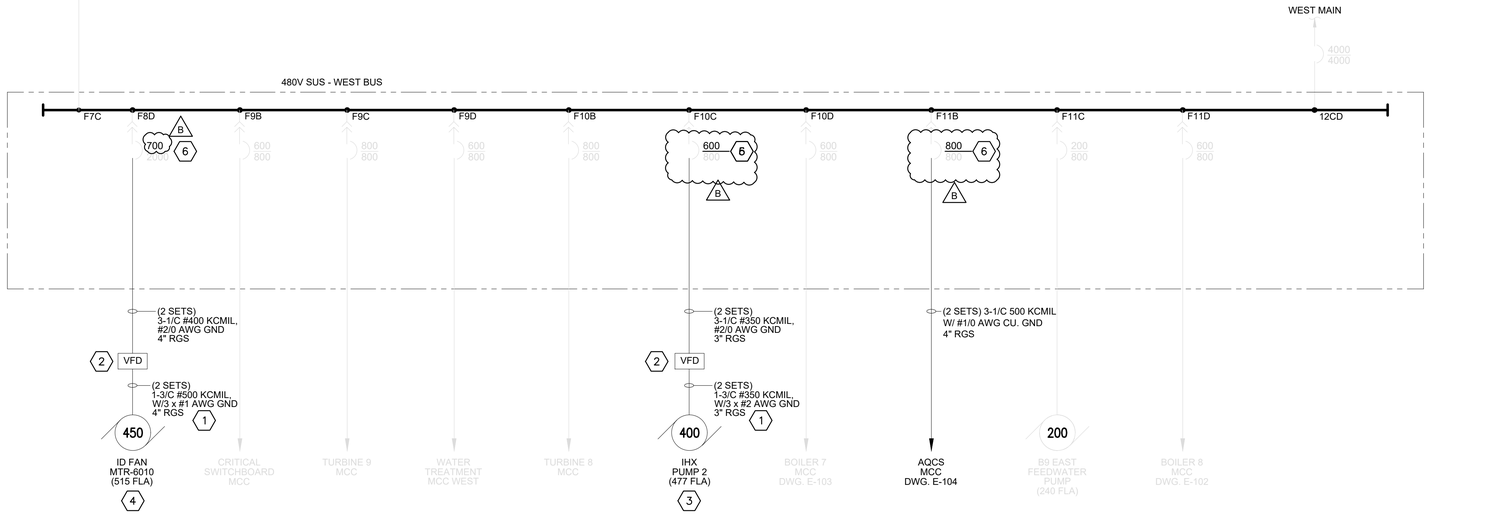
ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

NORTH POWER PLANT SUBSTATION GENERATOR 7/8 13.8KV SINGLE LINE DIAGRAM

DATE	DRAWN	CHK'D.
01/03/20	BLP	SDS
SCALE		APPROVED
NONE		MET

E-105





NOTES:

1. CONDUCTORS SHALL BE TYPE THHN/THWN-2 UNLESS NOTED OTHERWISE.
2. CONDUIT AND FITTINGS SHALL BE RIGID GALVANIZED STEEL. SIZE AS NOTED.
3. NEW BREAKER SHALL BE TESTED USING PRIMARY CURRENT INJECTION TEST PRIOR TO INSTALLING.

KEY NOTES:

1. XLPE/PVC, LOW VOLTAGE POWER, SHIELDED, 2000V, SEGMENTED EQUIPMENT GROUNDING CONDUCTORS, UL TYPE TC-ER, METHOD 4 COLOR CODE VFD CABLE.
2. IHX PUMPS 1 & 2 (400HP) VFDS SHALL BE AIR COOLED, AC INPUT W/PRE-CHARGE, NEMA 1/IP20, 480VAC, 3Ø, 477A, 400HP NORMAL DUTY, FRAME 7, FILTERED, CM JUMPER INSTALLED, DOOR MTD. FULL NUMERIC LCD HIM, NO FEEDBACK, NO BYPASS, 115VAC I/O, ETHERNET, DRIVE ONLY CONTROL POWER.
   ID FAN MOTOR -6010 (450HP) VFD SHALL BE AIR COOLED, AC INPUT W/PRE-CHARGE, NEMA 1/IP20, 480VAC, 3Ø, 515, 450HP NORMAL DUTY, FRAME 7, FILTERED, CM JUMPER INSTALLED, DOOR MTD, FULL NUMERIC LCD HIM, NO FEEDBACK, NO BYPASS, 115VAC I/O, ETHERNET, DRIVE ONLY CONTROL POWER.
3. IHX PUMPS 1 AND 2 WILL NEED TO HAVE HEATER IN MOTOR WINDINGS CONNECTED TO MOTORIZED BREAKER AUX NC CONTACTS SO THAT THE HEATER IS POWERED AND CONTROLLED BY 120V CONTROL TRANSFORMER. FUNCTIONALLY THE HEATER SHALL BE ENERGIZED WHEN THE MOTOR IS DE-ENERGIZED.
4. ID FAN WILL NEED TO HAVE HEATER IN MOTOR WINDINGS CONNECTED TO MOTORIZED BREAKER AUX NC CONTACTS SO THAT THE HEATER IS POWERED AND CONTROLLED BY 120V CONTROL TRANSFORMER. FUNCTIONALLY THE HEATER SHALL BE ENERGIZED WHEN THE MOTOR IS DE-ENERGIZED.
5. EC SHALL PROVIDE AND INSTALL NEW CUTLER HAMMER/WESTINGHOUSE, LOW VOLTAGE AC, DSL II 516 MOTORIZED POWER CIRCUIT BREAKER W/LSI TRIP UNIT RATED AT 200,000 AIC. EC SHALL FIELD VERIFY THAT THIS IS A FULLY PREPARED SPACE AND COMPLETELY WIRED FOR OPEN/CLOSE AND TRIP OPERATORS ON OUTSIDE DEAD FRONT OF SWITCHGEAR CUBICLE. IF IT IS NOT A COMPLETE PREPARED SPACE IT IS THE EC RESPONSIBILITY TO COMPLETE THE NECESSARY MODIFICATIONS.
6. EC SHALL PROVIDE AND INSTALL NEW CUTLER HAMMER/WESTINGHOUSE, DIGITRIP LSI TRIP UNIT/PLUG. REFER TO SOW FOR ADDITIONAL INFORMATION.

REFERENCE DRAWINGS:

REFER TO DRAWING E-001 FOR DRAWING INDEX

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
B	08/26/20	ADDENDUM 2	KLM
A	08/10/20	ISSUED FOR BID	KLM

SECURITY

PUBLIC ☐
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

480V UPPER SUS EAST & WEST BUS SINGLE LINE DIAGRAM

DATE	DRAWN	CHK'D.
02/24/20	BLP	SDS
SCALE NONE		APPROVED MET

E-106

PANEL: UPS INVERTER PANEL 1

LOCATION: BOILER 7, 8 & 9 MCC ROOM | VOLTAGE: 120V, 1Ø, 2W, 10 KAIC | REMARKS: SUPPLIED FROM NEW INVERTER 1 (125A)
MOUNTING: SURFACE MTD. | BUS RATING: 100A
DWG NO: | OCP: MLO (1) | MAIN BREAKER: 100A

CKT	PANEL NOTES	DESCRIPTION	BRKR	DIV %	LOAD KVA		LOAD KVA	DIV %	BRKR	DESCRIPTION	PANEL NOTES	CKT
1		ACID TANK HIGH LEVEL ALARM	20A	100%	0.1	A	0.4	100%	20A	ELECTRICAL SHOP PANEL		2
3		WATER TREATMENT CONT. PNL.	20A	100%	0.1	A	0.1	100%	20A	CEMS #1 CABINET		4
5		WATER TREATMENT CONT. PNL.	20A	100%	0.4	A	0.3	100%	20A	BOILER EQ. RM. NETWORK CAB.		6
7		WATER TREATMENT OFFICE	20A	100%	0.1	A	0.2	100%	20A	BOILER EQ. RM. COMPUTER RACK		8
9		B-10-UPS-103	20A	100%	0.3	A	1.0	80%	20A	LUBE OIL SKID RIO	12 AWG	10
11		BOILER 10 UPS-101-MTL	20A	100%	0.3	A	0.1	100%	20A	CARD ACCESS/JOHNSON CONTROLS		12
13		BOILER 10 UPS-101-MTL	20A	100%	0.2	A	1.0	80%	20A	PHX SKID RIO	12 AWG	14
15	12 AWG	PROCESS SKID RIO	20A	80%	1.7	A	1.9	80%	20A	CCS/BOP A	12 AWG	16
17	12 AWG	IHX SKID RIO	20A	80%	1.0	A	1.9	80%	20A	CCS/BOP B	12 AWG	18
19		SPACE		0%	0.0	A	0.0	0%		SPACE		20
21		SPACE		0%	0.0	A	0.0	0%		SPACE		22
23		SPACE		0%	0.0	A	0.0	0%		SPACE		24
25		SPACE		0%	0.0	A	0.0	0%		SPACE		26
27		SPACE		0%	0.0	A	0.0	0%		SPACE		28
29		SPACE		0%	0.0	A	0.0	0%		SPACE		30

A PHASE CONNECTED LOAD KVA: 10.9 | A PHASE LOAD AMPS: 90.6
TOTAL CONNECTED LOAD KVA: 10.9 | TOTAL LOAD AMPS: 90.6
KVA DEMAND LOAD: 9.2 | AMP DEMAND LOAD: 76.3

PANEL: UPS INVERTER PANEL 2

LOCATION: BOILER 7, 8 & 9 MCC ROOM | VOLTAGE: 120V, 1Ø, 2W, 10 KAIC | REMARKS: SUPPLIED FROM NEW INVERTER 2 (125A)
MOUNTING: SURFACE MTD. | BUS RATING: 100A
DWG NO: | OCP: MLO (1) | MAIN BREAKER: 100A

CKT	PANEL NOTES	DESCRIPTION	BRKR	DIV %	LOAD KVA		LOAD KVA	DIV %	BRKR	DESCRIPTION	PANEL NOTES	CKT
1	12 AWG	GENERATOR SKID RIO	20A	80%	1.0	A	0.1	100%	15A	BOILER CONT. RM S. RECEPT		2
3	12 AWG	PROCESS XM/PWR DYNAMIX CAB	20A	80%	1.2	A	0.0	0%	20A	SPARE		4
5		E315 TG-7 GOV.SLC	15A	100%	0.2	A	0.1	100%	15A	PLC S. BAGHOUSE BOILER 10		6
7		E318 TG-7 CONTROL PNL PNLVIA	15A	100%	0.1	A	1.9	80%	20A	BMS A	12 AWG	8
9		E319 TG-7 VOLTAGE REG. PNL.	15A	100%	0.1	A	1.9	80%	20A	BMS B	12 AWG	10
11		SPARE	15A	0%	0.0	A	0.0	0%	20A	SPARE		12
13	12 AWG	AQCS A	20A	80%	1.9	A	0.0	100%	20A	SPARE CKT IN CONTROL PANEL		14
15	12 AWG	AQCS B	20A	80%	1.9	A	0.0	0%	20A	SPARE		16
17		BOILER CONT. RM. N. RECEPTS.	20A	100%	0.1	A	0.0	0%	20A	SPARE		18
19		SPACE		0%	0.0	A	0.0	0%	20A	SPARE		20
21		SPACE		0%	0.0	A	0.0	0%	20A	SPARE		22
23		SPACE		0%	0.0	A	0.0	0%		SPACE		24
25		SPACE		0%	0.0	A	0.0	0%		SPACE		26
27		SPACE		0%	0.0	A	0.0	0%		SPACE		28
29		SPACE		0%	0.0	A	0.0	0%		SPACE		30

A PHASE CONNECTED LOAD KVA: 10.5 | A PHASE LOAD AMPS: 87.5
TOTAL CONNECTED LOAD KVA: 10.5 | TOTAL LOAD AMPS: 87.5
KVA DEMAND LOAD: 8.5 | AMP DEMAND LOAD: 71.1

PANEL: UPS INVERTER PANEL 3

LOCATION: BOILER 7, 8 & 9 MCC ROOM | VOLTAGE: 120V, 1PH, 2W | REMARKS: SUPPLIED FROM INVERTER 3 (50A)
MOUNTING: SURFACE MTD. | BUS RATING: 100A
DWG NO: | OCP: MLO | MAIN BREAKER: NONE

CKT	PANEL NOTES	DESCRIPTION	BRKR	DIV %	LOAD KVA		LOAD KVA	DIV %	BRKR	DESCRIPTION	PANEL NOTES	CKT
1		T-8 UPS #1	20A	100%	0.1	A	0.0	0%	20A	SPARE		2
3		T-8 VOLTAGE REGULATOR	20A	100%	0.1	A	0.1	100%	20A	BOILER CNTRL. RM. N. RECEPT.		4
5		T-8 UPS #2	20A	100%	0.1	A	0.1	100%	20A	TURBINE #6 UPS #1		6
7	12 AWG	POWER SKID RIO	20A	80%	1.5	A	0.1	100%	20A	TURBINE #6 UPS #2		8
9	12 AWG	GEN DYNAMIX CAB/ ICS SKID RIO	20A	80%	1.6	A	0.1	100%	20A	TURBINE #6 UPS #3		10
11		MAIN ASH PNL MAIN PROCESSOR	20A	100%	0.1	A	0.0	0%		SPACE		12
13		SPARE	20A	0%	0.0	A	0.1	100%	20A	BOILER CNTRL. RM. S. RECEPT.		14
15		SPARE	20A	0%	0.0	A	0.0	0%	20A			16
17		SPACE		0%	0.0	A	0.0	0%	20A			18
19		SPARE	20A	0%	0.0	A	0.0	0%		SPACE		20
21		SPARE	20A	0%	0.0	A	0.1	100%	20A	E-316-13.8 PLC		22
23		SPARE	20A	0%	0.0	A	0.4	100%	20A	CEMS CABINET #1		24
25		BOP-2	20A	100%	0.1	A	0.0	0%		SPACE		26
27		BOP-2	20A	100%	0.1	A	0.0	0%		SPACE		28
29		SPACE		0%	0.0	A	0.0	0%		SPACE		30
31		SPACE		0%	0.0	A	0.0	0%		SPACE		32
33		SPACE		0%	0.0	A	0.0	0%		SPACE		34
35		SPACE		0%	0.0	A	0.0	0%		SPACE		36
37		SPACE		0%	0.0	A	0.0	0%		SPACE		38
39		SPACE		0%	0.0	A	0.0	0%		SPACE		40
41		SPACE		0%	0.0	A	0.0	0%		SPACE		42

A CONNECTED LOAD KVA: 4.8 | A PHASE LOAD AMPS: 39.6
TOTAL CONNECTED LOAD KVA: 4.8 | TOTAL LOAD AMPS: 39.6
KVA DEMAND LOAD: 4.1 | AMP DEMAND LOAD: 34.4

NOTES:

1. ELECTRICAL CONTRACTOR SHALL REVISE NEW TYPED PANEL DIRECTORIES INDICATING PANEL DESIGNATION, CIRCUIT NUMBERS AND EQUIPMENT SERVED FOR ALL PANELS.
2. CLOUDED PORTIONS OF PANEL SCHEDULES INDICATE NEW WORK.

KEY NOTES:

(1) EC SHALL REMOVE MAIN LUGS AND INSTALL 100A MAIN CIRCUIT BREAKER. REFER TO DRAWING E-201-DEMO, E-107 AND E-107-DEMO FOR ADDITIONAL INFORMATION.

REFERENCE DRAWINGS:

REFER TO DWG. E-001 FOR DRAWING INDEX.

E-107 DC POWER DISTRIBUTION SYSTEM SINGLE LINE

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/10/20	ISSUED FOR BID	KLM

SECURITY
PUBLIC ☐
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

BOILER 7, 8 & 9 MCC ROOM INVERTER PANEL SCHEDULES

DATE	DRAWN	CHK'D.
01/03/20	BLP	SDS
SCALE: NONE		APPROVED: MET

E-201

PANEL: DP-1 (1)

LOCATION: **AQCS BUILDING** | VOLTAGE: **480/277V, 3Ø, 4W** | REMARKS: **SUPPLIED FROM**
MOUNTING: **STRUT** | BUS RATING: **800A** | **SUS EAST BUS F4C**
DWG NO: **E-404** | OCP: **800A** | **FEED THRU LUGS**
TO DP-1A

CKT	WIRE SIZE	DESCRIPTION	BRKR	DIV %	LOAD KVA		LOAD KVA	DIV %	BRKR	DESCRIPTION	WIRE SIZE	CKT
1	1/0 AWG	CO2 STORAGE VAPORIZER	150A	70%	33.2	A	11.1	100%	100A	CO2 REFRIG COMP 2 (PANEL)	3 AWG	2
3	1/0 AWG	|	|	70%	33.2	B	11.1	100%	|	|	3 AWG	4
5	1/0 AWG	|	|	70%	33.2	C	11.1	100%	|	|	3 AWG	6
7	1/0 AWG	HTR-8002 CDS PURGE ST HTR	150A	70%	33.2	A	25.0	100%	100A	75KVA TRANSFORMER TR-1	2 AWG	8
9	1/0 AWG	|	|	70%	33.2	B	25.0	100%	|	|	2 AWG	10
11	1/0 AWG	|	|	70%	33.2	C	25.0	100%	|	|	2 AWG	12
13	3 AWG	CO2 REFRIG COMP 1 (PANEL)	100A	100%	11.1	A	17.6	100%	80A	PNL-8607 AIR SLD HTR CNTRL PNL	4 AWG	14
15	3 AWG	|	|	100%	11.1	B	17.6	100%	|	|	4 AWG	16
17	3 AWG	|	|	100%	11.1	C	17.6	100%	|	|	4 AWG	18
19	4 AWG	PNL-8507 AIR SLD HTR CNTRL PNL	80A	100%	17.6	A	17.6	100%	80A	PNL-8301 PJFF HEATER CNTRL PNL	4 AWG	20
21	4 AWG	|	|	100%	17.6	B	17.6	100%	|	|	4 AWG	22
23	4 AWG	|	|	100%	17.6	C	17.6	100%	|	|	4 AWG	24
25	12 AWG	UNIT HEATER 1	20A	90%	4.4	A	4.4	90%	20A	UNIT HEATER 2	12 AWG	26
27	12 AWG	|	|	90%	4.4	B	4.4	90%	|	|	12 AWG	28
29	12 AWG	|	|	90%	4.4	C	4.4	90%	|	|	12 AWG	30
31	12 AWG	UNIT HEATER 3	20A	90%	4.4	A	4.4	90%	20A	UNIT HEATER 4	12 AWG	32
33	12 AWG	|	|	90%	4.4	B	4.4	90%	|	|	12 AWG	34
35	12 AWG	|	|	90%	4.4	C	4.4	90%	|	|	12 AWG	36
37	12 AWG	UNIT HEATER 5	20A	90%	4.4	A	4.4	90%	20A	UNIT HEATER 6	12 AWG	38
39	12 AWG	|	|	90%	4.4	B	4.4	90%	|	|	12 AWG	40
41	12 AWG	|	|	90%	4.4	C	4.4	90%	|	|	12 AWG	42

A PHASE CONNECTED LOAD KVA: **192.6** | A PHASE LOAD AMPS: **695.4**
B PHASE CONNECTED LOAD KVA: **192.6** | B PHASE LOAD AMPS: **695.4**
C PHASE CONNECTED LOAD KVA: **192.6** | C PHASE LOAD AMPS: **695.4**
TOTAL CONNECTED LOAD KVA: **577.9** | TOTAL LOAD AMPS: **695.9**

KVA DEMAND LOAD: **510.2** | AMP DEMAND LOAD: **614.4**

PANEL: LP-1 (3)

LOCATION: **AQCS BUILDING** | VOLTAGE: **208/120V, 3Ø, 4W** | REMARKS: **FED FROM 75KVA**
MOUNTING: **STRUT** | BUS RATING: **225A** | **XFMR TR-1** (4)
DWG NO: **E-404** | OCP: **200A**

CKT	WIRE SIZE	DESCRIPTION	BRKR	DIV %	LOAD KVA		LOAD KVA	DIV %	BRKR	DESCRIPTION	WIRE SIZE	CKT
1	12AWG	AQUEOUS AMMONIA PNL 5210	20A	100%	1.9	A	1.9	100%	20A	PROCEES H20 SKID PNL 7601	12AWG	2
3	12AWG	AQUEOUS AMMONIA PNL 5211	20A	100%	1.9	B	1.1	70%	20A	AIR SLIDE AERATION BLWR FANS	12AWG	4
5	12AWG	BAGHOUSE/PJFF CNTRL PNL 8303	20A	100%	1.9	C	1.1	70%	20A	BIN VENT BLWR MOTORS	12AWG	6
7	12AWG	BAGHOUSE/PJFF CNTRL PNL XXX	20A	100%	1.9	A	0.0	100%	20A	LIGHTING	12AWG	8
9	12AWG	AQCS CNTRL PNL	20A	100%	1.9	B	0.0	100%	20A	LIGHTING	12AWG	10
11	12AWG	LIGHTING	20A	100%	0.0	C	0.0	80%	20A	GENERAL RECEPTACLES	12AWG	12
13	12AWG	LIGHTING	20A	100%	0.0	A	0.0	80%	20A	GENERAL RECEPTACLES	12AWG	14
15	12AWG	GENERAL RECEPTACLES	20A	80%	0.0	B	0.0	0%	20A	SPARE		16
17		SPARE	20A	0%	0.0	C	0.0	0%	20A	SPARE		18
19		SPARE	20A	0%	0.0	A	0.0	0%	20A	SPARE		20
21		SPARE	20A	0%	0.0	B	0.0	0%	20A	SPARE		22
23		SPARE	20A	0%	0.0	C	0.0	0%	20A	SPARE		24
25		SPARE	20A	0%	0.0	A	0.0	0%	20A	SPARE		26
27		SPARE	20A	0%	0.0	B	0.0	0%	20A	SPARE		28
29		SPARE	20A	0%	0.0	C	0.0	0%	20A	SPARE		30
31		SPACE		0%	0.0	A	0.0	0%		SPACE		32
33		SPACE		0%	0.0	B	0.0	0%		SPACE		34
35		SPACE		0%	0.0	C	0.0	0%		SPACE		36
37		SPACE		0%	0.0	A	0.0	0%		SPACE		38
39		SPACE		0%	0.0	B	0.0	0%		SPACE		40
41		SPACE		0%	0.0	C	0.0	0%		SPACE		42

A PHASE CONNECTED LOAD KVA: **5.7** | A PHASE LOAD AMPS: **47.5**
B PHASE CONNECTED LOAD KVA: **4.9** | B PHASE LOAD AMPS: **41.1**
C PHASE CONNECTED LOAD KVA: **3.0** | C PHASE LOAD AMPS: **25.1**
TOTAL CONNECTED LOAD KVA: **13.6** | TOTAL LOAD AMPS: **37.9**

KVA DEMAND LOAD: **13.0** | AMP DEMAND LOAD: **36.1**

PANEL: DP-1A (2)

LOCATION: **AQCS BUILDING** | VOLTAGE: **480/277V, 3Ø, 4W** | REMARKS: **SUPPLIED FROM**
MOUNTING: **STRUT** | BUS RATING: **800A** | **SUS EAST BUS F4C**
DWG NO: **E-404** | OCP: **MLO** | **FEED THRU LUGS**
FROM DP-1

CKT	WIRE SIZE	DESCRIPTION	BRKR	DIV %	LOAD KVA		LOAD KVA	DIV %	BRKR	DESCRIPTION	WIRE SIZE	CKT
1	12 AWG	UNIT HEATER 7	20A	90%	4.4	A	4.4	90%	20A	UNIT HEATER 8	12 AWG	2
3	12 AWG	|	|	90%	4.4	B	4.4	90%	|	|	12 AWG	4
5	12 AWG	|	|	90%	4.4	C	4.4	90%	|	|	12 AWG	6
7	12 AWG	UNIT HEATER 9	20A	90%	4.4	A	4.4	90%	20A	UNIT HEATER 10	12 AWG	8
9	12 AWG	|	|	90%	4.4	B	4.4	90%	|	|	12 AWG	10
11	12 AWG	|	|	90%	4.4	C	4.4	90%	|	|	12 AWG	12
13		PJFF MODULE C HOPPER HTR	30A	0%		A		0%	15A	AIR SLIDE BYPRDCT ROTARY FDR		14
15		|	|	0%		B		0%	|	|		16
17		|	|	0%		C		0%	|	|		18
19		PJFF MODULE D HOPPER HTR	20A	0%		A		0%	30A	AIR SLIDE BYPRDCT ROTARY FDR		20
21		|	|	0%		B		0%	|	|		22
23		|	|	0%		C		0%	|	|		24
25		PJFF MODULE E HOPPER HTR	30A	0%		A		0%		SPACE		26
27		|	|	0%		B		0%	|	|		28
29		|	|	0%		C		0%	|	|		30
31		PJFF MODULE A HOPPER HTR	15A	0%		A		0%		SPACE		32
33		|	|	0%		B		0%	|	|		34
35		|	|	0%		C		0%	|	|		36
37		PJFF MODULE B HOPPER HTR	30A	0%		A		0%		SPACE		38
39		|	|	0%		B		0%	|	|		40
41		|	|	0%		C		0%	|	|		42

A PHASE CONNECTED LOAD KVA: **17.6** | A PHASE LOAD AMPS: **63.5**
B PHASE CONNECTED LOAD KVA: **17.6** | B PHASE LOAD AMPS: **63.5**
C PHASE CONNECTED LOAD KVA: **17.6** | C PHASE LOAD AMPS: **63.5**
TOTAL CONNECTED LOAD KVA: **52.8** | TOTAL LOAD AMPS: **63.6**

KVA DEMAND LOAD: **47.5** | AMP DEMAND LOAD: **57.2**

NOTES:

1. ELECTRICAL CONTRACTOR SHALL FURNISH AND INSTALL PHENOLIC PLATES, TYPED PANEL DIRECTORIES INDICATING PANEL DESIGNATION, CIRCUIT NUMBERS AND EQUIPMENT SERVED FOR ALL PANELS.
2. ALL UNIT HEATERS TO HAVE INTEGRAL DISCONNECT PROVIDED BY OTHERS.
3. FOR PRICING PURPOSES AT THIS TIME EC SHALL USE AN AVERAGE OF 80' FOR BRANCH CIRCUITS FOR UNIT HEATERS.

KEY NOTES:

(1) ELECTRICAL CONTRACTOR TO PROVIDE AND INSTALL DP-1: 480/277VAC, 3Ø, 4 WIRE, NEMA 12, 800A BUS, 65KAIC, FULLY RATED, 800A MCB, 42 CIRCUIT PANELBOARD W/ FEED THRU LUGS. PROVIDE BREAKERS PER PANEL SCHEDULE.

(2) ELECTRICAL CONTRACTOR TO PROVIDE AND INSTALL DP-1A: 480/277VAC, 3Ø, 4 WIRE, NEMA 12, 800A BUS, 65KAIC, FULLY RATED 800A MLO, 42 CIRCUIT PANELBOARD. PROVIDE BREAKERS PER PANEL SCHEDULE.

(3) ELECTRICAL CONTRACTOR TO PROVIDE AND INSTALL LP-1: 208/120VAC, 3Ø, 4 WIRE, NEMA 12, 200A BUS, 22KAIC, 200A MCB, 42 CIRCUIT PANELBOARD. FED FROM 4-1/C #4/0 AWG W/ #2 AWG GND. PROVIDE BREAKERS PER PANEL SCHEDULE.

(4) ELECTRICAL CONTRACTOR TO PROVIDE TR-1: 480V-208Y/120VAC, 3Ø, 3 WIRE, 75KVA NEMA 12 DRY TYPE TRANSFORMER.

REFERENCE DRAWINGS:

REFER TO DWG. E-001 FOR DRAWING INDEX.

PRELIMINARY
NOT FOR CONSTRUCTION

SECURITY
PUBLIC ☐
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

NO.	DATE	REVISION	BY
A	08/10/20	ISSUED FOR BID	KLM

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

AQCS
PANEL SCHEDULES
ELECTRICAL

DATE	DRAWN	CHK'D.
07/24/20	BLP	SDS
SCALE NONE		APPROVED MET

E-202

PANEL: DP-2 (1)

LOCATION: **BOILER BUILDING** | VOLTAGE: **480/277V, 3Ø, 4W** | REMARKS: **SUPPLIED FROM SUS EAST BUS F5B FEED THRU LUGS** TO DP-2A

MOUNTING: **STRUT** | BUS RATING: **800A**

DWG NO: **E-402** | OCP: **800A**

CKT	WIRE SIZE	DESCRIPTION	BRKR	DIV %	LOAD KVA		LOAD KVA	DIV %	BRKR	DESCRIPTION	WIRE SIZE	CKT
1	10 AWG	UNIT HEATER 1	30A	90%	5.3	A	25.0	100%	100A	75 KVA TRANSFORMER TR-2	2 AWG	2
3	10 AWG	|	|	90%	5.3	B	25.0	100%	|	|	2 AWG	4
5	10 AWG	|	|	90%	5.3	C	25.0	100%	|	|	2 AWG	6
7	10 AWG	UNIT HEATER 2	30A	90%	5.3	A	6.6	100%	30A	LUBE OIL CONTROL PNL	10 AWG	8
9	10 AWG	|	|	90%	5.3	B	6.6	100%	|	|	10 AWG	10
11	10 AWG	|	|	90%	5.3	C	6.6	100%	|	|	10 AWG	12
13	10 AWG	SEAL GAS COMPRESSOR PNL	30A	100%	6.6	A	33.2	100%	150A	DRY GAS SEAL CONTROL PNL	1/0 AWG	14
15	10 AWG	|	|	100%	6.6	B	33.2	100%	|	|	1/0 AWG	16
17	10 AWG	|	|	100%	6.6	C	33.2	100%	|	|	1/0 AWG	18
19	10 AWG	UNIT HEATER 3	30A	90%	5.3	A	5.3	90%	30A	UNIT HEATER 4	10 AWG	20
21	10 AWG	|	|	90%	5.3	B	5.3	90%	|	|	10 AWG	22
23	10 AWG	|	|	90%	5.3	C	5.3	90%	|	|	10 AWG	24
25	10 AWG	UNIT HEATER 5	30A	90%	5.3	A	5.3	90%	30A	UNIT HEATER 6	10 AWG	26
27	10 AWG	|	|	90%	5.3	B	5.3	90%	|	|	10 AWG	28
29	10 AWG	|	|	90%	5.3	C	5.3	90%	|	|	10 AWG	30
31	10 AWG	UNIT HEATER 7	30A	90%	5.3	A	5.3	90%	30A	UNIT HEATER 8	10 AWG	32
33	10 AWG	|	|	90%	5.3	B	5.3	90%	|	|	10 AWG	34
35	10 AWG	|	|	90%	5.3	C	5.3	90%	|	|	10 AWG	36
37	10 AWG	UNIT HEATER 9	30A	90%	5.3	A	5.3	90%	30A	UNIT HEATER 10	10 AWG	38
39	10 AWG	|	|	90%	5.3	B	5.3	90%	|	|	10 AWG	40
41	10 AWG	|	|	90%	5.3	C	5.3	90%	|	|	10 AWG	42

A PHASE CONNECTED LOAD KVA: **124.5** | A PHASE LOAD AMPS: **449.4**

B PHASE CONNECTED LOAD KVA: **124.5** | B PHASE LOAD AMPS: **449.4**

C PHASE CONNECTED LOAD KVA: **124.5** | C PHASE LOAD AMPS: **449.4**

TOTAL CONNECTED LOAD KVA: **373.4** | TOTAL LOAD AMPS: **449.7**

KVA DEMAND LOAD: **357.5** | AMP DEMAND LOAD: **430.6**

PANEL: LP-2 (3)

LOCATION: **BOILER BUILDING** | VOLTAGE: **208/120V, 3Ø, 4W** | REMARKS: **FED FROM 75KVA XFMR TR-2** (4)

MOUNTING: **STRUT** | BUS RATING: **225A**

DWG NO: **E-402** | OCP: **200A**

CKT	WIRE SIZE	DESCRIPTION	BRKR	DIV %	LOAD KVA		LOAD KVA	DIV %	BRKR	DESCRIPTION	WIRE SIZE	CKT
1	10AWG	GEN REM I/O CABINET A/C	25A	70%	2.1	A	2.1	70%	25A	LUBE OIL REM I/O CABINET A/C	10AWG	2
3	10AWG	GEN SKID REM I/O CABINET A/C	25A	70%	2.1	B	2.1	70%	25A	IHX SKID REM I/O CABINET A/C	10AWG	4
5	10AWG	PHX SKID REM I/O CABINET A/C	25A	70%	2.1	C	2.1	70%	25A	ICS REM I/O CABINET A/C	10AWG	6
7	10AWG	PWR SKID REM I/O CABINET A/C	25A	70%	2.1	A	2.1	70%	25A	PROC. SKID REM I/O CABINET A/C	10AWG	8
9	10AWG	GEN REMOTE I/O CABINET A/C	25A	70%	2.1	B	1.9	100%	20A	[RLY]BMS CNTRL PNL	12AWG	10
11	10AWG	GENERATOR HEATERS	25A	70%	2.3	C	1.9	100%	20A	[RLY] CCS/BOP PNL	12AWG	12
13	12AWG	POWER SKID RECEPTACLES 1	20A	80%	0.7	A	3.0	80%	60A	REXA UPS	6 AWG	14
15	12AWG	POWER SKID RECEPTACLES 2	20A	80%	0.7	B	3.0	80%	|	|	6 AWG	16
17	12AWG	POWER SKID RECEPTACLES 3	20A	80%	0.7	C	0.0	0%				18
19	12AWG	POWER SKID LIGHTS	20A	100%	0.7	A	0.0	0%				20
21	12AWG	[RLY] NAT. GAS CNTRL SKID PNL	20A	100%	1.9	B	0.0	0%				22
23	12AWG	[RLY]SSO SKID TERM PNL JB-1200	20A	100%	1.9	C	0.0	0%				24
25	12AWG	[RLY]SSO SKID TERM PNL JB-1300	20A	100%	1.9	A	0.0	0%				26
27	12AWG	[RLY]SHROUD TERM PNL 1204	20A	100%	1.9	B	0.0	0%				28
29	12AWG	[RLY]SHROUD TERM PNL 1304	20A	100%	1.9	C	0.0	0%				30
31	12AWG	[RLY]FLAME SCNR TER PNL 1200	20A	100%	1.9	A	0.9	70%	15A	POWER SKID DYN. I/O CABINET A/C	12AWG	32
33	12AWG	[RLY]FLAME SCNR TER PNL 1300	20A	100%	1.9	B	0.9	70%	15A	PROC. SKID DYN. I/O CABINET A/C	12AWG	34
35				0%	0.0	C	0.4	100%	15A	MCC RIO CABINET	12AWG	36
37				0%	0.0	A	0.9	70%	15A	GEN SKID DYN. I/O CABINET A/C	12AWG	38
39				0%	0.0	B	0.1	0%	15A	POWER SKID DAMPER GRV-1	12AWG	40
41				0%	0.0	C	0.1	0%	15A	POWER SKID DAMPER GIV-1	12AWG	42

A PHASE CONNECTED LOAD KVA: **18.5** | A PHASE LOAD AMPS: **154.3**

B PHASE CONNECTED LOAD KVA: **18.7** | B PHASE LOAD AMPS: **155.8**

C PHASE CONNECTED LOAD KVA: **13.5** | C PHASE LOAD AMPS: **112.3**

TOTAL CONNECTED LOAD KVA: **50.7** | TOTAL LOAD AMPS: **140.9**

KVA DEMAND LOAD: **41.6** | AMP DEMAND LOAD: **115.7**

PANEL: DP-2A (2)

LOCATION: **BOILER BUILDING** | VOLTAGE: **480/277V, 3Ø, 4W** | REMARKS: **SUPPLIED FROM SUS EAST BUS F5B FEED THRU LUGS** TO DP-2

MOUNTING: **STRUT** | BUS RATING: **800A**

DWG NO: **E-402** | OCP: **MLO**

CKT	WIRE SIZE	DESCRIPTION	BRKR	DIV %	LOAD KVA		LOAD KVA	DIV %	BRKR	DESCRIPTION	WIRE SIZE	CKT
1	10AWG	UNIT HEATER 11	30A	90%	5.3	A	5.3	90%	30A	UNIT HEATER 12	10AWG	2
3	10AWG	|	|	90%	5.3	B	5.3	90%	|	|	10AWG	4
5	10AWG	|	|	90%	5.3	C	5.3	90%	|	|	10AWG	6
7	10AWG	UNIT HEATER 13	30A	90%	5.3	A	5.3	90%	30A	UNIT HEATER 14	10AWG	8
9	10AWG	|	|	90%	5.3	B	5.3	90%	|	|	10AWG	10
11	10AWG	|	|	90%	5.3	C	5.3	90%	|	|	10AWG	12
13	10AWG	UNIT HEATER 15	30A	90%	5.3	A	5.3	90%	30A	UNIT HEATER 16	10AWG	14
15	10AWG	|	|	90%	5.3	B	5.3	90%	|	|	10AWG	16
17	10AWG	|	|	90%	5.3	C	5.3	90%	|	|	10AWG	18
19	10AWG	UNIT HEATER 17	30A	90%	5.3	A	5.3	90%	30A	UNIT HEATER 18	10AWG	20
21	10AWG	|	|	90%	5.3	B	5.3	90%	|	|	10AWG	22
23	10AWG	|	|	90%	5.3	C	5.3	90%	|	|	10AWG	24
25	10AWG	UNIT HEATER 19	30A	90%	5.3	A	5.3	90%	30A	UNIT HEATER 20	10AWG	26
27	10AWG	|	|	90%	5.3	B	5.3	90%	|	|	10AWG	28
29	10AWG	|	|	90%	5.3	C	5.3	90%	|	|	10AWG	30
31		SPARE	20A	0%		A		0%	20A	SPARE		32
33		|	|	0%		B		0%	|	|		34
35		|	|	0%		C		0%	|	|		36
37		SPACE		0%		A		0%		SPACE		38
39		|		0%		B		0%		|		40
41		|		0%		C		0%		|		42

A PHASE CONNECTED LOAD KVA: **53.0** | A PHASE LOAD AMPS: **191.3**

B PHASE CONNECTED LOAD KVA: **53.0** | B PHASE LOAD AMPS: **191.3**

C PHASE CONNECTED LOAD KVA: **53.0** | C PHASE LOAD AMPS: **191.3**

TOTAL CONNECTED LOAD KVA: **159.0** | TOTAL LOAD AMPS: **191.5**

KVA DEMAND LOAD: **143.1** | AMP DEMAND LOAD: **172.3**

NOTES:

1. ELECTRICAL CONTRACTOR SHALL FURNISH AND INSTALL PHENOLIC PLATES, TYPED PANEL DIRECTORIES INDICATING PANEL DESIGNATION, CIRCUIT NUMBERS AND EQUIPMENT SERVED FOR ALL PANELS.
2. ALL UNIT HEATERS TO HAVE INTEGRAL DISCONNECT PROVIDED BY OTHERS.

KEY NOTES:

(1) ELECTRICAL CONTRACTOR TO PROVIDE AND INSTALL DP-2: 480/277VAC, 3Ø, 4 WIRE, NEMA 12, 800A MCB, 65KAIC, FULLY RATED 800A MCB, 42 CIRCUIT PANELBOARD W/ FEED THRU LUGS. PROVIDE BREAKERS PER PANEL SCHEDULE.

(2) ELECTRICAL CONTRACTOR TO PROVIDE AND INSTALL DP-2A: 480/277VAC, 3Ø, 4 WIRE, NEMA 12, 800A MLO, 65KAIC, FULLY RATED, 800A MLO, 42 CIRCUIT PANELBOARD. PROVIDE BREAKERS PER PANEL SCHEDULE.

(3) ELECTRICAL CONTRACTOR TO PROVIDE AND INSTALL LP-2: 208/120VAC, 3Ø, 4 WIRE, NEMA 12, 200A MCB, 22KAIC, 200A MCB, 42 CIRCUIT PANELBOARD. FED FROM 4-1/C #4/0 AWG W/ #2 AWG GND. PROVIDE BREAKERS PER PANEL SCHEDULE.

(4) ELECTRICAL CONTRACTOR TO PROVIDE TR-2: 480V-208Y/120VAC, 3Ø, 3 WIRE, 75KVA DRY TYPE NEMA 12 TRANSFORMER.

PRELIMINARY
NOT FOR CONSTRUCTION

SECURITY

PUBLIC ☐
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

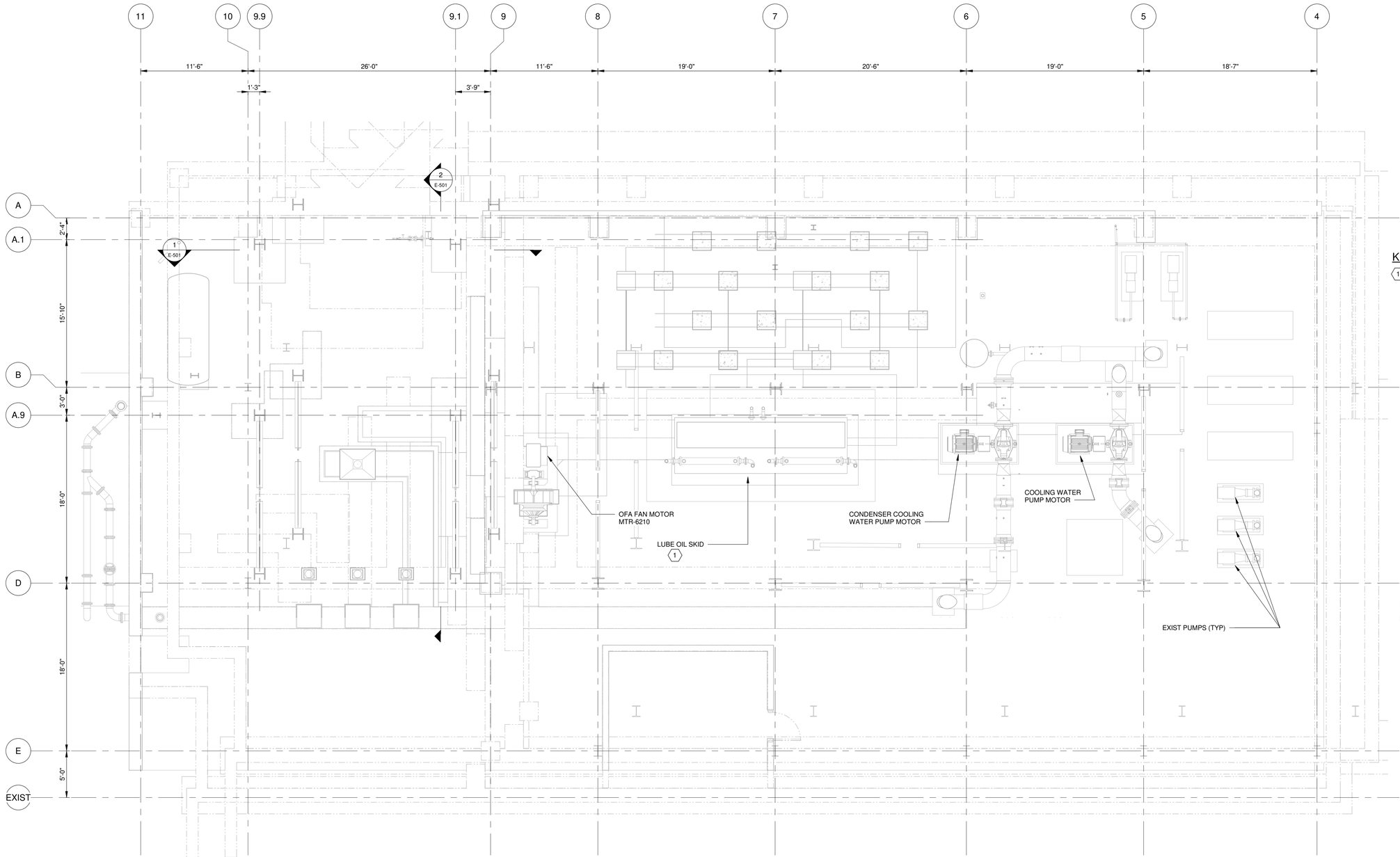
NO.	DATE	REVISION	BY
A	08/10/20	ISSUED FOR BID	KLM

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

BOILERHOUSE
PANEL SCHEDULES
ELECTRICAL

DATE	DRAWN	CHK'D.
07/24/20	BLP	SDS
SCALE: NONE		APPROVED: MET

E-203



KEY NOTES:

1. LUBE OIL SKID CONTAINS THE FOLLOWING 480VAC EQUIPMENT:
   - LUBE OIL HEATER HTR-1
   - LUBE OIL COOLING FAN EF-2
   - LUBE OIL PUMPS 1, 2 & 3
   - LUBE CONTROL PANEL
   - JACKING OIL PUMP P-10
   - JACKING OIL PUMP P-11
   - JACKING OIL PUMP P-XX

REFERENCE DRAWINGS:

REFER TO DRAWING E-001 FOR DRAWING INDEX

EXIST BOILER ROOM BASEMENT POWER PLAN

SCALE: 3/16" = 1'-0"

3/16" = 1'-0"

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/10/20	ISSUED FOR BID	KLM

SECURITY

PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

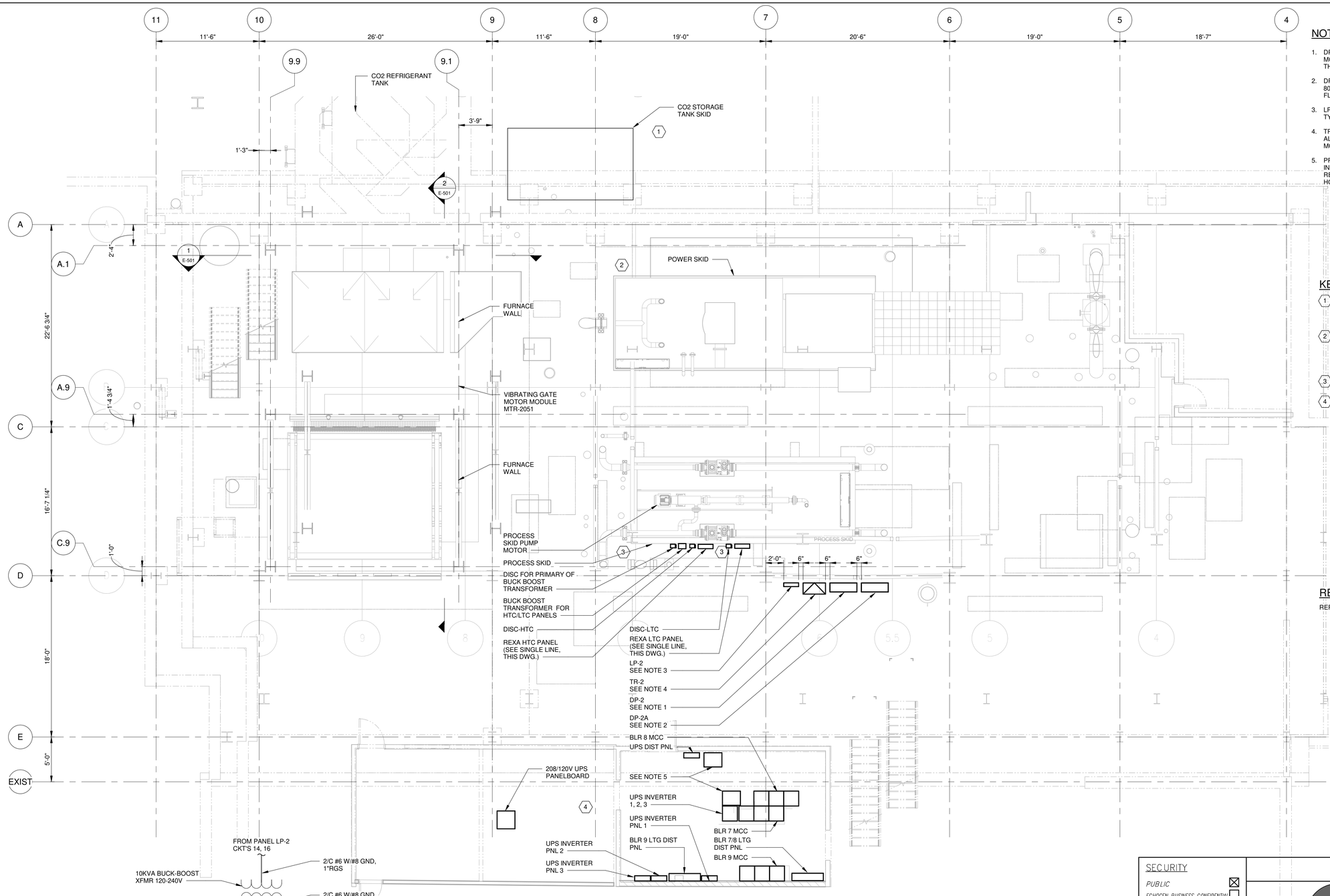
2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

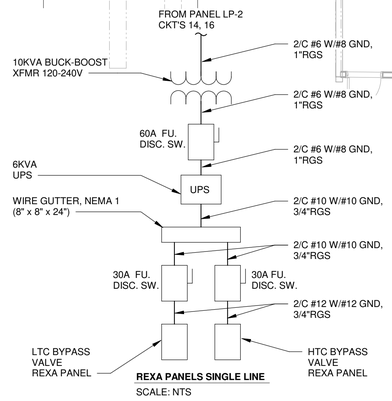
ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

ELECTRICAL
EXISTING BOILER ROOM BASEMENT FLOOR ELECTRICAL POWER PLAN

DATE	DRAWN	CHK'D.
04/30/20	BLP	SDS
SCALE 3/16" = 1'-0"		APPROVED MET

E-401





NOTES:

1. DP-2 POWER DISTRIBUTION PANEL: 480Y/277V, 3-PH, 4-WIRE, 800A MCB, FULLY-RATED, NEMA TYPE 12, 42 CIRCUIT W/ FEED THROUGH LUGS, 65KAIC, FLOOR MOUNTED.
2. DP-2A POWER DISTRIBUTION PANEL: 480Y/277V, 3-PH, 4-WIRE, 800A MLO, FULLY-RATED, NEMA TYPE 12, 42 CIRCUIT, 65KAIC, FLOOR MOUNTED.
3. LP-2 LIGHTING PANEL: 208Y/120V, 3-PH, 4-WIRE, 200A MCB, NEMA TYPE 12, 42 CIRCUIT, 22KAIC, MOUNTED ON UNISTRUT.
4. TR-2 TRANSFORMER: 75KVA, 480V-208Y/120V, 3-PH, 4-WIRE, ALUMINUM WINDINGS, NEMA TYPE 12, DRY TYPE, FLOOR MOUNTED.
5. PROPOSED LOCATIONS FOR NEW UPS INVERTER 1 AND UPS INVERTER 2. EC SHALL FIELD VERIFY INSTALLATION REQUIREMENTS FOR INVERTERS. EC SHALL FIELD INSTALL 4" HOUSEKEEPING PAD FOR FLOOR MOUNTED INVERTERS.

KEY NOTES:

1. CO2 STORAGE SKID CONTAINS THE FOLLOWING 480VAC EQUIPMENT:
   - TRANSFER PUMP P-7
   - COMP 1 & 2 PANELS
   - VAPORIZER
2. POWER SKID CONTAINS THE FOLLOWING 480VAC EQUIPMENT:
   - HVAC FAN
   - SEAL GAS COMPRESSOR & PANEL
   - DGS HEATERS (4)
   - DRY GAS SEAL CONTROL PANEL
3. EC SHALL MOUNT ELECTRICAL EQUIPMENT TO UNISTRUT RACK . TOP OF EQUIPMENT SHALL BE 6'-0" AFF.
4. EC SHALL DE-ENERGIZE, DISCONNECT, AND REMOVE UPS INVERTER 1, & UPS INVERTER 2. EC SHALL TURN OVER EQUIPMENT TO OWNER. EC SHALL FURNISH AND INSTALL NEW 15KVA INVERTERS. LOCATION OF NEW EQUIPMENT SHOWN ON DRAWING. SEE NOTE 3.

REFERENCE DRAWINGS:

REFER TO E-001 FOR DRAWING INDEX

EXIST BOILER ROOM OPERATOR FLOOR POWER PLAN

SCALE: 3/16" = 1'-0"

3/16" = 1'-0"

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/10/20	ISSUED FOR BID	KLM

SECURITY
PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

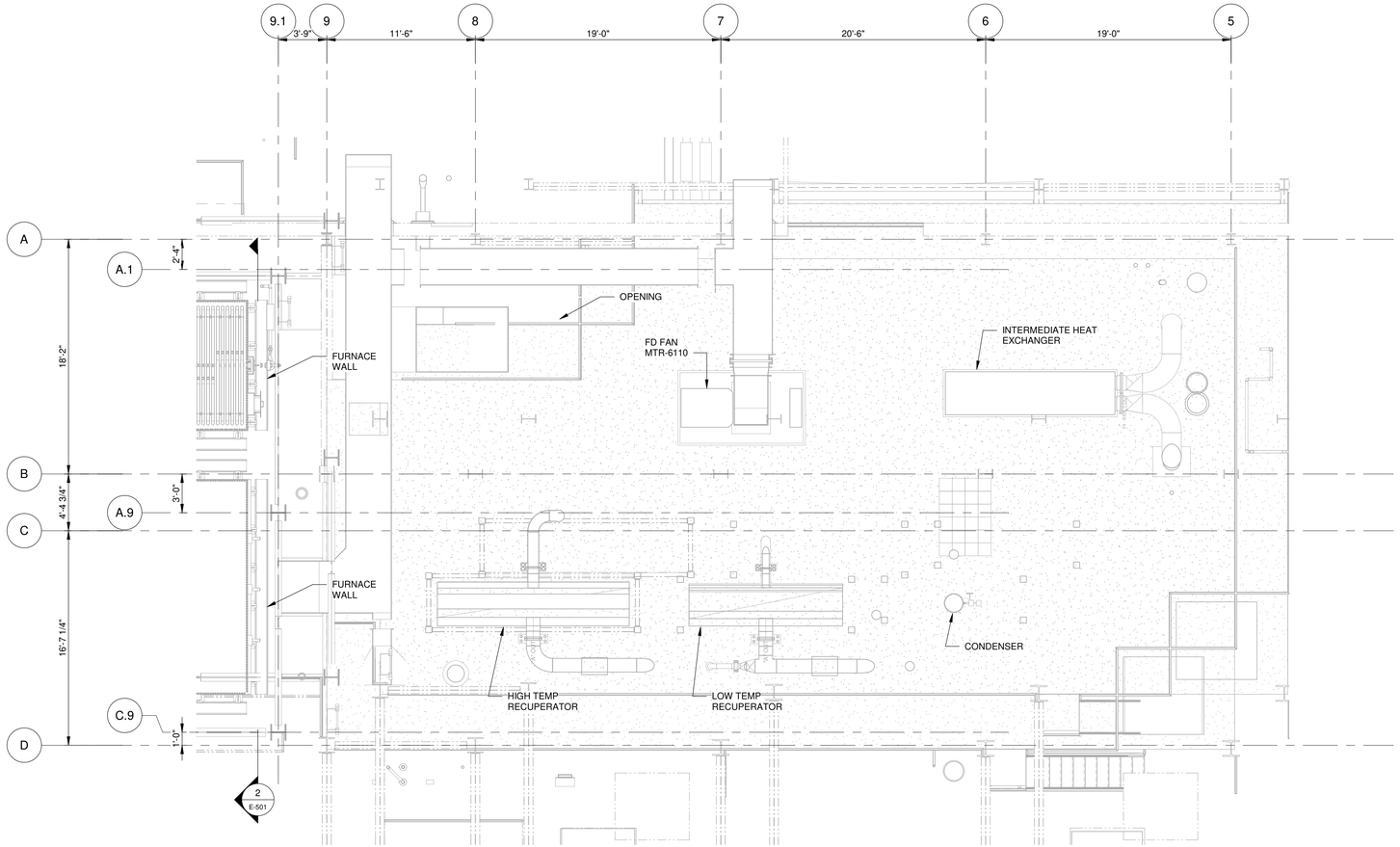
2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

ELECTRICAL
EXISTING BOILER ROOM OPERATOR FLOOR ELECTRICAL POWER PLAN

DATE	DRAWN	CHK'D.
04/30/20	BLP	SDS
SCALE 3/16" = 1'-0"		APPROVED MET

E-402



CONDENSOR SUPPT EL 723'-5"

SCALE: 3/16" = 1'-0"

3/16" = 1'-0"

1" 0 1' 2' 3' 4' 6' 8' 10'

PRELIMINARY
NOT FOR CONSTRUCTION

REFERENCE DRAWINGS:

REFER TO DRAWING E-001 FOR DRAWING INDEX

NO.	DATE	REVISION	BY
A	08/10/20	ISSUED FOR BID	KLM

SECURITY

PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

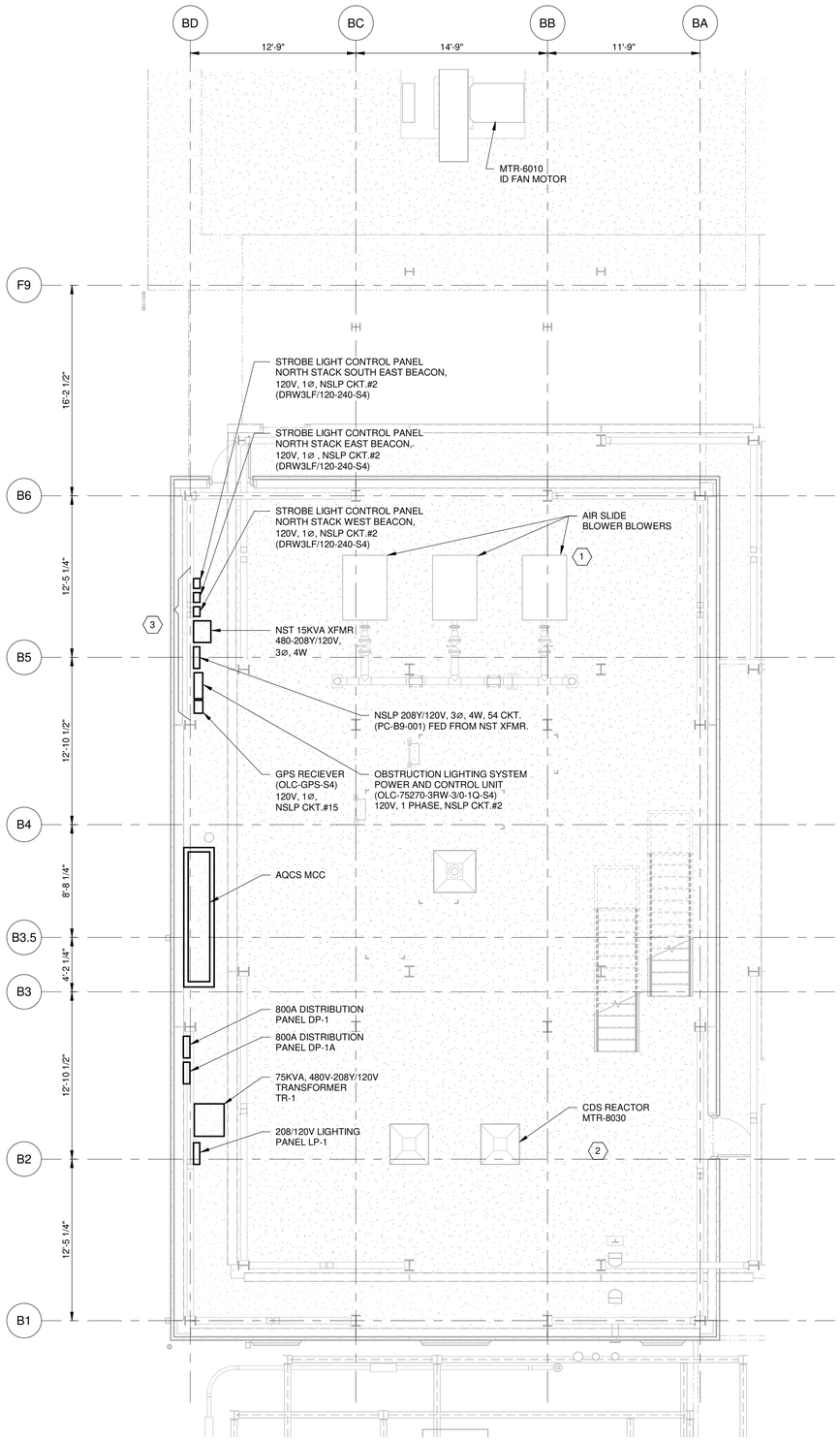
2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

ELECTRICAL
ELEVATED PLATFORM @ TOC EL 723'-5" ELECTRICAL PLAN

DATE	DRAWN	CHK'D.
04/30/20	AB	SDS
SCALE 3/16" = 1'-0"		APPROVED MET

E-403



EXIST BAGHOUSE FLOOR EL 736'-0"
SCALE: 3/16" = 1'-0"

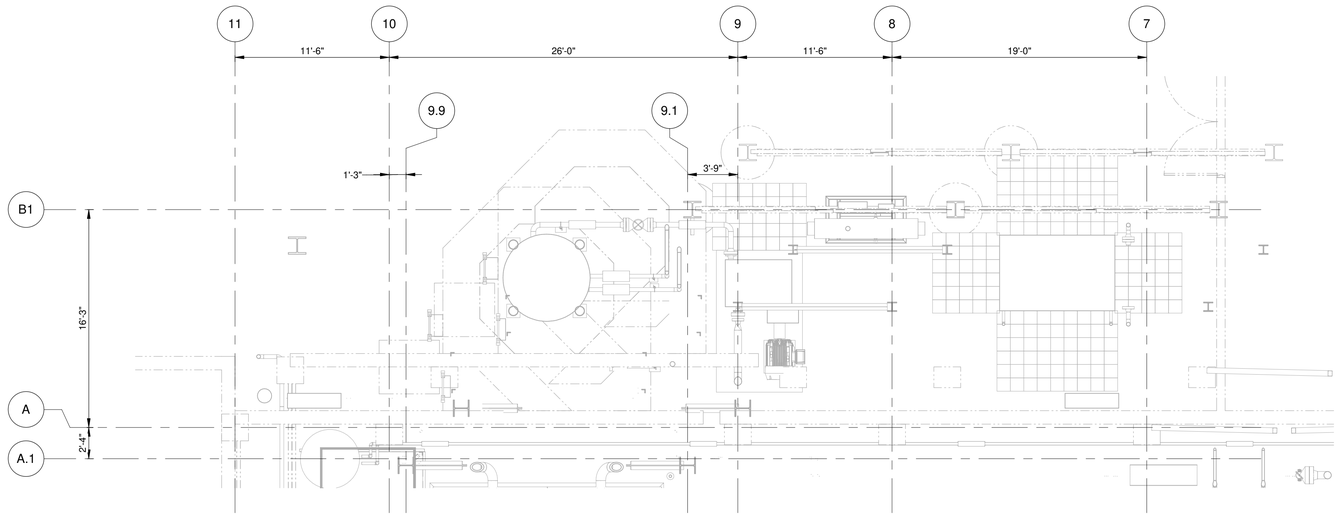
3/16" = 1'-0"
1' 0 1' 2' 3' 4' 6' 8' 10'

NOTES:

1. EC SHALL RE-LOCATE EXISTING ELECTRICAL EQUIPMENT FROM NOTH STACK. REFER TO DWG. E-417-DEMO.

KEY NOTES:

1. AIR SLIDE BLOWER CABINETS CONTAINS THE FOLLOWING 480VAC EQUIP.:
   - AIR SLIDE AERATION BLOWER MOTORS 8501A & 8501B
   - AIR SLIDE AERATION BLOWER MOTOR COMMON 8501
   - AIR SLIDE DISCHARGE ROTARY FEEDER MOTOR 8505A
   - AIR SLIDE BY PRODUCT ROTARY FEED MOTOR 8502, 8602 & 8605A
   - AIR SLIDE HEATER CONTROL PANELS 8507 & 8607
2. HTR-8002 CDS OUTLET TRANSMITTER PURGE STATION HEATER IS LOCATED IN THIS AREA. EC TO VERIFY LOCATION.
3. ELECTRICAL CONTRACTOR SHALL MOUNT EQUIPMENT RELOCATED FROM NORTH STACK. REFER TO DEMOLITION DWG. E-417-DEMO.



POWER PLAN @ TOC EL 705'-1"
SCALE: 3/16" = 1'-0"

REFERENCE DRAWINGS:

REFER TO DRAWING E-001 FOR DRAWING INDEX

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/10/20	ISSUED FOR BID	KLM

SECURITY
PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

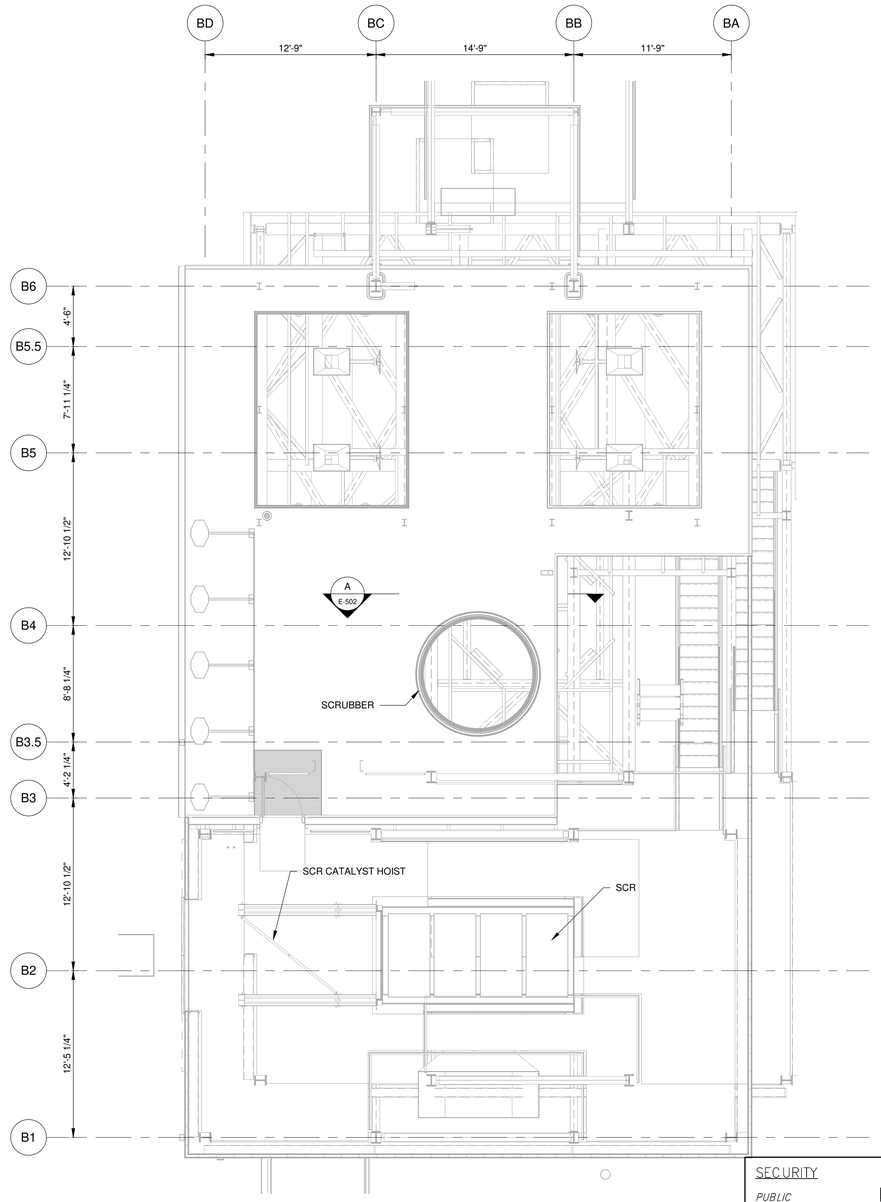
ELECTRICAL
EXISTING BAGHOUSE FLOOR ELECTRICAL PLAN

DATE	DRAWN	CHK'D.
04/30/20	BLP	SDS
SCALE 3/16" = 1'-0"		APPROVED MET

E-404



PLATF @ EL 751'-4"
SCALE: 3/16" = 1'-0"



PLATF @ EL 763'-2 1/2"
SCALE: 3/16" = 1'-0"

REFERENCE DRAWINGS:

REFER TO E-001 FOR DRAWING INDEX

3/16" = 1'-0"

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/10/20	ISSUED FOR BID	KLM

SECURITY

PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

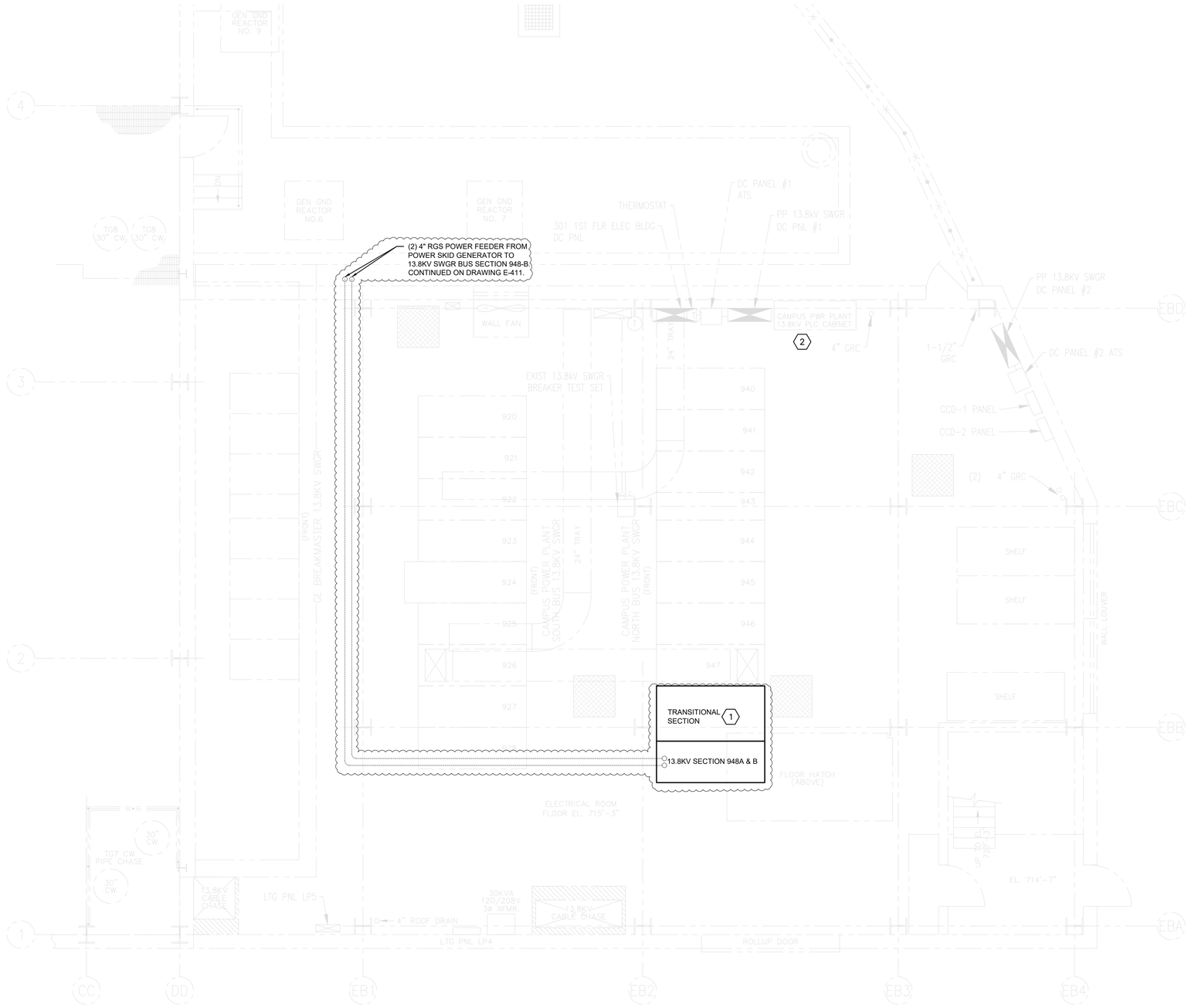
2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

ELECTRICAL
ELEVATED PLATFORMS @ TOC EL 751'-4" ELECTRICAL PLAN

DATE	DRAWN	CHK'D.
04/30/20	AB	SDS
SCALE 3/16" = 1'-0"		APPROVED MET

E-405



ELECTRICAL BUILDING
1ST FLOOR 13.8KV PLAN
SCALE: 1/4"=1'-0"

1/4" = 1'-0"

NOTES:

1. THE CONDUIT LAYOUT IS DIAGRAMMATICAL AND SHOW THE INTENT OF THE ELECTRICAL ENGINEER TO HAVE THE CONDUIT SYSTEM INSTALLED IN A NEAT AND ORGANIZED MANNER. EC SHALL REVIEW ALL VENDOR DRAWINGS, CONSTRUCTION DOCUMENTS AND FIELD CONDITIONS PRIOR TO THE INSTALLATION AND LAYOUT OF CONDUITS.
2. ELECTRICAL CONTRACTOR SHALL RECEIVE, STORE AND INSTALL NEW 13.8 KV SWITCHGEAR 48" TRANSITION SECTION ALONG W/ BREAKER, SYNCHROSCOPE, CONTROL AND PROTECTIVE RELAY, SECTION TO BE PROVIDED BY OTHERS. EC SHALL COORDINATE SHUTDOWN, RECEIVING SWGR, STORING SWGR AND INSTALLATION WITH UNIVERSITY OF MISSOURI, CONSTRUCTION MANAGEMENT AND OTHER TRADES.
3. ALL NEW 15 KV FEEDER CABLES SHALL BE TESTED USING A VERY LOW FREQUENCY TEST (VLF TEST).
4. HI-POT TESTING IS NOT ACCEPTABLE.
5. NEW BREAKER SHALL BE TESTED USING PRIMARY CURRENT INJECTION TEST PRIOR TO INSTALLING.
6. EC SHALL ASSIST FACTORY REP AND UNIVERSITY OF MISSOURI W/ START UP AND COMMISSIONING.

KEY NOTES:

1. TRANSITIONAL SECTION SHALL BE 48" WIDE. EC TO FIELD VERIFY PRIOR TO PROCUREMENT OF SWGR BY OTHERS TO ENSURE WIDTH DIMENSION EXCEEDS EDGE OF COLUMN EBB/EB2 TO ALLOW DOOR TO OPEN ON 13.8KV SECTION. IF CONFLICTS ARISE CONTACT CONSTRUCTION MANAGER.
2. EC SHALL PROVIDE AND INSTALL THE FOLLOWING CABLES FROM 13.8 KV CONTROL CUBICLE 948A TO THE CAMPUS PWR PLANT 13. KV PLC CABINET;
   - ONE (1) CAT 6 DATA CABLE
   - ONE (1) 4 PAIR XLPE/XL-CPE, INSTRUMENTATION CABLE, 600V, UL TYPE INDIVIDUAL AND OVERALL SHIELDED PAIRS 16 AWG, METHOD 1 COLOR CODE
   - ONE (1) 5 CONDUCTOR XLPE/XL-CPE CONTROL, UNSHIELDED, 600V, UL TYPE, 14 AWG, METHOD E2 COLOR CODE

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/10/20	ISSUED FOR BID	KLM

SECURITY
PUBLIC ☐
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

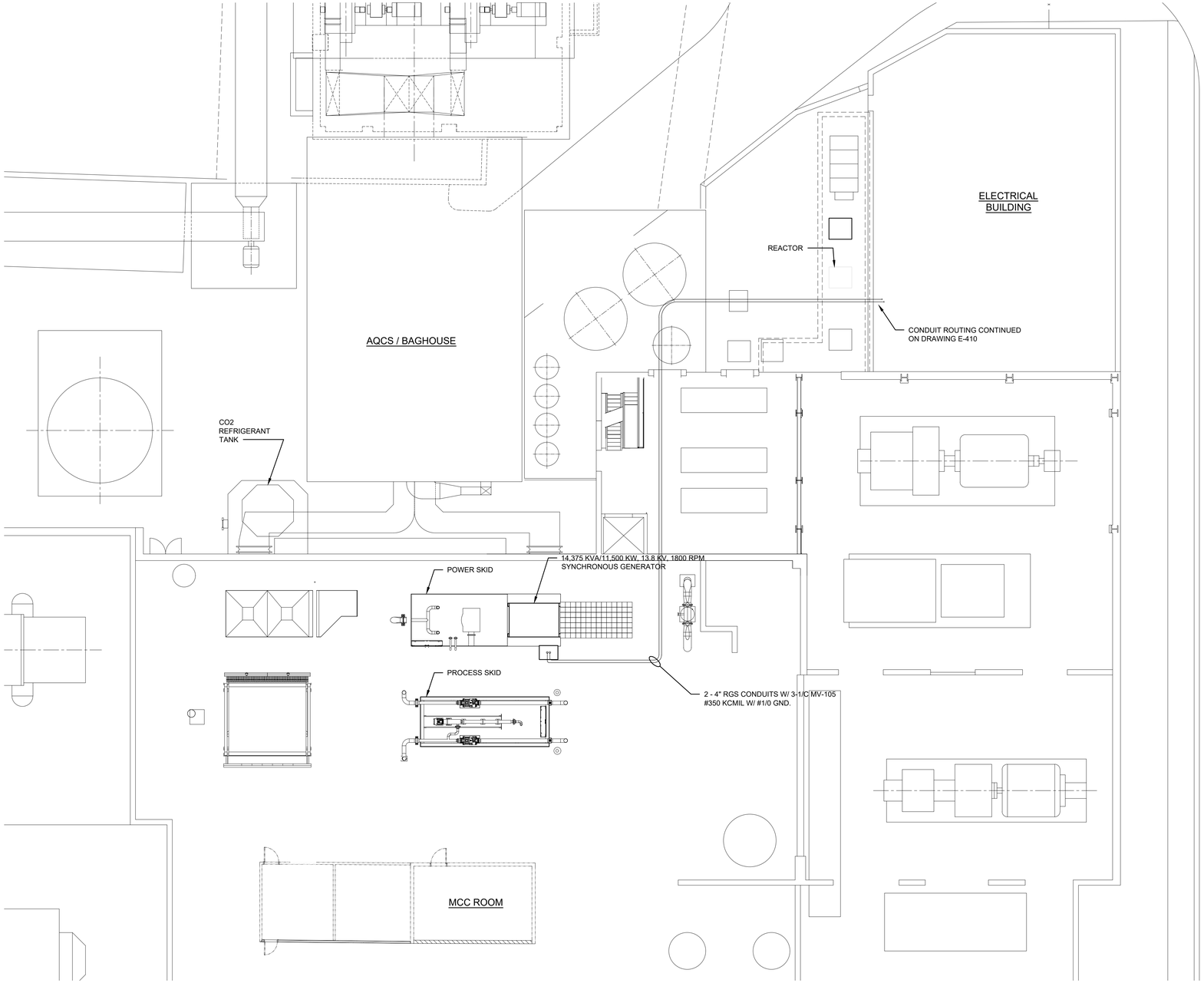
2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

ELECTRICAL BUILDING 1ST FLOOR 13.8KV ROUTING PLAN

DATE	DRAWN	CHK'D.
04/16/2020	BLP	SDS
SCALE: AS NOTED		APPROVED: MET

E-410



ELECTRICAL
1ST FLOOR PARTIAL PLAN
SCALE: 3/32" = 1'-0"

3/32" = 1'-0"
2' 0 2' 4' 6' 8' 12' 16' 24'

NOTES:

1. CONDUIT ROUTING IS CONCEPTUAL AND SHOWS THE INTENT OF THE ENGINEER. EC SHALL FIELD VERIFY INSTALLATION REQUIREMENTS.

REFERENCE DRAWINGS:

REFER TO E-001 FOR DRAWING INDEX.

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/10/20	ISSUED FOR BID	KLM

SECURITY
PUBLIC ☐
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

ELECTRICAL 1ST FLOOR 13.8KV ROUTING PLAN

DATE	DRAWN	CHK'D.
08/07/2020	JMS	SDS
SCALE: AS NOTED		APPROVED: MET

E-411

NOTES:

1. LOCATION OF EAST AND WEST DOUBLE ENDED SWITCHGEAR IS SHOWN IN APPROXIMATE LOCATION FOR REFERENCE ONLY. ALL OTHER ELECTRICAL AND MECHANICAL FACILITIES ARE NOT SHOWN. EC SHALL FIELD VERIFY ALL INSTALLATION REQUIREMENTS.
2. ELECTRICAL CONTRACTOR SHALL FURNISH AND INSTALL PHENOLIC PLATES INDICATING CUBICLE DESIGNATION AND EQUIPMENT SERVED.

KEY NOTES:

1. SUPPLY FOR PANELBOARD DP-1 REFER TO E-106 AND E-404
2. SUPPLY FOR PANELBOARD DP-2 REFER TO E-106 AND E-402
3. SUPPLY FOR AQCS MCC REFER TO E-106 AND E-404
4. SUPPLY FOR IXH PUMP 1 REFER TO E-106 AND E-402
5. SUPPLY FOR IXH PUMP 2 REFER TO E-106 AND E-402
   SUPPLY FOR ID FAN REFER TO E-106 AND E-404
6.















ELECTRICAL BUILDING
2ND FLOOR SUS BUS PLAN
SCALE: 1/4"=1'-0"

1/4" = 1'-0"

REFERENCE DRAWINGS:

REFER TO DRAWING E-001 FOR DRAWING INDEX

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/10/20	ISSUED FOR BID	KLM

SECURITY

PUBLIC ☐
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

ELECTRICAL BUILDING
2ND FLOOR SUS BUS PLAN
ELECTRICAL

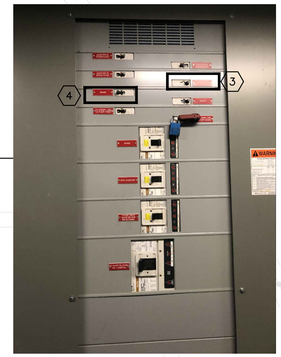
DATE	DRAWN	CHK'D.
06/26/20	BLP	SDS
SCALE 1/4"=1'-0"		APPROVED MET

E-412

NOTES:

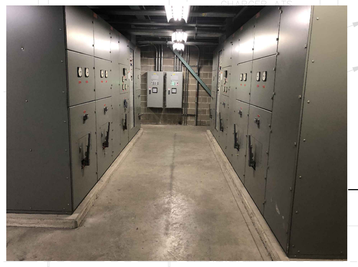
1. LOCATION OF CUBICLES ARE APPROXIMATE. EC SHALL FIELD VERIFY LOCATIONS AND ALL INSTALLATION REQUIREMENTS.
2. ELECTRICAL CONTRACTOR SHALL FURNISH AND INSTALL PHENOLIC PLATES INDICATING CUBICLE DESIGNATION AND EQUIPMENT SERVED.





SOUTH COMBINATION DC STARTER W/ DISC. SWITCH

NORTH COMBINATION DC STARTER W/ DISC. SWITCH



KEY NOTES:

1. SUPPLY FOR STEAM PLANT 15KV INVERTER 1, REFER TO E-107 AND E-107-DEMO.
2. SUPPLY FOR STEAM PLANT 15KV INVERTER 2, REFER TO E-107 AND E-107-DEMO.
3. SUPPLY FOR NORTH ATS, REFER TO E-107 AND E-107-DEMO.
4. SUPPLY FOR SOUTH ATS, REFER TO E-107 AND E-107-DEMO.
5. SUPPLY FOR NORTH ATS, REFER TO E-107 AND E-107-DEMO.
6. SUPPLY FOR SOUTH ATS, REFER TO E-107 AND E-107-DEMO.

REFERENCE DRAWINGS:

REFER TO DRAWING E-001 FOR DRAWING INDEX

AA CC DD EB1 EB2 EB3 EB4 EBD EBC EBB EBA

ELECTRICAL BUILDING
3RD FLOOR DC CABINET PLAN
SCALE: 1/4"=1'-0"

1/4" = 1'-0"

NO.	DATE	REVISION	BY
A	08/10/20	ISSUED FOR BID	KLM

PRELIMINARY
NOT FOR CONSTRUCTION

SECURITY
PUBLIC ☐
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

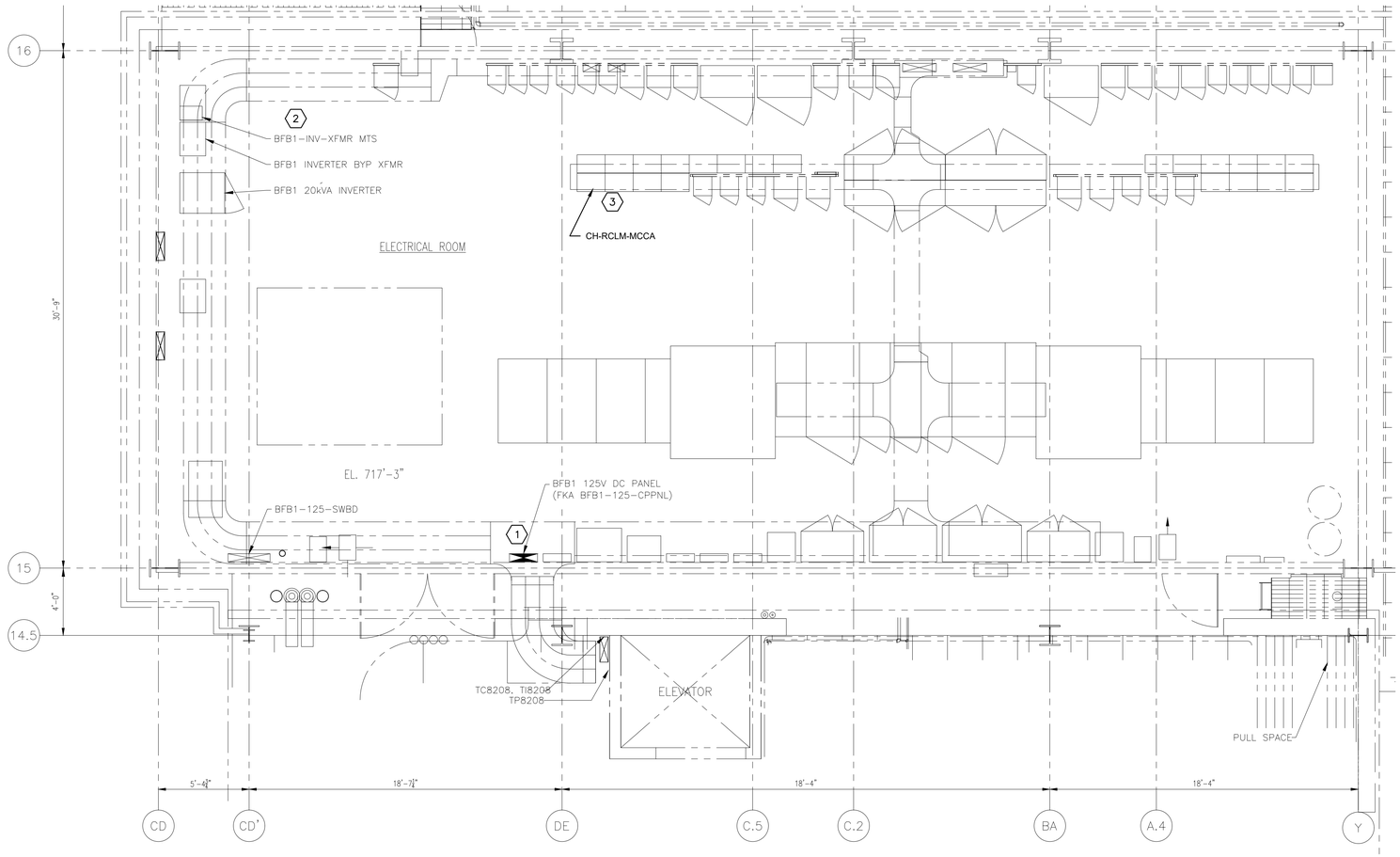
2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

ELECTRICAL BUILDING
3RD FLOOR DC CABINET PLAN
ELECTRICAL

DATE	DRAWN	CHK'D.
06/26/20	BLP	SDS
SCALE 1/4"=1'-0"		APPROVED MET

E-413



BFB1 ELECTRICAL ROOM
FLOOR PLAN

SCALE: 1/4"=1'-0"

NOTES:

1. LOADS DESIGNATED ON THIS DRAWING ARE DEEMED CRITICAL AND NEED TO BE MAINTAINED THROUGHOUT THIS PROJECT. EC SHALL COORDINATE ALL SHUTDOWNS W/ UNIVERSITY OF MISSOURI CONSTRUCTION MANAGEMENT AND OTHER TRADES. FEEDERS SHALL BE TEMPORARILY INSTALLED AND MAINTAINED. PRIOR TO THE COMPLETION OF THIS PROJECT THESE THREE FEEDERS SHALL BE PERMANENTLY INSTALLED.

KEY NOTES:

1. BFB1 125 VDC PANEL SUPPLIED FROM WATER TREATMENT BOOSTER PUMP ROOM DC PANEL 100A CB #1 ON E-416.
2. BFB1-INV-XFMR-MTS SUPPLIED FROM 250A CB IN NORTH 125 VDC SWBD LOCATED ON 3RD FLOOR ELECTRICAL ROOM IN THE ELECTRICAL BUILDING. REFER TO DRAWINGS E-416 AND E-413 FOR ADDITIONAL INFORMATION.
3. CH-RCLM-MCCA SUPPLIED FROM UPPER SUS EAST BUS. REFER TO DRAWINGS E-416 AND E-412.

REFERENCE DRAWINGS:

REFER TO E-001 FOR DRAWING INDEX

1/4" = 1'-0"

NO.	DATE	REVISION	BY
A	08/10/20	ISSUED FOR BID	KLM

PRELIMINARY
NOT FOR CONSTRUCTION

SECURITY
PUBLIC ☐
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

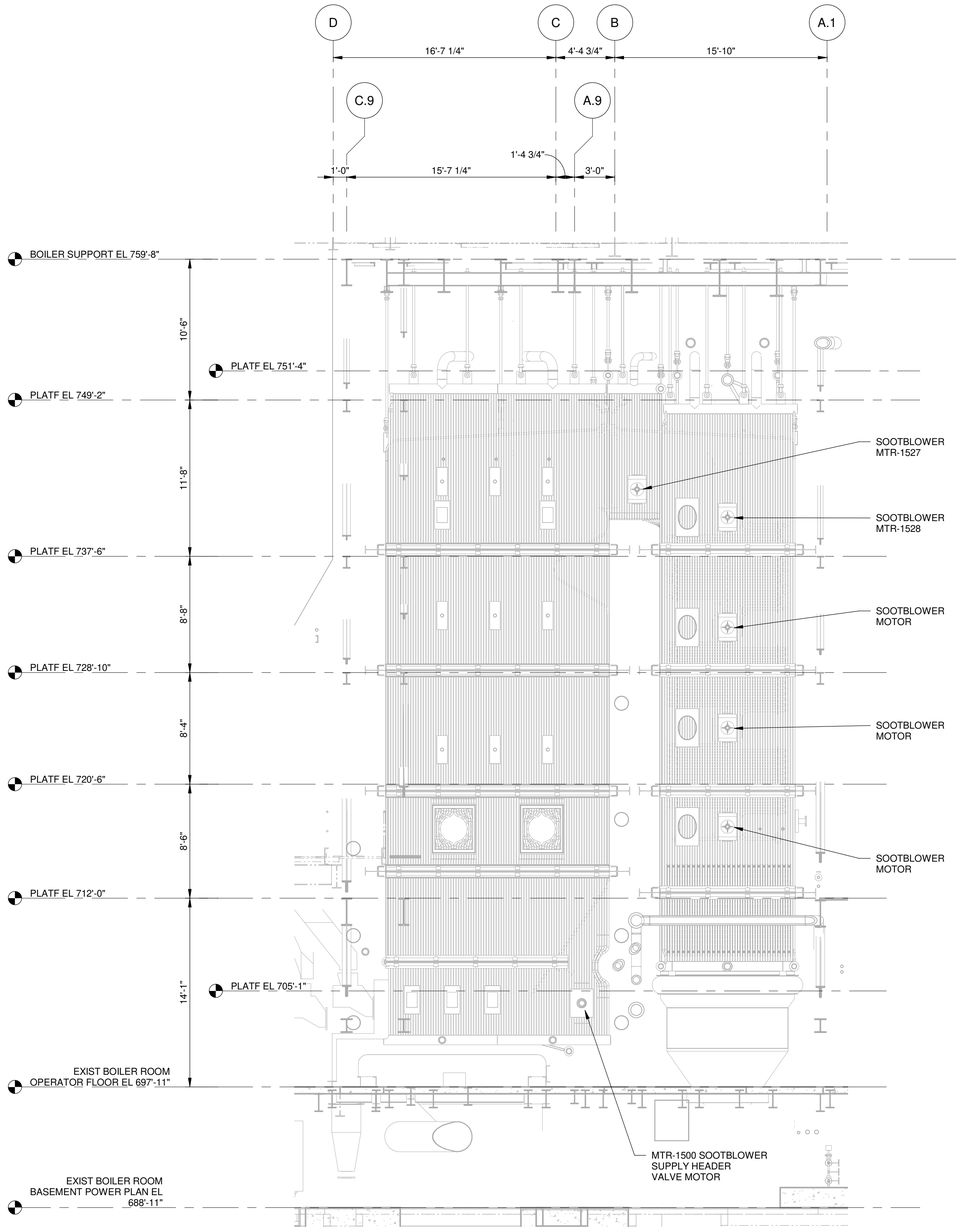
2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

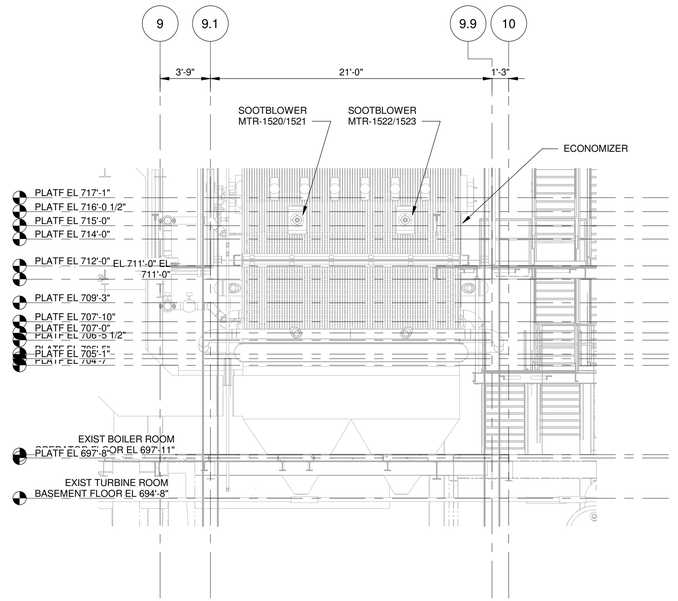
ELECTRICAL
BFB1 ELECTRICAL ROOM FLOOR PLAN

DATE	DRAWN	CHK'D.
06/26/20	BLP	SDS
SCALE 1/4"=1'-0"		APPROVED MET

E-414



SECTION
SCALE: 3/16" = 1'-0"



SECTION
SCALE: 3/16" = 1'-0"

REFERENCE DRAWINGS:

REFER TO DRAWING E-001 FOR DRAWING INDEX
E-401 EXISTING BOILER ROOM BASEMENT FLOOR ELECTRICAL PLAN

3/16" = 1'-0"
1' 0 1' 2' 3' 4' 6' 8' 10'

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/10/20	ISSUED FOR BID	KLM

SECURITY
PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

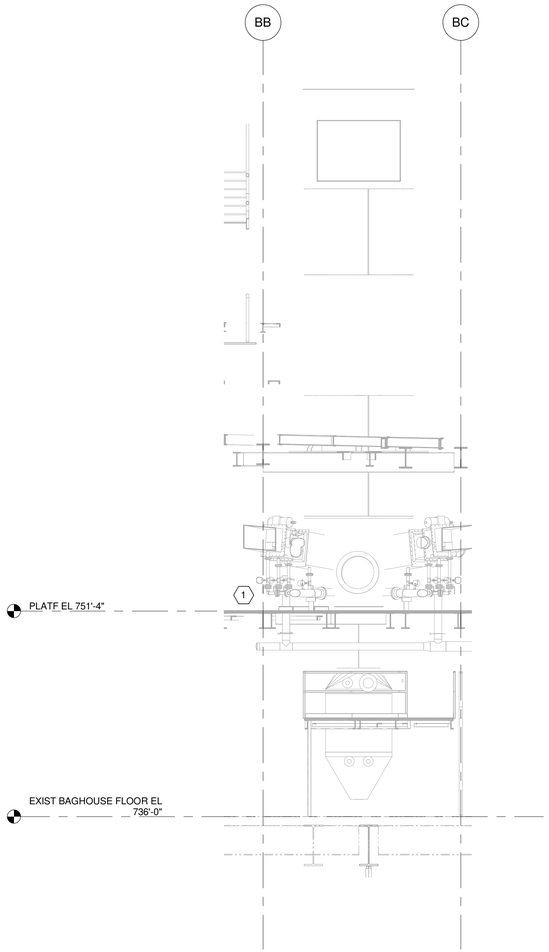
2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

ELECTRICAL
FURNACE SECTIONS

DATE	DRAWN	CHK'D.
04/30/20	AB	SDS
SCALE 3/16" = 1'-0"		APPROVED MET

E-501



A / E-405 SECTION
SCALE: 3/16" = 1'-0"

KEY NOTES:

1. THE AREA ON TOP OF THE BAG HOPPERS CONTAIN THE FOLLOWING 480VAC EQUIPMENT:
   - PNL-8301 PJFF HEATER CONTROL PANEL
   - HTR-8303A PJFF MODULE A HOPPER HEATER
   - HTR-8303A PJFF MODULE B HOPPER HEATER
   - HTR-8303A PJFF MODULE C HOPPER HEATER
   - HTR-8303A PJFF MODULE D HOPPER HEATER
   - MTR-8301 PJFF VENT FAN MOTOR
   - MTR-8310A PJFF MODULE A VIBRATOR MOTOR
   - MTR-8310A PJFF MODULE B VIBRATOR MOTOR
   - MTR-8310A PJFF MODULE C VIBRATOR MOTOR
   - MTR-8310A PJFF MODULE D VIBRATOR MOTOR

REFERENCE DRAWINGS:

REFER TO DRAWING E-001 FOR DRAWING INDEX

3/16" = 1'-0"
1' 0 1' 2' 3' 4' 6' 8' 10'

PRELIMINARY
NOT FOR CONSTRUCTION

NO.	DATE	REVISION	BY
A	08/10/20	ISSUED FOR BID	KLM

SECURITY

PUBLIC ☒
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

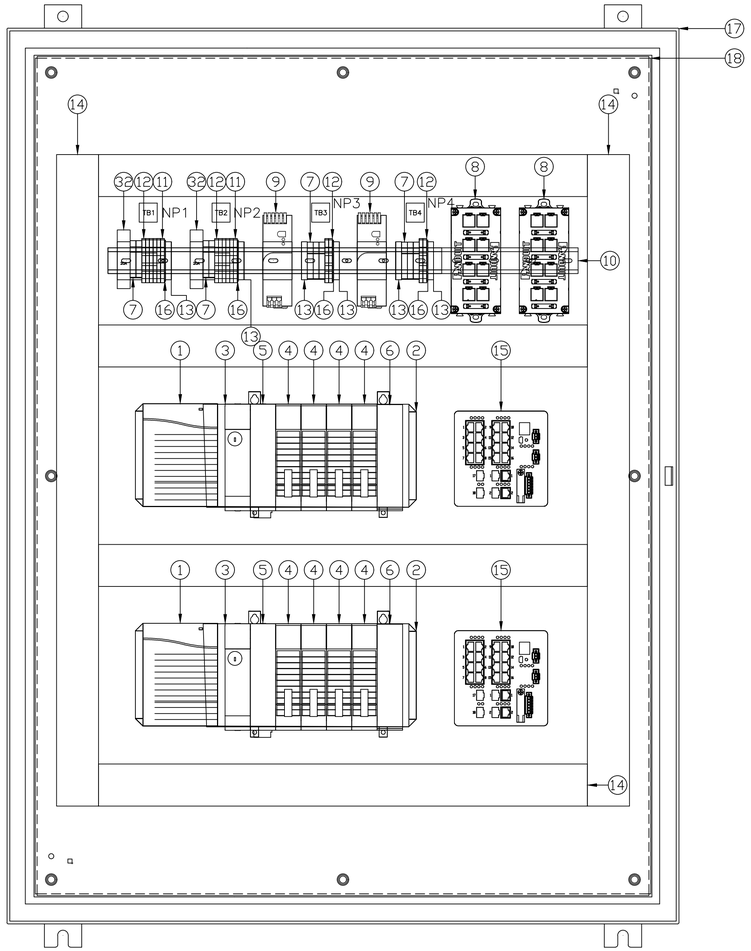
2019 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

ELECTRICAL
MISC. SECTIONS

DATE	DRAWN	CHK'D.
04/30/20	BLP	SDS
SCALE 3/16" = 1'-0"		APPROVED MET

E-502



MAIN PLC CABINET INTERIOR

SCALE 1"=4"

BILL OF MATERIAL				
ITEM	QTY	CATALOG	MFG	DESCRIPTION
1	2	1756-PA75	AB	1756 CONTROL LOGIX POWER SUPPLY 1756 POWER SUPPLY INPUT VOLTAGE: 120 VAC OR 220 VAC
2	2	1756-A7	AB	1756 CONTROL LOGIX RACK I/O, 7 SLOT CHASSIS 1756 RACK RACK I/O, 7 SLOT CONTROLLOGIX CHASSIS
3	2	1756-L75	AB	1756 L75 CONTROLLOGIX PAC
4	8	1756-EN2TR	AB	1756 CONTROL LOGIX ETHERNET / IP MODULE 1756 SPECIAL 2x RJ45 CABLE CONNECTOR, USB PORT
5	2	1756-RM2	AB	1756 REDUNDANCY MODULE
6	2	1756-N2	AB	1756 CONTROL LOGIX SLOT FILLER CARD 1756 SPECIAL EMPTY SLOT FILLER CARD, 2 FILLERS PER PACKAGE
7	10	1492-WFB4	AB	FUSED FEED THROUGH TERMINAL BLOCK
8	2	CDPP8RG	PANDUIT	DIN RAIL NETWORK PATCH PANEL
9	2	1606-XLS120E	AB	24VDC 120W POWER SUPPLY
10	2	199-DR1	AB	ZINC/STEEL DIN RAIL EN 50022 (35mm x 7.5mm x 1m) 35mm x 7.5mm SLOTTED
11	4	1492-JG3	AB	SCREW CONNECTION TERMINAL BLOCK; 1492-J FEED-THROUGH GROUND GREEN/YELLOW; 22-12AWG FEED-THROUGH GROUND BLOCK
12	12	1492-J3	AB	SCREW CONNECTION TERMINAL BLOCK; 1492-J FEED-THROUGH 25AMPS GRAY COLOR, 22-12AWG, RATED VOLTAGE 600VAC/DC STANDARD FEED-THROUGH BLOCK; SCREW CONNECTION
13	6	1492-EAJ35	AB	TERMINAL STRIP END BLOCK
14	6	G2X3WH6	PANDUIT	WIDE FINGER, SLOTTED WIRING DUCT 2.25 x 3.12 SLOTTED WHITE LEAD-FREE PVC, STANDARD MOUNTING HOLES
15	2	1783-BMS20CA	AB	STRATIX 5700 SERIES NETWORK SWITCH
16	4	1492-EBJ3	AB	J3 SERIES TERMINAL BLOCK END BARRIER
17	1	A483610LP	HOFFMAN	WALL-MOUNT ENCLOSURE NEMA 12, 13, IP65 48 x 36 x 10 IN, STEEL
18	1	A48P36G	HOFFMAN	BACK PANEL FOR 48" X 36" ENCLOSURES, CONDUCTIVE
19	1	1756-RMC1	AB	REDUNDANCY MODULE FIBER OPTIC CABLE
32	2	1492-SPM1B200	AB	20A MINIATURE CIRCUIT BREAKER

NAMEPLATE ENGRAVING				
NAMEPLATE	PLATE COLOR	LETTER COLOR	TEXT SIZE	ENGRAVED TEXT
NP1	WHITE	BLACK	0.25"	TB1
NP2	WHITE	BLACK	0.25"	TB2
NP3	WHITE	BLACK	0.25"	TB3
NP4	WHITE	BLACK	0.25"	TB4

NO.	DATE	REVISION	BY
A	07/24/20	ISSUED FOR BID	KLM

SECURITY

PUBLIC ☐
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

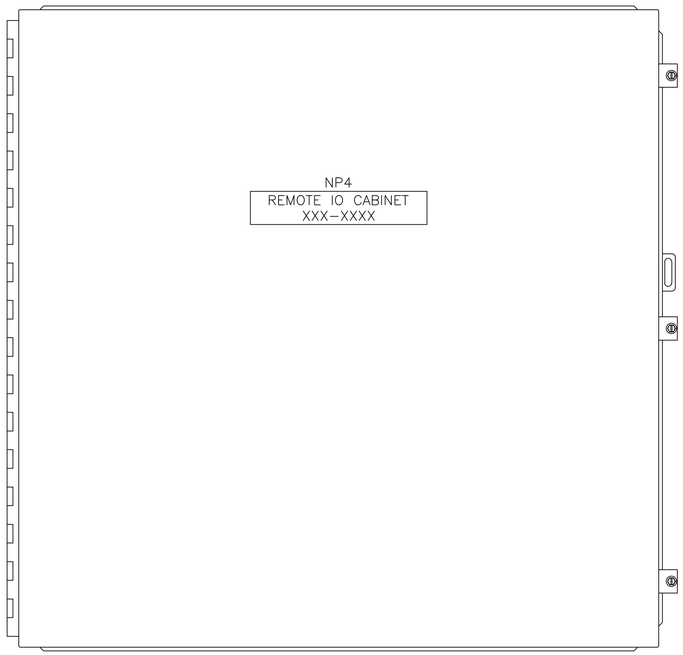
2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

CONTROLS
BALANCE OF PLANT PLC
MAIN PLC

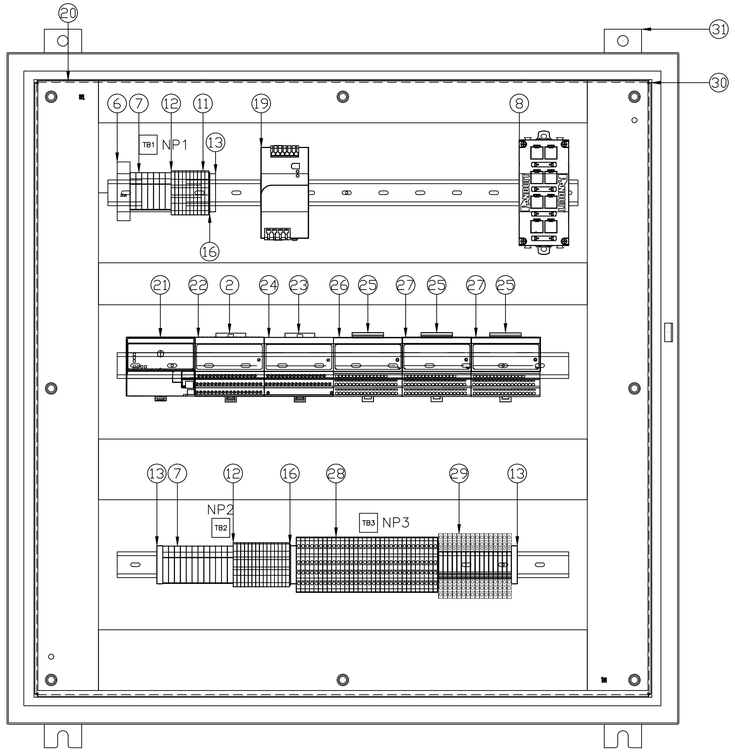
DATE	DRAWN	CHK'D.
07/20/20	JAK	EJB
SCALE 1/4"=1'-0"		APPROVED KLM

EC-101



REMOTE IO CABINET DOOR

SCALE 1"=4"



REMOTE IO CABINET INTERIOR

SCALE 1"=4"

BILL OF MATERIAL

ITEM	QTY	CATALOG	MFG	DESCRIPTION
2	1	1794-TB32	AB	FLEX IO TERMINAL BASE
6	1	1492-SPM1B200	AB	20A MINIATURE CIRCUIT BREAKER
7	19	1492-WFB4	AB	FUSED FEED THROUGH TERMINAL BLOCK
8	1	CDPP8RG	PANDUIT	DIN RAIL MOUNT PATCH PANEL
10	3	199-DR1	AB	ZINC/STEEL DIN RAIL EN 50022 (35mm x 7.5mm x 1m) 35mm x 7.5mm SLOTTED
11	2	1492-JG3	AB	SCREW CONNECTION TERMINAL BLOCK; 1492-J FEED-THROUGH GROUND GREEN/YELLOW; 22-12AWG FEED-THROUGH GROUND BLOCK
12	23	1492-J3	AB	SCREW CONNECTION TERMINAL BLOCK; 1492-J FEED-THROUGH 25AMPS GRAY COLOR, 22-12AWG, RATED VOLTAGE 600VAC/DC STANDARD FEED-THROUGH BLOCK; SCREW CONNECTION
13	4	1492-EAJ35	AB	TERMINAL BLOCK END BLOCK
16	2	1492-EBJ3	AB	1492 J3 SERIES TERMINAL END BARRIER
19	1	1606-XLS480E	AB	24VDC 20A POWER SUPPLY
20	1	G3X3WH6	PANDUIT	WIDE FINGER, SLOTTED WIRING DUCT 3.25 x 3.11 SLOTTED WHITE LEAD-FREE PVC, STANDARD MOUNTING HOLES
21	1	1794-AENTR	AB	FLEX IO ETHERNET/IP COMMUNICATION MODULE
22	1	1794-IB32	AB	FLEX IO 32 POINT DIGITAL INPUT CARD
23	1	1794-TB2	AB	FLEX IO TERMINAL BASE
24	1	1794-OB16	AB	FLEX IO 16 POINT DIGITAL OUTPUT CARD
25	3	1794-TB3G	AB	FLEX IO TERMINAL BASE
26	1	1794-OE12	AB	FLEX ANALOG OUTPUT MODULE 1794 ANALOG OUTPUT 12 SINGLE-ENDED OUTPUTS 12 ANALOG OUTPUTS
27	2	1794-IE8H	AB	HART ANALOG INPUT MODULE 1794 ANALOG INPUT 8 SINGLE-ENDED NON ISOLATED INPUTS 8 ANALOG INPUTS
28	32	1492-WD4	AB	TWO CIRCUIT FEED THROUGH TERMINAL BLOCK
29	16	700-HLT1U24	AB	24VDC COIL SPDT TERMINAL BLOCK RELAY
30	1	A36P36G	HOFFMAN	BACKPANEL FOR 36" X 36" ENCLOSURES, CONDUCTIVE
31	1	A363608LP	HOFFMAN	WALL-MOUNT ENCLOSURE NEMA 12, 13, IP65 36x 36 x 8 IN, STEEL

NAMEPLATE ENGRAVING

NAMEPLATE	PLATE COLOR	LETTER COLOR	TEXT SIZE	ENGRAVED TEXT
NP1	WHITE	BLACK	0.25"	TB1
NP2	WHITE	BLACK	0.25"	TB2
NP3	WHITE	BLACK	0.25"	TB3
NP4	WHITE	BLACK	0.5"	REMOTE IO CABINET XXX-XXXX

NO.	DATE	REVISION	BY
A	07/24/20	ISSUED FOR BID	KLM

SECURITY

PUBLIC ☐
ECHOGEN BUSINESS CONFIDENTIAL ☐
TOP SECRET ☐

THIS DOCUMENT CONTAINS PROPRIETARY AND CONFIDENTIAL INFORMATION AND IS THE EXCLUSIVE PROPERTY OF ECHOGEN POWER SYSTEMS, INC., AND SHALL NOT BE REPRODUCED, USED OR DISCLOSED TO OTHERS WITHOUT THE EXPRESS WRITTEN CONSENT OF ECHOGEN POWER SYSTEMS, INC.

2011 ALL RIGHTS RESERVED ECHOGEN POWER SYSTEMS, INC.

ECHOGEN power systems
405 S. High Street, Akron OH, 44311 USA

CONTROLS
BALANCE OF PLANT PLC
REMOTE IO PANEL

DATE	DRAWN	CHK'D.
07/20/20	JAK	EJB
SCALE 1/4"=1'-0"		APPROVED KLM

EC-201

IV. Design Report (Process Hazard Analysis)

ioMosaic®
Minimizing risk. Maximizing potential.®

Process Hazard Analysis of Echogen Supercritical CO_2 Power Cycle

Large-Scale Pilot Plant (Columbia, MO)

SUMMARY PHA REPORT to: Echogen Power Systems

ECHOGEN power systems

Date: January 8, 2021

ioMosaic Reference: 20105

Proprietary Information Use or disclosure of data contained on this sheet is subject to the restriction on page i of this document.

Notice:

This report was prepared by ioMosaic Corporation for the account of Echogen Power Systems (Echogen). This report represents ioMosaic Corporation's best judgment in light of information made available to us. Opinions in this report are based in part upon data and information provided by Echogen and / or Echogen advisors and affiliates. The reader is advised that ioMosaic Corporation has not independently verified the data or the information contained therein. This report must be read in its entirety. The reader understands that no assurances can be made that all liabilities have been identified. This report does not constitute a legal opinion.

No person has been authorized by ioMosaic Corporation to provide any information or make any representation not contained in this report. Any use the reader makes of this report, or any reliance upon or decisions to be made based upon this report are the responsibility of the reader. ioMosaic Corporation does not accept any responsibility for damages, if any, suffered by the reader based upon this report.

Table of Contents

1 Executive Summary 1

2 Introduction 3

2.1 Purpose of Study 3

2.2 Scope of Study 3

2.3 Process Description 4

3 PHA Approach 5

3.1 PHA Methodology 5

3.2 Identification of Hazards and Consequences 5

3.3 Engineering and Administrative Controls 6

3.4 Human Factors 6

3.5 Facility Siting 6

3.6 Qualitative and Quantitative Evaluation 6

3.7 PHA Team and Attendance 8

4 PHA Results 10

4.1 Documentation 10

4.2 Summary of PHA Results 10

4.3 List of Recommendations 13

4.4 Follow-up 15

Proprietary Information Use or disclosure of data contained on this sheet is subject to the restriction on page i of this document.

List of Tables

Table 1: Summary of PHA Recommendations 2

Table 2: Selected Study Nodes or Study Areas..... 3

Table 3: Consequence 7

Table 4: Likelihood 7

Table 5: Risk Level..... 8

Table 6: Attendance 9

Table 7: High Risk Hazard Events..... 11

Table 8: Priority Recommendations 14

Proprietary Information Use or disclosure of data contained on this sheet is subject to the restriction on page i of this document.

1 Executive Summary

A process hazard analysis (PHA) was conducted on the Echogen Power Systems (EPS) Supercritical Carbon Dioxide (sCO_2) Primary Power Large-Scale Pilot Plant located at the University of Missouri campus in Columbia, MO. The boundary of the process included the recompression Brayton cycle (RCBC), dual-fuel fired process heater, and balance of plant pollution control systems. The PHA was conducted using documentation resulting from the front-end engineering design (FEED) project phase.

A PHA involves examination of a system by individuals familiar with design, operation and maintenance. Structured brainstorming techniques are used to identify potential hazardous scenarios and to identify existing safeguards to prevent or mitigate the consequences. This PHA employed the Hazard and Operability (HAZOP) methodology.

The PHA was conducted during eight Webinar sessions over the period of September 10-22, 2020.

The PHA team was comprised of representatives from Echogen, Electric Power Research Institute (EPRI), Riley Power Inc., CDM Smith, University of Missouri (MU), and ioMosaic Corporation.

The study was initiated to identify significant safety, environmental, and asset-cost issues associated with this new pilot power plant.

During the PHA, the team addressed the following:

- Hazards of the process
- Previous incidents at similar facilities
- Engineering and administrative controls and their interrelationships
- Consequences of failure of these controls
- Human factors
- Facility siting
- A range of the possible safety and health effects to employees at the workplace, as well as consequences to adjacent structures, the MU Campus and the environment

Proprietary Information Use or disclosure of data contained on this sheet is subject to the restriction on page i of this document.

All the recommendations from the PHA, were prioritized as listed below (Table 1). During the PHA, recommendations made to mitigate previously addressed hazard scenarios may also be appropriate to mitigate the risk of other scenarios with a similar consequence and are restated or cross referenced. Hence the total number of recommendations shown in Summary Table 1 will be higher that the number of unique recommendations needing to be addressed.

Table 1: Summary of PHA Recommendations

Risk Ranking	Priority	# of Recommendations
A	High	2
B	Medium	11
C	Low	23
D	Very Low	30
O	Operability	1
Total		**67**

Some of the same recommendations may be repeated for different scenarios. In addition, there is one unranked action items for the PHA team to consider.

It is the responsibility of Echogen and its associates to fully address each recommendation listed in the PHA. These recommendations were made at the time of the PHA discussions and do not necessarily reflect the only or best means to address the hazard. These recommendations should be reviewed and considered in developing the action plan from the study. For some items, it may be determined that an alternate action or no action is necessary. If so, the rationale for choosing the final course of action shall be documented and agreed upon by the key members of the original PHA Team.

For each recommendation, the action required to resolve the recommendation should be documented and a written schedule for completion of those actions in a timely manner should be developed.

Proprietary Information Use or disclosure of data contained on this sheet is subject to the restriction on page i of this document.

2 Introduction

2.1 Purpose of Study

The purpose of this PHA was to evaluate the hazards of the Supercritical Carbon Dioxide (sCO_2) Primary Power Large-Scale Pilot Plant to be located at the University of Missouri campus in Columbia, MO. The boundary of the process included the recompression Brayton cycle (RCBC), dual-fuel fired process heater, and balance of plant pollution control systems. The PHA was conducted using documentation resulting from the front-end engineering design (FEED) project phase.

Process hazard analyses (PHAs) are conducted to identify hazards associated with various kinds of industrial activities. When hazards are identified, existing or proposed designs and operations are assessed to determine if appropriate safeguards are in place. If the current level of protection is determined to be insufficient, recommendations are made to eliminate and/or mitigate the hazard(s).

Most commonly, PHAs are applied to facilities using highly hazardous chemicals or hazardous processes. Typically, the focus is on hazards that could potentially lead to acute, catastrophic incidents, such as fires, explosions, and toxic releases. The hazard and operability (HAZOP) study technique was chosen for review of the front-end engineering design (FEED) to ensure a thorough analysis of all of the possible hazards. A HAZOP is a fully structured methodology to guide the PHA team through all potential deviations of a system.

2.2 Scope of Study

The scope of this PHA included the processes in the 25 P&IDs provided. The study nodes selected are described in Table 2 below.

Table 2: Selected Study Nodes or Study Areas

Node #	Description
1	sCO_2 Circulation Loop LTC/HTCs and Drivers
2	Power Turbine/ Generator and auxiliaries
3	Fired Heater/ PHX1 & 2A/B
4	CO_2 Storage and Refrigeration
5	SCR, CDS, Fabric Filter

Proprietary Information Use or disclosure of data contained on this sheet is subject to the restriction on page i of this document.

2.3 Process Description

This project involves an indirect-fired sCO_2 power system designed by Echogen Power Systems, Inc. (Echogen), which employs a closed-loop cycle using CO_2 as the working fluid. The thermophysical properties of CO_2 make it a superior power-cycle fluid; allowing flexible and efficient coupling with multiple types of heat sources. The pilot plant facility is designed to produce 10 MW of power.

The main compressor, or low temperature compressor (LTC), compresses relatively dense fluid after the final heat rejection step in the cycle. The recompressor, or high-temperature compressor (HTC), compresses a lower density fluid that bypasses heat rejection. Heat addition from the fired heater occurs in the primary heat exchangers (PHX). An s CO_2 economizer (PHX-2A/B) is in series with the main PHX (PHX-1) in the flue gas stream, reducing the heat that is exhausted through the stack. Drive turbines (LTC DT and HTC DT) power the LTC and HTC, respectively. Net and auxiliary electrical power are supplied by a synchronous generator driven by the power turbine (PT). Recuperators use the relatively high temperature CO_2 leaving the turbines to preheat the CO_2 going to the PHX. To minimize the exergetic destruction associated with recuperation, the flow between the low temperature recuperator (LTR) and high temperature recuperator (HTR) is split. This split, along with the addition of the HTC, allows for better matching of the temperature glide between the hot and cold CO_2 streams.

Heat rejection to the cooling fluid occurs in the condensing heat exchanger (CHX). A clean-water cooling loop with an intermediate heat exchanger (IHX) is used to transfer heat to an existing plant water loop and cooling tower. Water in both loops is circulated by pumps (WP1 and WP2, respectively).

The heat addition system (fired heater) includes coal combustion (with natural gas co-firing) in a stoker-fired heater. Combustion air is supplied from a forced draft (FD) fan through an air preheater (APH). Air quality control systems (AQCS) include selective catalytic reduction (SCR) for NO_x reduction, a circulating dry scrubber (CDS) for SO_2 reduction, and a baghouse (BH) for particulate management. The unit is balanced draft, with an induced draft (ID) fan discharging flue gas to an existing stack. The CO_2 economizer is split into sections downstream (PHX-2A) and upstream (PHX-2B) of the SCR in order to optimize the gas temperature for effective NO_x reduction.

Proprietary Information Use or disclosure of data contained on this sheet is subject to the restriction on page i of this document.

3 PHA Approach

3.1 PHA Methodology

Prior to the start of each PHA section, the team was provided with a brief review of the equipment being covered in that node and how it was intended to operate. The results of the PHA were recorded using ioMosaic's proprietary software, Process Safety Office® PHAGlobal®. The large-scale pilot plant systems were evaluated using the HAZOP methodology.

The PHA was used to address hazards of the process, engineering and administrative controls and consequences of failures of those controls, human factors, and a qualitative evaluation of a range of possible safety, environmental, and asset damage effects.

The consequence level identified from the PHA scenario was used in conjunction with the frequency to determine the risk level using the applied risk matrix. The initiating event frequency was quantified along with any enabling event modifiers. Existing independent protective layers (IPLs) were identified and probability of failure on demand frequencies documented. If the combination of the scenario frequency and the existing IPLs did not achieve a tolerable risk, then additional recommendations were made to fill that gap. In some cases, the team could not identify any reasonable additional IPLs to fill the gap and opted to accept the business risk associated with that scenario.

3.2 Identification of Hazards and Consequences

The HAZOP methodology is a structured approach using guide words to evaluate all potential deviations from the design intent.

During the PHA the team addressed the following:

- Hazards of the process
- Previous incidents at similar facilities
- Engineering and administrative controls and their interrelationships
- Consequences of failure of these controls
- Human factors
- Facility siting
- A range of the possible safety and health effects to employees at the workplace, as well as offsite consequences to the public and the environment

Proprietary Information Use or disclosure of data contained on this sheet is subject to the restriction on page i of this document.

Deviations which could lead to the consequences listed below were postulated:

- Personnel injury-on/off site consequences
- Environmental pollution impacts
- Customer service/business disruption
- Equipment damage/business cost

The causes of these deviations and the mechanisms for indication or protection against these consequences were also documented. An effort was made to fully record the analysis, irrespective of whether or not the team perceived a need to make a recommendation.

3.3 Engineering and Administrative Controls

During the PHA, the team identified existing engineering and administrative controls for the equipment under consideration. For scenarios where the controls were considered to fail, the control was documented in the “Cause” column of the PHAGlobal® log sheets.

Those engineering and administrative controls identified as preventing and/or mitigating scenarios and consequences were documented under the “Safeguards” column within the PHAGlobal® log sheets.

3.4 Human Factors

Issues regarding human factors were addressed as an integral part of the PHA. The PHAGlobal® log sheets reflect this focus, with reference to various human factors as possible causes for process upsets, as well as a possible deviation. In addition, human factors is one of the specific guidewords considered.

3.5 Facility Siting

Issues regarding facility siting were addressed as an integral part of the PHA. The PHAGlobal® log sheets reflect this focus, with a specific deviation guide word for facility siting in the PHAGlobal® study sections.

3.6 Qualitative and Quantitative Evaluation

The PHA’s qualitative evaluation of the possible safety, environmental, and business impacts of failure and controls at the facility was conducted using a risk-ranking approach. The risk matrix utilized is shown below:

Proprietary Information Use or disclosure of data contained on this sheet is subject to the restriction on page i of this document.

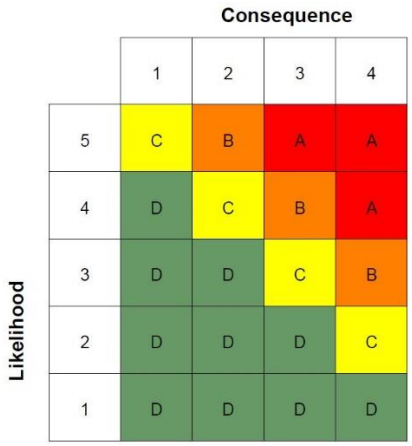


Table 3: Consequence

Range	Safety Criteria:	Public Criteria:	Environment Criteria:	Business Interruption:
1	Minor worker injuries	Odor or noise nuisance, no direct impact	Contained release with localized impact; exceed discharge limit	No significant loss
2	Lost workday injury	Potential for an injury requiring first aid	Uncontained release with potential for moderate environmental impact	Plant damage/loss value up to $100,000
3	Disabling injury	Potential for an injury requiring physician's care	Significant environmental damage	Plant damage/loss value in excess of $100,000 to 1 million
4	One or more worker fatalities	Potential for a disabling injury or fatality	Uncontained release with potential for major environmental impact	Plant damage/loss value in excess of $1 million

Table 4: Likelihood

Range	Event Frequency	Impact Frequency
1	<10-4 (Once per 10000 years)	Is likely to occur once in 1000 up to once in 10000 years
2	10-2 to 10-3/yr	Is likely to occur between once in 100 up to once in 1000 years
3	10-1 to 10-2/yr	Is likely to occur between once in 10 up to once in 100 years
4	1/yr to 10-1/yr	Is likely to occur between once a year up to once in 10 years
5	>1/yr	Is likely to occur once a year or more

Proprietary Information Use or disclosure of data contained on this sheet is subject to the restriction on page i of this document.

Table 5: Risk Level

Range	Team Action	Operability
A	Risk mitigation to risk level “D”	High Priority
B	Risk mitigation to risk level “D”	Medium Priority
C	Risk mitigation to risk level “D”	Low Priority
D	No further risk mitigation required	Very Low Priority
O	Operability issue	Operability

The risk matrix was implemented as follows:

- Deviations for which a possible cause was identified were further developed if a hazardous consequence could result. If not, the scenario was terminated at that point by indicating “No Hazardous Consequences Identified” or “Operating Issue”
- Deviations for which a possible hazardous consequence existed were risk ranked
- Risk ranking levels ranged from A: High Risk to D: Very Low Risk

Recommendations were made for all deviations resulting in a rank of “A, B, or C.” In some cases, recommendations were also recorded for deviations resulting in a rank of “D,” although these items were already at an acceptable risk level.

Operability issues were not risk ranked; however, recommendations are sometimes made for some of these scenarios. Operability issues that have recommendations have an “O” listed in the “Risk (R)” column of the worksheets.

In some cases, the team identified design issues which needed to be clarified or reviewed. If these didn’t have any hazardous impact which required a risk ranking, these scenarios were flagged as an “O” risk and the recommendations are grouped with the “Operability” issues.

3.7 PHA Team and Attendance

The PHA leader has extensive experience with facilitating PHAs using a variety of methodologies, including HAZOPs. A balanced team was provided, including individuals involved in the design, operation, and maintenance of this type of facility. Please see below the list of the members for the PHA meetings (Attendance: F (Full); P (Partial), N (None)).

Proprietary Information Use or disclosure of data contained on this sheet is subject to the restriction on page i of this document.

Table 6: Attendance

Name	Node 1	Node 2	Node 3	Node 4	Node 5
Peter Stickles	F	F	F	F	F
Emilio Flores	F	N	N	N	N
Harry Frank	F	F	N	F	F
Horst Hack	F	F	F	F	N
Mike Johnson	F	F	F	F	F
Jason Lee	N	F	F	F	N
Jason Mallinak	F	F	F	F	F
Andy Maxson	F	F	F	F	N
Jason Miller	F	F	F	F	F
Kevin Montesano	F	F	F	F	F
Jim Wilbur	F	F	F	F	N
Mike O'Connor	F	F	F	F	F
Jacky Lau	F	F	F	F	F
Dwayne Coffey	F	F	F	N	F

Proprietary Information Use or disclosure of data contained on this sheet is subject to the restriction on page i of this document.

4 PHA Results

4.1 Documentation

A number of documentation guidelines and conventions were followed to ensure efficient and comprehensive recording of the discussions during the PHA sessions. A summary of these conventions and guidelines appears below:

- ***HAZOP Study*** – The PHA was recorded using PHAGlobal® PHA software.
- ***Study Sections (Nodes)*** – The PHA was recorded by study nodes, typically where each node represented a different part of the Echogen project process and included one or more items of equipment and systems.
- ***Design Intent*** – The recording sheet description lists the design intent of equipment under consideration in the node.
- ***Numbering Items*** – The numbering system for PHA items was "*a.b"*, where "*a"* reflects the node number and "*b*" reflects the scenario number in that sheet.

4.2 Summary of PHA Results

The Recompression Brayton Cycle (RCBC) employs supercritical CO_2 as the energy transfer fluid. The power cycle operates between 25 MPa (3610 psig) and 7.79 MPa (1095 psig). The major hazard of concern is loss of containment events (equipment and piping leaks and ruptures) that rapidly release significant quantities of CO_2 into confined or semi-confined spaces. Such releases have the potential to cause oxygen depletion leading to asphyxiation. The threshold level of concern is 4% (40,000p pm). Since a significant amount of the power cycle equipment is located inside a containment building, the risk of high CO_2 levels is a possibility.

This safety concern has been partially addressed in the design by providing housing enclosures for rotating equipment (compressors, pumps, turbines) located inside the building. These enclosures will be provided with a vent stack to evacuate the CO_2 to a safe location outside the building. During the PHA it was assumed that the structural integrity and vent capacity of the enclosures will be designed to withstand the pressure resulting from credible CO_2 releases.

However, some scenarios were identified that could result in piping leak/rupture in the building outside the containment enclosures as indicated in Table 7 (Scenarios 1.4.3, 1.24.2). The ventilation for the main building is in accordance with NFPA 55 which requires a minimum rate of 1 CFM per 1 ft^2 of floor area. The risk to operators from these events was assessed and recommendations to mitigate the risk were made. It is further recommended that the maximum

Proprietary Information Use or disclosure of data contained on this sheet is subject to the restriction on page i of this document.

CO_2 leakage rate be determined for an end-point concentration of 40,000ppm coupled with the ventilation rate and adjustments considered if necessary.

Table 7: High Risk Hazard Events

#	Cause	Consequence	Risk	Recommendation
1.1.4	Premature opening of ERV1006 due to operator error or control malfunction	Flow of hot CO_2 from fired heater into piping not rated to temperature and pipe rupture release of CO_2 into building with health impacts	A	Consider changing the fail position of ERV1006 to FC.
				Perform a transient analysis to determine whether the temperature in the carbon steel piping exceeds the minimum exposure temperature.
1.1.1	Relocated ERV1003 (FO) fails open	CO_2 blowdown to vent stack and possible health impacts on campus	B	Determine safe location of vent stacks based on dispersion modeling to avoid campus health impacts.
1.1.2	ERV1006 (FO) on CHX shell side fails pen	CO_2 blowdown to vent stack and possible health impacts on campus	B	Determine safe location of vent stacks based on dispersion modeling to avoid campus health impacts.
1.3.1	Inadvertent opening of ERV1006 due to operator error	Major process upset requiring venting of CO_2 and possible health impacts on campus	B	Consider automatic master firing control trip on ERV1006 valve position indicator.
				Refer to recommendation for [1.1.1] above
1.4.3	HTC/LTC-DTs trip from common cause events including loss of seal gas or process cooling in IHX/CHX	Flow of hot CO_2 (600C) from fired heater into piping not rated to temperature and pipe rupture release of CO_2 into building with health impacts	B	Provide interlock to open PCV0503 on loss of cooling or seal gas.
				Add a second check valve in series with NRV0211 and NRV0231
1.10.1	Some PSV release may produce two-phase flow at a temperature of minus 55C and release dry ice from vent stack	Vent release expected to impact campus based on preliminary dispersion analysis	B	Mitigation options include adding dispersion air movers and increasing the height of the stack.
1.24.2	Residual moisture in power cycle system after hydrotesting equipment	Formation of carbonic acid and accelerated corrosion resulting in CO_2 leaks into building	B	Investigate alternatives fluids for hydrotesting the equipment.
5.8	Fabric filter inlet damper ABD-8302A close against ID Fan	ID Fan draws on fabric filter resulting in housing collapse	B	Verify that fabric filter housing will be designed for maximum negative pressure of the ID Fan test block.
4.5.2	CO_2 Inventory control equipment failure due to vehicle impact	Release of LCO_2 to atmosphere with some degree of confinement resulting in possible health impact risk	C	Provide crash barriers to protect vulnerable equipment near CO_2 storage system.

Proprietary Information Use or disclosure of data contained on this sheet is subject to the restriction on page i of this document.

Another area of concern is at the location of the carbon dioxide bulk storage tank (Scenario 4.5.2. It is located near a traffic lane between some building which provides partial confinement and CO_2 being heavier than air (44 v 29 mol weight), will sink to grade. While the operating pressure (~220 psig) is much less, a leak in this area has potential to affect the campus population.

There is also an equipment damage risk for the fired heater that could result in an unscheduled outage and repair costs. The main causes for the damage are partial or total loss of CO_2 flow through the heating elements (PHX, convention walls, etc.) resulting in over heating of tube bundles and tube rupture inside the fired heater. While existing safeguards exist, a risk ranking of C requires additional mitigation (see PHA complete recommendation summary for these Node 1 and 3 scenarios).

A Facility Siting impact issue is the possible venting from the emergency relief valves (ERV) and pressure relief valves (PRV) as indicated by scenarios 1.1.1, 1.1.2, 1.3.1, and 1.10.1 in Table 7. The location and height of the vent stacks needs to be determined based on dispersion modeling results for a worst-case release from ERV1003 or ERV1006.

Moreover, a few Human Factors issues were also identified and recorded for consideration.

4.3 List of Recommendations

The recommendations from the PHA are grouped by risk level; with “A” being the highest risk level and “D” being the lowest level. This grouping provides a prioritization of the recommendations for follow up. In addition, recommendations that had no safety or business impact were listed as “Operability” and have the letter designation of “O.”

Please find below the complete reporting summary of High (A) and Medium (B) priority recommendations:

Proprietary Information Use or disclosure of data contained on this sheet is subject to the restriction on page i of this document.

Table 8: Priority Recommendations

Nodes	Item	Cause	Consequences	Safeguards	L	C	R	Recommendations
Node 1: sCO2 Circulation Loop LTC/HTCs and Drivers	High flow	Premature opening of ERV1006 due to operator error or control malfunction	Flow of hot CO2 from fired heater into areas not designed for that temperature, and potential for pipe rupture and deinventory of CO2 from the system into building with life-threatening health impacts	none	4	4	A	Consider changing the fail position to fail close Perform a transient analysis to determine whether the temperature in the carbon steel piping exceeds the allowable operating temperature
Node 1: sCO2 Circulation Loop LTC/HTCs and Drivers	High flow	ERV1003 (FO)relocared after PHX1 fails open	CO2 inventory blowdown to vent header and release of CO2 to the environment, resulting in possible health effect impact on campus	FI0035 low flow alarm. No credit taken	4	3	B	Determine the location of the vents based on air modeling to avoid campus impacts
		ERV1006 (FO) on CHX SS fails open	CO2 inventory blowdown to vent header and release of CO2 to the environment, resulting in possible health effect impact on campus	FI0035 low flow alarm. No credit taken.	4	3	B	Determine the location of the vents based on air modeling to avoid campus impacts
	Misdirected Flow	Premature opening of ERV1006 due to operator error or control malfunction	Major operating upset requiring system shut down and venting of CO2 and potential public impact	none	4	3	B	Consider automatic master fuel trip based on ERV valve position Determine the location of the vents based on air modeling to avoid campus impacts
	Reverse Flow	HTC/LTC-DTs trips for a common cause event including loss of sealing gas and loss of process cooling via IHX/CHX	Hot (600C) CO2 from fired heater enters carbon steel piping (425C operating limit) resulting in rupture and major release of CO2 in building and potential life-threatening impacts.	NRV0211, and NRV0231	3	4	B	Provide a interlock to open PCV0530 on loss of cooling or loss of sealing gas (1 IPL mitigation) Add a second check valve in series with NRV0211 and NRV0231 to provide a second IPL mitigation.
	Low temperatur e	Certain pressure relief valves may produce two phase CO2 flow at a temperature of -55 C resulting in 2-phase (gas and solid) flow	Vent release may impact public at unacceptable level based on preliminary results of dispersion analysis	none	5	2	B	Mitigation options include adding dispersion fans and increasing the height of the vent discharge
	Corrosion/ erosion	Residual water in the system after hydrotesting equipment	Formation of carbonic acid, and accelerated corrosion, with the potential for a perforation leak, resulting in CO2 release into the building or fired heater or outside storage area, and potential personnel health impacts	System design includes self draining	4	3	B	Investigate alternative fluids for hydrotesting the equipment
				General building ventilation is designed per NFPA 55 (1 CFM per SQ.Ft of floor area), no credit	4	3	B	Monitor the moisture content of the inert gas during the dry out process Provide CO2 detection at high risk areas in the building and escape packs/respirators for emergency
Node 5: SCR, CDS, Fabric Filter	Vacuum	No flue gas flow due to fabric filter inlet damper ABD-8302A closed	ID fan draws pressure down in the fabric filter with the potential for housing implosion	Fabric filter is to be designed for the maximum negative operating pressure of the	4	3	B	Verify the fabric filters is designed for the negative operating pressure

Proprietary Information Use or disclosure of data contained on this sheet is subject to the restriction on page i of this document.

4.4 Follow-up

It is the responsibility of Echogen and its affiliates to fully address each recommendation listed in the PHA record for this process. For each recommendation, the action required to resolve the recommendation should be documented and a written schedule for completion of the actions in a timely manner should be developed.

Finally, the actions taken should be communicated to all employees whose work assignments are in the process and who may be affected by the recommendations or actions.

Proprietary Information Use or disclosure of data contained on this sheet is subject to the restriction on page i of this document.

V. Design Report (Performance Test Plan)

Supercritical Carbon Dioxide Primary Power Large-Scale Pilot Plant

Phase II

Performance Test Plan

December 2020

CONTENTS

***1* INTRODUCTION 1-1**
Test Objectives 1-1
Schedule of Testing 1-2
Proposed Schedule (1 week): 1-2
Testing Procedure 1-3
***2* SYSTEM BOUNDARY 2-1**
Determining the Incoming Energy Flows 2-2
Air 2-3
Fuel 2-4
Other Credits 2-4
Determining the Outgoing Energy Flows 2-4
Flue Gas 2-5
Ash/Solids 2-6
Power Island 2-6
Thermal Losses 2-6
Determining Fired-Heater Efficiency 2-6
***3* ANTICIPATED UNCERTAINTY 3-1**
Measurement Error 3-1
Combining Uncertainties 3-1
Representative Example 3-2
***A* COMBUSTION AIR MANUAL TRAVERSE PORTS A-1**
Inlet Air Measurement A-1
Flue Gas Measurement A-2

LIST OF FIGURES

Figure 2-1 System Boundary Definition 2-2
Figure 2-2 Fired Heater Working Fluid Interfaces 2-7
Figure 3-1 Determination of calculated energy and combined uncertainty for incoming air streams 3-2

Figure A-1 Existing location for air measurement ports A-1
Figure A-2 Proposed location for air measurement ports A-2
Figure A-3 Existing location for flue gas measurement ports A-2
Figure A-4 Proposed location for flue gas measurement ports A-3

1
INTRODUCTION

The purpose of this document is to detail the required measurements, anticipated uncertainty, calculation procedure, and reporting strategy, combined together to form a test plan, for the Echogen Large-Scale Pilot unit, a coal-fired supercritical CO_2 generator with a nominal 10 MW_e output power.

The test plan defines the required preparations needed for conducting the test, responsible personnel needed, how to conduct the test, data management, calculation methods for the results calculation, and the format of the final report. This preliminary test plan document serves to define the framework needed for the final test plan; the full definition of which will be carried out in Phase 3.

Test Objectives

The primary objective of conducting a performance test is to verify the installed equipment meets the designed operating characteristics. This can be of critical importance to verify the performance of the system as installed or to identify corrective actions that may be needed. For this unit, the primary performance indicator is overall net plant efficiency.

Equation 1 – Overall System Efficiency

$$\eta = \frac{W_{Net}}{Q_{total}} = \frac{W_{PT} - \sum W_{Aux}}{\sum M_F \, HHV_F}$$

Where: η = Overall Net Plant Efficiency (%, HHV basis)

W_{Net} = Net power exported (MW_e)

Q_{total} = Total fuel heat input (MW_{th})

And: W_{PT} = Gross power turbine generation (MW_e)

W_{Aux} = Auxiliary power consumption (MW_e)

M_F = Mass flowrate of fuel consumed (kg/s)

HHV_F = Higher heating calorific value of fuel (MJ/kg)

Each of these parameters needs to be either directly measured or derived from other measurable process conditions to calculate the overall net plant efficiency. This objective will be tested for a specified net power delivery. If this power delivery is not achievable during the testing period, possibly due to differences in ambient conditions, the design performance values will be adjusted using appropriate heat rate curves that correct for the difference between the design basis conditions and the tested condition.

Several secondary objectives will also be defined to be able to validate the performance of key equipment and systems making up the plant. A key division point for thermal generation systems is the efficiency of the fired heater to deliver thermal energy to the working fluid and the power cycle system efficiency to convert that thermal energy to gross power. This will be covered in more detail in later sections.

Schedule of Testing

For the overall test plan, a schedule should be prepared to detail the sequence of events needed to prepare the system for the test, the anticipated test duration, specification of the parties required to carry out the test, team conduct and expectations throughout the test period, data collection requirements, and the calculation of results.

The testing team members will be identified and assigned roles needed for system operation during the tests, the required data acquisition, manual sampling and analysis, along with other groups needed to support test preparations. For example, outside work such as laboratory services will determine properties of the coal and ash and perform an analysis on extractive emission samples. Test execution will be led by a designated test coordinator, who will develop a communication plan for all test personnel and all test parties and oversee the progression of the test to ensure it meets all defined test requirements. Part of the duties of the test coordinator is to work with the plant operators to prepare the system for testing, establishing the appropriate operating conditions and dwell time prior to testing to achieve steady-state conditions. Finally, the test coordinator will ensure that all parties performing testing activities will produce complete written records of the test with time coordination based on the unit distributed control system's (DCS) official time.

Proposed Schedule (1 week):

Day 1 – Test team mobilization to site, equipment establishment, preliminary audits and test measurements.

Day 2 – Establish plant at the baseline 100% Power Island Load condition with steady state established for 2 hours prior to test commencement – a minimum of 3 individual tests comprising of a steady state operation at the defined 100% gross output for a minimum of 1-hour duration each confirming within a defined degree of stability, such as ASME PTC-4 that states allowable variance in operating conditions such as turbine inlet pressure 4%, working fluid flow 4%, 1% volume oxygen concentration in flue gas leaving the fired heater, turbine inlet temperature 20°F, fuel flowrate variance of 10% with a 2 in bed depth and a bed temperature variance of no greater than 50°F.

Day 3 – Establish plant at part load condition (exact load TBD) ensuring that steady state operation has been established for 2 hours prior to test commencement – a minimum of 3 individual tests comprising of a steady state operation at the agreed part load output for a minimum of 1-hour duration each confirming within a defined degree of stability (TBD).

Day 4 – Establish plant at minimum generation load condition (exact load TBD) ensuring that steady state operation has been established for 2 hours prior to test commencement – a minimum of 3 individual tests comprising of a steady state operation at the agreed part load output for a minimum of 1-hour duration each confirming within a defined degree of stability (TBD).

Day 5 – Contingency day to allow for re-testing for prior tests that did not achieve steady state conditions throughout the testing period.

Day 6 – Test team disestablishment if prior day used for testing.

Testing Procedure

Prior to the testing period, the following parameters need to be defined:

- Base reference conditions
- Test boundary identifying inputs and outputs and measurements locations
- Complete pretest uncertainty analysis, with systematic uncertainties established for each measurement and an estimate of random uncertainties
- Specific type, location, and calibration requirements for all relevant instrumentation and measurement systems and frequency of data acquisition
- Agreed to correction curves if test baseline conditions cannot be achieved
- Data storage plan (DCS and test records)
- Test reporting requirements (format, sections, and index) and distribution

For each test, the test records will document the following details:

- Objective of test (power rating/load case/fuel selection)
- Test duration and number of runs (1-hour duration/3 tests)
- Acceptance criteria for test completion (pretest stabilization criteria of over 1 hour and steady-state confirmation throughout test period and manual measurement success confirmation, see ASME PTC-4 criteria)
- Records of sample collection, traceability for analysis (fuel, ash, and sorbent)
- Data collection through testing period (start/stop times, DCS tags needed for analysis, data acceptance, and rejection criteria)

The test data needs to be structured with precision assessment and bias incorporated alongside each measured parameter to enable easy traceability of both the calculated values and the combined uncertainty for each performance metric determined.

2
SYSTEM BOUNDARY

When defining the overall thermal input and energy export from a fired-heater system, the overall system boundary needs to be defined and all crossing materials or energy flows need to be accounted for – this interface is referred to as the test boundary. The test boundary identifies the energy streams that must be accurately measured to calculate the desired results. American Society of Mechanical Engineers Performance Test Code 46[1] defines the test boundary as an accounting concept used to define the streams that must be measured to determine performance. All input and output energy streams required for test calculations must be determined with reference to the point at which they cross the test boundary.

For this system, energy and material flows crossing the test boundary are:

- Incoming to the fired heater – Coal fuel, natural gas fuel, combustion air, infiltration, atomizing and selective catalytic reduction (SCR) blower air, ammonia reagent for SCR, and hydrated lime for SOx removal

- Outgoing from the fired heater – Flue gas, solid ash, thermal losses (radiation and convective), and heat transfer to the working fluid (supercritical CO_2)

The power cycle has incoming heat from the working fluid and several outgoing energy flows – electrical power, rejected thermal energy to the cooling water, and thermal losses (radiative and convection). Figure 2-1 shows a block diagram with the main system energy vectors crossing the system boundary.

The energy streams within the boundary need not be determined unless they verify base operating conditions or unless they relate functionally to conditions outside the boundary. For the purposes of this test plan, the interface between the fired heater and the power cycle is of specific interest to allow the determination of the total heat to the working fluid, thereby determining the overall fired-heater efficiency and the gross heat rate needed by the power cycle to produce electrical power for export.

[1] https://www.osti.gov/biblio/697183-asme-ptc-acceptance-test-code-overall-plant-performance

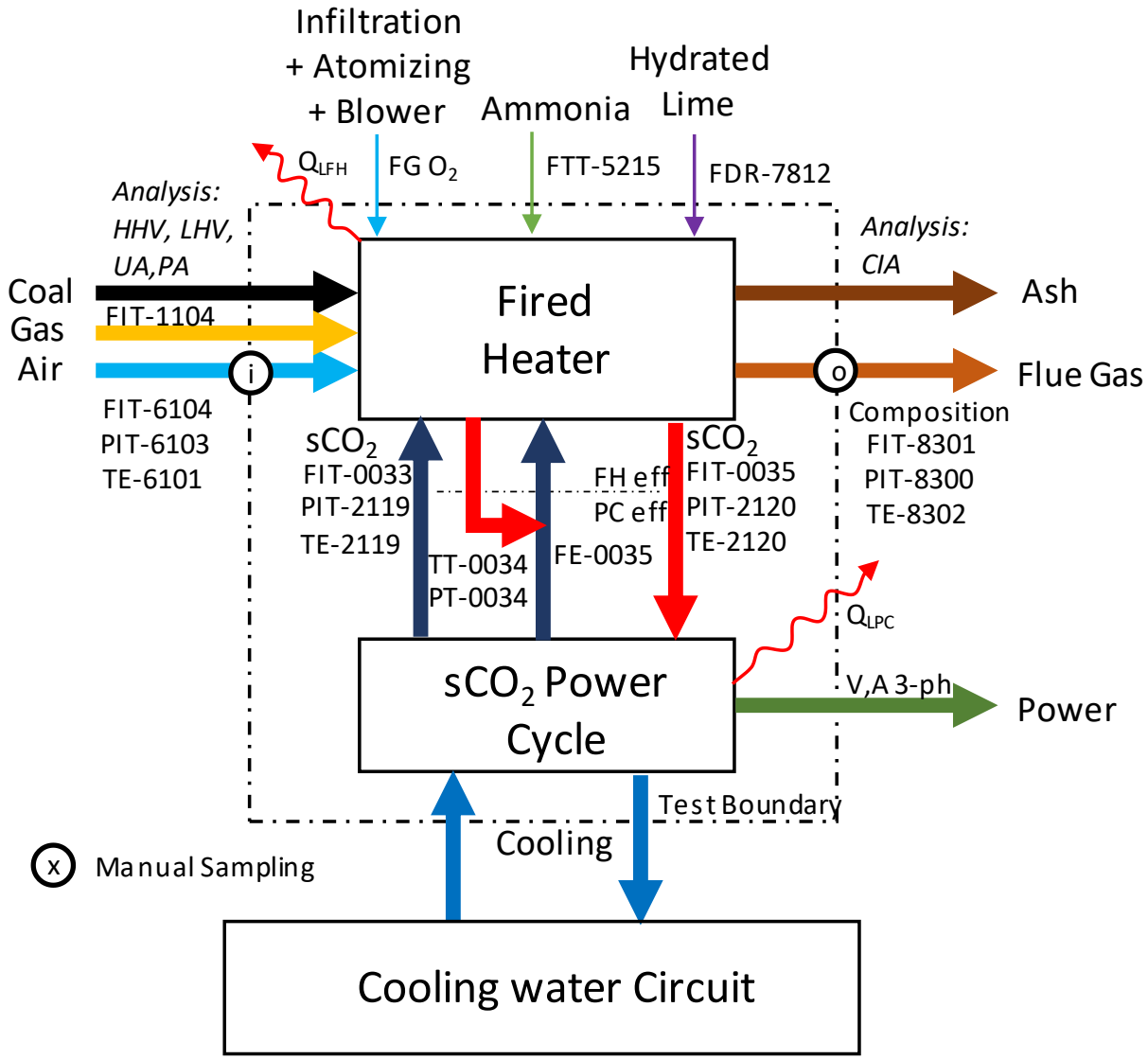


Figure 2-1
System Boundary Definition

Determining the Incoming Energy Flows

To establish how much energy is entering the system, each process stream must be evaluated individually taking into account the impact the injection will have on the overall thermal balance, i.e., does the process stream add sensible heat or will the components react to form products and release or consume some of the free energy available.

Reference conditions need to be defined and applied to all quoted enthalpies used in the energy flow determination calculations. The overall calibration uncertainty of the calibrated instrument should be determined at a 95% confidence level.

Equation 2 – Incoming Energy Vectors Crossing Test Boundary

$$E_{EN} = (M_{IF} + M_A)H_A + M_{FG}H_{FG} + M_{FG}HHV_{FG} + M_{FC}HHV_{FC} + M_{FC}H_{FC} + M_{AM}H_{AM} + M_{HL}H_{HL} + W_{FDF} + W_{BAF} + W_{AMP}$$

Where: E_{EN} = Total energy rate entering test boundary (kW)

M_{IF} = Mass flowrate of air infiltration (kg/s)

M_A = Mass flowrate of combustion air (kg/s)

H_A = Enthalpy of ambient air (kJ/kg)

M_{FG} = Mass flowrate of fuel gas (kg/s)

H_{FG} = Enthalpy of fuel gas (kJ/kg)

HHV_{FG} = Higher heating value of fuel gas (kJ/kg)

M_{FC} = Mass flowrate of coal (kg/s)

H_{FC} = Enthalpy of coal (kJ/kg)

HHV_{FC} = Higher heating value of coal (kJ/kg)

M_{AM} = Mass flowrate of ammonia injection (kg/s)

H_{AM} = Enthalpy of ammonia (kJ/kg)

M_{HL} = Mass flowrate of hydrated lime (kg/s)

H_{HL} = Enthalpy of hydrated lime (kJ/kg)

W_{FDF} = Work from forced draft fan (kW_e)

W_{BAF} = Work from boosted air fan (kW_e)

W_{AMB} = Work from ammonia pumps (kW_e)

The determination of each of these factors during the testing and the uncertainty of the measurements for the key parameters is essential for the overall assessment. The primary considerations for the entering energy flows are the fuel quantities, fuel analysis, and the combustion airflow measurements.

Air

M_{IF} Air infiltration is determined as a derivative parameter based on the actual combustion air measurements, flue gas measurements, and oxygen measurements at the furnace exit and airheater inlet/outlet. Part of the overall air infiltration will come from atomizing air for ammonia distribution that is measured (FIT-5260[2]); however, the balance of the overall infiltration will be through the system boundary due to the negative gauge pressure in the flue gas path caused by the balance draft combustion arrangement.

M_A Combustion air is directly measured by the system at FIT-6104 and will be verified by manual velocity traverses at the appropriate sampling ports (see Appendix 1).

H_A Ambient air enthalpy is derived by the direct measurement of the temperature (T_A), pressure (P_A), and absolute humidity (φ_A) of the air entering the system during the test. The sensible and latent heat of humidity contained within the incoming air will be treated separately as this contributes to the moisture loss in the flue gas.

[2] This, and other similar labels used in this report, denote DCS tags

Fuel

M_{FG} Fuel gas flow is directly measured by the system with FIT-1104

H_{FG} Fuel gas enthalpy is derived from TT-1104 (T_{FG}), PT-1104 (P_{FG}), and the gas composition evaluated heat capacity (Cp_{FG})

HHV_{FG} Fuel gas calorific energy content including moisture latent heat, derived from gas composition and oxidation reaction energy

M_{FC} Coal flow is difficult to measure directly; hence, determination is based on the measured combustion air flowrate, the flue gas composition, the measured flue gas flow (FIT-8301), and the coal composition (ultimate analysis)

H_{FC} Enthalpy of coal (kJ/kg) is derived from T_A and the coal composition evaluated heat capacity (Cp_{FC})

HHV_{FC} Coal calorific energy content including moisture latent heat, derived from coal composition and oxidation reaction energy (ultimate analysis)

Other Credits

M_{AM} Ammonia flow directly measured from FTT-5215

H_{AM} Ammonia enthalpy derived from the ammonia temperature and pressure entering the system. It should be noted that only pressure gauges are available (not recorded) and temperature is not directly measured. As this is an anhydrous ammonia configuration that maintains liquid status through the pumps, the incoming temperature will be taken as T_A. The heat capacity of pure ammonia is used to determine the resultant enthalpy.

M_{HL} Hydrated lime flow is measured directly from FDR-7812. Due to the relatively crude nature of this type of measurement, this should be verified against the gas composition and flue gas measurements.

H_{HL} Hydrated lime enthalpy is based on a temperature that is not measured directly but is taken as T_A.

W_{FDF} Forced draft fan power thermal energy credit, which is measured across all three phases with manufacturer's efficiency included

W_{BAF} Booster fan power thermal energy credit, which is measured across all three phases with manufacturer's efficiency included

W_{AMP} Ammonia pump energy credit, which is measured across all three phases with manufacturer's efficiency included

Determining the Outgoing Energy Flows

To establish how much energy is leaving the system, each process stream must be evaluated individually, and the energy exported from the power cycle must also be accounted for. Thermal losses from the system, normally from radiation losses through the fired heater envelope are in the order of 0.4-0.5% ratio of total heat input for a (31.4MWth/107 MMBtu/hr heat input with 4 water-cooled walls (sCO_2 cooled walls are expected to be similar to water cooled walls in this regard). However, this quantity isn't measurable and so will form part of the deficit between the measured input energy and leaving energy.

Reference conditions need to be defined and applied to all quoted enthalpies used in the energy flow determination calculations. The overall calibration uncertainty of the instrument should be determined at a 95% confidence level.

Equation 3 – Outgoing Energy Vectors Crossing Test Boundary

$$E_{LV} = M_G H_G + M_{H2O}(H_{H2O} + \Delta H_{LH2O}) + M_{ASH}(H_{ASH} + Fm_{CIA} HHV_{FC}) + W_{PT} + M_{CW}(H_{CWo} - H_{CWi}) + Q_{LFH} + Q_{LPC}$$

Where:

E_{LV} = Total energy rate leaving test boundary (kW)

M_G = Mass flowrate of dry flue gas (kg/s)

H_G = Enthalpy of dry flue gas (kJ/kg)

M_{H2O} = Mass flowrate of moisture in flue gas (kg/s)

H_{H2O} = Enthalpy of moisture in flue gas (kJ/kg)

ΔH_{LH2O} = Latent heat of moisture in flue gas (kJ/kg)

M_{ASH} = Mass flowrate of ash exiting stoker (kg/s)

H_{ASH} = Enthalpy of ash exiting stoker (kJ/kg)

Fm_{CIA} = Carbon-in-ash fraction (-)

HHV_{FC} = Higher heating value of coal (kJ/kg)

W_{PT} = Work exported from power turbine (kW_e)

M_{CW} = Mass flowrate of cooling water (kg/s)

H_{CWi} = Enthalpy of cooling water at inlet (kJ/kg)

H_{CWo} = Enthalpy of cooling water at outlet (kJ/kg)

Q_{LFH} = Fired-heater radiative and convective losses (kW)

Q_{LPC} = Power cycle thermal losses (kW)

The determination of each of these factors during the testing and the determination of the uncertainty of the measurements for the key parameters is essential for the overall assessment. The primary considerations for the exiting energy flows are the flue gas flow and conditions, flue gas moisture content, power turbine export power, and the heat rejection to the cooling system.

Flue Gas

M_G Flue gas flow will be directly measured by the system FIT-8301 and will be verified by manual velocity traverses at the appropriate duct ports during the testing periods (see Appendix 2)

H_G Dry flue gas enthalpy is based on composition and temperature (T_G) TE-8302 and pressure (P_G) PIT-8300

M_{H2O} Moisture in flue gas is derived from flue gas composition and M_G

H_{H2O} Moisture vapor enthalpy is based on flue gas temperature TE-8302 and pressure PIT-8300

ΔH_{LH2O} Latent heat of moisture in flue gas at reference temperature (T_{ref})

Ash/Solids

M_{ASH} Mass of ash exiting system is derived from the coal ultimate analysis and the M_{FC}

H_{ASH} Ash enthalpy is based on T_{ASH} and average specific heat capacity of the ash (Cp_{ASH})

Fm_{CIA} Ash samples taken during the testing period and laboratory carbon-in-ash analysis will be carried out to determine the unburnt loss (energy loss based on coal HHV_{FC})

Power Island

W_{PT} Electrical power exported from the generator driven by the power turbine; the summation of all 3 phases of the voltage, current integrated over the test period

M_{CW} Cooling water flow is measured from the amount drawn from the main system FE-4110

H_{CWi} Enthalpy of cooling water at inlet is determined by the temperature of the cooling water entering the system TE-4110

H_{CWo} Enthalpy of cooling water at outlet is determined by the temperature of the cooling water exiting the system TE-4120

Thermal Losses

Q_{LFH} Fired-heater losses are assumed to be 1% of the overall heat input, representing radiative and convective losses from the insulated fired heater walls, ducting, and equipment up to the airheater module

Q_{LPC} Power cycle thermal losses represent the thermal energy losses from piping, turbine casing, and bearings and cooling systems – these losses are not considered directly as they are generally considered to be part of the power cycle heat rate (i.e., heat rate is higher due to these losses). This cannot be determined in the test but will impact the overall rate.

Determining Fired-Heater Efficiency

To establish how much energy is delivered to the working fluid from the fired heater or primary heater (PHX), the CO_2 streams need to be assessed. The proposed arrangement uses three separate heat exchanger circuits that connect in series with each other and partially in parallel with the high-temperature recuperative heat exchanger (HTR) as shown in Figure 2-2.

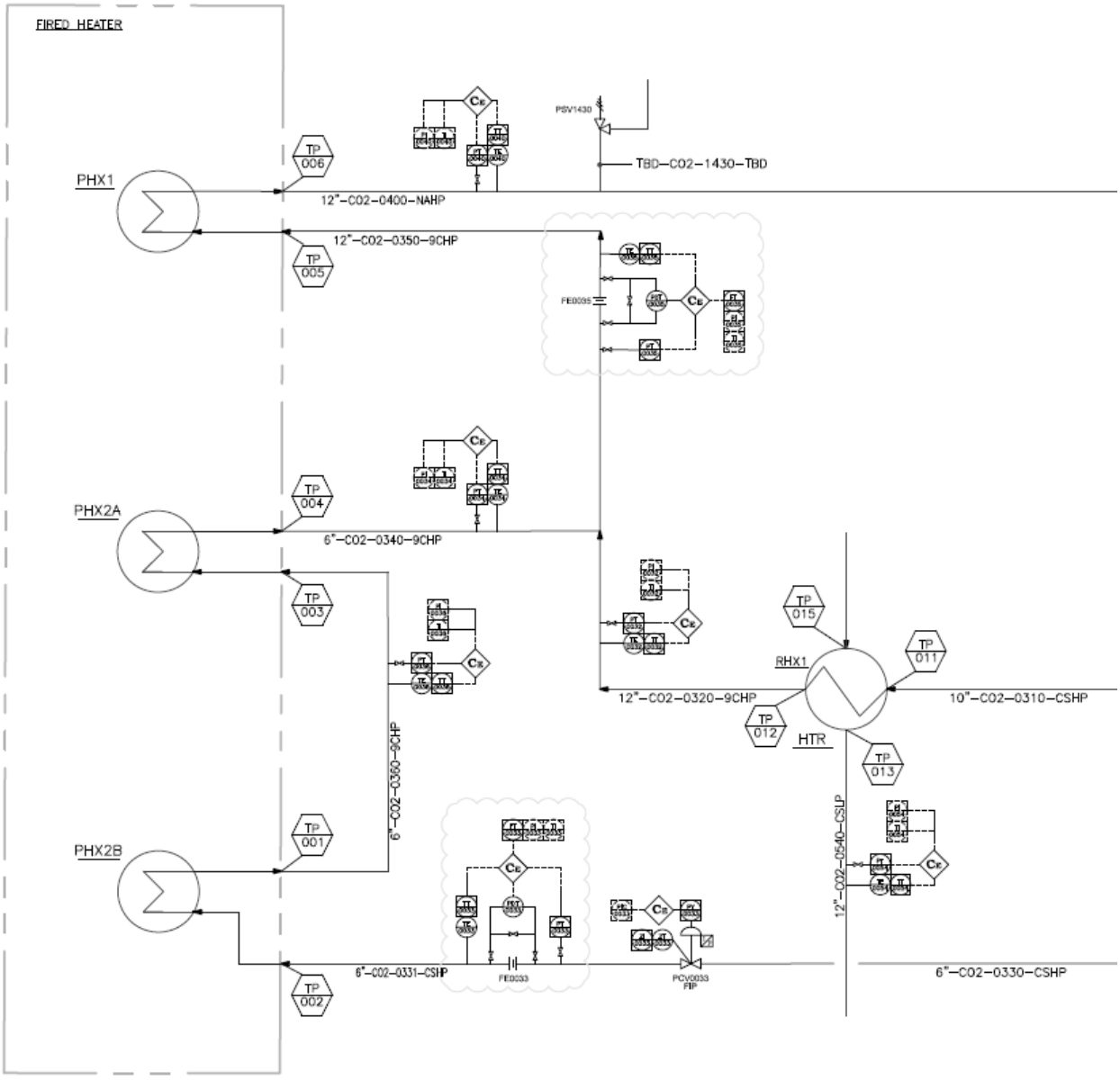


Figure 2-2
Fired Heater Working Fluid Interfaces

The determination of total thermal absorption into the working fluid can therefore be broken down into two main parameters: the main PHX 1 circuit and the back-end PHX 2 banks.

Equation 4 – Heat to Working Fluid

$$E_{WF} = M_{WF1}(H_{WF1o} - H_{WF1i}) + M_{WF2}(H_{WF2o} - H_{WF2i})$$

Where: E_{WF} = Total heat absorbed by working fluid (kW_{th})

M_{WF1} = Mass flowrate of working fluid passing through PHX 1 (kg/s)

H_{WF1i} = Enthalpy of working fluid entering PHX 1 (kJ/kg)

H_{WF1o} = Enthalpy of working fluid exiting PHX 1 (kJ/kg)

M_{WF2} = Mass flowrate of working fluid passing through PHX 2 (kg/s)

H_{WF2i} = Enthalpy of working fluid entering PHX 2 (kJ/kg)

H_{WF2o} = Enthalpy of working fluid exiting PHX 2 (kJ/kg)

The determination of each of these factors during the testing and the determination of the uncertainty of the measurements for the largest key parameters is essential for the overall assessment.

M_{WF1} CO_2 working fluid mass flowrate is measured by FT-0035

H_{WF1i} CO_2 working fluid enthalpy is derived from TT-0035 and PT-0035

H_{WF1o} CO_2 working fluid enthalpy is derived from TT-0040 and PT-0040

M_{WF2} CO_2 working fluid mass flowrate is measured by FT-0033

H_{WF2i} CO_2 working fluid enthalpy is derived from TT-0033 and PT-0033

H_{WF2o} CO_2 working fluid enthalpy is derived from TT-0034 and PT-0034

The overall fired-heater efficiency is therefore determined by Equation 5.

Equation 5 – Fired-Heater Efficiency

$$\eta_{FH} = \frac{E_{WF}}{\sum M_F HHV_F}$$

3
ANTICIPATED UNCERTAINTY

Measurement Error

Each measurement taken throughout the testing periods is subject to both accuracy and precision error. Accuracy error is often described as the difference between the average measurements from an instrument to the true value, as defined by a referenceable standard. Precision error is the random error of individual measurements around the average (for multiple measurements of a single measurand), i.e. it is a determination of the repeatability of the measurement. Hence accuracy can be considered 'trueness' and precision the 'variability' of measurements.

The precision of the average value is defined as the standard deviation of the process data divided by the square root of the number of measurements averaged. For well sampled, long duration testing, the precision error of the average value will statistically balance out to an insignificant low value leaving only accuracy error of overall significance. This does not mean precision error isn't important, as control applications or dynamic response analysis use real-time measurement values that are impacted by the precision error. However, for this testing, using minute resolution data for a minimum of 1-hour tests, sufficient data points should be available to eliminate the precision error, making the accuracy error determination the main uncertainty factor.

The accuracy error is often defined by instrument manufacturers based around the overall measurement range – hence selection of the best instrument for the known measurement range needed can greatly reduce the accuracy error of measurement delivering greater confidence in the overall analysis. The determination of the energy flows entering and leaving the control volume of this system requires multiple measurements of flow, temperature, pressure and composition (where relevant for property assessment).

Combining Uncertainties

Combining each of these measurements to deliver the key parameters defined in Equations 1-5 allows for the analysis of the uncertainty of the overall result based on the combined uncertainties of the measured values. If each measurement can be considered as statistically independent, then the summation in quadrature method for combining uncertainties can be used.

Equation 6 – Combining uncertainties for additive parameters

$$U_P = \sum_{i=1}^{n} u_i MV_i$$

Equation 7 – Combining uncertainties for products and quotients

$$U_P = \sqrt{\sum_{i=1}^{n} [u_i MV_i]^2}$$

Where: U_P = Combined uncertainty for calculated parameter

u_i = Uncertainty of individual measurement

MV_i = Measured value or measurement range of instrument

n = total number of measurements needed to calculate parameter

It should be noted that this only applies when the measured values combine directly for the parameter in question, pressure and temperature generally only impact density, viscosity or transport properties – hence the impact of these measurements should be factored using the relative impact of the measurement error, not the direct uncertainty.

Representative Example

Example of uncertainty assessment for highlighted term in Equation 2 (data included not representative):

$$E_{EN} = (M_{IF} + M_A)H_A + M_{FG}H_{FG} + M_{FG}HHV_{FG} + M_{FC}HHV_{FC} + M_{FC}H_{FC} + M_{AM}H_{AM} + M_{HL}H_{HL} + W_{FDF} + W_{BAF} + W_{AMP}$$

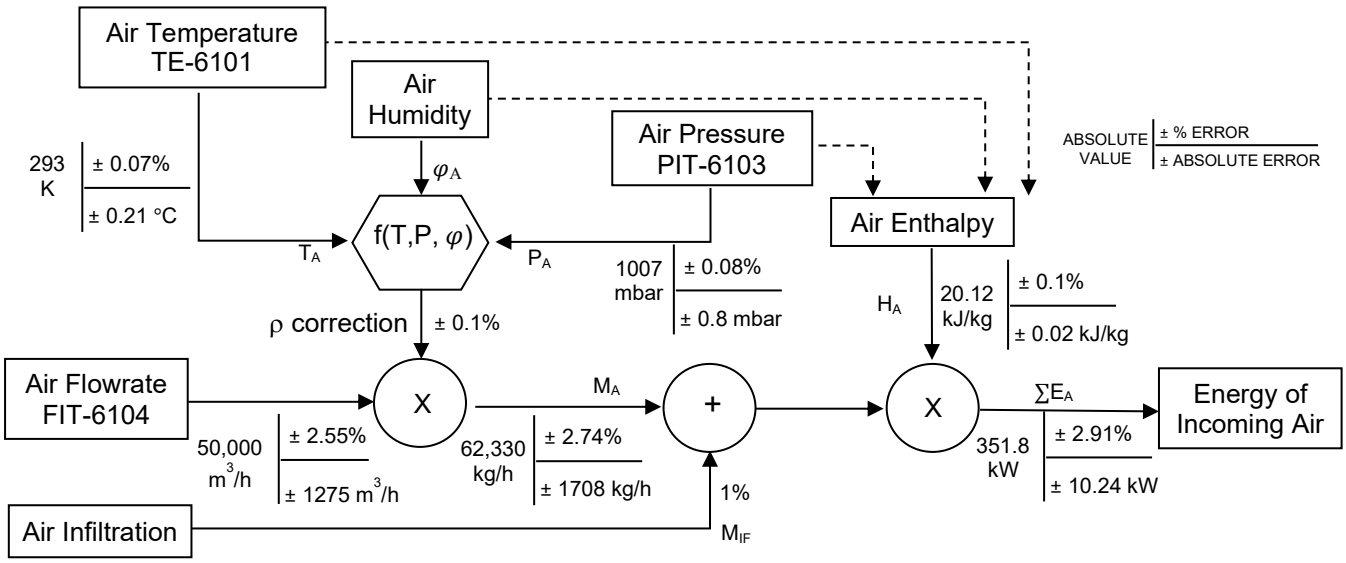


Figure 3-1
Determination of calculated energy and combined uncertainty for incoming air streams

A
COMBUSTION AIR MANUAL TRAVERSE PORTS

Inlet Air Measurement

The location of the test ports as currently defined is too close to adjacent discontinuities to be compliant with Environmental Protection Agency (EPA) Method 1 - the outlet of the fan is a large discontinuity to flow. To achieve fully developed (and easily measured) flow, 8-10 equivalent diameters of the duct are recommended. Additionally, the duct splits immediately after the port location, recommend at least 2 equivalent diameters to downstream flow disturbances, this is not the case at this location, see Figure A-1.



Figure A-1
Existing location for air measurement ports

Measuring here would require a larger number of sample points and systematic error is likely. Proposed alternative location is shown in Figure A-2.

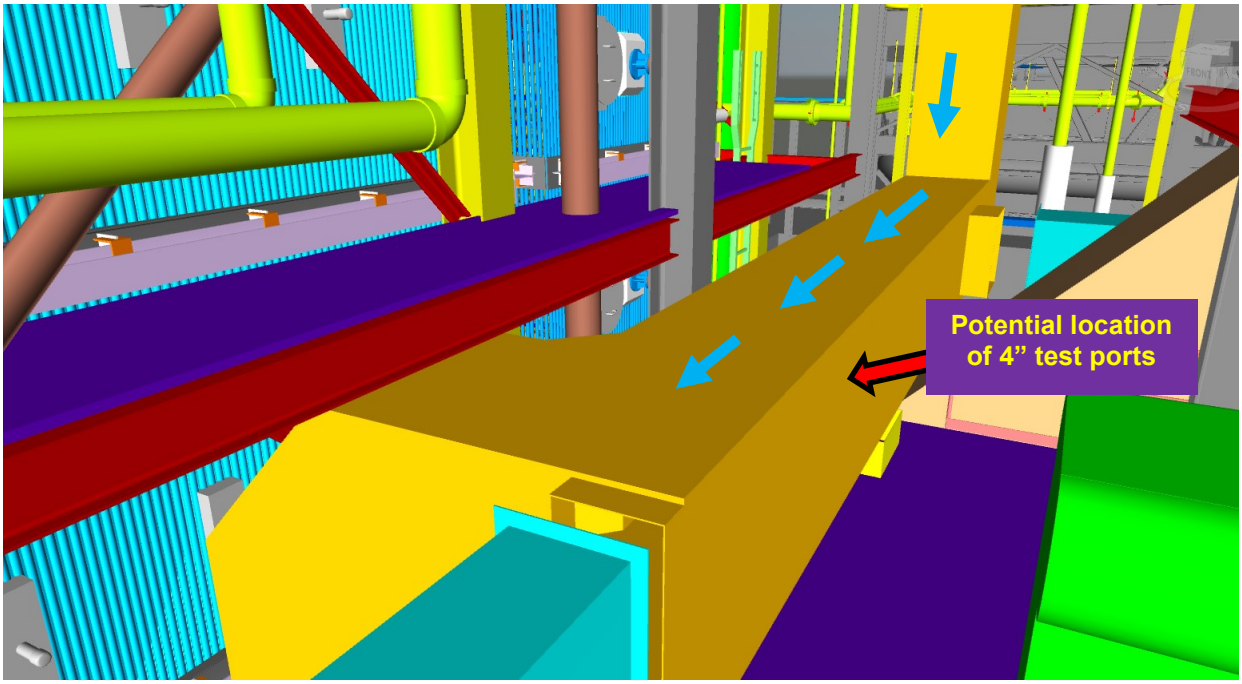


Figure A-2
Proposed location for air measurement ports

Flue Gas Measurement

Current location of the test ports is too close to upstream discontinuities to be compliant with EPA Method 13 due to the proximity of the ID fan, recycle port and valve. Additionally, positive pressure is a safety risk for testing personnel (opening ports will result in flue gas ejection).

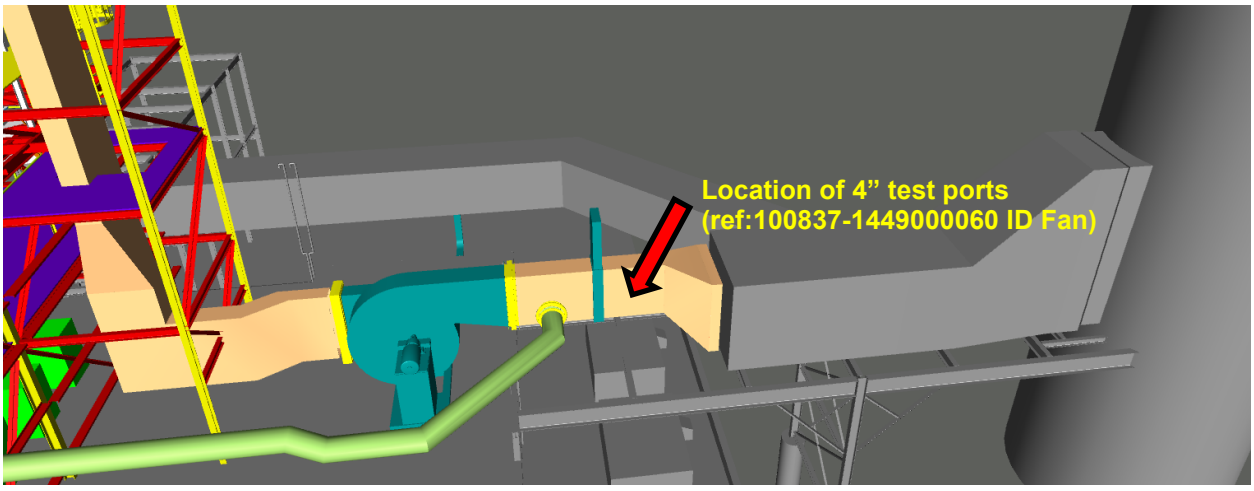


Figure A-3
Existing location for flue gas measurement ports

Potential location with good flow development before and after location:

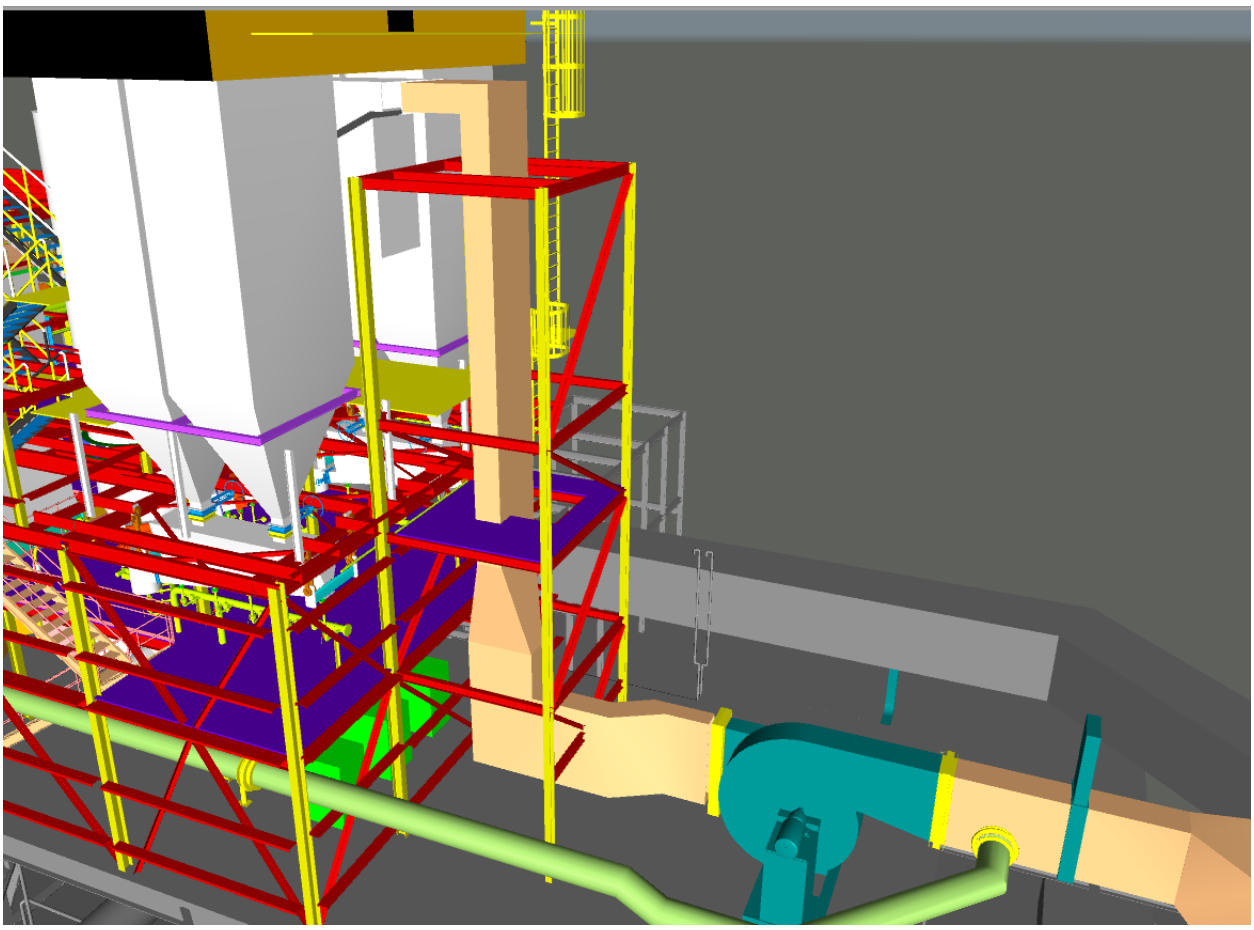


Figure A-4
Proposed location for flue gas measurement ports

VI. Phase III Budget (EPC)

Project:	DOE Phase II sCO2 Pilot Plant - MU	**Estimate By:**	LPA & PGL
Project No.:	19-1092	**Date:**	10/01/20
		Reviewed By:	KLM
Total OPCC:	$ 63,200,000	**Date:**	10/20/20

CDM SMITH
OPINION OF PROBABLE CONSTRUCTION COST
SUMMARY PAGE

Item No.	Division No.	Item Description	Total Material Cost	Total Labor Cost	Total Equipment Cost	Total Cost	Notes
3	DIVISION 02	EXISTING CONDITIONS	$ 306,876	$ 5,854,920	$ 417,101	$ 6,578,897	Demolition including Asbestos Abatement of existing boilers
4	DIVISION 03	CONCRETE	$ 1,675,316	$ 621,778	$ 1,121,895	$ 3,418,989	Crane Mat, Laydown Area Prep, Foundations & Elevated Slabs
6	DIVISION 05	METALS	$ 1,099,962	$ 196,000	$ 66,000	$ 1,361,962	Structural Steel Fab and Metal Siding Panels & Closures
12	DIVISION 11	EQUIPMENT	$ 3,615,629	$ 17,207,201	$ 4,255,862	$ 25,078,693	Equipment, Structural Steel Erection and sCO2 Piping
14	DIVISION 13	SPECIAL CONSTRUCTION	$ -	$ 95,000	$ 430,000	$ 525,000	CEMS, Stack Testing, 3rd Party Inspections
18	DIVISION 23	HEATING, VENTILATING, AND AIR CONDITIONING (HVAC)	$ 193,935	$ 243,441	$ 185,871	$ 623,247	Makeup air, ductwork and exhuast systems
19	DIVISION 25	INTEGRATED AUTOMATION	$ 258,000	$ 50,000	$ -	$ 308,000	Network Equipment, CO2 monitoring & alarms
20	DIVISION 26	ELECTRICAL	$ 2,673,453	$ 3,405,200	$ 132,733	$ 6,211,386	Equipment, power, control, network & grounding wiring
25	DIVISION 33	UTILITIES	$ 1,294,883	$ 559,605	$ 185,792	$ 2,040,280	Balance of Plant Piping
		Subtotal Direct Construction Costs	**$ 11,118,054**	**$ 28,233,145**	**$ 6,795,255**	**$ 46,146,454**	

Description of Mark-up and Add-ons	Rate	Amount	Totals
Bonds:	0.00%	$ -	
Permits:	0.10%	$ 46,146	
Builder's Risk Insurance:	0.50%	$ 230,732	
General Liability Insurance:	0.50%	$ 230,732	
Standard General Conditions:	3.50%	$ 1,615,126	
State & Local Taxes: (Included Above)	0.00%	$ -	
Final Engineering:	3.50%	$ 1,615,126	
Field Construction Management:	9.50%	$ 4,383,913	
Construction Engineering / In House Construction Mgmt/Admin:	3.00%	$ 1,384,394	
Subtotal Prior to Overhead & Profit		**$ 9,506,170**	**$ 55,652,624**
Contractor Overhead:	3.00%	$ 1,669,579	
Contractor Profit:	5.00%	$ 2,782,631	
Subtotal with Overhead & Profit		**$ 4,452,210**	**$ 60,104,833**
Construction Contingency:	5.00%	$ 3,005,242	
Subtotal with Contingency		**$ 3,005,242**	**$ 63,110,075**
Annual Inflation Escalation Factor:	0.00%	$ -	
Contracting Method Adjustment:	0.00%	$ -	
Location Factor:	0.00%	$ -	
Remoteness Factor:	0.00%	$ -	
Prevailing Wage Used in Subcontractors	0.00%	$ -	
Subtotal with Adjustments & Factors		**$ -**	**$ 63,110,075**

TOTAL OPCC	**$**	**63,200,000**

Project: sCO2 Pilot Plant - MU
Project No.: 19-1092

DIVISION 02 - TOTAL COST: $ 6,578,897

Estimate By: KJR, NJP
Date: 10/05/20
Reviewed By: KLM & THW
Date: Date

CDM SMITH
OPINION OF PROBABLE CONSTRUCTION COST
DIVISION 02 - EXISTING CONDITIONS

Item No.	Item Description	Quantity	Unit	MATERIAL Total Material Cost	LABOR Man Hours	LABOR Total Labor Cost	EQUIPMENT Total Equipment Cost	Total Cost	Total Unit Cost	NOTES
1.0	**ASBESTOS ABATEMENT**									
1.1		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
1.2	Demolition of boiler #7 casing, refractory & insulation	0	Unit	$ 42,948	8,396	$ 773,066	$ 42,948	$ 858,962	#DIV/0!	
1.3	Demolition of boiler #8 casing, refractory & insulation	0	Unit	$ 42,948	8,396	$ 773,066	$ 42,948	$ 858,962	#DIV/0!	
1.4	Demolition of boiler #9 casing, refractory & insulation	0	Unit	$ 59,054	11,550	$ 1,062,968	$ 59,054	$ 1,181,075	#DIV/0!	
		1.0 - SUBTOTAL		$ 144,950	28,342	$ 2,609,100	$ 144,950	$ 2,899,000		
2.0	**MECHANICAL DEMOLITION**									
2.1		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
2.2	Boilers 7, 8 & 9 Area	900	Ton	$ -	14,000	$ 1,557,772	$ 161,673	$ 1,719,445	$ 1,910.49	
2.3	Baghouse Area	720	Ton	$ -	10,500	$ 1,188,944	$ -	$ 1,188,944	$ 1,651.31	
2.4	Vacuum Trucks	0	Unit	$ -	0		$ 23,000	$ 23,000	#DIV/0!	
2.5	Utility Piping & Ventilation System	0	Unit	$ -	275	$ 29,764	$ 2,228	$ 31,992	#DIV/0!	
		2.0 - SUBTOTAL		$ -	24,775	$ 2,776,480	$ 186,901	$ 2,963,381		
3.0	**ELECTRICAL DEMOLITION**									
3.1		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
3.2	Boilers 7, 8 & 9 Area	0	Unit	$ 134,708	2,520	$ 249,570	$ 12,128	$ 396,406	#DIV/0!	
3.3	Baghouse Area	0	Unit	$ 27,218	1,812	$ 178,497	$ 6,284	$ 211,999	#DIV/0!	
		3.0 - SUBTOTAL		$ 161,926	4,332	$ 428,067	$ 18,412	$ 608,405		
4.0	**Concrete**									
4.1		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
4.2	Floor & Fan Areas	0	Unit	$ -	566	$ 41,273	$ 66,838	$ 108,111	#DIV/0!	
		4.0 - SUBTOTAL		$ -	566	$ 41,273	$ 66,838	$ 108,111		
	DIVISION 02 - EXISTING CONDITIONS TOTAL			**Total Material Cost** $ 306,876	58,015	**Total Labor Cost** $ 5,854,920	**Total Equipment Cost** $ 417,101	**Total Cost** $ 6,578,897		

Project: sCO2 Pilot Plant - MU
Project No.: 19-1092

DIVISION 03 - TOTAL COST: $ 3,418,989

Estimate By: EMJ, JWO, THW
Date: 10/06/20
Reviewed By: KLM
Date: 10/20/20

CDM SMITH
OPINION OF PROBABLE CONSTRUCTION COST
DIVISION 03 - CONCRETE

Item No.	Item Description	Quantity	Unit	MATERIAL Total Material Cost	LABOR Man Hours	LABOR Total Labor Cost	EQUIPMENT Total Equipment Cost	Total Cost	Total Unit Cost	NOTES
1.0	**CIVIL ROADWAYS**									
1.1		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
1.2	Demolition/Preparation for Stewart Street	0	Unit	$ 90,200	900	$ 59,263	$ 138,936	$ 288,398	#DIV/0!	
1.3	Crane Mat/Stabilized Wall on Stewart Street	0	Unit	$ 388,122	650	$ 40,882	$ 89,342	$ 518,345	#DIV/0!	
1.4	Laydown Areas Preparation & Fencing	0	Unit	$ 469,118	2,200	$ 133,660	$ 557,973	$ 1,160,751	#DIV/0!	
1.5	Roadway Signage	0	Unit	$ 8,800	80	$ 4,646	$ 1,100	$ 14,546	#DIV/0!	
1.6	Restoration of Stewart Street	0	Unit	$ 172,170	1,200	$ 78,645	$ 20,994	$ 271,808	#DIV/0!	
1.7	Restoration of Laydown Areas	0	Unit	$ 423,502	1,100	$ 72,292	$ 253,000	$ 748,794	#DIV/0!	
	1.0 - SUBTOTAL			$ 1,551,912	6,130	$ 389,387	$ 1,061,344	$ 3,002,643		
2.0	**CONCRETE & FOUNDATIONS**									
2.1		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
2.2		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
2.3	Column (Fired Heater Area) Foundations	1,600	SF	$ 47,631	1,220	$ 79,691	$ 18,973	$ 146,295	$ 91.43	
2.4	Equipment Foundations/Pedestals	60	CY	$ 31,295	508	$ 37,654	$ 13,966	$ 82,915	$ 1,381.92	
2.5	Elevated Concrete Slabs at Operating Floor (697'-11")	1,540	SF	$ 8,477	175	$ 17,398	$ 12,080	$ 37,955	$ 24.65	
2.6	Elevated Slabs at Mezzanine (715'-0" & 721'-5")	2,464	SF	$ 11,201	275	$ 23,348	$ 12,782	$ 47,331	$ 19.21	
2.7	CO2 Equipment & A.5 Column	18	CY	$ 13,500	325	$ 27,000	$ -	$ 40,500	$ 2,250.00	
2.8	Cast In-Place Anchors for Columns	32	EA	$ 4,800	75	$ 4,800	$ -	$ 9,600	$ 300.00	
	2.0 - SUBTOTAL			$ 116,904	2,578	$ 189,891	$ 57,801	$ 364,596		
3.0	**MASONRY**									
3.1		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
3.2	Demolition	0	Unit	$ 5,500	250	$ 22,000	$ -	$ 27,500	#DIV/0!	
3.3	Lintels	0	Unit	$ 1,000	200	$ 16,500	$ 2,750	$ 20,250	#DIV/0!	
3.4	Painting	0	Unit	$ -	60	$ 4,000	$ -	$ 4,000	#DIV/0!	
	3.0 - SUBTOTAL			$ 6,500	510	$ 42,500	$ 2,750	$ 51,750		
				Total Material Cost		**Total Labor Cost**	**Total Equipment Cost**	**Total Cost**		
	DIVISION 03 - CONCRETE TOTAL			**$ 1,675,316**	**9,218**	**$ 621,778**	**$ 1,121,895**	**$ 3,418,989**		

Project: sCO2 Pilot Plant - MU
Project No.: 19-1092

DIVISION 05 - TOTAL COST: $ 1,361,962

Estimate By: MLB, JHO, THW
Date: 10/06/20
Reviewed By: KLM
Date: 10/20/20

CDM SMITH
OPINION OF PROBABLE CONSTRUCTION COST
DIVISION 05 - METALS

Item No.	Item Description	Quantity	Unit	MATERIAL Total Material Cost	LABOR Man Hours	LABOR Total Labor Cost	EQUIPMENT Total Equipment Cost	Total Cost	Total Unit Cost	NOTES
1.0	**METAL WALL PANELS**									
1.1		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
1.2	North Baghouse Wall Panels	9,900	SF	$ 94,000	1,400	$ 154,900	$ 44,000	$ 292,900	$ 29.59	
1.3	Existing Building Infill Panels	120	SF	$ 1,000	70	$ 7,600	$ 4,000	$ 12,600	$ 105.00	
1.4	Doors, Accessories, Hardware & Lock Sets	1	LOT	$ 44,000	260	$ 28,500	$ 18,000	$ 90,500	$ 90,500.00	
1.5	Sealants & Touch-Up Painting	1	LOT	$ 1,000	50	$ 5,000	$ -	$ 6,000	$ 6,000.00	
	1.0 - SUBTOTAL			$ 140,000	1,780	$ 196,000	$ 66,000	$ 402,000		
2.0	**STRUCTURAL STEEL FABRICATION FIRED HEATER**									
2.1		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
2.2	Structural and Miscellaneous Steel	156,000	Lbs	$ 265,655	156,000	$ -	$ -	$ 265,655	$ 1.70	
2.3	Grating	1,124	SF	$ 23,734	1,124	$ -	$ -	$ 23,734	$ 21.12	
2.4	Deck	1,000	SF	$ 2,222	1,000	$ -	$ -	$ 2,222	$ 2.22	
2.5	Railing	500	LF	$ 23,242	500	$ -	$ -	$ 23,242	$ 46.48	
	2.0 - SUBTOTAL			$ 314,852		$ -	$ -	$ 314,852		
3.0	**STRUCTURAL STEEL FABRICATION ECHOGEN EQUIPMENT**									
3.1		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
3.2	Structural and Miscellaneous Steel	70,000	Lbs	$ 135,359	70,000	$ -	$ -	$ 135,359	$ 1.93	
3.3	Structural Steel used to Reinforce Existing Structure	12,300	SF	$ 19,206	12,300	$ -	$ -	$ 19,206	$ 1.56	
3.4	Grating	402	SF	$ 6,582	402	$ -	$ -	$ 6,582	$ 16.37	
3.5	Deck	4,200	SF	$ 9,183	4,200	$ -	$ -	$ 9,183	$ 2.19	
3.6	Railing	330	LF	$ 14,699	330	$ -	$ -	$ 14,699	$ 44.54	
	3.0 - SUBTOTAL			$ 185,029		$ -	$ -	$ 185,029		
4.0	**STRUCTURAL STEEL FABRICATION AIR POLLUTION CONTROL**									
4.1		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
4.2	Structural and Miscellaneous Steel	203,660	Lbs	$ 371,003	203,660	$ -	$ -	$ 371,003	$ 1.82	
4.3	Structural Steel used to Reinforce Existing Structure	18,900	Lbs	$ 24,544	18,900	$ -	$ -	$ 24,544	$ 1.30	
4.4	Grating	2,875	SF	$ 38,045	2,875	$ -	$ -	$ 38,045	$ 13.23	
4.5	Deck	3,600	SF	$ 7,576	3,600	$ -	$ -	$ 7,576	$ 2.10	
4.6	Railing	420	LF	$ 18,913	420	$ -	$ -	$ 18,913	$ 45.03	
	4.0 - SUBTOTAL			$ 460,081		$ -	$ -	$ 460,081		

	Total Material Cost		Total Labor Cost	Total Equipment Cost	Total Cost
DIVISION 05 - METALS TOTAL	**$ 1,099,962**		**$ 196,000**	**$ 66,000**	**$ 1,361,962**

Project: sCO2 Pilot Plant - MU
Project No.: 19-1092

Estimate By: KJR, NJP
Date: 10/06/20
Reviewed By: KLM
Date: 10/20/20

DIVISION 11 - TOTAL COST: $ 25,078,693

CDM SMITH
OPINION OF PROBABLE CONSTRUCTION COST
DIVISION 11 - EQUIPMENT

Item No.	Item Description	Quantity	Unit	MATERIAL Total Material Cost	LABOR Man Hours	LABOR Total Labor Cost	EQUIPMENT Total Equipment Cost	Total Cost	Total Unit Cost	NOTES
1.0	**FIRED HEATER**									
1.1		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
1.2	Tube Assembely	0	Unit	$ -	38,755	$ 5,039,123	$ 1,306,431	$ 6,345,554	#DIV/0!	
1.3	Cleaning & Testing	0	Unit	$ -	200	$ 22,891	$ -	$ 22,891	#DIV/0!	
1.4	Heater Casing & Insulation	8,730	SF	$ 133,999	3,600	$ 399,279	$ 71,691	$ 604,968	$ 69.30	
1.5	Stoker & Grate System	1	LOT	$ -	4,745	$ 616,974	$ 159,955	$ 776,929	$ 776,928.78	
1.6	Structural and Miscellaneous Steel	117	TONS	$ -	4,615	$ 599,689	$ 155,474	$ 755,163	$ 6,457.10	
1.7	Grating	1,417	SF	$ -	600	$ 77,419	$ 20,071	$ 97,490	$ 68.80	
1.8	Deck	4,111	SF	$ -	1,290	$ 167,211	$ 43,351	$ 210,561	$ 51.22	
1.9	Railing	1,235	LF	$ -	480	$ 61,988	$ 16,071	$ 78,059	$ 63.21	
1.10	Post Installed Anchors	8	EA	$ 2,400			$ -	$ 2,400	$ 300.00	
		1.0 - SUBTOTAL		$ 136,399	54,285	$ 6,984,572	$ 1,773,043	$ 8,894,015		
2.0	**AIR POLLUTION CONTROL EQUIPMENT**									
2.1		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
2.2	SCR, Economizer & Air Heater Stack Up	0	Unit	$ -	4,540	$ 590,463	$ 153,082	$ 743,546	#DIV/0!	
2.3	CDS & Baghouse	0	Unit	$ -	10,920	$ 1,420,117	$ 368,176	$ 1,788,294	#DIV/0!	
2.4	Entire Breeching & ID Fan	0	Unit	$ -	4,480	$ 583,055	$ 151,161	$ 734,217	#DIV/0!	
2.5	Lagging & Insulation	26,361	SF	$ 229,612	5,460	$ 602,281	$ 24,044	$ 855,938	$ 32.47	
2.6	Structural and Miscellaneous Steel	106	TONS	$ -	4,900	$ 637,680	$ 165,323	$ 803,004	$ 7,573.13	
2.7	Structural Steel used to Reinforce Existing Structure	20	TONS	$ -	3,390	$ 440,532	$ 114,211	$ 554,743	$ 27,317.15	
2.8	Grating	2,966	SF	$ -	1,237	$ 160,854	$ 41,703	$ 202,557	$ 68.29	
2.9	Deck	2,998	SF	$ -	940	$ 121,942	$ 31,614	$ 153,557	$ 51.22	
2.10	Railing	571	LF	$ -	220	$ 28,257	$ 7,326	$ 35,582	$ 62.37	
		2.0 - SUBTOTAL		$ 229,612	36,087	$ 4,585,182	$ 1,056,642	$ 5,871,436		
3.0	**ECHOGEN EQUIPMENT & PIPING**									
3.1		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
3.2	Combustion Air Ductwork, OFA & FD Fans	0	Unit	$ -	11,900	$ 1,547,160	$ 401,113	$ 1,948,273	#DIV/0!	
3.3	sCO2 Turbine, Gearbox & Generator	0	Unit	$ -	1,710	$ 222,354	$ 57,647	$ 280,001	#DIV/0!	
3.4	sCO2 Heat Exchangers & Recuperators	0	Unit	$ -	2,350	$ 305,872	$ 79,300	$ 385,172	#DIV/0!	
3.5	sCO2 Piping	2,000	LF	$ 1,475,167	10,900	$ 1,412,886	$ 366,301	$ 3,254,355	$ 1,627.18	
3.6	Cooling Water Piping & Pumps	554	LF	$ 805,317	5,900	$ 771,317	$ 199,970	$ 1,776,604	$ 3,206.87	
3.7	CEMS	600	LF	$ -	2,400	$ 311,838	$ 80,846	$ 392,684	$ 654.47	
3.8	Steam & Condensate Piping	800	LF	$ 558,016	4,110	$ 534,457	$ 138,562	$ 1,231,035	$ 1,538.79	
3.9	Cleaning & Testing	.	Unit	$ -	0	$ -	$ 50,000	$ 50,000	#VALUE!	
3.10	Lagging & Insulation	3,466	SF	$ 267,118	2,420	$ 270,563	$ 10,438	$ 548,118	$ 158.14	
3.11	Miscellaneous Pipe Support Steel	7	TONS	$ 26,000	300	$ 39,000	$ -	$ 65,000	$ 10,000.00	
3.12	CO2 Vent Structure	12	TONS	$ 48,000	550	$ 72,000	$ -	$ 120,000	$ 10,000.00	
3.13	CO2 Vents & Dilution Blower	0	Unit	$ 20,000	220	$ 28,000	$ 42,000	$ 90,000	#DIV/0!	
3.14	Spring & Constant Supports	10	EA	$ 50,000	380	$ 50,000	$ -	$ 100,000	$ 10,000.00	
3.15	Equipment Alignments	0	Unit	$ -	0	$ 72,000	$ -	$ 72,000	#DIV/0!	
		3.0 - SUBTOTAL		$ 3,249,618	43,140	$ 5,637,446	$ 1,426,177	$ 10,313,242		
				Total Material Cost		**Total Labor Cost**	**Total Equipment Cost**	**Total Cost**		
	DIVISION 11 - EQUIPMENT TOTAL			**$ 3,615,629**	**133,513**	**$ 17,207,201**	**$ 4,255,862**	**$ 25,078,693**		

Project: sCO2 Pilot Plant - MU
Project No.: 19-1092

DIVISION 13 - TOTAL COST: $ 525,000

Estimate By: KLM, NJP
Date: 10/06/20
Reviewed By: KLM
Date: 10/20/20

CDM SMITH
OPINION OF PROBABLE CONSTRUCTION COST
DIVISION 13 - SPECIAL CONSTRUCTION

Item No.	Item Description	Quantity	MATERIAL		LABOR		EQUIPMENT	Total Cost	Total Unit Cost	NOTES
			Unit Cost	Total Material Cost	Man Hours	Total Labor Cost	Total Equipment Cost			
1.0										
1.1		0	$ -	$ -	0	$ -	$ -	$ -	#DIV/0!	
1.2	Stack Testing	0	$ -	$ -	0	$ -	$ 80,000	$ 80,000	#DIV/0!	
1.3	CEMS Equipment & Startup	0	$ -	$ -	0	$ -	$ 350,000	$ 350,000	#DIV/0!	
1.4	Additional Welding NDE	0	$ -	$ -	0	$ 20,000	$ -	$ 20,000	#DIV/0!	
1.5	3rd Party Services	0	$ -	$ -	0	$ 75,000	$ -	$ 75,000	#DIV/0!	

	Total Material Cost		Total Labor Cost	Total Equipment Cost	Total Cost	
DIVISION 13 - SPECIAL CONSTRUCTION TOTAL	**$ -**		**$ 95,000**	**$ 430,000**	**$ 525,000**	

Project: sCO2 Pilot Plant - MU

Project No.: 19-1092

DIVISION 23 - TOTAL COST: $ 623,247

Estimate By: KJR, NJP

Date: 10/06/20

Reviewed By: KLM

Date: 10/20/20

CDM SMITH
OPINION OF PROBABLE CONSTRUCTION COST
DIVISION 23 - HEATING, VENTILATING, & AIR CONDITIONING (HVAC)

Item No.	Item Description	Quantity	Unit	MATERIAL Total Material Cost	LABOR Man Hours	LABOR Total Labor Cost	EQUIPMENT Total Equipment Cost	Total Cost	Total Unit Cost	NOTES
1.0										
1.1		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
1.2	Exhaust Fans	15	EA	$ 87,337	550	$ 48,103	$ 13,695	$ 149,135	$ 9,942.33	
1.3	Makeup Air & Ductwork	1	LOT	$ 45,000	1,800	$ 161,412	$ 162,518	$ 368,930	$ 368,929.84	
1.4	Unit Heaters	30	EA	$ 61,598	400	$ 33,926	$ 9,659	$ 105,182	$ 3,506.08	

	Total Material Cost		Total Labor Cost	Total Equipment Cost	Total Cost	
DIVISION 23 - HEATING, VENTILATING, & AIR CONDITIONING (HVAC) TOTAL	**$ 193,935**	**2,750**	**$ 243,441**	**$ 185,871**	**$ 623,247**	

Project: sCO2 Pilot Plant - MU

Project No.: 19-1092

DIVISION 25 - TOTAL COST: $ 308,000

Estimate By: JAK

Date: 10/06/20

Reviewed By: KLM

Date: 10/20/20

CDM SMITH
OPINION OF PROBABLE CONSTRUCTION COST
DIVISION 25 - CONTROLS, INSTRUMENTATION & AUTOMATION

Item No.	Item Description	Quantity	Unit	MATERIAL Total Material Cost	LABOR Man Hours	LABOR Total Labor Cost	EQUIPMENT Total Equipment Cost	Total Cost	Total Unit Cost	NOTES
1.0										
1.1		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
1.2	Programming	0	Unit	$ -	350	$ 50,000	$ -	$ 50,000	#DIV/0!	
1.3	Central System PLC	1	EA	$ 70,000	0		$ -	$ 70,000	$ 70,000.00	
1.4	Remote IO Cabinets	2	EA	$ 20,000	0	$ -	$ -	$ 20,000	$ 10,000.00	
1.5	CO2 Sensors	32	EA	$ 160,000	0	$ -	$ -	$ 160,000	$ 5,000.00	
1.6	CO2 Alarm Horn/Strobe	32	EA	$ 8,000	0	$ -	$ -	$ 8,000	$ 250.00	

	Total Material Cost		Total Labor Cost	Total Equipment Cost	Total Cost	
DIVISION 25 - CONTROLS, INSTRUMENTATION & AUTOMATION TOTAL	**$ 258,000**		**$ 50,000**	**$ -**	**$ 308,000**	

Project: sCO2 Pilot Plant - MU
Project No.: 19-1092

DIVISION 26 - TOTAL COST: $ 6,211,386

Estimate By: SDS, NJP
Date: 10/06/20
Reviewed By: KLM
Date: 10/20/20

CDM SMITH
OPINION OF PROBABLE CONSTRUCTION COST
DIVISION 26 - ELECTRICAL

Item No.	Item Description	Quantity	Unit	MATERIAL Total Material Cost	LABOR Man Hours	LABOR Total Labor Cost	EQUIPMENT Total Equipment Cost	Total Cost	Total Unit Cost	NOTES
1.0	**POWER DISTRIBUTION**									
1.1		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
1.2	13.8KV Distribution	0	Unit	$ 111,510	1,105	$ 110,158	$ 6,216	$ 227,884	#DIV/0!	
1.3	480V Distribution equipment to 120/208V panels	0	Unit	$ 808,545	4,615	$ 464,562	$ 36,215	$ 1,309,322	#DIV/0!	
1.4	Emergency 125VDC System and inverter UPS panel modifications	0	Unit	$ 164,950	1,270	$ 126,518	$ 8,230	$ 299,698	#DIV/0!	
1.5	13.8 KV Section & Breaker W/Realys	0	Unit	$ 80,000	0	$ -		$ 80,000	#DIV/0!	
1.6	13.8 KV Testing	0	Unit	$ -	60	$ 7,000	$ -	$ 7,000	#DIV/0!	
1.7	800Amp MCC	0	Unit	$ 90,000	0	$ -		$ 90,000	#DIV/0!	
1.8	Grounding Reactor	0	Unit	$ 20,000	40	$ 4,000		$ 24,000	#DIV/0!	
1.9		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
1.10		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
1.11		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
1.12		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
1.13		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
1.14		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
1.15		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
	1.0 - SUBTOTAL			$ 1,275,005	7,090	$ 712,238	$ 50,661	$ 2,037,904		
2.0	**BOILER AREA**									
2.1		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
2.2	Lighting	0	Unit	$ 66,395	910	$ 91,763	$ 3,060	$ 161,218	#DIV/0!	
2.3	All other branch circuits	0	Unit	$ 129,162	1,510	$ 150,406	$ 5,505	$ 285,073	#DIV/0!	
2.4	CO2 Detectors	0	Unit	$ -	800	$ 80,000	$ -	$ 80,000	#DIV/0!	
	2.0 - SUBTOTAL			$ 195,557	3,220	$ 322,169	$ 8,565	$ 526,291		
3.0	**AIR POLLUTION CONTROL**									
3.1		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
3.2	Lighting and associated branch circuits	0	Unit	$ 144,002	1,100	$ 109,813	$ 5,000	$ 258,815	#DIV/0!	
3.3	General power and associated branch circuits	0	Unit	$ 19,733	575	$ 56,990	$ 1,510	$ 78,233	#DIV/0!	
3.4	All other branch circuits	0	Unit	$ 181,158	1,490	$ 148,564	$ 6,495	$ 336,217	#DIV/0!	
	3.0 - SUBTOTAL			$ 344,893	3,165	$ 315,367	$ 13,005	$ 673,265		
4.0	**GENERAL ITEMS**									
4.1		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
4.2	Grounding	0	Unit	$ 14,100	140	$ 13,720	$ 1,800	$ 29,620	#DIV/0!	
4.3	Temporary lighting and power in construction area	0	Unit	$ 19,350	625	$ 61,712	$ 1,570	$ 82,632	#DIV/0!	
4.4	Temporary power for construction trailers	0	Unit	$ 23,360	250	$ 24,892	$ 1,060	$ 49,312	#DIV/0!	
4.5	Dilution blower	0	Unit	$ -	50	$ 5,000	$ -	$ 5,000	#DIV/0!	
4.6	Startup & Commisioning	0	Unit	$ 16,638	1,450	$ 144,340	$ 5,132	$ 166,110	#DIV/0!	
	4.0 - SUBTOTAL			$ 73,448	2,515	$ 249,664	$ 9,562	$ 332,674		
5.0	**INSTRUEMNTATION & CONTROLS**									
5.1		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
5.2	Installation, loop checks, termination of inst. and control circuits	0	Unit	$ 784,550	18,260	$ 1,805,762	$ 50,940	$ 2,641,252	#DIV/0!	
	5.0 - SUBTOTAL			$ 784,550	18,260	$ 1,805,762	$ 50,940	$ 2,641,252		
				Total Material Cost		**Total Labor Cost**	**Total Equipment Cost**	**Total Cost**		
	DIVISION 26 - ELECTRICAL TOTAL			**$ 2,673,453**	**34,250**	**$ 3,405,200**	**$ 132,733**	**$ 6,211,386**		

Project: sCO2 Pilot Plant - MU
Project No.: 19-1092

Estimate By: KJR, NJP
Date: 10/06/20
Reviewed By: KLM
Date: 10/20/20

DIVISION 33 - TOTAL COST: $ 2,040,280

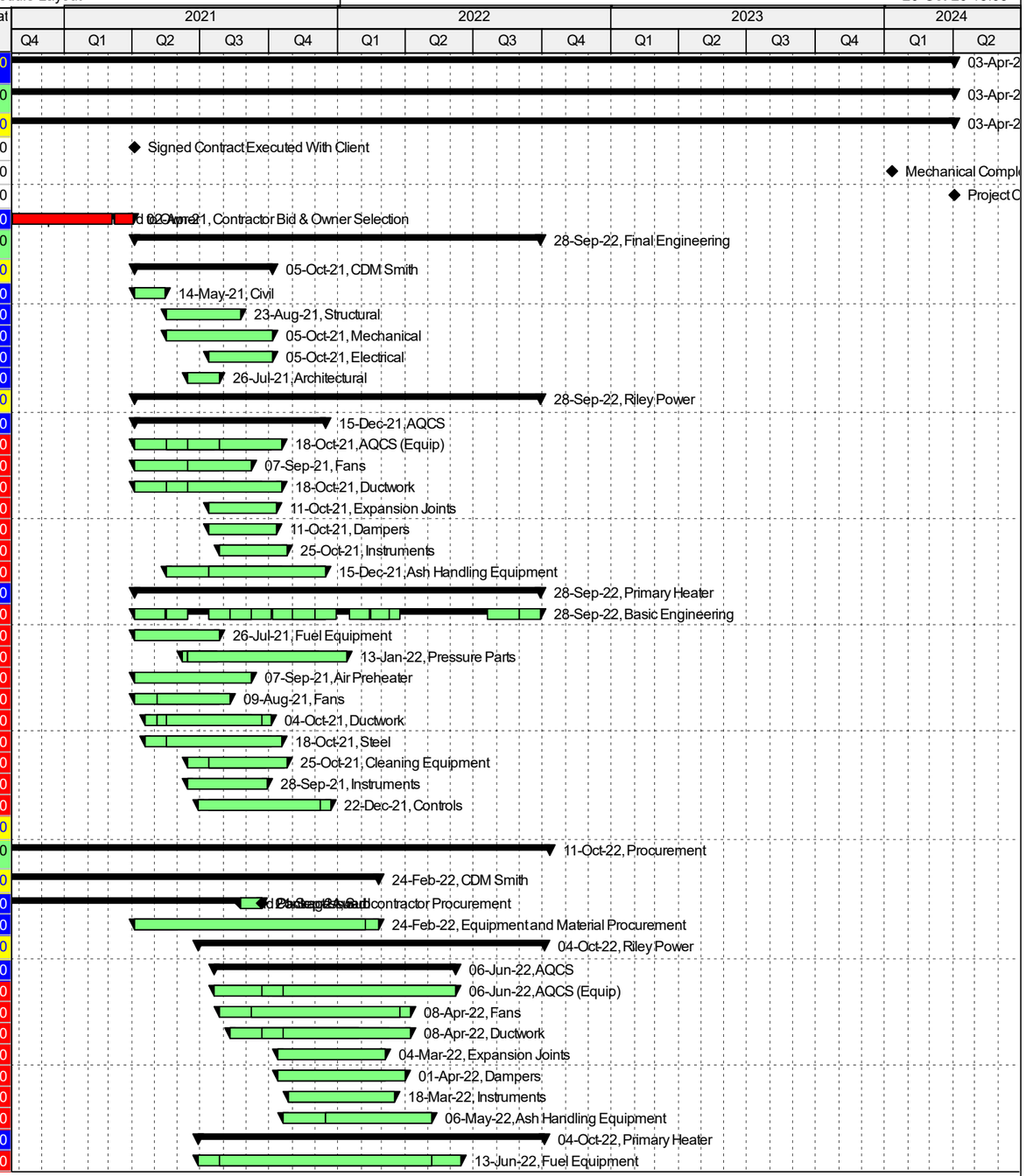
CDM SMITH
OPINION OF PROBABLE CONSTRUCTION COST
DIVISION 33 - UTILITIES

Item No.	Item Description	Quantity	Unit	MATERIAL Total Material Cost	LABOR Man Hours	LABOR Total Labor Cost	EQUIPMENT Total Equipment Cost	Total Cost	Total Unit Cost	NOTES
1.0										
1.1		0	Unit	$ -	0	$ -	$ -	$ -	#DIV/0!	
1.2	Natural Gas Piping	330	LF	$ 123,283	750	$ 67,900	$ 19,331	$ 210,514	$ 637.92	
1.3	Compressed Air Piping	1,210	LF	$ 295,813	1,800	$ 162,925	$ 46,384	$ 505,122	$ 417.46	
1.4	Lime Conveying Piping & Equipment	75	LF	$ 406,535	500	$ 44,712	$ 48,065	$ 499,312	$ 6,657.49	
1.5	Ash Conveying Piping	350	LF	$ 149,878	1,000	$ 83,948	$ 23,501	$ 257,327	$ 735.22	
1.6	Plant Water Piping	701	LF	$ 200,111	1,350	$ 119,943	$ 31,378	$ 351,432	$ 501.33	
1.7	Fuel Oil Piping	122	LF	$ 21,449	130	$ 11,813	$ 3,363	$ 36,625	$ 300.21	
1.8	NDE : X-Ray	1	LOT	$ 51,461	1	$ 28,343	$ 8,069	$ 87,874	$ 87,873.63	
1.9	Ammonia Piping	192	Unit	$ 36,353	220	$ 20,021	$ 5,700	$ 62,074	$ 323.30	
1.10	Tubing	1,500	LF	$ 10,000	220	$ 20,000	$ -	$ 30,000	$ 20.00	

	Total Material Cost		Total Labor Cost	Total Equipment Cost	Total Cost
DIVISION 33 - UTILITIES TOTAL	**$ 1,294,883**	**5,971**	**$ 559,605**	**$ 185,792**	**$ 2,040,280**

VII. Phase III Schedule

Activity ID	Activity Name	Start	Finish	Original Duration	Free Float
Echogen DOE SCo2 System Phase 2		22-Sep-20 A	03-Apr-24	897	0
General		22-Sep-20 A	03-Apr-24	897	0
Milestones		22-Sep-20 A	03-Apr-24	897	0
A1107	Signed Contract Executed With Client	05-Apr-21		0	0
A1058	Mechanical Completion		10-Jan-24	0	60
A1116	Project Complete		03-Apr-24	0	0
Contractor Bid & Owner Selection		22-Sep-20 A	02-Apr-21	134	0
Final Engineering		05-Apr-21	28-Sep-22	379	0
CDM Smith		05-Apr-21	05-Oct-21	130	0
Civil		05-Apr-21	14-May-21	30	0
Structural		17-May-21	23-Aug-21	70	0
Mechanical		17-May-21	05-Oct-21	100	0
Electrical		13-Jul-21	05-Oct-21	60	0
Architectural		15-Jun-21	26-Jul-21	30	0
Riley Power		05-Apr-21	28-Sep-22	379	0
AQCS		05-Apr-21	15-Dec-21	179	0
AQCS (Equip)		05-Apr-21	18-Oct-21	139	0
Fans		05-Apr-21	07-Sep-21	110	0
Ductwork		05-Apr-21	18-Oct-21	139	0
Expansion Joints		13-Jul-21	11-Oct-21	64	0
Dampers		13-Jul-21	11-Oct-21	64	0
Instruments		27-Jul-21	25-Oct-21	64	0
Ash Handling Equipment		17-May-21	15-Dec-21	149	0
Primary Heater		05-Apr-21	28-Sep-22	379	0
Basic Engineering		05-Apr-21	28-Sep-22	379	0
Fuel Equipment		05-Apr-21	26-Jul-21	80	0
Pressure Parts		07-Jun-21	13-Jan-22	154	0
Air Preheater		05-Apr-21	07-Sep-21	110	0
Fans		05-Apr-21	09-Aug-21	90	0
Ductwork		19-Apr-21	04-Oct-21	119	0
Steel		19-Apr-21	18-Oct-21	129	0
Cleaning Equipment		14-Jun-21	25-Oct-21	95	0
Instruments		15-Jun-21	28-Sep-21	75	0
Controls		29-Jun-21	22-Dec-21	124	0
Echogen Power Systems				0	0
Procurement		28-Sep-20 A	11-Oct-22	488	0
CDM Smith		28-Sep-20 A	24-Feb-22	328	0
Subcontractor Procurement		28-Sep-20 A	21-Sep-21	220	0
Equipment and Material Procurement		05-Apr-21	24-Feb-22	228	0
Riley Power		29-Jun-21	04-Oct-22	323	0
AQCS		20-Jul-21	06-Jun-22	224	0
AQCS (Equip)		20-Jul-21	06-Jun-22	224	0
Fans		27-Jul-21	08-Apr-22	179	0
Ductwork		10-Aug-21	08-Apr-22	169	0
Expansion Joints		12-Oct-21	04-Mar-22	100	0
Dampers		12-Oct-21	01-Apr-22	120	0
Instruments		26-Oct-21	18-Mar-22	100	0
Ash Handling Equipment		19-Oct-21	06-May-22	140	0
Primary Heater		29-Jun-21	04-Oct-22	323	0
Fuel Equipment		29-Jun-21	13-Jun-22	244	0



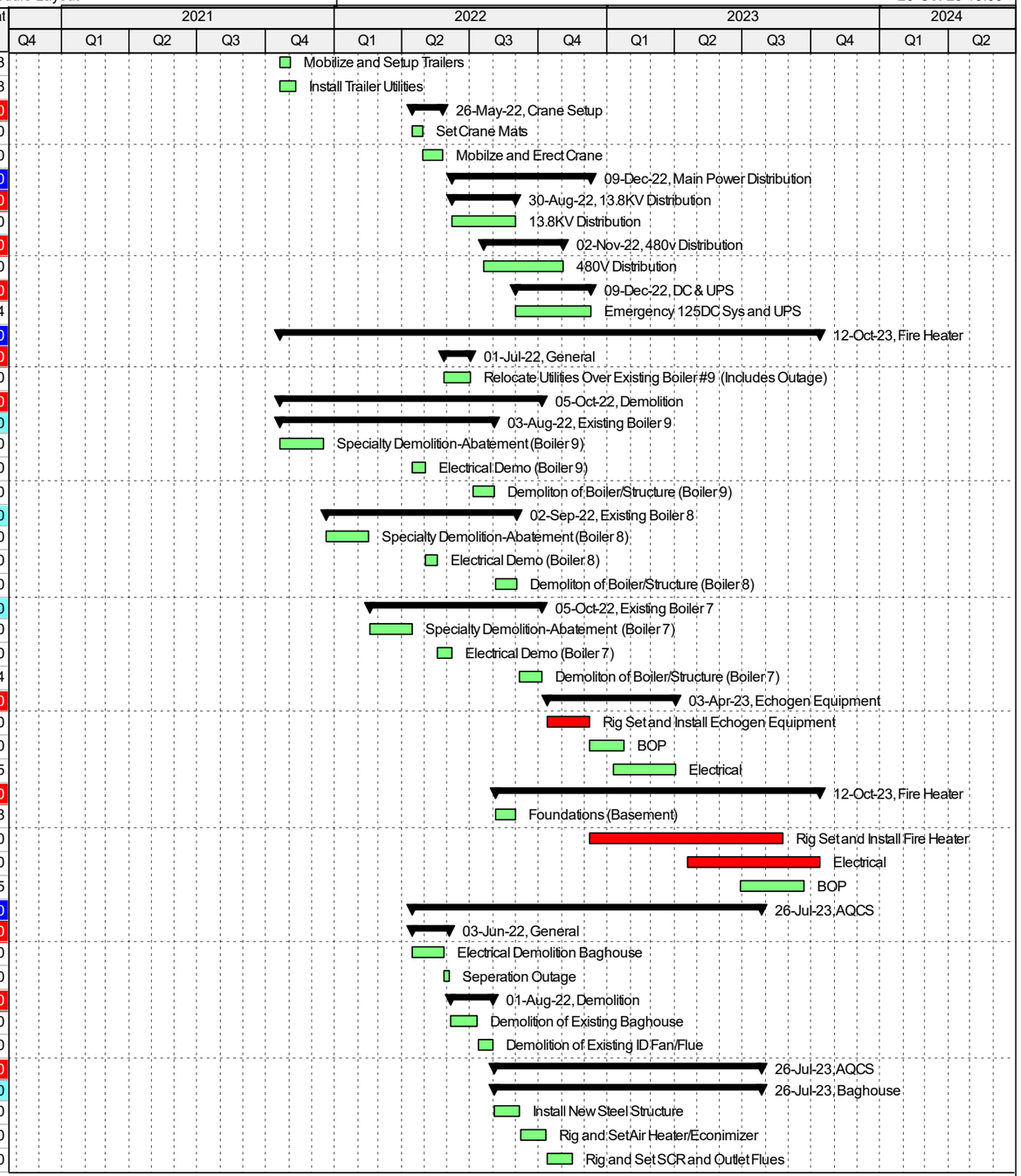
© Oracle Corporation

Activity ID	Activity Name	Start	Finish	Original Duration	Free Float
	Pressure Parts	19-Jul-21	04-Oct-22	309	0
	Air Preheater	08-Sep-21	06-May-22	169	0
	Fans	27-Jul-21	06-May-22	199	0
	Ductwork	24-Aug-21	25-Mar-22	149	0
	Steel	05-Oct-21	06-Jun-22	170	0
	Cleaning Equipment	28-Sep-21	13-May-22	160	0
	Instruments	29-Sep-21	07-Feb-22	90	0
	Controls	09-Dec-21	13-May-22	110	0
	Echogen Power Systems	05-Apr-21	11-Oct-22	388	0
	Power Skid (Potential Stick Build)	05-Apr-21	10-Aug-22	345	0
	Generator	05-Apr-21	08-Jul-22	322	0
	Gearbox	05-Apr-21	10-Aug-22	345	0
	CO2 Turbine	05-Apr-21	10-Aug-22	345	0
	Lube Oil Skid	05-Apr-21	06-May-22	279	0
	Process Skid (Potential Stick Build)	05-Apr-21	10-Aug-22	345	0
	High Temperature Recuperator	05-Apr-21	11-Oct-22	388	0
	Low Temperature Recuperator	05-Apr-21	11-Oct-22	388	0
	Water Cooled Condenser	05-Apr-21	11-Oct-22	388	0
	Intermediate Heat Exchanger	05-Apr-21	06-Jan-22	193	0
	Construction	22-Sep-21	12-Oct-23	523	0
	General Conditions	22-Sep-21	19-Oct-21	20	0
	Equipment Delivery	06-Jan-22	01-Nov-22	210	0
	CDM Smith	07-Feb-22	28-Feb-22	15	0
	Steel	25-Feb-22	25-Feb-22	0	0
	IHX Pump	07-Feb-22	28-Feb-22	15	0
	Cooling Tower Water Booster Pump	07-Feb-22	28-Feb-22	15	0
	Riley Power	20-Jan-22	25-Oct-22	195	0
	AQCS	28-Jan-22	27-Jun-22	105	0
	Primary Heater	20-Jan-22	25-Oct-22	195	0
	Echogen Power Systems	06-Jan-22	01-Nov-22	210	0
	General	11-Oct-22	11-Oct-22	0	0
	Power Skid (Potential Stick Build)	08-Jul-22	31-Aug-22	38	0
	Lube Oil Skid	06-May-22	27-May-22	15	0
	Process Skid (Potential Stick Build)	10-Aug-22	31-Aug-22	15	0
	High Temperature Recuperator	11-Oct-22	01-Nov-22	15	0
	Low Temperature Recuperator	11-Oct-22	01-Nov-22	15	0
	Water Cooled Condenser	11-Oct-22	01-Nov-22	15	0
	Intermediate Heat Exchanger	06-Jan-22	27-Jan-22	15	0
	Construction	20-Oct-21	12-Oct-23	503	0
	General Site	20-Oct-21	26-May-22	153	0
	Stewart Ave	20-Oct-21	17-Jan-22	60	0
A1312	Security Fencing/Barriers/Signage	20-Oct-21	09-Nov-21	15	0
A1318	Build Crane Pad/Ramp	03-Dec-21	17-Jan-22	30	63
	Lay Down Lot 1 (South Providence Road)	20-Oct-21	02-Dec-21	30	0
A1314	Security Fencing/Barriers/Signage	20-Oct-21	16-Nov-21	20	603
A1315	Grade Level Area	20-Oct-21	02-Dec-21	30	0
	Lay Down Lot 2 (RC 16 Lot)	20-Oct-21	09-Dec-21	35	0
A1316	Security Fencing/Barriers/Signage	20-Oct-21	02-Nov-21	10	0
A1317	Grade Level Area	03-Nov-21	16-Nov-21	10	0
A1319	Temporary Sidewalk	17-Nov-21	09-Dec-21	15	588
	Lay Down Lot 3 (West Plant Prop.)	20-Oct-21	09-Nov-21	15	0



© Oracle Corporation

Activity ID	Activity Name	Start	Finish	Original Duration	Free Float
A1320	Mobilize and Setup Trailers	20-Oct-21	02-Nov-21	10	613
A1322	Install Trailer Utilities	20-Oct-21	09-Nov-21	15	608
Crane Setup		15-Apr-22	26-May-22	30	0
A1418	Set Crane Mats	15-Apr-22	28-Apr-22	10	0
A1324	Mobilze and Erect Crane	29-Apr-22	26-May-22	20	0
Main Power Distribution		07-Jun-22	09-Dec-22	130	0
13.8KV Distribution		07-Jun-22	30-Aug-22	60	0
A1503	13.8KV Distribution	07-Jun-22	30-Aug-22	60	0
480v Distribution		20-Jul-22	02-Nov-22	75	0
A1504	480V Distribution	20-Jul-22	02-Nov-22	75	0
DC & UPS		31-Aug-22	09-Dec-22	70	0
A1505	Emergency 125DC Sys and UPS	31-Aug-22	09-Dec-22	70	334
Fire Heater		20-Oct-21	12-Oct-23	503	0
General		27-May-22	01-Jul-22	25	0
A1323	Relocate Utilities Over Existing Boiler #9 (Includes Outage)	27-May-22	01-Jul-22	25	0
Demolition		20-Oct-21	05-Oct-22	244	0
Existing Boiler 9		20-Oct-21	03-Aug-22	200	0
A1325	Specialty Demolition-Abatement (Boiler 9)	20-Oct-21	17-Dec-21	41	0
A1421	Electrical Demo (Boiler 9)	15-Apr-22	02-May-22	12	0
A1328	Demoliton of Boiler/Structure (Boiler 9)	05-Jul-22	03-Aug-22	22	0
Existing Boiler 8		20-Dec-21	02-Sep-22	181	0
A1326	Specialty Demolition-Abatement (Boiler 8)	20-Dec-21	16-Feb-22	41	0
A1422	Electrical Demo (Boiler 8)	03-May-22	18-May-22	12	0
A1329	Demoliton of Boiler/Structure (Boiler 8)	04-Aug-22	02-Sep-22	22	0
Existing Boiler 7		17-Feb-22	05-Oct-22	162	0
A1327	Specialty Demolition-Abatement (Boiler 7)	17-Feb-22	14-Apr-22	41	0
A1423	Electrical Demo (Boiler 7)	19-May-22	06-Jun-22	12	0
A1330	Demoliton of Boiler/Structure (Boiler 7)	06-Sep-22	05-Oct-22	22	4
Echogen Equipment		12-Oct-22	03-Apr-23	120	0
A1331	Rig Set and Install Echogen Equipment	12-Oct-22	08-Dec-22	40	0
A1488	BOP	09-Dec-22	23-Jan-23	30	0
A1496	Electrical	10-Jan-23	03-Apr-23	60	255
Fire Heater		04-Aug-22	12-Oct-23	303	0
A1420	Foundations (Basement)	04-Aug-22	31-Aug-22	20	68
A1332	Rig Set and Install Fire Heater	09-Dec-22	23-Aug-23	180	0
A1497	Electrical	18-Apr-23	12-Oct-23	125	0
A1489	BOP	28-Jun-23	21-Sep-23	60	15
AQCS		15-Apr-22	26-Jul-23	325	0
General		15-Apr-22	03-Jun-22	35	0
A1424	Electrical Demolition Baghouse	15-Apr-22	27-May-22	30	470
A1333	Seperation Outage	27-May-22	03-Jun-22	5	0
Demolition		06-Jun-22	01-Aug-22	40	0
A1335	Demolition of Existing Baghouse	06-Jun-22	11-Jul-22	25	0
A1336	Demolition of Existing ID Fan/Flue	12-Jul-22	01-Aug-22	15	0
AQCS		02-Aug-22	26-Jul-23	250	0
Baghouse		02-Aug-22	26-Jul-23	250	0
A1337	Install New Steel Structure	02-Aug-22	06-Sep-22	25	0
A1338	Rig and SetAir Heater/Econimizer	07-Sep-22	11-Oct-22	25	0
A1339	Rig and Set SCR and Outlet Flues	12-Oct-22	15-Nov-22	25	0

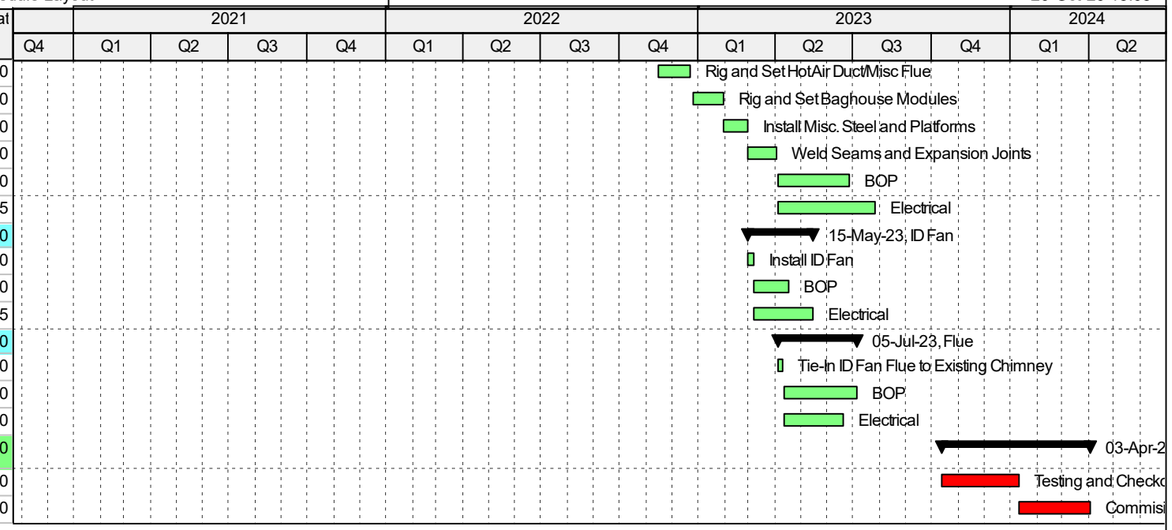


Actual Work | Critical Remaining Work | Summary
Remaining Work | Milestone

TASK filter: Activities Less Than 100%.

© Oracle Corporation

Activity ID	Activity Name	Start	Finish	Original Duration	Free Float
A1340	Rig and Set HotAir Duct/Misc Flue	16-Nov-22	22-Dec-22	25	0
A1341	Rig and Set Baghouse Modules	26-Dec-22	30-Jan-23	25	0
A1342	Install Misc. Steel and Platforms	31-Jan-23	27-Feb-23	20	0
A1344	Weld Seams and Expansion Joints	28-Feb-23	03-Apr-23	25	0
A1490	BOP	04-Apr-23	27-Jun-23	60	0
A1493	Electrical	04-Apr-23	26-Jul-23	80	55
ID Fan		28-Feb-23	15-May-23	55	0
A1343	Install ID Fan	28-Feb-23	06-Mar-23	5	0
A1491	BOP	07-Mar-23	17-Apr-23	30	0
A1495	Electrical	07-Mar-23	15-May-23	50	105
Flue		04-Apr-23	05-Jul-23	65	0
A1345	Tie-In ID Fan Flue to Existing Chimney	04-Apr-23	10-Apr-23	5	0
A1492	BOP	11-Apr-23	05-Jul-23	60	0
A1494	Electrical	11-Apr-23	20-Jun-23	50	80
Testing and Commissioning		13-Oct-23	03-Apr-24	120	0
A1108	Testing and Checkout	13-Oct-23	10-Jan-24	60	0
A1115	Commisioning	11-Jan-24	03-Apr-24	60	0



Actual Work | Critical Remaining Work | Summary
Remaining Work | Milestone

TASK filter: Activities Less Than 100%.

© Oracle Corporation

VIII. Detailed Overall Commercial Plant Cost Estimates

Table XIV-1
FOAK Capital Costs for Sub-Bituminous Coal

Acct No.	Item/Description	Equipment Cost	Material	Labor		Bare Erected Cost $	Eng'g CM H.O.& Fee		Process Contingency		Project Contingency		Total Plant Cost ($x1000)	Total Plant Cost ($/kW)
			Cost	Direct	Indirect		%	Total	%	Total	%	Total		
1	**COAL & SORBENT HANDLING**													
1.1	Coal Receive & Unload	$0	$989	$1,429	$0	$2,418	20.0%	$484	0%	$0	15%	$435	$3,337	28.4
1.2	Coal Stackout & Reclaim	w/ 1.1	w/ 1.1	w/ 1.1	$0	$0	0.0%	$0	0%	$0	15%	$0	$0	0.0
1.3	Coal Conveyors	$0	$1,022	$1,046	$0	$2,068	20.0%	$414	0%	$0	15%	$372	$2,854	24.3
1.4	Other Coal Handling	$0	$938	$1,407	$0	$2,345	20.0%	$469	0%	$0	15%	$422	$3,236	27.5
SUBTOTAL 1.		**$0**	**$2,949**	**$3,882**	**$0**	**$6,831**		**$1,366**		**$0**		**$1,230**	**$9,427**	**80.2**
2	**COAL & SORBENT PREP & FEED**													
2.1	Fuel System: Coal Feeders, Coal Mills, Coal Pipe, Burners, Natural Gas Skids	$10,011	*Included in 4.1 Material	*Included in 4.1 Direct	$0	$10,011	0.0%	$0	0%	$0	15%	$1,502	$11,513	97.9
2.2	Fired Heater Fuel System Foundations	w/ 4.4	$0	$0	$0	$0	0.0%	$0	0%	$0	15%	$0	$0	0.0
SUBTOTAL 2.		**$10,011**	**$0**	**$0**	**$0**	**$10,011**		**$0**		**$0**		**$1,502**	**$11,513**	**97.9**
4	**PC BOILER & ACCESSORIES**													
4.1	Furnace and Radiant Platens, Convective and Economizer Elements, Air Preheaters, Dry Ash System, Sootblowers, Heater Intimate Steel.	$98,238	$1,415	$110,000	$0	$209,653	9.7%	$20,307	15%	$31,448	10%	$26,141	$287,549	2,445.1
4.2	Fans – Forced Draft, Primary Air, and Booster Fan	$3,233	w/4.1 Material	w/4.1 Direct	$0	$3,233	9.7%	$314	0%	$0	10%	$355	$3,901	33.2
4.3	Major Component Rigging	w/ 4..1	w/ 4..1	w/ 4..1	$0	$0	9.7%	$0	0%	$0	10%	$0	$0	0.0
4.4	Fired Heater & Accessories Foundations and Support Steel	$0	$773	$1,036	$0	$1,809	0.0%	$0	0%	$0	0%	$0	$1,809	15.4
4.5	Fired Heater Ducting: Combustion Air, Flue Gas	$6,332	w/ 4.1	w/4.1	$0	$6,332	0.0%	$0	0%	$0	0%	$0	$6,332	53.8
SUBTOTAL 4.		**$107,803**	**$2,188**	**$111,036**	**$0**	**$221,027**		**$20,621**		**$31,448**		**$26,496**	**$299,592**	**2,547.5**

5 FLUE GAS CLEANUP													
5.1 Circulating Dry Scrubber: Scrubber Vessel, Lime System, Water System, Air System, Air Slide – Product Recirculation	$8,770	w/ 4.1 Material	w/ 4.1 Direct	$0	$8,770	0.0%	$0	0%	$0	15%	$1,316	$10,086	85.8
5.2 Selective Catalytic Reduction (SCR)	$4,788	w/ 4.1 Material	w/ 4.1 Direct	$0	$4,788	0.0%	$0	0%	$0	15%	$718	$5,506	46.8
5.3 Bag House & Accessories	$5,881	w/ 4.1 Material	w/ 4.1 Direct	$0	$5,881	0.0%	$0	0%	$0	15%	$882	$6,763	57.5
5.4 Installation, foundations, stack, and support steel	$0	$2,682	$1,262	$0	$3,945	20.0%	$789	0%	$0	15%	$710	$5,443	46.3
SUBTOTAL 5.	**$19,439**	**$2,682**	**$1,262**	**$0**	**$23,384**		**$789**		**$0**		**$3,626**	**$27,798**	**236.4**
8B sCO2 POWER CYCLE													
8B.1 Compressor (High and Low Temperature)	$8,327	$0	$0	$0	$8,327	20.0%	$1,665	0%	$0	15%	$1,499	$11,491	97.7
8B.2 Internal Recuperation (HTR and LTR)	$25,042	$0	$0	$0	$25,042	9.3%	$2,329	0%	$0	15%	$4,106	$31,477	267.7
8B.3 CO2 Air-Cooled Condenser	$5,507	$38	$43	$0	$5,589	9.3%	$520	0%	$0	15%	$916	$7,025	59.7
8B.4 CO2 Power Turbine (Includes 130 MW generator and turbine throttle valve)	$9,283	$51	$58	$0	$9,392	20.0%	$1,878	0%	$0	15%	$1,691	$12,961	110.2
8B.5 System Piping and Valves	$0	$5,312	$21,254	$0	$26,566	9.3%	$2,471	0%	$0	15%	$4,355	$33,392	283.9
8B.6 CO2 System Foundations, Storage Tanks, and Utility Rack	$685	$552	$777	$0	$2,014	9.3%	$187	0%	$0	15%	$330	$2,532	21.5
SUBTOTAL 8.	**$48,844**	**$5,953**	**$22,132**	**$0**	**$76,930**		**$9,050**		**$0**		**$12,897**	**$98,877**	**840.8**
10 ASH/SPENT SORBENT HANDLING SYS													
10.6 Ash Storage Silos	$0	$444	$181	$0	$625	20.0%	$125	0%	$0	15%	$112	$862	7.3
10.7 Ash Transport & Feed Equipment	$0	$254	$65	$0	$319	20.0%	$64	0%	$0	15%	$57	$440	3.7
10.9 Ash/Spent Sorbent Foundations and Steel	$0	$393	$526	$0	$920	20.0%	$184	0%	$0	20%	$221	$1,324	11.3
SUBTOTAL 10.	**$0**	**$1,091**	**$772**	**$0**	**$1,863**		**$373**		**$0**		**$391**	**$2,627**	**22.3**
11 ACCESSORY ELECTRIC PLANT													
11.1 Generator Equipment	$6,468	$0	$4,682	$0	$11,149	20.0%	$2,230	0%	$0	15%	$2,007	$15,386	130.8
11.3 Switchgear & Motor Control	$4,538	$0	$5,346	$0	$9,884	20.0%	$1,977	0%	$0	15%	$1,779	$13,639	116.0

11.5 Wire & Cable	$461	$0	$394	$0	$855	20.0%	$171	0%	$0	15%	$154	$1,180	10.0
11.8 Main Power Transformers	$8,159	$0	$6,272	$0	$14,431	20.0%	$2,886	0%	$0	15%	$2,598	$19,915	169.3
11.9 Electrical Foundations	w/ 11.1, 11.3, 11.8	$0	$0	$0	$0	20.0%	$0	0%	$0	20%	$0	$0	0.0
SUBTOTAL 11.	**$19,625**	**$0**	**$16,694**	**$0**	**$36,320**		**$7,264**		**$0**		**$6,538**	**$50,121**	**426.2**
12 INSTRUMENTATION & CONTROL													
12.1 Fired Heater Control Equipment	$1,414	w/ Equipment Cost	w/ Equipment Cost	$0	$1,414	0.0%	$0	0%	$0	15%	$212	$1,626	13.8
12.2 Combustion Turbine Control	w/6.1	$0	$0	$0	$0	0.0%	$0	0%	$0	0%	$0	$0	0.0
12.3 sCO2 Power Cycle Control	w/8B.4	$0	$0	$0	$0	0.0%	$0	0%	$0	0%	$0	$0	0.0
12.4 Signal Processing Equipment	w/12.1, 6.1, 8B4	$0	$0	$0	$0	0.0%	$0	0%	$0	0%	$0	$0	0.0
12.6 Distributed Control System Equipment	w/12.1, 6.1, 8B4	$0	$0	$0	$0	0.0%	$0	0%	$0	0%	$0	$0	0.0
12.8 Other I & C Equipment	$0	$886	w/ 11.5	$0	$886	20.0%	$177	0%	$0	15%	$160	$1,223	10.4
SUBTOTAL 12.	**$1,414**	**$886**	**$0**	**$0**	**$2,300**		**$177**		**$0**		**$372**	**$2,849**	**24.2**
13 IMPROVEMENTS TO SITE													
13.1 Site Preparation	$339	$261	$257	$0	$857	20.0%	$171	0%	$0	20%	$206	$1,235	10.5
13.2 Site Improvements	$87	$618	$77	$0	$782	20.0%	$156	0%	$0	20%	$188	$1,126	9.6
13.3 Site Facilities	$462	$804	$565	$0	$1,831	20.0%	$366	0%	$0	20%	$439	$2,636	22.4
SUBTOTAL 13.	**$887**	**$1,683**	**$900**	**$0**	**$3,470**		**$694**		**$0**		**$833**	**$4,997**	**42.5**
14 BUILDINGS & STRUCTURES													
14.1 Boiler Building	$0	$9,982	$2,924	$0	$12,906	20.0%	$2,581	0%	$0	15%	$2,323	$17,811	151.5
14.2 Turbine Building (Gas Turbine)	$0	$0	$0	$0	$0	20.0%	$0	0%	$0	15%	$0	$0	0.0
14.3 Administration Building	$0	$2,625	w/ Material Cost	$0	$2,625	20.0%	$525	0%	$0	15%	$473	$3,623	30.8
14.4 Circulation Water Pumphouse	$0	$0	w/ Material Cost	$0	$0	20.0%	$0	0%	$0	15%	$0	$0	0.0

14.5 Water Treatment Buildings	$0	$0	w/ Material Cost	$0	$0	20.0%	$0	0%	$0	15%	$0	$0	0.0
14.7 Warehouse	$0	$4,014	w/ Material Cost	$0	$4,014	20.0%	$803	0%	$0	15%	$723	$5,539	47.1
14.8 Other Buildings & Structures (ETES System / sCO2 Power Cycle)	$0	$2,543	w/ Material Cost	$0	$2,543	20.0%	$509	0%	$0	15%	$458	$3,510	29.8
SUBTOTAL 14.	**$0**	**$19,164**	**$2,924**	**$0**	**$22,089**		**$4,418**		**$0**		**$3,976**	**$30,482**	**259.2**
TOTAL COST	**$208,024**	**$36,597**	**$159,603**	**$0**	**$404,224**		**$44,752**		**$31,448**		**$57,858**	**$538,282**	**4,577.2**

Table XIV-2
FOAK Capital Costs for Bituminous Coal

Acct No.	Item/Description	Equipment Cost	Material	Labor		Bare Erected Cost $	Eng'g CM H.O.& Fee		Process Contingency		Project Contingency		Total Plant Cost ($x1000)	Total Plant Cost ($/kW)
			Cost	Direct	Indirect		%	Total	%	Total	%	Total		
1	**COAL & SORBENT HANDLING**													
1.1	Coal Receive & Unload	$0	$802	$1,159	$0	$1,960	20.0%	$392	0%	$0	15%	$353	$2,705	23.0
1.2	Coal Stackout & Reclaim	w/ 1.1	w/ 1.1	w/ 1.1	$0	$0	0.0%	$0	0%	$0	15%	$0	$0	0.0
1.3	Coal Conveyors	$0	$829	$848	$0	$1,677	20.0%	$335	0%	$0	15%	$302	$2,314	19.7
1.4	Other Coal Handling	$0	$760	$1,140	$0	$1,901	20.0%	$380	0%	$0	15%	$342	$2,623	22.3
	SUBTOTAL 1.	**$0**	**$2,391**	**$3,147**	**$0**	**$5,538**		**$1,108**		**$0**		**$997**	**$7,642**	**65.0**
2	COAL & SORBENT PREP & FEED													
2.1	Fuel System: Coal Feeders, Coal Mills, Coal Pipe, Burners, Natural Gas Skids	$8,007	*Included in 4.1 Material	*Included in 4.1 Direct	$0	$8,007	0.0%	$0	0%	$0	15%	$1,201	$9,208	78.3
2.2	Fired Heater Fuel System Foundations	w/ 4.4	$0	$0	$0	$0	0.0%	$0	0%	$0	15%	$0	$0	0.0
	SUBTOTAL 2.	**$8,007**	**$0**	**$0**	**$0**	**$8,007**		**$0**		**$0**		**$1,201**	**$9,208**	**78.3**
4	**PC BOILER & ACCESSORIES**													
4.1	Furnace and Radiant Platens, Convective and Economizer Elements, Air Preheaters, Dry Ash System, Sootblowers, Heater Intimate Steel.	$92,329	$1,330	$103,383	$0	$197,042	9.7%	$19,086	15%	$29,556	10%	$24,568	$270,253	2,298.1
4.2	Fans – Forced Draft, Primary Air, and Booster Fan	$3,039	w/4.1 Material	w/4.1 Direct	$0	$3,039	9.7%	$295	0%	$0	10%	$333	$3,667	31.2
4.3	Major Component Rigging	w/ 4..1	w/ 4..1	w/ 4..1	$0	$0	9.7%	$0	0%	$0	10%	$0	$0	0.0
4.4	Fired Heater & Accessories Foundations and Support Steel	$0	$726	$974	$0	$1,700	0.0%	$0	0%	$0	0%	$0	$1,700	14.5
4.5	Fired Heater Ducting: Combustion Air, Flue Gas	$5,951	w/ 4.1	w/4.1	$0	$5,951	0.0%	$0	0%	$0	0%	$0	$5,951	50.6
	SUBTOTAL 4.	**$101,319**	**$2,056**	**$104,357**	**$0**	**$207,732**		**$19,381**		**$29,556**		**$24,902**	**$281,571**	**2,394.3**

5 FLUE GAS CLEANUP													
5.1 Circulating Dry Scrubber: Scrubber Vessel, Lime System, Water System, Air System, Air Slide – Product Recirculation	$16,901	w/ 4.1 Material	w/ 4.1 Direct	$0	$16,901	0.0%	$0	0%	$0	15%	$2,535	$19,436	165.3
5.2 Selective Catalytic Reduction (SCR)	$3,740	w/ 4.1 Material	w/ 4.1 Direct	$0	$3,740	0.0%	$0	0%	$0	15%	$561	$4,301	36.6
5.3 Bag House & Accessories	$5,198	w/ 4.1 Material	w/ 4.1 Direct	$0	$5,198	0.0%	$0	0%	$0	15%	$780	$5,977	50.8
5.4 Installation, foundations, stack, and support steel	$0	$2,563	$1,206	$0	$3,770	20.0%	$754	0%	$0	15%	$679	$5,202	44.2
SUBTOTAL 5.	**$25,838**	**$2,563**	**$1,206**	**$0**	**$29,608**		**$754**		**$0**		**$4,554**	**$34,916**	**296.9**
8B sCO2 POWER CYCLE													
8B.1 Compressor (High and Low Temperature)	$8,327	$0	$0	$0	$8,327	20.0%	$1,665	0%	$0	15%	$1,499	$11,491	97.7
8B.2 Internal Recuperation (HTR and LTR)	$25,042	$0	$0	$0	$25,042	9.3%	$2,329	0%	$0	15%	$4,106	$31,477	267.7
8B.3 CO2 Air-Cooled Condenser	$5,507	$38	$43	$0	$5,589	9.3%	$520	0%	$0	15%	$916	$7,025	59.7
8B.4 CO2 Power Turbine (Includes 130 MW generator and turbine throttle valve)	$9,283	$51	$58	$0	$9,392	20.0%	$1,878	0%	$0	15%	$1,691	$12,961	110.2
8B.5 System Piping and Valves	$0	$5,312	$21,254	$0	$26,566	9.3%	$2,471	0%	$0	15%	$4,355	$33,392	283.9
8B.6 CO2 System Foundations, Storage Tanks, and Utility Rack	$685	$552	$777	$0	$2,014	9.3%	$187	0%	$0	15%	$330	$2,532	21.5
SUBTOTAL 8.	**$48,844**	**$5,953**	**$22,132**	**$0**	**$76,930**		**$9,050**		**$0**		**$12,897**	**$98,877**	**840.8**
10 ASH/SPENT SORBENT HANDLING SYS													
10.6 Ash Storage Silos	$0	$392	$160	$0	$552	20.0%	$110	0%	$0	15%	$99	$762	6.5
10.7 Ash Transport & Feed Equipment	$0	$224	$58	$0	$282	20.0%	$56	0%	$0	15%	$51	$389	3.3
10.9 Ash/Spent Sorbent Foundations and Steel	$0	$348	$465	$0	$813	20.0%	$163	0%	$0	20%	$195	$1,170	10.0
SUBTOTAL 10.	**$0**	**$964**	**$683**	**$0**	**$1,647**		**$329**		**$0**		**$345**	**$2,321**	**19.7**
11 ACCESSORY ELECTRIC PLANT													
11.1 Generator Equipment	$6,468	$0	$4,682	$0	$11,149	20.0%	$2,230	0%	$0	15%	$2,007	$15,386	130.8
11.3 Switchgear & Motor Control	$4,538	$0	$5,346	$0	$9,884	20.0%	$1,977	0%	$0	15%	$1,779	$13,639	116.0

11.5 Wire & Cable	$461	$0	$394	$0	$855	20.0%	$171	0%	$0	15%	$154	$1,180	10.0
11.8 Main Power Transformers	$8,159	$0	$6,272	$0	$14,431	20.0%	$2,886	0%	$0	15%	$2,598	$19,915	169.3
11.9 Electrical Foundations	w/ 11.1, 11.3, 11.8	$0	$0	$0	$0	20.0%	$0	0%	$0	20%	$0	$0	0.0
SUBTOTAL 11.	**$19,625**	**$0**	**$16,694**	**$0**	**$36,320**		**$7,264**		**$0**		**$6,538**	**$50,121**	**426.2**
12 INSTRUMENTATION & CONTROL													
12.1 Fired Heater Control Equipment	$1,414	w/ Equipment Cost	w/ Equipment Cost	$0	$1,414	0.0%	$0	0%	$0	15%	$212	$1,626	13.8
12.2 Combustion Turbine Control	w/6.1	$0	$0	$0	$0	0.0%	$0	0%	$0	0%	$0	$0	0.0
12.3 sCO2 Power Cycle Control	w/8B.4	$0	$0	$0	$0	0.0%	$0	0%	$0	0%	$0	$0	0.0
12.4 Signal Processing Equipment	w/12.1, 6.1, 8B4	$0	$0	$0	$0	0.0%	$0	0%	$0	0%	$0	$0	0.0
12.6 Distributed Control System Equipment	w/12.1, 6.1, 8B4	$0	$0	$0	$0	0.0%	$0	0%	$0	0%	$0	$0	0.0
12.8 Other I & C Equipment	$0	$886	w/ 11.5	$0	$886	20.0%	$177	0%	$0	15%	$160	$1,223	10.4
SUBTOTAL 12.	**$1,414**	**$886**	**$0**	**$0**	**$2,300**		**$177**		**$0**		**$372**	**$2,849**	**24.2**
13 IMPROVEMENTS TO SITE													
13.1 Site Preparation	$339	$261	$257	$0	$857	20.0%	$171	0%	$0	20%	$206	$1,235	10.5
13.2 Site Improvements	$87	$618	$77	$0	$782	20.0%	$156	0%	$0	20%	$188	$1,126	9.6
13.3 Site Facilities	$462	$804	$565	$0	$1,831	20.0%	$366	0%	$0	20%	$439	$2,636	22.4
SUBTOTAL 13.	**$887**	**$1,683**	**$900**	**$0**	**$3,470**		**$694**		**$0**		**$833**	**$4,997**	**42.5**
14 BUILDINGS & STRUCTURES													
14.1 Boiler Building	$0	$9,382	$2,748	$0	$12,130	20.0%	$2,426	0%	$0	15%	$2,183	$16,739	142.3
14.2 Turbine Building (Gas Turbine)	$0	$0	$0	$0	$0	20.0%	$0	0%	$0	15%	$0	$0	0.0
14.3 Administration Building	$0	$2,625	w/ Material Cost	$0	$2,625	20.0%	$525	0%	$0	15%	$473	$3,623	30.8
14.4 Circulation Water Pumphouse	$0	$0	w/ Material Cost	$0	$0	20.0%	$0	0%	$0	15%	$0	$0	0.0

14.5 Water Treatment Buildings	$0	$0	w/ Material Cost	$0	$0	20.0%	$0	0%	$0	15%	$0	$0	0.0
14.7 Warehouse	$0	$4,014	w/ Material Cost	$0	$4,014	20.0%	$803	0%	$0	15%	$723	$5,539	47.1
14.8 Other Buildings & Structures (ETES System / sCO2 Power Cycle)	$0	$2,543	w/ Material Cost	$0	$2,543	20.0%	$509	0%	$0	15%	$458	$3,510	29.8
SUBTOTAL 14.	**$0**	**$18,564**	**$2,748**	**$0**	**$21,312**		**$4,262**		**$0**		**$3,836**	**$29,411**	**250.1**
TOTAL COST	**$205,935**	**$35,061**	**$151,868**	**$0**	**$392,864**		**$43,020**		**$29,556**		**$56,474**	**$521,914**	**4,438.0**

Table XIV-3
NOAK Capital Costs for Sub-Bituminous Coal

Acct No.	Item/Description	Equipment Cost	Material	Labor		Bare Erected Cost $	Eng'g CM H.O.& Fee		Process Contingency		Project Contingency		Total Plant Cost ($x1000)	Total Plant Cost ($/kW)
			Cost	Direct	Indirect		%	Total	%	Total	%	Total		
1	**COAL & SORBENT HANDLING**													
1.1	Coal Receive & Unload	$0	$989	$1,429	$0	$2,418	20.0%	$484	0%	$0	15%	$435	$3,337	27.8
1.2	Coal Stackout & Reclaim	w/ 1.1	w/ 1.1	w/ 1.1	$0	$0	0.0%	$0	0%	$0	15%	$0	$0	0.0
1.3	Coal Conveyors	$0	$1,022	$1,046	$0	$2,068	20.0%	$414	0%	$0	15%	$372	$2,854	23.8
1.4	Other Coal Handling	$0	$938	$1,407	$0	$2,345	20.0%	$469	0%	$0	15%	$422	$3,236	27.0
	SUBTOTAL 1.	**$0**	**$2,949**	**$3,882**	**$0**	**$6,831**		**$1,366**		**$0**		**$1,230**	**$9,427**	**78.6**
2	**COAL & SORBENT PREP & FEED**													
2.1	Fuel System: Coal Feeders, Coal Mills, Coal Pipe, Burners, Natural Gas Skids	$10,011	*Included in 4.1 Material	*Included in 4.1 Direct	$0	$10,011	0.0%	$0	0%	$0	15%	$1,502	$11,513	95.9
2.2	Fired Heater Fuel System Foundations	w/ 4.4	$0	$0	$0	$0	0.0%	$0	0%	$0	15%	$0	$0	0.0
	SUBTOTAL 2.	**$10,011**	**$0**	**$0**	**$0**	**$10,011**		**$0**		**$0**		**$1,502**	**$11,513**	**95.9**
4	**PC BOILER & ACCESSORIES**													
4.1	Furnace and Radiant Platens, Convective and Economizer Elements, Air Preheaters, Dry Ash System, Sootblowers, Heater Intimate Steel.	$71,790	$1,415	$46,663	$0	$119,868	9.7%	$11,611	0%	$0	10%	$13,148	$144,626	1,205.2
4.2	Fans – Forced Draft, Primary Air, and Booster Fan	$3,233	w/4.1 Material	w/4.1 Direct	$0	$3,233	9.7%	$314	0%	$0	10%	$355	$3,901	32.5
4.3	Major Component Rigging	w/ 4..1	w/ 4..1	w/ 4..1	$0	$0	9.7%	$0	0%	$0	10%	$0	$0	0.0
4.4	Fired Heater & Accessories Foundations and Support Steel	$0	$773	$1,036	$0	$1,809	0.0%	$0	0%	$0	0%	$0	$1,809	15.1
4.5	Fired Heater Ducting: Combustion Air, Flue Gas	$6,332	w/ 4.1	w/4.1	$0	$6,332	0.0%	$0	0%	$0	0%	$0	$6,332	52.8
	SUBTOTAL 4.	**$81,355**	**$2,188**	**$47,700**	**$0**	**$131,242**		**$11,924**		**$0**		**$13,503**	**$156,669**	**1,305.6**
5	**FLUE GAS CLEANUP**													

5.1 Circulating Dry Scrubber: Scrubber Vessel, Lime System, Water System, Air System, Air Slide – Product Recirculation	$8,770	w/ 4.1 Material	w/ 4.1 Direct	$0	$8,770	0.0%	$0	0%	$0	15%	$1,316	$10,086	84.0
5.2 Selective Catalytic Reduction (SCR)	$4,788	w/ 4.1 Material	w/ 4.1 Direct	$0	$4,788	0.0%	$0	0%	$0	15%	$718	$5,506	45.9
5.3 Bag House & Accessories	$5,881	w/ 4.1 Material	w/ 4.1 Direct	$0	$5,881	0.0%	$0	0%	$0	15%	$882	$6,763	56.4
5.4 Installation, foundations, stack, and support steel	$0	$2,682	$1,262	$0	$3,945	20.0%	$789	0%	$0	15%	$710	$5,443	45.4
SUBTOTAL 5.	**$19,439**	**$2,682**	**$1,262**	**$0**	**$23,384**		**$789**		**$0**		**$3,626**	**$27,798**	**231.7**
8B sCO2 POWER CYCLE													
8B.1 Compressor (High and Low Temperature)	$8,327	$0	$0	$0	$8,327	9.3%	$774	0%	$0	15%	$1,365	$10,466	87.2
8B.2 Internal Recuperation (HTR and LTR)	$18,300	$0	$0	$0	$18,300	5.0%	$915	0%	$0	15%	$2,882	$22,097	184.1
8B.3 CO2 Air-Cooled Condenser	$5,507	$38	$43	$0	$5,589	9.3%	$520	0%	$0	15%	$916	$7,025	58.5
8B.4 CO2 Power Turbine (Includes 130 MW generator and turbine throttle valve)	$9,283	$51	$58	$0	$9,392	9.3%	$873	0%	$0	15%	$1,540	$11,805	98.4
8B.5 System Piping and Valves	$0	$5,312	$21,254	$0	$26,566	9.3%	$2,471	0%	$0	15%	$4,355	$33,392	278.3
8B.6 CO2 System Foundations, Storage Tanks, and Utility Rack	$685	$552	$777	$0	$2,014	9.3%	$187	0%	$0	15%	$330	$2,532	21.1
SUBTOTAL 8.	**$42,102**	**$5,953**	**$22,132**	**$0**	**$70,188**		**$5,741**		**$0**		**$11,389**	**$87,317**	**727.6**
10 ASH/SPENT SORBENT HANDLING SYS													
10.6 Ash Storage Silos	$0	$444	$181	$0	$625	20.0%	$125	0%	$0	15%	$112	$862	7.2
10.7 Ash Transport & Feed Equipment	$0	$254	$65	$0	$319	20.0%	$64	0%	$0	15%	$57	$440	3.7
10.9 Ash/Spent Sorbent Foundations and Steel	$0	$393	$526	$0	$920	20.0%	$184	0%	$0	20%	$221	$1,324	11.0
SUBTOTAL 10.	**$0**	**$1,091**	**$772**	**$0**	**$1,863**		**$373**		**$0**		**$391**	**$2,627**	**21.9**
11 ACCESSORY ELECTRIC PLANT													
11.1 Generator Equipment	$6,468	$0	$4,682	$0	$11,149	20.0%	$2,230	0%	$0	15%	$2,007	$15,386	128.2
11.3 Switchgear & Motor Control	$4,538	$0	$5,346	$0	$9,884	20.0%	$1,977	0%	$0	15%	$1,779	$13,639	113.7
11.5 Wire & Cable	$461	$0	$394	$0	$855	20.0%	$171	0%	$0	15%	$154	$1,180	9.8

11.8 Main Power Transformers	$8,159	$0	$6,272	$0	$14,431	20.0%	$2,886	0%	$0	15%	$2,598	$19,915	166.0
11.9 Electrical Foundations	w/ 11.1, 11.3, 11.8	$0	$0	$0	$0	20.0%	$0	0%	$0	20%	$0	$0	0.0
SUBTOTAL 11.	**$19,625**	**$0**	**$16,694**	**$0**	**$36,320**		**$7,264**		**$0**		**$6,538**	**$50,121**	**417.7**
12 INSTRUMENTATION & CONTROL													
12.1 Fired Heater Control Equipment	$1,414	w/ Equipment Cost	w/ Equipment Cost	$0	$1,414	0.0%	$0	0%	$0	15%	$212	$1,626	13.6
12.2 Combustion Turbine Control	w/6.1	$0	$0	$0	$0	0.0%	$0	0%	$0	0%	$0	$0	0.0
12.3 sCO2 Power Cycle Control	w/8B.4	$0	$0	$0	$0	0.0%	$0	0%	$0	0%	$0	$0	0.0
12.4 Signal Processing Equipment	w/12.1, 6.1, 8B4	$0	$0	$0	$0	0.0%	$0	0%	$0	0%	$0	$0	0.0
12.6 Distributed Control System Equipment	w/12.1, 6.1, 8B4	$0	$0	$0	$0	0.0%	$0	0%	$0	0%	$0	$0	0.0
12.8 Other I & C Equipment	$0	$886	w/ 11.5	$0	$886	20.0%	$177	0%	$0	15%	$160	$1,223	10.2
SUBTOTAL 12.	**$1,414**	**$886**	**$0**	**$0**	**$2,300**		**$177**		**$0**		**$372**	**$2,849**	**23.7**
13 IMPROVEMENTS TO SITE													
13.1 Site Preparation	$339	$261	$257	$0	$857	20.0%	$171	0%	$0	20%	$206	$1,235	10.3
13.2 Site Improvements	$87	$618	$77	$0	$782	20.0%	$156	0%	$0	20%	$188	$1,126	9.4
13.3 Site Facilities	$462	$804	$565	$0	$1,831	20.0%	$366	0%	$0	20%	$439	$2,636	22.0
SUBTOTAL 13.	**$887**	**$1,683**	**$900**	**$0**	**$3,470**		**$694**		**$0**		**$833**	**$4,997**	**41.6**
14 BUILDINGS & STRUCTURES													
14.1 Boiler Building	$0	$9,982	$2,924	$0	$12,906	20.0%	$2,581	0%	$0	15%	$2,323	$17,811	148.4
14.2 Turbine Building (Gas Turbine)	$0	$0	$0	$0	$0	20.0%	$0	0%	$0	15%	$0	$0	0.0
14.3 Administration Building	$0	$2,625	w/ Material Cost	$0	$2,625	20.0%	$525	0%	$0	15%	$473	$3,623	30.2
14.4 Circulation Water Pumphouse	$0	$0	w/ Material Cost	$0	$0	20.0%	$0	0%	$0	15%	$0	$0	0.0
14.5 Water Treatment Buildings	$0	$0	w/ Material Cost	$0	$0	20.0%	$0	0%	$0	15%	$0	$0	0.0

14.7 Warehouse	$0	$4,014	w/ Material Cost	$0	$4,014	20.0%	$803	0%	$0	15%	$723	$5,539	46.2
14.8 Other Buildings & Structures (ETES System / sCO2 Power Cycle)	$0	$2,543	w/ Material Cost	$0	$2,543	20.0%	$509	0%	$0	15%	$458	$3,510	29.2
SUBTOTAL 14.	**$0**	**$19,164**	**$2,924**	**$0**	**$22,089**		**$4,418**		**$0**		**$3,976**	**$30,482**	**254.0**
TOTAL COST	**$174,834**	**$36,597**	**$96,266**	**$0**	**$307,697**		**$32,745**		**$0**		**$43,357**	**$383,800**	**3,198.3**

Table XIV-4
NOAK Capital Costs for Bituminous Coal

Acct No.	Item/Description	Equipment Cost	Material	Labor		Bare Erected Cost $	Eng'g CM H.O.& Fee		Process Contingency		Project Contingency		Total Plant Cost ($x1000)	Total Plant Cost ($/kW)
			Cost	Direct	Indirect		%	Total	%	Total	%	Total		
1	**COAL & SORBENT HANDLING**													
1.1	Coal Receive & Unload	$0	$802	$1,159	$0	$1,960	20.0%	$392	0%	$0	15%	$353	$2,705	22.5
1.2	Coal Stackout & Reclaim	w/ 1.1	w/ 1.1	w/ 1.1	$0	$0	0.0%	$0	0%	$0	15%	$0	$0	0.0
1.3	Coal Conveyors	$0	$829	$848	$0	$1,677	20.0%	$335	0%	$0	15%	$302	$2,314	19.3
1.4	Other Coal Handling	$0	$760	$1,140	$0	$1,901	20.0%	$380	0%	$0	15%	$342	$2,623	21.9
	SUBTOTAL 1.	**$0**	**$2,391**	**$3,147**	**$0**	**$5,538**		**$1,108**		**$0**		**$997**	**$7,642**	**63.7**
2	**COAL & SORBENT PREP & FEED**													
2.1	Fuel System: Coal Feeders, Coal Mills, Coal Pipe, Burners, Natural Gas Skids	$8,007	*Included in 4.1 Material	*Included in 4.1 Direct	$0	$8,007	0.0%	$0	0%	$0	15%	$1,201	$9,208	76.7
2.2	Fired Heater Fuel System Foundations	w/ 4.4	$0	$0	$0	$0	0.0%	$0	0%	$0	15%	$0	$0	0.0
	SUBTOTAL 2.	**$8,007**	**$0**	**$0**	**$0**	**$8,007**		**$0**		**$0**		**$1,201**	**$9,208**	**76.7**
4	**PC BOILER & ACCESSORIES**													
4.1	Furnace and Radiant Platens, Convective and Economizer Elements, Air Preheaters, Dry Ash System, Sootblowers, Heater Intimate Steel.	$67,493	$1,330	$43,870	$0	$112,693	9.7%	$10,916	0%	$0	10%	$12,361	$135,969	1,133.1
4.2	Fans – Forced Draft, Primary Air, and Booster Fan	$3,039	w/4.1 Material	w/4.1 Direct	$0	$3,039	9.7%	$295	0%	$0	10%	$333	$3,667	30.6
4.3	Major Component Rigging	w/ 4..1	w/ 4..1	w/ 4..1	$0	$0	9.7%	$0	0%	$0	10%	$0	$0	0.0
4.4	Fired Heater & Accessories Foundations and Support Steel	$0	$726	$974	$0	$1,700	0.0%	$0	0%	$0	0%	$0	$1,700	14.2
4.5	Fired Heater Ducting: Combustion Air, Flue Gas	$5,951	w/ 4.1	w/4.1	$0	$5,951	0.0%	$0	0%	$0	0%	$0	$5,951	49.6
	SUBTOTAL 4.	**$76,482**	**$2,056**	**$44,844**	**$0**	**$123,382**		**$11,210**		**$0**		**$12,694**	**$147,287**	**1,227.4**

5 FLUE GAS CLEANUP													
5.1 Circulating Dry Scrubber: Scrubber Vessel, Lime System, Water System, Air System, Air Slide – Product Recirculation	$16,901	w/ 4.1 Material	w/ 4.1 Direct	$0	$16,901	0.0%	$0	0%	$0	15%	$2,535	$19,436	162.0
5.2 Selective Catalytic Reduction (SCR)	$3,740	w/ 4.1 Material	w/ 4.1 Direct	$0	$3,740	0.0%	$0	0%	$0	15%	$561	$4,301	35.8
5.3 Bag House & Accessories	$5,198	w/ 4.1 Material	w/ 4.1 Direct	$0	$5,198	0.0%	$0	0%	$0	15%	$780	$5,977	49.8
5.4 Installation, foundations, stack, and support steel	$0	$2,563	$1,206	$0	$3,770	20.0%	$754	0%	$0	15%	$679	$5,202	43.4
SUBTOTAL 5.	**$25,838**	**$2,563**	**$1,206**	**$0**	**$29,608**		**$754**		**$0**		**$4,554**	**$34,916**	**291.0**
8B sCO2 POWER CYCLE													
8B.1 Compressor (High and Low Temperature)	$8,327	$0	$0	$0	$8,327	9.3%	$774	0%	$0	15%	$1,365	$10,466	87.2
8B.2 Internal Recuperation (HTR and LTR)	$18,300	$0	$0	$0	$18,300	5.0%	$915	0%	$0	15%	$2,882	$22,097	184.1
8B.3 CO2 Air-Cooled Condenser	$5,507	$38	$43	$0	$5,589	9.3%	$520	0%	$0	15%	$916	$7,025	58.5
8B.4 CO2 Power Turbine (Includes 130 MW generator and turbine throttle valve)	$9,283	$51	$58	$0	$9,392	9.3%	$873	0%	$0	15%	$1,540	$11,805	98.4
8B.5 System Piping and Valves	$0	$5,312	$21,254	$0	$26,566	9.3%	$2,471	0%	$0	15%	$4,355	$33,392	278.3
8B.6 CO2 System Foundations, Storage Tanks, and Utility Rack	$685	$552	$777	$0	$2,014	9.3%	$187	0%	$0	15%	$330	$2,532	21.1
SUBTOTAL 8.	**$42,102**	**$5,953**	**$22,132**	**$0**	**$70,188**		**$5,741**		**$0**		**$11,389**	**$87,317**	**727.6**
10 ASH/SPENT SORBENT HANDLING SYS													
10.6 Ash Storage Silos	$0	$392	$160	$0	$552	20.0%	$110	0%	$0	15%	$99	$762	6.3
10.7 Ash Transport & Feed Equipment	$0	$224	$58	$0	$282	20.0%	$56	0%	$0	15%	$51	$389	3.2
10.9 Ash/Spent Sorbent Foundations and Steel	$0	$348	$465	$0	$813	20.0%	$163	0%	$0	20%	$195	$1,170	9.8
SUBTOTAL 10.	**$0**	**$964**	**$683**	**$0**	**$1,647**		**$329**		**$0**		**$345**	**$2,321**	**19.3**
11 ACCESSORY ELECTRIC PLANT													
11.1 Generator Equipment	$6,468	$0	$4,682	$0	$11,149	20.0%	$2,230	0%	$0	15%	$2,007	$15,386	128.2
11.3 Switchgear & Motor Control	$4,538	$0	$5,346	$0	$9,884	20.0%	$1,977	0%	$0	15%	$1,779	$13,639	113.7

11.5 Wire & Cable	$461	$0	$394	$0	$855	20.0%	$171	0%	$0	15%	$154	$1,180	9.8
11.8 Main Power Transformers	$8,159	$0	$6,272	$0	$14,431	20.0%	$2,886	0%	$0	15%	$2,598	$19,915	166.0
11.9 Electrical Foundations	w/ 11.1, 11.3, 11.8	$0	$0	$0	$0	20.0%	$0	0%	$0	20%	$0	$0	0.0
SUBTOTAL 11.	**$19,625**	**$0**	**$16,694**	**$0**	**$36,320**		**$7,264**		**$0**		**$6,538**	**$50,121**	**417.7**
12 INSTRUMENTATION & CONTROL													
12.1 Fired Heater Control Equipment	$1,414	w/ Equipment Cost	w/ Equipment Cost	$0	$1,414	0.0%	$0	0%	$0	15%	$212	$1,626	13.6
12.2 Combustion Turbine Control	w/6.1	$0	$0	$0	$0	0.0%	$0	0%	$0	0%	$0	$0	0.0
12.3 sCO2 Power Cycle Control	w/8B.4	$0	$0	$0	$0	0.0%	$0	0%	$0	0%	$0	$0	0.0
12.4 Signal Processing Equipment	w/12.1, 6.1, 8B4	$0	$0	$0	$0	0.0%	$0	0%	$0	0%	$0	$0	0.0
12.6 Distributed Control System Equipment	w/12.1, 6.1, 8B4	$0	$0	$0	$0	0.0%	$0	0%	$0	0%	$0	$0	0.0
12.8 Other I & C Equipment	$0	$886	w/ 11.5	$0	$886	20.0%	$177	0%	$0	15%	$160	$1,223	10.2
SUBTOTAL 12.	**$1,414**	**$886**	**$0**	**$0**	**$2,300**		**$177**		**$0**		**$372**	**$2,849**	**23.7**
13 IMPROVEMENTS TO SITE													
13.1 Site Preparation	$339	$261	$257	$0	$857	20.0%	$171	0%	$0	20%	$206	$1,235	10.3
13.2 Site Improvements	$87	$618	$77	$0	$782	20.0%	$156	0%	$0	20%	$188	$1,126	9.4
13.3 Site Facilities	$462	$804	$565	$0	$1,831	20.0%	$366	0%	$0	20%	$439	$2,636	22.0
SUBTOTAL 13.	**$887**	**$1,683**	**$900**	**$0**	**$3,470**		**$694**		**$0**		**$833**	**$4,997**	**41.6**
14 BUILDINGS & STRUCTURES													
14.1 Boiler Building	$0	$9,382	$2,748	$0	$12,130	20.0%	$2,426	0%	$0	15%	$2,183	$16,739	139.5
14.2 Turbine Building (Gas Turbine)	$0	$0	$0	$0	$0	20.0%	$0	0%	$0	15%	$0	$0	0.0
14.3 Administration Building	$0	$2,625	w/ Material Cost	$0	$2,625	20.0%	$525	0%	$0	15%	$473	$3,623	30.2
14.4 Circulation Water Pumphouse	$0	$0	w/ Material Cost	$0	$0	20.0%	$0	0%	$0	15%	$0	$0	0.0

14.5 Water Treatment Buildings	$0	$0	w/ Material Cost	$0	$0	20.0%	$0	0%	$0	15%	$0	$0	0.0
14.7 Warehouse	$0	$4,014	w/ Material Cost	$0	$4,014	20.0%	$803	0%	$0	15%	$723	$5,539	46.2
14.8 Other Buildings & Structures (ETES System / sCO2 Power Cycle)	$0	$2,543	w/ Material Cost	$0	$2,543	20.0%	$509	0%	$0	15%	$458	$3,510	29.2
SUBTOTAL 14.	**$0**	**$18,564**	**$2,748**	**$0**	**$21,312**		**$4,262**		**$0**		**$3,836**	**$29,411**	**245.1**
TOTAL COST	**$174,356**	**$35,061**	**$92,355**	**$0**	**$301,772**		**$31,539**		**$0**		**$42,759**	**$376,071**	**3,133.9**

IX. Construction Permit

MISSOURI
DEPARTMENT OF
NATURAL RESOURCES

MISSOURI AIR CONSERVATION COMMISSION

PERMIT TO CONSTRUCT

Under the authority of RSMo 643 and the Federal Clean Air Act the applicant is authorized to construct the air contaminant source(s) described below, in accordance with the laws, rules and conditions as set forth herein.

Permit Number:

Project Number: 2020-02-016
Installation Number: 019-0004

Owner/Operator Name: University of Missouri Power Plant

Owner/Operator Address: Fifth Street and Stewart Road, Columbia, MO 65211-2030

Location Information: Boone County, S13, T48N, R13W

Application for Authority to Construct was made for:

Installation of a new multi-fuel process heater. This review was conducted in accordance with Section (5), Missouri State Rule 10 CSR 10-6.060, *Construction Permits Required*.

☐ Standard Conditions (on reverse) are applicable to this permit.

☐ Standard Conditions (on reverse) and Special Conditions are applicable to this permit.

Director or Designee
Department of Natural Resources

Effective Date

DRAFT

STANDARD CONDITIONS:

Permission to construct may be revoked if you fail to begin construction or modification within two years from the effective date of this permit. Permittee should notify the Enforcement and Compliance Section of the Air Pollution Control Program if construction or modification is not started within two years after the effective date of this permit, or if construction or modification is suspended for one year or more.

You will be in violation of 10 CSR 10-6.060 if you fail to adhere to the specifications and conditions listed in your application, this permit and the project review. In the event that there is a discrepancy between the permit application and this permit, the conditions of this permit shall take precedence. Specifically, all air contaminant control devices shall be operated and maintained as specified in the application, associated plans and specifications.

You must notify the Enforcement and Compliance Section of the Department's Air Pollution Control Program of the anticipated date of start up of this (these) air contaminant source(s). The information must be made available within 30 days of actual startup. Also, you must notify the Department's regional office responsible for the area within which you are located within 15 days after the actual start up of this (these) air contaminant source(s).

A copy of the permit application and this permit and permit review shall be kept at the installation address and shall be made available to Department's personnel upon request.

You may appeal this permit or any of the listed special conditions to the Administrative Hearing Commission (AHC), P.O. Box 1557, Jefferson City, MO 65102, as provided in RSMo 643.075.6 and 621.250.3. If you choose to appeal, you must file a petition with the AHC within 30 days after the date this decision was mailed or the date it was delivered, whichever date was earlier. If any such petition is sent by registered mail or certified mail, it will be deemed filed on the date it is mailed. If it is sent by any method other than registered mail or certified mail, it will be deemed filed on the date it is received by the AHC.

If you choose not to appeal, this certificate, the project review and your application and associated correspondence constitutes your permit to construct. The permit allows you to construct and operate your air contaminant source(s), but in no way relieves you of your obligation to comply with all applicable provisions of the Missouri Air Conservation Law, regulations of the Missouri Department of Natural Resources and other applicable federal, state and local laws and ordinances.

The Air Pollution Control Program invites your questions regarding this air pollution permit. Please contact the Construction Permit Unit using the contact information below.

Contact Information:
Missouri Department of Natural Resources
Air Pollution Control Program
P.O. Box 176
Jefferson City, MO 65102-0176
(573) 751-4817

The regional office information can be found at the following website:
http://dnr.mo.gov/regions/

DRAFT

SPECIAL CONDITIONS:

The permittee is authorized to construct and operate subject to the following special conditions:
The special conditions listed in this permit were included based on the authority granted to the Missouri Air Pollution Control Program by the Missouri Air Conservation Law (specifically 643.075) and by the Missouri Rules listed in Title 10, Division 10 of the Code of State Regulations (specifically 10 CSR 10-6.060). For specific details regarding conditions, see 10 CSR 10-6.060 paragraph (3)(E). "Conditions required by permitting authority."

University of Missouri Power Plant
Boone County, S13, T48N, R13W

1. Superseding Condition
   A. The conditions of this permit supersede the following special conditions found in the previously issued construction permits from the Air Pollution Control Program.
      1) Special Condition No. 9 in Permit No. 112016-004A
      2) Special Condition No. 5 in Permit No. 112016-004

2. SO_2 Emission Limitation
   A. The permittee shall emit less than 2,000 tons per calendar year (tpy) of SO_2 from the entire installation as defined in Attachment A. The installation shall include all actual emissions in the limit including SSM emissions as well as any excess SSM emissions as reported to the Air Pollution Control Program's Compliance/Enforcement Section in accordance with the requirements of 10 CSR 10-6.050 *Start-Up, Shutdown, and Malfunction Conditions*.

   B. The permittee shall develop and use forms to demonstrate compliance with Special condition 2.A. The forms shall contain, at a minimum, the following information:
      1) Installation name
      2) Installation ID
      3) Emission unit
      4) Current month
      5) Current calendar year
      6) Monthly throughput of each fuel fired in each emission unit
      7) SO_2 emission factors used to calculate emissions.
         a) SO_2 emission factors in Attachment A unless the facility has performed stack testing or installed CEMS. If stack testing has been performed, the results from the most recent stack test shall be used. If the installation has installed CEMS, data from the CEMS shall be used instead of the factors in Attachment A or results from stack testing.
         b) When the installation tests for the fuel sulfur weight percentage (%) or receive vendor documented sulfur weight %, the installation may develop new SO_2 emission factors to demonstrate compliance with Special Condition 2.A. SO_2 emission factors may be based upon the monthly weighted

SPECIAL CONDITIONS:
The permittee is authorized to construct and operate subject to the following special conditions:

average of respective fuel sulfur weight % and respective fuel usage. The tested emission factors may be used retroactively to replace the issued emission factors if approved to do so by the Missouri Air Pollution Control Program.

.

8) Monthly emissions for each fuel calculated using the following equation.

SO_2 Emissions = Fuel Usage (in tons, mmcf, or gallons) x Fuel Specific Emission Factors (in lb of SO_2 per tons, mmcf, or gallons of fuel fired) x (1 tons of SO_2 per 2,000 lb of SO_2)

All of the emission factors from Attachment A are either uncontrolled or have the control device efficiencies accounted for in the factor. If the facility ever uses an uncontrolled emission factor but need to account for control device efficiency, multiply the equation above by a factor of (100-Control Efficiency)/100.

9) Emission unit specific monthly SO_2 emissions calculated by summing SO_2 emissions from all fuel for that unit.
10) Monthly SO_2 emissions calculated by summing SO_2 emissions from all emission units.
11) Calendar year total SO_2 emissions and the sum of all SO_2 emissions from startup, shutdown, and malfunction.
12) Indication of Compliance with Special condition 2.A.

3. SO_2 Emission Limit and Monitoring

A. The permittee shall emit no more than 0.42 pounds of SO_2 per MMBtu of coal, 0.0015 pounds of SO_2 per MMBtu of natural gas, and 0.025 pounds of SO_2 per MMBtu of biomass from the North Stack from the multi-fuel process heater (EP43), on a 30-day rolling average. These limits are only for emissions from the process heater (EP43). A biomass boiler (BFB-1, EP-19) and two diesel generators (EP-29) also vent out of the North Stack and their emissions are not to be counted in the limits.

B. The permittee shall maintain compliance with Special Condition 3.A. by monitoring the SO_2 emissions using a continuous emissions monitoring system (CEMS).

C. The permittee shall operate and maintain the CEMS required in Special Condition 3.B. in accordance with 40 CFR 60 Subpart Db and the manufacturer's specifications.

D. The University of Missouri Power Plant shall install and operate a data acquisition and handling system for the CEMS to calculate emissions in

SPECIAL CONDITIONS:

The permittee is authorized to construct and operate subject to the following special conditions:

term of the emission limitations specified in Special Condition 3.A.

4. CO Emission Limit and Testing

A. The permittee shall emit less than or equal to 0.17 pounds of CO per MMBtu (lb/MMBtu) from the North Stack from the process heater (EP43) while combusting coal. A biomass boiler (BFB-1, EP-19) and two diesel generators (EP-29) also vent out of the North Stack and their emissions are not to be counted in the limits.

B. The permittee shall maintain compliance with Special Condition 4.A. by performing stack tests on the North Stack in accordance with the procedure given below.

1) Testing shall be performed within 180 days of equipment startup.
2) The test shall be performed within 10% of the maximum capacity (121 MMBtu/hr). If it is impractical to test at maximum capacity, testing may be performed at less than the maximum capacity. However, subsequent operation of the multi-fuel process heater shall be limited to a maximum of 110% of the test rate unless new testing is performed within 10% of the maximum capacity.
3) A completed Proposed Test Plant Form (enclosed) shall be submitted to the Missouri Air Pollution Control program 30 days prior to the proposed test date so that the Air Pollution Control Program may arrange a pretest meeting, if necessary, and assure that the test date is acceptable for an observer to be present. The Proposed test Plan may serve the purpose of notification and must be approved by the Director prior to conducting the required emission testing. Each proposed test method shall be approved by the Air Pollution Control Program prior to conducting the respective test.
4) One electronic copy of a written report of the performance test results shall be submitted to StackTesting@dnr.mo.gov within 60 days of completion of any required testing. The report must include legible copies of the raw data sheets, analytical instrument laboratory data, and complete sample calculations from the required U.S. EPA Method for at least one sample run.
5) The test report is to fully account for all operational and emission parameters addressed both in the permit conditions as well as in any other applicable state or federal rules or regulations.

5. Removal of Coal/Biomass-Fired Boilers

The permittee shall render inoperable and remove the coal/biomass-fired boilers no. 7, no. 8, and no. 9 (EP07, EP08, and EP09) from the site before starting construction on the new multi-fuel process heater (EP43).

6. Control Device Requirement-Baghouse (CD43-c)

A. The permittee shall control particulate emissions from the multi-fuel

SPECIAL CONDITIONS:

The permittee is authorized to construct and operate subject to the following special conditions:

process heater (EP43) using a baghouse as specified in the permit application.

B. The baghouses shall be operated and maintained in accordance with the manufacturer's specifications.

C. The baghouse shall be equipped with a gauge or meter, which indicates the pressure drop across the control device. These gauges or meters shall be located such that Department of Natural Resources' employees may easily observe them.

D. Replacement filters for the baghouses shall be kept on hand at all times. The bags shall be made of fibers appropriate for operating conditions expected to occur (i.e. temperature limits, acidic and alkali resistance, and abrasion resistance).

E. The permittee shall monitor and record the operating pressure drop across the baghouses at least once every 24 hours when the associated equipment is in operation. The operating pressure drop shall be maintained within the design conditions specified by the manufacturer's performance warranty.

F. The permittee shall maintain a copy of the baghouse manufacturer's performance warranty on site.

G. The permittee shall maintain an operating and maintenance log for the baghouses which shall include the following:
   1) Incidents of malfunction, with impact on emissions, duration of event, probable cause, and corrective actions; and
   2) Maintenance activities, with inspection schedule, repair actions, and replacements, etc.

7. Control Device Requirements – Selective Catalytic Reduction (CD43-a)

A. The permittee shall control nitrogen oxide (NO_X) emissions from the multi-fuel process heater (EP43) using selective catalytic reduction (SCR) as specified in the permit application.

B. The SCR system shall be maintained and operated in accordance with the manufacturer's specifications.

C. The permittee shall maintain an operating and maintenance log for the SCR, which shall include the following:
   1) Incidents of malfunction, with impact on emissions, duration of event, probable cause, and corrective actions; and
   2) Maintenance activities, with inspection schedule, repair actions, and replacements, etc.

SPECIAL CONDITIONS:
The permittee is authorized to construct and operate subject to the following special conditions:

8. Control Device Requirements – Circulating Dry Scrubber (CD43-b)
   A. The permittee shall control sulfur dioxide (SO_2) emissions from the multi-fuel process heater using a circulating dry scrubber as specified in the permit application.

   B. The circulating dry scrubber shall be maintained and operated in accordance with the manufacturer's specifications.

   C. If the permittee stops operating the CEMS required in Special Condition ~~3.A.~~, they shall monitor and record the lime feed rate, the water flow rate, and the operating temperature during the CEMS outage to ensure the proper operation of the circulating dry scrubber. The values of these parameters shall be maintained within the range specified by the manufacturer and shall be recorded in accordance with the following schedule.
      1) If the CEMS outage is less than 24 hours, then the parameters shall be recorded once during the outage.
      2) If the outage is greater than 24 hours, then the parameters shall be recorded at least once every 24 hours while the CEMS is not in operation.

   D. The permittee shall maintain an operating and maintenance log for the circulating dry scrubber, which shall include the following:
      1) Incidents of malfunction, with impact on emissions, duration of event, probable cause, and corrective actions;
      2) Maintenance activities, with inspection schedule, repair actions, and replacements, etc.; and
      3) The time when the CEMS is not in operation and the lime feed rate, the water flow rate, and the operating temperature recorded during the CEMS outage in accordance with Special Condition 9.C.

9. Emission Limits and Monitoring Methods from the New Source Performance Standard Subpart Db
   A. While combusting coal, oil, natural gas, a mixture of these fuels, or a mixture of these fuels with any other fuels, the permittee shall not emit SO_2 in excess of 0.20 lb/MMBtu heat input or 8% of the potential SO_2 emission rate (i.e. 92% reduction) and 1.2 lb/MMBtu heat input from the new multi-fuel process heater. (40 CFR §60.42b(a))
      1) The permittee shall install, calibrate, maintain, and operated CEMS for measuring SO_2 concentrations. For units complying with the percent reduction standard, the SO_2 concentrations shall both be monitored at the inlet and outlet of the control device. (40 CFR §60.47b(a))
      2) While combusting coal, as an alternative to operating CEMS as required under 40 CFR §60.47b(a) (also listed above in Special

SPECIAL CONDITIONS:
The permittee is authorized to construct and operate subject to the following special conditions:

Condition 9.A.1)), the installation may collect coal samples in an as-fired condition at the inlet and analyze them for sulfur and heat content according to Method 19 of Appendix A of 40 CFR Part 60 (40 CFR §60.47b(b)(1))

B. While combusting coal, oil, wood, or mixtures of these fuels with any other fuels, the permittee shall not discharge from the multi-fuel heater into the atmosphere any gases that exhibit greater than 20 percent opacity (on a 6-minute average), except for one 6-minute period per hour of not more than 27 percent opacity. If the facility elects to install, calibrate, maintain, and operate a continuous emissions monitoring system (CEMS) for measuring PM emissions and is subject to a federally enforceable PM limit of 0.03 lb/MMBtu or less for the multi-fuel heater, the equipment is exempt from the opacity standard. (40 CFR §60.43b(f))

1) The permittee shall install, calibrate, maintain, and operate a continuous opacity monitoring system (COMS) for measuring the opacity of emissions discharged to the atmosphere and record the output of the system. (40 CFR §60.48b(a))
2) The permittee is not required to install or operate a COMS if the installation uses a PM CEMS to monitor PM emissions. (40 CFR §60.48b(j)(1)).

C. While combusting coal, oil, wood, a mixture of these fuels, or a mixture of these fuels with any other fuels, the permittee shall not emit PM in excess of 0.03 lb/MMBtu heat input from the new multi-fuel process heater. (40 CFR §60.43b(h)(1)). There are no monitoring requirements for this PM emission limit unless the facility has an enforceable PM limit of 0.03 lb/MMBtu and operates a CEMS for PM in lieu of COMS, as specified in Special Condition 9.B.

D. The permittee shall not emit NOx in excess of 0.20 lb/MMBtu heat input from the new multi-fuel process heater, based on a 30-day rolling average.

1) The permittee shall install, calibrate, maintain, and operate CEMS for measuring NOx emissions discharged to the atmosphere, and shall record the output of the system. (40 CFR §60.48b(b)(1))

C. The permittee shall maintain compliance with all other applicable requirements in 40 CFR Part 60, Subpart Db, including, but not limited to, the compliance and performance test methods and procedures for SO_2(§60.45b) and the compliance and performance test methods and procedures for PM and NOx (§60.46b).

10. Fuel Usage Requirements
The installation shall not combust fuel in the multi-fuel process heater (EP43) that is not covered under NSPS Subpart Db, *Standards of Performance for Industrial-Commercial-Institutional Steam Generating Units.*

SPECIAL CONDITIONS:
The permittee is authorized to construct and operate subject to the following special conditions:

11. Record Keeping and Reporting Requirements

A. The permittee shall maintain all records required by this permit for not less than five years and shall make them available immediately to any Missouri Department of Natural Resources' personnel upon request. These records shall include SDS for all materials used.

B. The permittee shall report to the Air Pollution Control Program's Compliance/Enforcement Section, by mail at P.O. Box 176, Jefferson City, MO 65102 and by e-mail at AirComplainceReporting@dnr.mo.gov, no later than 10 days after the end of the month during which any record required by this permit shows an exceedance of a limitation imposed by this permit.

DRAFT

REVIEW OF APPLICATION FOR AUTHORITY TO CONSTRUCT AND OPERATE
SECTION (5) REVIEW
Project Number: 2020-02-016
Installation ID Number: 019-0004
Permit Number:

Installation Address:
University of Missouri Power Plant
Fifth Street and Stewart Road
Columbia, MO 65211-2030

Boone County, S13, T48N, R13W

REVIEW SUMMARY

- The University of Missouri Power Plant has applied for authority to install a multi-fuel process heater (EP43).

- The application was deemed complete on March 18, 2020.

- HAP emissions are expected from the proposed equipment. HAPs of concern from this process are products of combustion. The hydrogen fluoride (HF) emissions are expected to be greater than the SMAL.

- 40 CFR 60 Subpart Db, "Standards of Performance for Industrial-Commercial-Institutional Steam Generating Units," of the NSPS applies to the equipment. The installation uses supercritical CO_2 instead of water so no steam will be produced. However, this subpart defines a “steam generating unit” as “a device that combusts any fuel or byproduct/waste and produces steam or heats water or heats any heat transfer medium.”

- The following NSPS do not apply to the multi-fuel process heater
  - 40 CFR 60, Subpart D, “Standards of Performance for Fossil-Fuel-Fired Steam Generators,” does not apply because the heater does not have heat input rate greater than 250 MMBtu/hr.
  - 40 CFR 60, Subpart Da, “Standards of Performance for Electric Utility Steam Generating Units,” does not apply because the heater does not have maximum design input capacity over 250 MMBtu/hr and it does not fit the definition of an electric utility steam generating unit.
  - 40 CFR 60 Subpart Dc, ” Standards of performance for Small Industrial-Commercial-Institutional Steam Generating Units,” does not apply because the heater does not have maximum design input capacity under 100 MMBtu/hr.

- None of the NESHAPs apply to this installation. None of the currently promulgated

MACT regulations apply to the proposed equipment.

- Subpart DDDDD, "National Emission Standards for Hazardous Air Pollutants for Major Sources: Industrial, Commercial, and Institutional Boilers and Process Heaters," of the MACT does not apply because the heater is considered to be used specifically for research and development (§63.7491 (c)). This is a demonstration project for developing alternative power generation technology. If the facility ever decides to operate the multi-fuel process heater for any purpose other than research and development, this subpart would apply.

- A baghouse, selective catalytic reduction system, and a dry scrubber will be used to control the particulate, NOx, and SO_2 emissions, respectively, from the multi-fuel process heater.

- This review was conducted in accordance with Section (5) of Missouri State Rule 10 CSR 10-6.060, *Construction Permits Required*. Potential emissions of all pollutants are below de minimis levels.

- This installation is located in Boone County, an attainment/unclassifiable area for all criteria pollutants.

- This installation is on the List of Named Installations found in 10 CSR 10-6.020(3)(B), Table 2. The installation is classified as item number 21. Fossil-fuel boilers (or combination thereof) totaling more than 250 million British thermal units per hour heat input. The installation's major source level is 100 tons per year and fugitive emissions are counted toward major source applicability.

- Ambient air quality modeling was performed to determine the ambient impact of HF.

- Emissions testing is not required for the equipment as a part of this permit. Testing may be required as part of other state, federal or applicable rules. .

- A modification to the facility's Part 70 Operating Permit is required for this installation within 1 year of equipment startup.

- Approval of this permit is recommended with special conditions.

INSTALLATION DESCRIPTION

The University of Missouri, Columbia operates a combined heat and power facility to generate steam and electricity to serve the University of Missouri campus. It is a major source for $PM_{2.5}$, PM_{10}, PM, SO_2, NO_X, CO, GHG, and HAPs for Construction Permits and a Part 70 source for operating permits. The following NSR permits have been issued to University of Missouri Power Plant from the Air Pollution Control Program.

Table 1: NSR Permit History

DRAFT

Permit Number	Description
0866-004	Major review for installation of Boiler No. 11
0294-018	Installation of emergency generator for North Well
0494-020	Major review for installation of Boiler No. 12
0296-007	Installation of emergency generator for Southwest Well and twin fuel oil storage tanks
1096-021	Replacement IC Engine for East Well
0697-002	Installation of solvent-based parts washer
072000-005	Major review for installation of two turbines, two duct burners, and a back-up diesel generator
072000-005A	Amendment to change CEMS requirements
042007-019	Temporary permit to burn biomass fuel in boiler
032008-002	Replacement of four existing cooling towers with a new cooling tower and a closed loop cooling system cooling tower
042007-019A	Addition of a feedwagon for temporary burning of biomass
032008-002A	Amendment to remove the closed loop heat-exchanger cooling tower, lower the drift loss limit to less than 0.0010% for the remaining cooling tower
042010-002	Replacement of Boiler No. 11 with biomass-fired bubbling fluidized bed boiler (BFB-1)
042010-002C	Amendment to temporarily allow operation of BFB-1 fuel handling/storage system without the baghouse
032008-002B	Amendment to remove monthly TDS sampling requirement
092015-001	Increased hydrated lime injection for Boilers No. 7, 8, 9, and 10
092015-001A	Amendment for ash silo
112016-004	Installation of new gas burners in existing Boiler No. 10 and 2,000 tpy facility-wide SO_2 limit
042019-008	Pellet trial burn
112016-004A	Reclassifying Boilers No. 7, 8, and 9 as “limited-use” boilers
042019-008A	Extend the expiration date for the pellet trial burn

PROJECT DESCRIPTION

The University of Missouri, Columbia proposes to install a new multi-fuel process heater. The unit has a maximum hourly design rate of 121 MMBtu/hr. The heater will use a combination of three different type of fuels: Coal, natural gas, and biomass. Instead of heating water to create steam, the heater will use supercritical carbon dioxide (sCO_2). The heated sCO_2 will be used to drive a high-speed CO_2 expander turbine to drive the electrical generator. This is a demonstration project for developing alternative power generation technology.

As part of this project, Boilers No. 7, 8, and 9 (EP07, EP08, EP09) will be removed. The new process heater will be installed at the same location as the removed boilers.

In Permit No. 112016-004, the installation took a 2,000 tons of SO_2 per calendar year limit on the entire installation as a compliance option for 40 CFR 51, Subpart BB, *Data Requirements for Characterizing Air Quality for the Primary SO_2 NAAQS,* §51.1203(e)(1). The SO_2 emissions from the new heater needs to be included in this

limit so the limit was restated in this current permit.

EMISSIONS/CONTROLS EVALUATION

The installation is an existing major source. Under EPA regulations, the process for determining whether a project at an existing major source triggers the requirements to obtain a PSD permit is a two-step process. Step 1 requires determination of whether the proposed project, by itself, is projected to results in a significant emissions increase. If such an increase is projected to occur, the process moves to Step 2, which evaluates whether the project will results in a significant net emissions increase. Step 2 considers any other increases and decreases in actual emissions at the source that are contemporaneous with the particular project and are otherwise creditable.

In the past, emissions decreases for a project was not accounted for until Step 2. However, in accordance with EPA memorandum issued on March 13, 2018, the decreases related to the project can now be accounted for in Step 1 of the analysis.

PSD Emissions Increases

For this project, there will be emissions increases from the addition of the new process heater. Since the heater will be using three (3) different types of fuels (coal, natural gas, and biomass), the potential emissions from four separate scenarios were evaluated: 100% coal, 100% natural gas, 100% biomass and 20% biomass with 80% coal.

The maximum emissions from each scenario for each pollutant were used for the emissions increases. The emission factors used to calculate emissions from natural gas were taken from EPA document AP-42, Chapter 1.4, *Natural Gas Combustion 7/1998*. The emission factors used for coal and biomass were from a variety of sources as given below in Tables 2 and 3.

Table 2: Emission Factor Sources for Coal

Pollutants	Emission Factor	Sources
$PM_{2.5}$	0.07 lb/MMBtu	PM limit from NSPS Subpart Db plus Condensable PM from AP-42, Chapter 1.1, *Bituminous and Subbituminous Coal Combustion,* 9/1998.
PM_{10}	0.07 lb/MMBtu	
PM	0.03 lb/MMBtu	NSPS Subpart Db limit (§60.43b(h)(1))
NO_X	0.2 lb/MMBtu	NSPS Subpart Db limit (§60.44b(l)(1))
SO_2	0.42 lb/MMBtu	Sulfur content testing results assuming 100% conversion of sulfur to SO_2 (5.25 lb/MMBtu). Assumed 92% control from dry scrubbing based on limit in NSPS subpart Db (0.42 lb/MMBtu) (§60.42b(k)(1))
CO	0.17 lb/MMBtu	Vendor Guarantee

VOC	0.05 lb/ton	AP-42, Chapter 1.1
CO_2	4,810 lb/ton	AP-42, Chapter 1.1
N_2O	0.04 lb/ton	AP-42, Chapter 1.1
CH_4	0.06 lb/ton	AP-42, Chapter 1.1
GHG-Mass	-	Sum of CO_2, N_2O, and CH_4 Emissions
GHG-CO2e	-	Sum of CO_2, N_2O and CH_4 Emissions multiplied by their respective GWP

Table 3: Emission Factor Sources for Biomass

Pollutants	Emission Factor	Sources
$PM_{2.5}$	0.082 lb/MMBtu	AP-42, Chapter 1.6, *Wood Residue in Boilers,* 9/2003, Control device efficiency included in the emission factor
PM_{10}	0.091 lb/MMBtu	
PM	0.03 lb/MMBtu	NSPS Subpart Db limit (§60.43b(h)(1))
NO_X	0.2 lb/MMBtu	NSPS Subpart Db limit (§60.44b(l))
SO_2	0.025 lb/MMBtu	AP-42, Chapter 1.6 emission factor with 92% control as limited in the NSPS Subpart Db (§60.42b(k)(1))
CO	0.6 lb/MMBtu	AP-42, Chapter 1.6
VOC	0.017 lb/MMBtu	AP-42, Chapter 1.6
CO_2	195.00	AP-42, Chapter 1.6
N_2O	0.01	AP-42, Chapter 1.6
CH_4	0.02	AP-42, Chapter 1.6
GHG-Mass	-	Sum of CO_2, N_2O, and CH_4 Emissions
GHG-CO2e	-	Sum of CO_2, N_2O and CH_4 Emissions multiplied by their respective GWP

The installation is required to verify the SO_2 emission factors for all three fuels through the use of CEMS. For CO, the installation is required to perform stack testing while combusting coal, in accordance with Special Condition 4, to ensure compliance with the CO limit.

PSD Emissions Decreases

There will be emissions decreases from the removal of Boilers No. 7, 8, and 9. The throughputs were taken from October 2012 to September 2014. Both coal and biomass were used during that time. For coal, emission factors from stack testing results were used to calculate the PM, SO_X, NO_X, and CO emissions. Filterable $PM_{2.5}$ and PM_{10} were not tested. Their emissions were calculated by applying the particle size distribution in AP-42, Chapter 1.1, to the filterable PM emissions from stack testing and adding the results to the condensable PM emissions from stack testing. For VOC, emissions were calculated using the emission factor from AP-42, Chapter 1.1. For Biomass, all emissions were calculated using emission factors from AP-42, Chapter 1.5.

In 2019, the installation was issued an amendment (112016-004A) that required the

installation to limit the operation of Boilers No. 7, 8 and 9 to 10% of its maximum capacity. The limit is needed to reclassify the boilers to a "limited-use" category so that the boilers will not be subjected to the emissions standards under 40 CFR Part 63, Subpart DDDDD. According to 40 CFR 52.21(b)(48)(c), the average rate shall be adjusted downward to exclude any emissions that would have exceeded an emissions limitation with which the source must currently comply, had such source been required to comply with the limit during the consecutive 24-month period chosen for the baseline. However, if the emissions limit is part of the MACT, then the emissions need to be adjusted only if the state has taken credit for such emissions reduction in an attainment demonstration or maintenance plan in the State Implementation Plant (SIP).

During the period between October 2012 and September 2014, the boilers did not operate at a capacity above 10% of maximum. Furthermore, the emissions did not exceed the MACT limits nor did the Missouri State Implementation plan include this installation in any attainment demonstration or maintenance plan. Therefore, all of the Baseline Actual Emissions from October 2012 to September 2014 can be accounted for in the emissions decreases for this project.

PSD Applicability

The emissions increases from this project, after accounting for both the increases from the addition of the multi-fuel heater and the decreases from the coal-fired boilers, are below the significance level for PSD applicability. However, this is contingent on the facility being in compliance with the NSPS limits for PM, NOx, SOx, and CO while using both coal and any biomass. If the installation ever uses any fuel not covered under the NSPS, Subpart Db, this analysis will no longer be valid and a request for a new analysis shall be submitted by the installation.

HAP emissions

HAP is not a PSD criteria pollutant. Therefore, the project emissions are emissions increases from the process heater. No decreases are taken into account. Some of the HAP emissions were calculated using stack testing results from Boiler No. 10, performed in October, 2016. For HAP that were not tested, emissions were calculated using emission factors from AP-42, Chapter 1.1, 1.4, or 1.6, depending on the fuel used. Emissions were calculated for the four scenarios (100% coal, 100% natural gas, 100% biomass, and 20% biomass with 80% coal) and the maximum were used for the emissions from this project. For all of the HAPs, except for hydrogen fluoride (HF), the emissions are expected to be below the SMAL. Modeling was performed on HF to ensure that the significance level for the pollutant for the Risk Assessment Levels (RAL) are not exceeded. Results show that the ambient impact of HF from the project will be below the significance level at any distance from the property boundary.

State Project Emissions

Although PSD regulations allow for the inclusion of emissions decreases, Missouri state rules currently do not allow for decreases in calculating emissions increases from a

project. Emissions increase from this project are then the potential emissions of the new multi-fuel process heater. For $PM_{2.5}$, PM_{10}, SOx, and NOx, emissions increase from this project are greater than the *de minimis* level, which indicates that modeling would be required for this project. More information regarding modeling for these pollutants are given below in the "Ambient Air Quality Impact Analysis" section of this permit.

The following table provides an emissions summary for this project. Existing potential emissions were not noted in previous permits issued to the installation but has been noted as major. Existing actual emissions were taken from the installation's 2019 EIQ. For PSD Emissions Increase, emissions of criteria pollutants include both the increases from the new heater as well as decreases from the removal of the coal-fired boilers. For State Project Emissions, only increases in emissions from the new heater are accounted for.

Table 4: Emissions Summary (tpy)

Pollutant	Regulatory *De Minimis* Levels	Existing Potential Emissions	Existing Actual Emissions (2019 EIQ)	PSD Emissions Increase	State Project Emissions
PM	25.0	Major	N/D	17.56	18.18
PM_{10}	15.0	Major	23.13	10.11	37.11
$PM_{2.5}$	10.0	Major	21.93	6.39	37.11
SOx	40.0	Major	531.67	-2249.59	222.59
NOx	40.0	Major	229.31	-100.16	106.00
VOC	40.0	Major	13.62	3.55	2.85
CO	100.0	Major	78.66	79.52	83.87
GHG (CO_2e)	N/A	Major	N/D	112,717.42	112,717.42
GHG (mass)	N/A	Major	N/D	112,715.07	112,715.07
Combined HAPs	10.0/25.0	Major	1.59	6.72	6.72
HF	10.0/0.1	Major	N/D	0.64	0.64

N/D = Not Determined

PERMIT RULE APPLICABILITY

This review was conducted in accordance with Section (5) of Missouri State Rule 10 CSR 10-6.060, *Construction Permits Required*. Potential emissions of $PM_{2.5}$, PM_{10}, SOx and NOx are above de minimis levels.

APPLICABLE REQUIREMENTS

University of Missouri Power Plant shall comply with the following applicable requirements. The Missouri Air Conservation Laws and Regulations should be consulted for specific record keeping, monitoring, and reporting requirements. Compliance with these emission standards, based on information submitted in the

application, has been verified at the time this application was approved. For a complete list of applicable requirements for your installation, please consult your operating permit.

GENERAL REQUIREMENTS

- *Operating Permits*, 10 CSR 10-6.065
- *Start-Up, Shutdown, and Malfunction Conditions,* 10 CSR 10-6.050
- *Submission of Emission Data, Emission Fees and Process Information,* 10 CSR 10-6.110
    - Per 10 CSR 10-6.110(4)(B)2.B(II) and (4)(B)2.C(II) a full EIQ is required for the first full calendar year the equipment (or modifications) approved by this permit are in operation.
    - A full EIQ is required each year for Part 70 sources.
- *Restriction of Particulate Matter to the Ambient Air Beyond the Premises of Origin*, 10 CSR 10-6.170
- *Restriction of Emission of Visible Air Contaminants*, 10 CSR 10-6.220
- *Restriction of Emission of Odors*, 10 CSR 10-6.165

SPECIFIC REQUIREMENTS

- *Restriction of Emission of Particulate Matter From Industrial Processes*, 10 CSR 10-6.400
- *Restriction of Particulate Matter Emissions From Fuel Burning Equipment Used for Indirect Heating*, 10 CSR 10-6.405

AMBIENT AIR QUALITY IMPACT ANALYSIS

Ambient air quality modeling was performed to determine the ambient impact of HF. The insignificance level of HF is 4% of the Risk Assessment Level (RAL). If the ambient impact contribution from just the new heater is below the insignificance level, then no further modeling is needed. If the ambient impact contribution from the new heater is greater than the insignificance level, then the entire facility need to be evaluated for HF ambient impact and the results compared with the RAL.

The emissions from the new heater will go through the same stack as two diesel generators (EP-29) and a biomass boiler (EP-19). The number of equipment operating at the same time will affect the air flow rate through the stack. Therefore, two separate scenarios were modeled. For both scenarios, it was assumed that only the new heater

DRAFT

is in operation. However, the air flow used for modeling is different. For scenario one, it was assumed that the air flow through the stack is only from the new heater. For scenario two, it was assumed that the air flow through the stack is from all three sources. The modeling was performed using the AerScreen modeling program. Results show that for both scenarios, the HF ambient impacts are expected to be less than the significance levels.

Table 5: HF Ambient Air Quality Impact Analysis

Scenarios	Modeled Impacts	Significance Levels (µg/m3)	Time Period
1. Solitary Operation	0.92	32.8	One-Hour
1. Solitary Operation	0.55	0.64	24-Hour
1. Solitary Operation	0.092	0.56	Annual
2. Combined Operation	0.56	32.8	One-Hour
2. Combined Operation	0.34	0.64	24-Hour
2. Combined Operation	0.056	0.56	Annual

Table 6: Modeled Stack Parameter

Scenarios	Stack Diameter (ft)	Stack Height (ft)	Flow Rate (acfm)
1. Solitary Operation	10	320	34,500
2. Combined Operation	10	320	171,250

For $PM_{2.5}$, PM_{10}, SOx, and NOx, only a qualitative analysis was performed. For all of these pollutants, due to the removal of Boilers 7, 8, and 9 and the associated emissions decrease, significant impacts on NAAQS are not expected.

STAFF RECOMMENDATION

On the basis of this review conducted in accordance with Section (5), Missouri State Rule 10 CSR 10-6.060, *Construction Permits Required*, it is recommended that this permit be granted with special conditions.

PERMIT DOCUMENTS

The following documents are incorporated by reference into this permit:

- The Application for Authority to Construct form, dated February 2, 2020, received February 11, 2020, designating Curator of the University of Missouri as the owner and operator of the installation.

DRAFT

Attachment A – SO_2 Emission Units and Emission Factors

Emission Point	Description	Bituminous Coal (lb/ton or lb/MMBtu)	[3]Natural Gas (lb/MMCF)	[4]Biomass Wood Chips (lb/MMBtu)	[5]TDF (lb/MMBtu)	[6]Fuel Oil, Diesel, Kerosene (lb/MGal)
EP10	Boiler No. 10	[1]38 x S	1.5	0.025	1.0	-
EP19	BFB-1 Biomass Boiler	-	1.5	0.025	-	-
EP20	Boiler No. 12	-	1.5	-	-	142 x S
EP18	North Well RICE	-	-	-	-	142 x S
EP23	Soutwest Well RICE	-	-	-	-	142 x S
EP31	South Well RICE	-	1.5	-	-	-
EP25	East Well RICE	-	1.5	-	-	-
EP26	Turbine 1: Turbine	-	1.5	-	-	142 x S
	Turbine 1: Duct Burner	-	1.5	-	-	142 x S
EP27	Turbine 2: Turbine	-	1.5	-	-	142 x S
	Turbine 2: Duct Burner	-	1.5	-	-	142 x S
EP29	Power Plant Backup RICE	-	-	-	-	142 x S
EP16	Kerosene Space Heaters	-	-	-	-	142 x S
EP43	Multi-Fuel Process Heater	[2]0.42	1.5	0.025	-	-

S is sulfur weight in %, e.g. if sulfur content is 00015%, then S if 0.0015.

[1]Bitumious Coal Emission Factor for EP10 obtained from AP-42, Table 1.1-3

[2]Bituminous Coal Emission factor for EP43 from sulfur content of 5.25 lb SO_2/MMBtu and applying a 92% control efficiency. The installation will use SO_2 CEMS to monitor emissions. CEMS data may also be used to calculate SO_2 emissions from the multi-fuel process heater.

[3]The natural gas combustion emission factor in AP-42, table 1.4-2 (0.6 lb/mmscf) is based on sulfur content of 2,000 grains per mmscf. A pipeline-grade natural gas is defined as having sulfur content less than 0.5 gr/100 scf, or 5,000 gr/mmscf. Therefore, the emission factor of 0.6 lb/mmscf is scaled up to 1.5 lb/mmscf by multiplying by the ratio of 5000/2000.

[4]Biomass emission factor obtained from AP-42, Table 1.6-2.

[5]TDF emission factor obtained from EPA document, *Burning Tires for Fuel and Tire Pyrolysis: Air Implications,* EPA-450/3-91-024.

[6]Boiler and duct burner fuel oil emission factor obtained from AP-42, Table 1.3-2 (142 x S). For the RICE and turbine, fuel oil emission factor can be taken from AP-42, Table 3.4-1 and Table 3.1-2a, respectively. However, all fuel oil combustion types should have the same emission factor as long as there is good combustion since SO_2 emissions are based upon fuel sulfur content. Therefore, the emission factor in AP-42, Table 1.3-2 was chosen as the only emission factor. This emission factor is confirmed by mass balance using fuel density 7.1 lb/gal, multiplied by 2 parts mass SO_2 created for every 1 part mass of sulfur combusted.

DRAFT

APPENDIX A

Abbreviations and Acronyms

% ..... percent
ºF ..... degrees Fahrenheit
acfm ..... actual cubic feet per minute
BACT..... Best Available Control Technology
BMPs ..... Best Management Practices
Btu..... British thermal unit
CAM ..... Compliance Assurance Monitoring
CAS..... Chemical Abstracts Service
CEMS ..... Continuous Emission Monitor System
CFR..... Code of Federal Regulations
CO..... carbon monoxide
CO_2 ..... carbon dioxide
CO_2e..... carbon dioxide equivalent
COMS..... Continuous Opacity Monitoring System
CSR..... Code of State Regulations
dscf..... dry standard cubic feet
EIQ ..... Emission Inventory Questionnaire
EP..... Emission Point
EPA..... Environmental Protection Agency
EU ..... Emission Unit
fps..... feet per second
ft ..... feet
GACT ..... Generally Available Control Technology
GHG ..... Greenhouse Gas
gpm ..... gallons per minute
gr ..... grains
GWP ..... Global Warming Potential
HAP ..... Hazardous Air Pollutant
hr..... hour
hp ..... horsepower
lb ..... pound
lbs/hr..... pounds per hour
MACT..... Maximum Achievable Control Technology
$\mu g/m^3$..... micrograms per cubic meter
m/s..... meters per second
Mgal ..... 1,000 gallons
MW ..... megawatt
MHDR ..... maximum hourly design rate
MMBtu .... Million British thermal units
MMCF ..... million cubic feet
MSDS..... Material Safety Data Sheet
NAAQS .... National Ambient Air Quality Standards
NESHAPs National Emissions Standards for Hazardous Air Pollutants
NO_x..... nitrogen oxides
NSPS ..... New Source Performance Standards
NSR..... New Source Review
PM..... particulate matter
$PM_{2.5}$..... particulate matter less than 2.5 microns in aerodynamic diameter
PM_{10} ..... particulate matter less than 10 microns in aerodynamic diameter
ppm ..... parts per million
PSD ..... Prevention of Significant Deterioration
PTE ..... potential to emit
RACT..... Reasonable Available Control Technology
RAL..... Risk Assessment Level
SCC..... Source Classification Code
scfm..... standard cubic feet per minute
SDS..... Safety Data Sheet
SIC ..... Standard Industrial Classification
SIP..... State Implementation Plan
SMAL ..... Screening Model Action Levels
SO_x ..... sulfur oxides
SO_2 ..... sulfur dioxide
SSM..... Startup, Shutdown & Malfunction
tph ..... tons per hour
tpy ..... tons per year
VMT..... vehicle miles traveled
VOC ..... Volatile Organic Compound

DRAFT

MISSOURI DEPARTMENT OF NATURAL RESOURCES

Air Pollution Control Program
Table of Hazardous Air Pollutants and Screening Model Action Levels

Chemical	CAS #	SMAL tons/yr	Group ID	VOC	PM	Chemical	CAS #	SMAL tons/yr	Group ID	VOC	PM
ACETALDEHYDE	75-07-0	9		Y	N	CHLOROMETHYL METHYL ETHER	107-30-2	0.1		Y	N
ACETAMIDE	60-35-5	1		Y	N	CHLOROPRENE	126-99-8	1		Y	N
ACETONITRILE	75-05-8	4		Y	N	CHROMIUM (VI) COMPOUNDS		0.002	L	N	Y
ACETOPHENONE	98-86-2	1		Y	N	CHROMIUM COMPOUNDS		5	L	N	Y
ACETYLAMINOFLUORINE, [2-]	53-96-3	0.005	V	Y	Y	CHRYSENE	218-01-9	0.01	V	Y	N
ACROLEIN	107-02-8	0.04		Y	N	COBALT COMPOUNDS		0.1	M	N	Y
ACRYLAMIDE	79-06-1	0.02		Y	N	COKE OVEN EMMISIONS	8007-45-2	0.03	N	Y	N
ACRYLIC ACID	79-10-7	0.6		Y	N	CRESOL, [META-]	108-39-4	1	B	Y	N
ACRYLONITRILE	107-13-1	0.3		Y	N	CRESOL, [ORTHO-]	95-48-7	1	B	Y	N
ALLYL CHLORIDE	107-05-1	1		Y	N	CRESOL, [PARA-]	106-44-5	1	B	Y	N
AMINOBIPHENYL, [4-]	92-67-1	1	V	Y	N	CRESOLS (MIXED ISOMERS)	1319-77-3	1	B	Y	N
ANILINE	62-53-3	1		Y	N	CUMENE	98-82-8	10		Y	N
ANISIDINE, [ORTHO-]	90-04-0	1		Y	N	CYANIDE COMPOUNDS		0.1	O	Y	N
ANTHRACENE	120-12-7	0.01	V	Y	N	DDE	72-55-9	0.01	V	Y	Y
ANTIMONY COMPOUNDS		5	H	N	Y	DI(2-ETHYLHEXYL) PHTHALATE, (DEHP)	117-81-7	5		Y	N
ANTIMONY PENTAFLUORIDE	7783-70-2	0.1	H	N	Y	DIAMINOTOLUENE, [2,4-]	95-80-7	0.02		Y	N
ANTIMONY POTASSIUM TARTRATE	28300-74-5	1	H	N	Y	DIAZOMETHANE	334-88-3	1		Y	N
ANTIMONY TRIOXIDE	1309-64-4	1	H	N	Y	DIBENZ(A,H)ANTHRACENE	53-70-3	0.01	V	Y	N
ANTIMONY TRISULFIDE	1345-04-6	0.1	H	N	Y	DIOXINS/FURANS		6E-07	D,V	Y	N
ARSENIC COMPOUNDS		0.005	I	N	Y	DIBENZOFURAN	132-64-9	5	V	Y	N
ASBESTOS	1332-21-4	0	A	N	Y	DIBROMO-3-CHLOROPROPANE, [1,2-]	96-12-8	0.01		Y	N
BENZ(A)ANTHRACENE	56-55-3	0.01	V	Y	N	DIBROMOETHANE, [1,2-]	106-93-4	0.1		Y	N
BENZENE	71-43-2	2		Y	N	DIBUTYL PHTHALATE	84-74-2	10		Y	Y
BENZIDINE	92-87-5	0.0003	V	Y	N	DICHLOROBENZENE, [1,4-]	106-46-7	3		Y	N
BENZO(A)PYRENE	50-32-8	0.01	V	Y	N	DICHLOROBENZIDENE, [3,3-]	91-94-1	0.2	V	Y	Y
BENZO(B)FLUORANTHENE	205-99-2	0.01	V	Y	N	DICHLOROETHANE, [1,1-]	75-34-3	1		Y	N
BENZO(K)FLUORANTHENE	207-08-9	0.01	V	Y	N	DICHLOROETHANE, [1,2-]	107-06-2	0.8		Y	N
BENZOTRICHLORIDE	98-07-7	0.006		Y	N	DICHLOROETHYLENE, [1,1-]	75-35-4	0.4		Y	N
BENZYL CHLORIDE	100-44-7	0.1		Y	N	DICHLOROMETHANE	75-09-2	10		N	N
BERYLLIUM COMPOUNDS		0.008	J	N	Y	DICHLOROPHENOXY ACETIC ACID, [2,4-]	94-75-7	10	C	Y	Y
BERYLLIUM SALTS		2E-05	J	N	Y	DICHLOROPROPANE, [1,2-]	78-87-5	1		Y	N
BIPHENYL, [1,1-]	92-52-4	10	V	Y	N	DICHLOROPROPENE, [1,3-]	542-75-6	1		Y	N
BIS(CHLOROETHYL)ETHER	111-44-4	0.06		Y	N	DICHLORVOS	62-73-7	0.2		Y	N
BIS(CHLOROMETHYL)ETHER	542-88-1	0.0003		Y	N	DIETHANOLAMINE	111-42-2	5		Y	N
BROMOFORM	75-25-2	10		Y	N	DIETHYL SULFATE	64-67-5	1		Y	N
BROMOMETHANE	74-83-9	10		Y	N	DIETHYLENE GLYCOL MONOBUTYL ETHER	112-34-5	5	P	Y	N
BUTADIENE, [1,3-]	106-99-0	0.07		Y	N	DIMETHOXYBENZIDINE, [3,3-]	119-90-4	0.1	V	Y	Y
BUTOXYETHANOL ACETATE, [2-]	112-07-2	5	P	Y	N	DIMETHYL BENZIDINE, [3,3-]	119-93-7	0.008	V	Y	Y
BUTYLENE OXIDE, [1,2-]	106-88-7	1		Y	N	DIMETHYL CARBAMOYL CHLORIDE	79-44-7	0.02		Y	N
CADMIUM COMPOUNDS		0.01	K	N	Y	DIMETHYL FORMAMIDE	68-12-2	1		Y	N
CALCIUM CYANAMIDE	156-62-7	10		Y	Y	DIMETHYL HYDRAZINE, [1,1-]	57-14-7	0.008		Y	N
CAPROLACTAM (Delisted)	105-60-2					DIMETHYL PHTHALATE	131-11-3	10		Y	N
CAPTAN	133-06-2	10		Y	Y	DIMETHYL SULFATE	77-78-1	0.1		Y	N
CARBARYL	63-25-2	10	V	Y	Y	DIMETHYLAMINOAZOBENZENE, [4-]	60-11-7	1		Y	N
CARBON DISULFIDE	75-15-0	1		Y	N	DIMETHYLANILINE, [N-N-]	121-69-7	1		Y	N
CARBON TETRACHLORIDE	56-23-5	1		Y	N	DINITRO-O-CRESOL, [4,6-] (Note 6)	534-52-1	0.1	E	Y	Y
CARBONYL SULFIDE	463-58-1	5		Y	N	DINITROPHENOL, [2,4-]	51-28-5	1		Y	N
CATECHOL	120-80-9	5		Y	N	DINITROTOLUENE, [2,4-]	121-14-2	0.02		Y	N
CHLORAMBEN	133-90-4	1		Y	Y	DIOXANE, [1,4-]	123-91-1	6		Y	N
CHLORDANE	57-74-9	0.01		Y	Y	DIPHENYLHYDRAZINE, [1,2-]	122-66-7	0.09	V	Y	Y
CHLORINE	7782-50-5	0.1		N	N	DIPHENYLMETHANE DIISOCYANATE, [4,4-]	101-68-8	0.1	V	Y	N
CHLOROACETIC ACID	79-11-8	0.1		Y	N	EPICHLOROHYDRIN	106-89-8	2		Y	N
CHLOROACETOPHENONE, [2-]	532-27-4	0.06		Y	N	ETHOXYETHANOL, [2-]	110-80-5	10	P	Y	N
CHLOROBENZENE	108-90-7	10		Y	N	ETHOXYETHYL ACETATE, [2-]	111-15-9	5	P	Y	N
CHLOROBENZILATE	510-15-6	0.4	V	Y	Y	ETHYL ACRYLATE	140-88-5	1		Y	N
CHLOROFORM	67-66-3	0.9		Y	N	ETHYL BENZENE	100-41-4	10		Y	N

Air Pollution Control Program
Table of Hazardous Air Pollutants and Screening Model Action Levels

ETHYL CHLORIDE	75-00-3	10		Y	N	NITROBENZENE	98-95-3	1		Y	N
ETHYLENE GLYCOL	107-21-1	10		Y	N	NITROBIPHENYL, [4-]	92-93-3	1	V	Y	N
ETHYLENE GLYCOL MONOBUTYL ETHER (Delisted)	111-76-2					NITROPHENOL, [4-]	100-02-7	5		Y	N
ETHYLENE GLYCOL MONOHEXYL ETHER	112-25-4	5	P	Y	N	NITROPROPANE, [2-]	79-46-9	1		Y	N
ETHYLENE IMINE [AZIRIDINE]	151-56-4	0.003		Y	N	NITROSODIMETHYLAMINE, [N-]	62-75-9	0.001		Y	N
ETHYLENE OXIDE	75-21-8	0.1		Y	N	NITROSOMORPHOLINE, [N-]	59-89-2	1		Y	N
ETHYLENE THIOUREA	96-45-7	0.6		Y	Y	NITROSO-N-METHYLUREA, [N-]	684-93-5	0.0002		Y	N
FORMALDEHYDE	50-00-0	2		Y	N	OCTACHLORONAPTHALENE	2234-13-1	0.01	V	Y	N
GLYCOL ETHER (ETHYLENE GLYCOL ETHERS)		5	P	Y	N	PARATHION	56-38-2	0.1		Y	Y
GLYCOL ETHER (DIETHYLENE GLYCOL ETHERS)		5	P	Y	N	PCB [POLYCHLORINATED BIPHENYLS]	1336-36-3	0.009	X	Y	Y
HEPTACHLOR	76-44-8	0.02		Y	N	PENTACHLORONITROBENZENE	82-68-8	0.3		Y	N
HEXACHLOROBENZENE	118-74-1	0.01		Y	N	PENTACHLOROPHENOL	87-86-5	0.7		Y	N
HEXACHLOROBUTADIENE	87-68-3	0.9		Y	N	PHENOL	108-95-2	0.1		Y	N
HEXACHLOROCYCLOHEXANE, [ALPHA-]	319-84-6	0.01	F	Y	N	PHENYLENEDIAMINE, [PARA-]	106-50-3	10		Y	N
HEXACHLOROCYCLOHEXANE, [BETA-]	319-85-7	0.01	F	Y	N	PHOSGENE	75-44-5	0.1		Y	N
HEXACHLOROCYCLOHEXANE, [DELTA-]	319-86-8	0.01	F	Y	N	PHOSPHINE	7803-51-2	5		N	N
HEXACHLOROCYCLOHEXANE, [TECHNICAL]	608-73-1	0.01	F	Y	N	PHOSPHOROUS (YELLOW OR WHITE)	7723-14-0	0.1		N	N
HEXACHLOROCYCLOPENTADIENE	77-47-4	0.1		Y	N	PHTHALIC ANHYDRIDE	85-44-9	5		Y	N
HEXACHLOROETHANE	67-72-1	5		Y	N	POLYCYLIC ORGANIC MATTER		0.01	V	Y	N
HEXAMETHYLENE,-1,6-DIISOCYANATE	822-06-0	0.02		Y	N	PROPANE SULTONE, [1,3-]	1120-71-4	0.03		Y	Y
HEXAMETHYLPHOSPHORAMIDE	680-31-9	0.01		Y	N	PROPIOLACTONE, [BETA-]	57-57-8	0.1		Y	N
HEXANE, [N-]	110-54-3	10		Y	N	PROPIONALDEHYDE	123-38-6	5		Y	N
HYDRAZINE	302-01-2	0.004		N	N	PROPOXUR [BAYGON]	114-26-1	10		Y	Y
HYDROGEN CHLORIDE	7647-01-0	10		N	N	PROPYLENE OXIDE	75-56-9	5		Y	N
HYDROGEN FLUORIDE	7664-39-3	0.1		N	N	PROPYLENEIMINE, [1,2-]	75-55-8	0.003		Y	N
HYDROQUINONE	123-31-9	1		Y	N	QUINOLINE	91-22-5	0.006		Y	N
INDENO(1,2,3CD)PYRENE	193-39-5	0.01	V	Y	N	QUINONE	106-51-4	5		Y	N
ISOPHORONE	78-59-1	10		Y	N	RADIONUCLIDES		Note 1	Y	N	Y
LEAD COMPOUNDS		0.01	Q	N	Y	SELENIUM COMPOUNDS		0.1	W	N	Y
LINDANE [GAMMA-HEXACHLOROCYCLOHEXANE]	58-89-9	0.01	F	Y	N	STYRENE	100-42-5	1		Y	N
MALEIC ANHYDRIDE	108-31-6	1		Y	N	STYRENE OXIDE	96-09-3	1		Y	N
MANGANESE COMPOUNDS		0.8	R	N	Y	TETRACHLORODIBENZO-P-DIOXIN,[2,3,7,8]	1746-01-6	6E-07	D,V	Y	Y
MERCURY COMPOUNDS		0.01	S	N	N	TETRACHLOROETHANE, [1,1,2,2-]	79-34-5	0.3		Y	N
METHANOL	67-56-1	10		Y	N	TETRACHLOROETHYLENE	127-18-4	10		N	N
METHOXYCHLOR	72-43-5	10	V	Y	Y	TITANIUM TETRACHLORIDE	7550-45-0	0.1		N	N
METHOXYETHANOL, [2-]	109-86-4	10	P	Y	N	TOLUENE	108-88-3	10		Y	N
METHYL CHLORIDE	74-87-3	10		Y	N	TOLUENE DIISOCYANATE, [2,4-]	584-84-9	0.1		Y	N
METHYL ETHYL KETONE (Delisted)	78-93-3					TOLUIDINE, [ORTHO-]	95-53-4	4		Y	N
METHYL HYDRAZINE	60-34-4	0.06		Y	N	TOXAPHENE	8001-35-2	0.01		Y	N
METHYL IODIDE	74-88-4	1		Y	N	TRICHLOROBENZENE, [1,2,4-]	120-82-1	10		Y	N
METHYL ISOBUTYL KETONE	108-10-1	10		Y	N	TRICHLOROETHANE, [1,1,1-]	71-55-6	10		N	N
METHYL ISOCYANATE	624-83-9	0.1		Y	N	TRICHLOROETHANE, [1,1,2-]	79-00-5	1		Y	N
METHYL METHACRYLATE	80-62-6	10		Y	N	TRICHLOROETHYLENE	79-01-6	10		Y	N
METHYL TERT-BUTYL ETHER	1634-04-4	10		Y	N	TRICHLOROPHENOL, [2,4,5-]	95-95-4	1		Y	N
METHYLCYCLCOPENTADIENYL MANGANESE	12108-13-3	0.1	R	N	Y	TRICHLOROPHENOL, [2,4,6-]	88-06-2	6		Y	N
METHYLENE BIS(2-CHLOROANILINE), [4,4-]	101-14-4	0.2	V	Y	Y	TRIETHYLAMINE	121-44-8	10		Y	N
METHYLENEDIANILINE, [4,4-]	101-77-9	1	V	Y	N	TRIFLURALIN	1582-09-8	9		Y	Y
METHYLNAPHTHALENE, [2-]	91-57-6	0.01	V	Y	N	TRIMETHYLPENTANE, [2,2,4-]	540-84-1	5		Y	N
MINERAL FIBERS		0	T	N	Y	URETHANE [ETHYL CARBAMATE]	51-79-6	0.8		Y	N
NAPHTHALENE	91-20-3	10	V	Y	N	VINYL ACETATE	108-05-4	1		Y	N
NAPHTHYLAMINE, [ALPHA-]	134-32-7	0.01	V	Y	N	VINYL BROMIDE	593-60-2	0.6		Y	N
NAPHTHYLAMINE, [BETA-]	91-59-8	0.01	V	Y	N	VINYL CHLORIDE	75-01-4	0.2		Y	N
NICKEL CARBONYL	13463-39-3	0.1	U	N	Y	XYLENE, [META-]	108-38-3	10	G	Y	N
NICKEL COMPOUNDS		1	U	N	Y	XYLENES (MIXED ISOMERS)	1330-20-7	10	G	Y	N
NICKEL REFINERY DUST		0.08	U	N	Y						
NICKEL SUBSULFIDE	12035-72-2	0.04	U	N	Y						

Air Pollution Control Program
Table of Hazardous Air Pollutants and Screening Model Action Levels

Legend	
Group ID	
A	Asbestos
B	Cresols/Cresylic Acid (isomers and mixtures)
C	2,4 - D, Salts and Esters
D	Dibenzofurans, Dibenzodioxins
E	4, 6 Dinitro-o-cresol, and Salts
F	Lindane (all isomers)
G	Xylenes (all isomers and mixtures)
H	Antimony Compounds
I	Arsenic Compounds
J	Beryllium Compounds
K	Cadmium Compounds
L	Chromium Compounds
M	Cobalt Compounds
N	Coke Oven Emissions
O	Cyanide Compounds
P	Glycol Ethers
Q	Lead Compounds (except elemental Lead)
R	Manganese Compounds
S	Mercury Compounds
T	Fine Mineral Fibers
U	Nickel Compounds
V	Polycyclic Organic Matter
W	Selenium Compounds
X	Polychlorinated Biphenyls (Aroclors)
Y	Radionuclides
Notes	The SMAL for radionuclides is defined as the effective dose equivalent to 0.3 millirems per year for 7 years exposure associated with a cancer risk of 1 in 1 million

Harry Frank
Managing Engineer
University of Missouri Power Plant
417 South Fifth Street
CF - Energy Management
Columbia, MO 65211-2030

RE: New Source Review Permit - Project Number: 2020-02-016

Dear Harry Frank:

Enclosed with this letter is your permit to construct. Please study it carefully and refer to Appendix A for a list of common abbreviations and acronyms used in the permit. Also, note the special conditions, if any, on the accompanying pages. The document entitled, "Review of Application for Authority to Construct," is part of the permit and should be kept with this permit in your files. Operation in accordance with these conditions, your new source review permit application and your amended operating permit is necessary for continued compliance. The reverse side of your permit certificate has important information concerning standard permit conditions and your rights and obligations under the laws and regulations of the State of Missouri.

This permit may include requirements with which you may not be familiar. If you would like the department to meet with you to discuss how to understand and satisfy the requirements contained in this permit, an appointment referred to as a Compliance Assistance Visit (CAV) can be set up with you. To request a CAV, please contact your local regional office or fill out an online request. The regional office contact information can be found at the following website: http://dnr.mo.gov/regions/. The online CAV request can be found at http://dnr.mo.gov/cav/compliance.htm.

If you were adversely affected by this permit decision, you may be entitled to pursue an appeal before the administrative hearing commission pursuant to Sections 621.250 and 643.075.6 RSMo. To appeal, you must file a petition with the administrative hearing commission within thirty days after the date this decision was mailed or the date it was delivered, whichever date was earlier. If any such petition is sent by registered mail or certified mail, it will be deemed filed on the date it is mailed; if it is sent by any method other than registered mail or certified mail, it will be deemed filed on the date it is received by the administrative hearing commission, whose contact information is: Administrative Hearing Commission, United States Post Office Building, 131 West High Street, Third Floor, P.O. Box 1557, Jefferson City, Missouri 65102, phone: 573-751-2422, fax: 573-751-5018, website: www.oa.mo.gov/ahc.

If you have any questions regarding this permit, please do not hesitate to contact Chia-Wei Young, at the Department of Natural Resources' Air Pollution Control Program, P.O. Box 176, Jefferson City, MO 65102 or at (573) 751-4817. Thank you for your attention to this matter.

Sincerely,

AIR POLLUTION CONTROL PROGRAM

Susan Heckenkamp
New Source Review Unit Chief

SH:cya

Enclosures

c: Northeast Regional Office
PAMS File: 2020-02-016

Permit Number:

MISSOURI DEPARTMENT OF NATURAL RESOURCES
FOLDER TRANSMITTAL ROUTING SHEET

Document #:
Division Log #:
Program Log #:

DEADLINE: Penalty for Missing Deadline: $

University of Missouri Power Plant 2020-02-016

Originator: Chia-Wei Young Telephone: 6-3835 Date: 12/9/2020

Typist: Angela File Name: Document1

FOR SIGNATURE APPROVAL OF:

☐ DNR Director ☐ DNR Deputy Director ☐ Division Director ☐ Division Deputy Director X Other: Darcy A. Bybee

PROGRAM APPROVAL: Approved by: _____ Program: APCP Date: _____

Other Program Approval (Section/Unit): _____ Date: _____

Comments:

ROUTE TO:

☐ DIVISION DIRECTOR APPROVAL: _____ Date: _____

Comments:

☐ FINANCIAL REVIEW – DIVISION OF ADIMINSTRATIVE SUPPORT:

DAS Director: _____ Date: _____

☐ Fee Worksheet Received By: _____ Date: _____

Accounting: _____ Date: _____

Budget: _____ Date: _____

General Services: _____ Date: _____

Internal Audit: _____ Date: _____

Purchasing: _____ Date: _____

Comments:

☐ LEGAL REVIEW:

☐ General Counsel: _____ Date: _____

☐ AGO: _____ Date: _____

Comments:

☐ DEPARTMENT DIRECTOR APPROVAL: _____ Date: _____

Comments:

☐ NOTARIZATION NEEDED

INITIALS/DATE

X. NEPA Environmental Questionnaire

NETL F 451.1-1/3
Revised: 12/3/2014
Reviewed: 12/3/2014
(Previous Editions Obsolete)

U.S. DEPARTMENT OF ENERGY

ENVIRONMENTAL QUESTIONNAIRE

I. INSTRUCTIONS

The proposer shall prepare this Environmental Questionnaire (EQ) as accurately and completely as possible. Supporting information can be provided as attachments. The proposer must identify the location of the project and specifically describe the activities that would occur at that location. The proposer must provide specific information and quantities, regarding air emissions, wastewater discharges, solid wastes, etc., to facilitate the necessary review. In addition, the proposer must submit with this EQ a FINAL copy of the project's statement of work (SOW) or statement of project objective (SOPO) that will be used in the contract/agreement between the proposer and the U.S Department of Energy (DOE).

II. QUESTIONNAIRE

A. PROJECT SUMMARY

1. Solicitation/Project Number: DE-FOA-0001788 Proposer: Echogen Power Systems (DE), Inc.
2. This Environmental Questionnaire pertains to a: □ Recipient or Prime Contractor X Sub-recipient or Subcontractor
3. Principal Investigator: Timothy Held Telephone Number: 234-542-4379
4. Project Title: Supercritical Carbon Dioxide Primary Power Large-Scale Pilot Plant
5. Expected Project Duration: 54 months
6. Location of Activities covered by **this** Environmental Questionnaire: (City/Township, County, State):
   University of Missouri, MU Power Plant in Columbia, Boone County, Missouri,
7. List the full scope of activities planned (only for the location that is the subject of this Environmental Questionnaire).

   Site preparation, construction and operation of a 10MWe coal-fired supercritical carbon dioxide (sCO_2) large-scale pilot.

8. List all other locations where work would be performed by the primary contractor of the project and subcontractor(s). Each of the following must have an individual Environmental Questionnaire.

Subcontractor or sub-recipient	Location of activities for this project
Echogen Power Systems	Akron, OH
University of Missouri	Columbia, MO
Electric Power Research Institute	Palo Alto, CA

9. Identify and select the checkbox with the predominant project work activities under Group A, B, or C

Group A

□ Routine administrative, procurement, training, and personnel actions. Contract activities/awards for management support, financial assistance, and technical services in support of agency business, programs, projects, and goals. Literature searches and information gathering, material inventories, property surveys; data analysis, computer modeling, analytical reviews, technical summary, conceptual design, feasibility studies, document preparation, data dissemination, and paper studies. Technical assistance including financial planning, assistance, classroom training, public meetings, management training, survey participation, academic contribution, technical consultation, and stakeholders surveys. Workshop and conference planning, preparation, and implementation which may involve promoting energy efficiency, renewable energy, and energy conservation.

STOP! ***If all work activities related to this project can be classified and described within categories under Group A, proceed directly to Section III CERTIFICATION BY PROPOSER. No additional information is required.***
If project work activities are described in either Group(s) B or C; then continue filling out questionnaire.

U.S. DEPARTMENT OF ENERGY

ENVIRONMENTAL QUESTIONNAIRE

Group B

□ Laboratory Scale Research, Bench Scale Research, Pilot Scale Research, Proof-of-Concept Scale Research, or Field Test Research. Work DOES NOT involve new building/facilities construction and site excavation/groundbreaking activities. This work typically involves routine operation of existing laboratories, commercial buildings/properties, offices and homes, project test facilities, factories/power plants, vehicles test stands and components, refueling facilities, utility systems, or other existing structures/facilities. Work will NOT involve major change in facilities missions and operations, land use planning, new/modified regulatory/operating permit requirements. Includes work specific to routine DOE Site operations and Lab research work activities, but NOT building construction and site preparation. DOE work typically involves laboratory facilities and lab equipment operations, buildings and grounds management activities; and buildings and facilities maintenance, repairs, reconfiguration, remodeling, equipment use and replacement.

Group C

X Pilot Test Facilities Construction, Pilot Scale Research, Field Scale Demonstration, or Commercial Scale Application. Work typically involves facility construction, site preparation/excavation/groundbreaking, and/or demolition. This work would include construction, retrofit, replacement, and/or major modifications of laboratories, test facilities, energy system prototypes, and power generation infrastructure. Work may also involve construction and maintenance of utilities system right-of-ways, roads, vehicle test facilities, commercial buildings/properties, fuel refinery/mixing facilities, refueling facility, power plants, underground wells, and pipelines, and other types of energy research related facilities. This work may require new or modified regulatory permits, environmental sampling and monitoring requirements, master planning, public involvement, and environmental impact review. Includes work specific to DOE Site Operations and Lab operation activities involving building and facilities construction, replacement, decommissioning/demolition, site preparation, land use changes, or change in research facilities mission or operations.

B. PROPOSED PROJECT ALTERNATIVES

1. If applicable, list any project alternatives considered to achieve the project objectives.

Alternative Sites: The Echogen team conducted a nationwide search for potentially suitable locations for the sCO_2 pilot plant. In addition to the MU Power Plant, sites in Ohio, Pennsylvania, and Alabama were thoroughly evaluated as potential project sites. The Painesville Electric Plant in Painesville, Ohio offered ease of construction and close proximity to Echogen headquarters in Akron, Ohio, but this site was eliminated from consideration due to ongoing environmental litigation at the facility. A site near a coal mine in Green County, Pennsylvania was briefly considered, but was eliminated from consideration due to the lack of existing infrastructure. A site at the National Carbon Capture Center in Wilsonville, Alabama was also considered due to the Center's focus on advanced coal technologies. This site was considered less favorable than the MU site due to cost concerns and limited existing onsite infrastructure.

Alternative Technologies: The sCO_2 process is proposed as an alternative to traditional steam Rankine processes for coalfired generation. The proposed sCO_2 process is more efficient than the traditional Rankine power cycle, and with respect to HHV and coal consumption, requires less cooling water usage, and has a smaller physical footprint. The specific purpose of the proposed project is to demonstrate sCO_2 technology; no other advanced power cycle technologies were considered as alternatives. There are two proposed alternative design configurations for the sCO_2 system, the RCBC and RCBC-E processes. The primary difference is that the RCBC-E process includes a two-stage PHX, whereas the RCBC includes a single PHX. The two-stage PHX can be operated to reduce flue gas temperatures and provide low-grade heat suitable for air preheating and emissions controls systems. Both configurations have a similar physical footprint and could be accommodated in the MU Power Plant boiler room. The waste products and emissions from the sCO_2 process would be similar in nature and quantity to those already produced at the MU Power Plant, and existing waste disposal systems would be expected to fully accommodate pilot plant wastes. No alternative waste disposal sites or measures are therefore being considered for this project.

No Action Alternative: Under the no action alternative, the proposed sCO_2 pilot plant would not be designed or constructed by Echogen and its collaborators. Without DOE funding, there would be no pilot-scale application of the novel, high-efficiency Echogen process, and this opportunity for demonstration of the innovative sCO_2 technology would not be pursued. The MU Power Plant would continue energy generation operations with its existing infrastructure. MU would continue use of Boilers 7, 8, and 9 for the foreseeable future.

U.S. DEPARTMENT OF ENERGY

ENVIRONMENTAL QUESTIONNAIRE

C. PROJECT LOCATION

1. Provide a brief description of the project location (physical location, surrounding area, adjacent structures).
The proposed site for the sCO_2 pilot plant is within the existing University of Missouri (MU) Power Plant, an operational combined heat and power (CHP) facility located on the MU campus in the city of Columbia in Boone County, Missouri. The MU Power Plant is owned by University of Missouri and occupies approximately 8 acres in the northwest corner of campus. This site was selected because of the availability of space and existing infrastructure in place to support the pilot plant project. Additionally, the site location would not require infringement on any undeveloped, natural areas. The proposed plan is to install the new sCO_2 power cycle and appurtenances in the approximately 8,000 ft^2 space that is currently occupied by three steam boilers (Boilers 7, 8, and 9) within the MU Power Plant boiler room. These three boilers would be decommissioned and removed to make room for the new sCO_2 power cycle equipment, the fired heater, and associated appurtenances. Additionally, an economizer tube bank, air heater, and environmental systems (SCR as well as a scrubber unit and baghouse) would be installed within an existing 4,000 ft^2 platform adjacent to the boiler room. The entire pilot plant footprint would be contained within the existing 12,000 ft^2 MU Power Plant footprint.

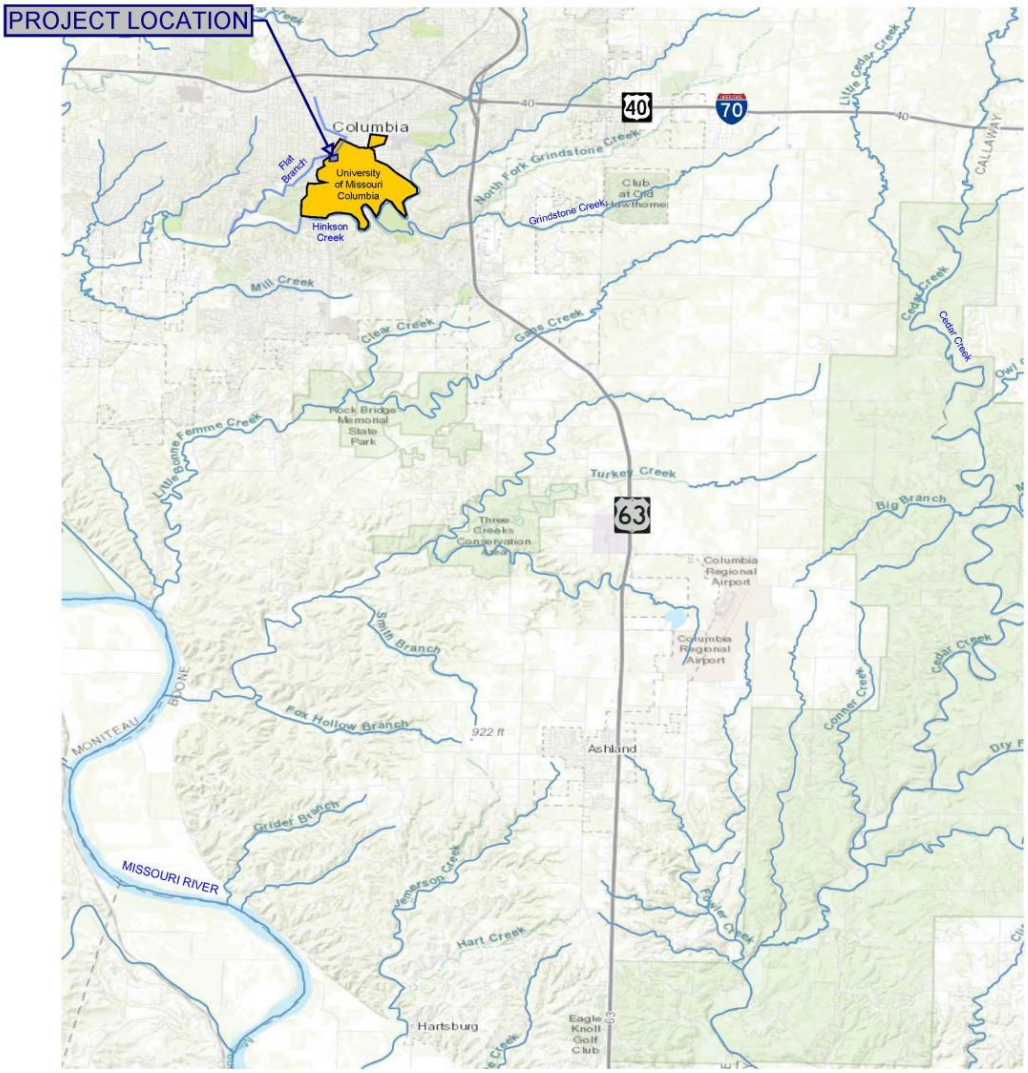
   University of Missouri campus residence halls, academic buildings, and office spaces surround the MU Power Plant to the north, east, and south. The historic Francis Quadrangle is located approximately two blocks east of the MU Power Plant. Columbia Cemetery is to the west and northwest of the plant, on the west side of South Providence Road. There are residential neighborhoods to the west and southwest of the plant and a commercial strip mall located directly west of the power plant across South Providence Road. The Missouri-Kansas-Texas (M-K-T) Nature/Fitness Trail runs along Flat Branch Creek directly adjacent the west border of the MU Power Plant property. The M-K-T Trail includes a series of small box drains and tunnels under Elm Street, South Providence Road, and East Stewart Road until the trail becomes all above ground to the southwest of the MU Power Plant property.

2. **Attach** a project site location map of the project work area.

   See Figure 1, Figure 2, and Figure 3 below.

U.S. DEPARTMENT OF ENERGY

ENVIRONMENTAL QUESTIONNAIRE



Legend

USA Detailed Streams

AR_MajorLakes_...

N W E S

0 1.75 3.5

Miles

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., Gebco, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance, Survey, Esri Japan, METI, Esri China (Hong Kong), swisstop, MapMyIndia, © OpenStreetMap contributors, and the GIS User Community.

CDM Smith | ECHOGEN power systems

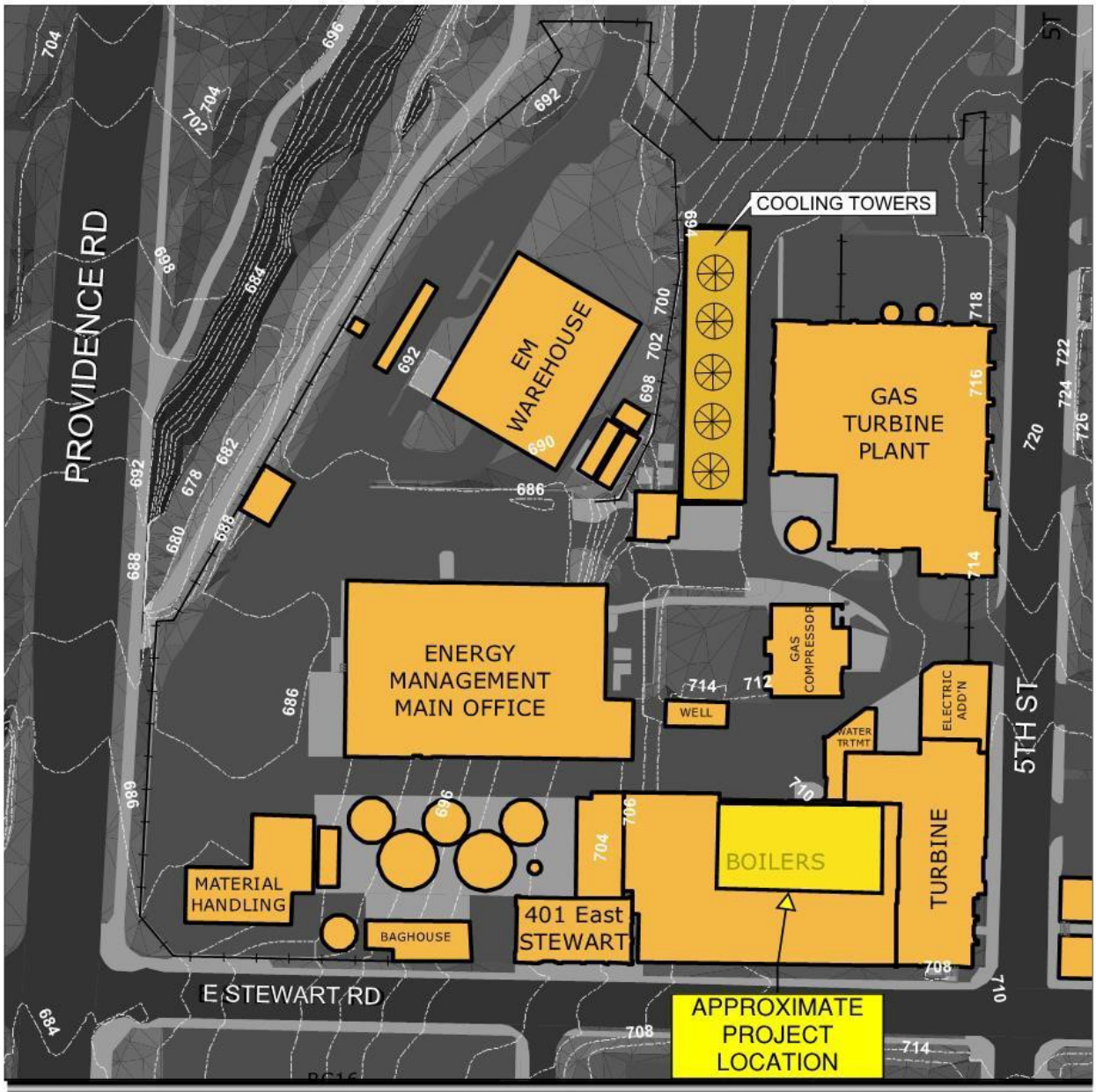
SITE LOCATION MAP

FIGURE NO. 1

©2015 CDM SMITH ALL RIGHTS RESERVED. REUSE OF DOCUMENTS: THESE DOCUMENTS AND DESIGNS PROVIDED BY PROFESSIONAL SERVICE, INCORPORATED HEREIN, ARE THE PROPERTY OF CDM SMITH AND ARE NOT TO BE USED, IN WHOLE OR PART, FOR ANY OTHER PROJECT WITHOUT THE WRITTEN AUTHORIZATION OF CDM SMITH.

U.S. DEPARTMENT OF ENERGY

ENVIRONMENTAL QUESTIONNAIRE



© 2015 CDM SMITH ALL RIGHTS RESERVED. REUSE OF DOCUMENTS. THESE DOCUMENTS AND DESIGNS PROVIDED BY PROFESSIONAL SERVICE, INCORPORATED HEREIN, ARE THE PROPERTY OF CDM SMITH AND ARE NOT TO BE USED, IN WHOLE OR PART, FOR ANY OTHER PROJECT WITHOUT THE WRITTEN AUTHORIZATION OF CDM SMITH.

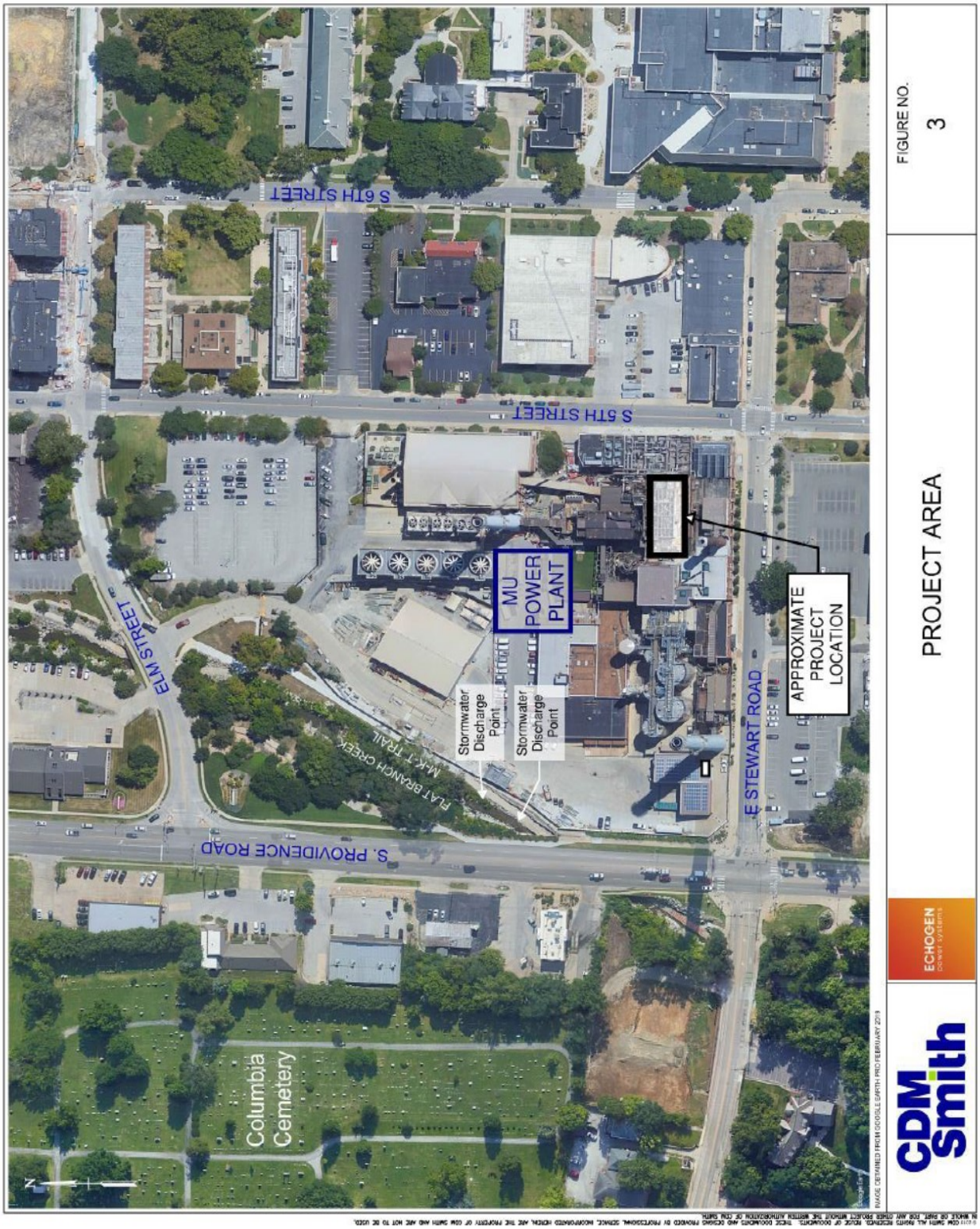
CDM Smith | ECHOGEN power systems

MU CHP PLANT SITE TOPO MAP

FIGURE NO. 2

U.S. DEPARTMENT OF ENERGY

ENVIRONMENTAL QUESTIONNAIRE



U.S. DEPARTMENT OF ENERGY

ENVIRONMENTAL QUESTIONNAIRE

D. ENVIRONMENTAL IMPACTS

NEPA procedures require evaluations of possible effects (including land use, energy resource use, natural, historic and cultural resources, and pollutants) from proposed projects on the environment.

1. Land Use

a. Characterize present land use where the proposed project would be located.

□	Urban	□	Industrial	□	Commercial	□	Agricultural
□	Suburban	□	Rural	□	Residential	□	Research Facilities
□	Forest	X	University Campus	□	Other: _____		

b. Identify the total size of the facility, structure, or system and what portion would be used for the proposed project.

The MU power plant occupies approximately 8 acres, of that surveying and field measurements will be taken over approximately 12,000 ft^2 of the existing plant.

c. Describe planned construction, installation, and/or demolition activities, i.e., roads, utilities system rights-of-way, parking lots, buildings, laboratories, storage tanks, fueling facilities, underground wells, pipelines, or other structures.

□ No construction would be anticipated for this project.

Fabrication and plant construction are estimated to take approximately 30 months. The proposed plan is to install the new sCO_2 power cycle and appurtenances in the approximately 8,000 ft^2 space that is currently occupied by three steam boilers (Boilers 7, 8, and 9) within the MU Power Plant boiler room. These three boilers would be decommissioned and removed to make room for the new sCO_2 power cycle equipment, the fired heater, and associated appurtenances. Additionally, a scrubber unit and baghouse would be installed within an existing 4,000 ft^2 platform adjacent to the boiler room. The entire pilot plant footprint would be contained within the existing 12,000 ft^2 MU Power Plant footprint. Construction of the proposed pilot plant within the existing MU Power Plant grounds would not result in any land use changes as the existing site is already a highly developed industrial facility. Construction of the proposed pilot plant would result in temporary, intermittent, and localized impacts to air quality due to construction-related emissions. These emissions would primarily be associated with operation of construction machinery, increased vehicle traffic for the approximately 35-person construction crew, and construction waste handling, trucking, and disposal. These emissions would occur intermittently over the course of the 30-month fabrication and installation period. No land disturbances with potential to impact air quality would be required for this project. Similar construction-related emissions would occur during the dismantling of the pilot plant, if MU decides to decommission the pilot plant after the demonstration term ends. Minor excavations within the existing plant would be required to make minor modifications to the ash system and install new foundations for the pilot plant equipment and emission control equipment. Construction impacts would also occur if the pilot plant were to be decommissioned in the future. Best management practices and mitigation measures, including MU's robust construction management standards and protocols, would be put in place to reduce any construction-related environmental impacts. No stream diversions or intrusions into streams, wetlands, or other surface waters would be required for construction and operation of the proposed pilot plant. The potable water well and underground potable water storage reservoir located to the north of the boiler room would not be impacted by construction or operation of the proposed pilot plant.

d. Describe how land use would be affected by operational activities associated with the proposed project.

□ No land areas would be affected.

The proposed pilot plant would be installed within the current MU Power Plant on the University campus in Columbia, MO. The plant occupies approximately 8 acres of the northwest corner of the MU campus. It is bordered by South Providence Road to the west, South 5th Street to the east, Elm Street to the north, and East Stewart Road to the south (Figure 3). Land cover at the MU Power Plant consists primarily of developed, impervious surfaces with approximately 45% concrete/asphalt pavement, 38% rooftops and structures, 6% semi-pervious gravel, and 11% landscaped vegetation (MU Power Plant 2014). The sCO_2 equipment and fired heater would be installed within the 8,000 ft^2 area currently occupied by Boilers 7, 8, and 9 in the existing, fully developed boiler room building. An economizer tube bank, air heater,

and environmental systems (SCR, CDS, and baghouse) would be installed on an existing 4,000 ft^2 platform just north of the boiler room. Therefore, the immediate land use within the project area is a 100% impervious, built environment.

e. Describe any plans to reclaim areas that would be affected by the proposed project.

X No land areas would be affected.

f. Would the proposed project affect any unique or unusual landforms (e.g., cliffs, waterfalls, etc.)?

X No □ Yes (describe)

g. Would the proposed project be located in or near local, state, or federal parks; forests; monuments; scenic waterways; wilderness; recreation facilities; or tribal lands? □ No X Yes (describe)

The Missouri-Kansas-Texas (M-K-T) Nature/Fitness Trail runs along Flat Branch Creek directly adjacent the west border of the MU Power Plant property. The M-K-T Trail includes a series of small box drains and tunnels under Elm Street, South Providence Road, and East Stewart Road until the trail becomes all above ground to the southwest of the MU Power Plant property.

Flat Branch Park, located immediately to the north of the MU Power Plant property, is owned by the city of Columbia, Missouri, and hosts a variety of local downtown festivals and events. The park is located on the former site of Columbia's Market Square, which was established in the 1820s. At the turn of the twentieth century, a railway depot known as Katy Station was built in the Flat Branch area. Park redevelopment activities occurred in recent years (Phase 1 in 2000 and Phase 2 in 2006). Park development included a playground, spray-grounds, stone amphitheater, benches, drinking fountain, lamp posts, an art sculpture, pedestrian bridge, bike racks, 19-car parking lot, rain garden, and a concrete portion of the M-K-T Trail that runs through the park.

McAlester Park, better known as Peace Park, is situated one block away (approximately 400 feet from the east border) from the MU Power Plant property. This park contains the oldest undisturbed land on the main MU campus. This four-acre tract contains more than 100 trees of 43 varieties. Ongoing and future development plans include adding several genera of trees and shrubs important to the mid-Missouri region. The drainage creek flowing through the area is slated to be developed. The park contains a memorial, constructed in the shape of a peace symbol, honoring students killed during anti-war protests at Kent State University on May 4,1970.

The Columbia Cemetery, located approximately 300 feet from the west border of the MU Power Plant property, has been in use as a cemetery since 1820. This 33-acre cemetery contains many burials of prominent people associated with Missouri history, the University of Missouri, or the city of Columbia. It was listed on the National Register of Historic Places in 2007.

2. Construction Activities and/or Operation

a. Identify project structure(s), power line(s), pipeline(s), utilities system(s), right-of-way(s) or road(s) that will be constructed and clearly mark them on a project site map or topographic map as appropriate. □ None

Figure 2 and Figure 3 indicate the location of the proposed plant to be constructed, superimposed upon the existing facility layout.

b. Would the proposed project require the construction of waste pits or settling ponds?

X No □ Yes (describe and identify location, and estimate surface area disturbed)

No effluent discharges associated with the project would require development of settling ponds or other similar waste/wastewater management infrastructure. Stormwater management controls would be used during construction. The laydown/site plan, shown in Figure 4 below, identifies the areas to be used during the construction phase.

U.S. DEPARTMENT OF ENERGY

ENVIRONMENTAL QUESTIONNAIRE

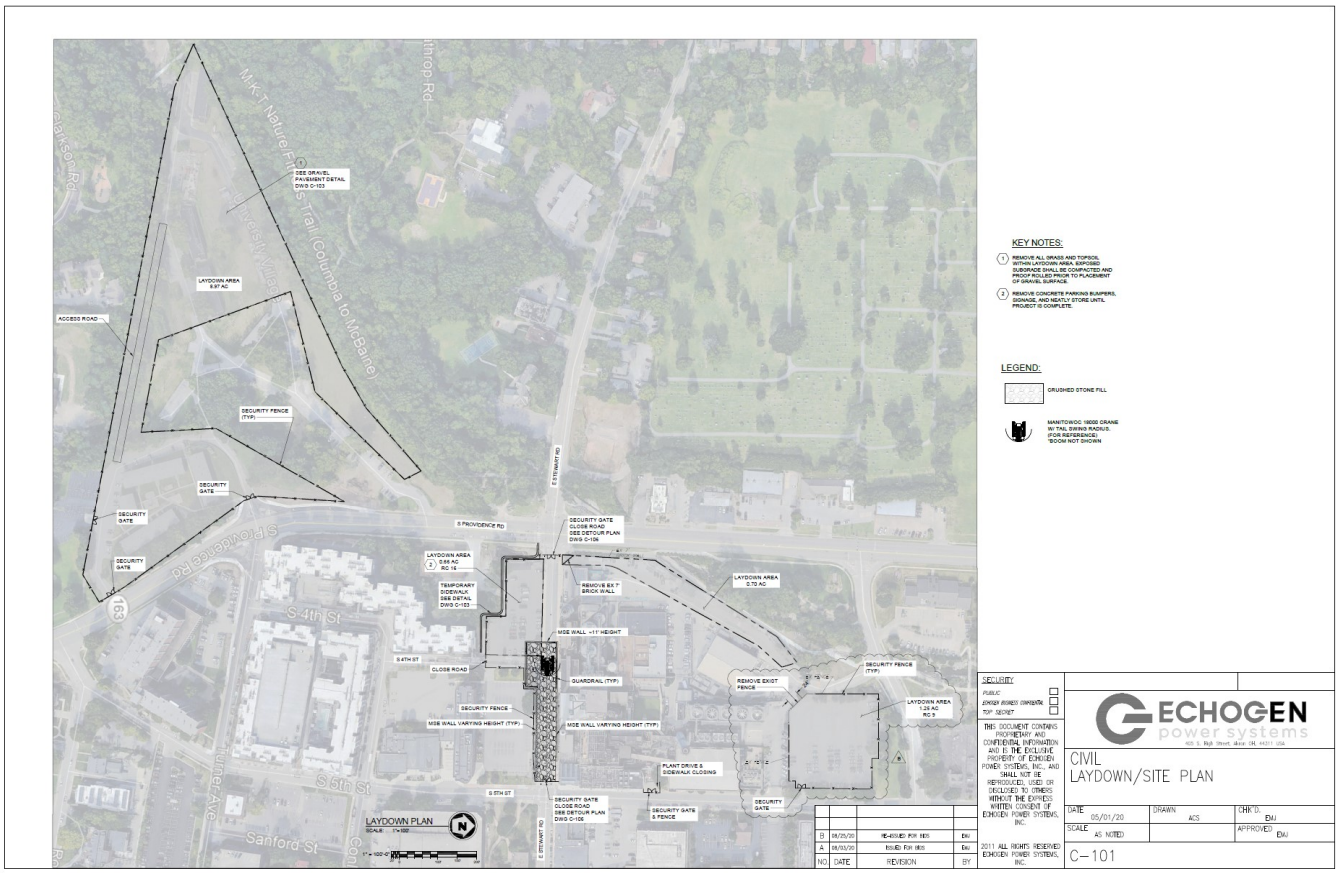


Figure 4. Laydown / Site Plan

c. Would the proposed project affect any existing body of water? X No □ Yes (describe)

It is not anticipated that there would be any change to groundwater or surface water quality or quantity due to the proposed pilot plant. No stream diversions or intrusions into streams, wetlands, or other surface waters would be required for construction and operation of the proposed pilot plant.

d. Would the proposed project impact a floodplain or wetland? X No □ Yes (describe)

No impacts are anticipated. The MU Power Plant is not located within a FEMA-mapped 100-year floodplain.

e. Would the proposed project potentially cause runoff/sedimentation/erosion? X No □ Yes (describe)

No sediment or runoff is expected from surfaces utilized for construction. No changes to site surface water hydrology (e.g., increases in impervious surfaces) are expected, as the proposed pilot plant would be contained within existing structures in a 100% impervious area. Stormwater discharges to Flat Branch Creek via the culverts on the west border of the MU Power Plant would continue subject to the conditions of the 2017 No-Exposure Certification. The No-Exposure Certification expires in April 2022, at which point the facility would apply to renew the certification. Stormwater runoff would continue to be managed according to best management practices outlined in the facility SWPPP. This project would not necessitate the use of storage piles or other open materials storage areas from which runoff may be a concern. The preparation of the laydown area to receive gravel would follow industry standard erosion control and best management practices. Coal at the plant is stored in silos; coal required for the pilot plant would not be expected to exceed silo storage capacity. Ash would continue to be disposed of offsite at an externally permitted disposal site; the permitted disposal site is equipped to mitigate leachates and runoff from ash storage.

U.S. DEPARTMENT OF ENERGY

ENVIRONMENTAL QUESTIONNAIRE

f. Would the proposed project include activities located on perma-frost, near fault zones, or involve fracturing, well drilling, geologic stimulation, sequestration, active seismic data collection, and/or deepwater operations?
X No □ Yes (describe)

g. Would the proposed project involve any of the following: nanotechnology; recombinant DNA or genetic engineering; facility decommissioning or disposition of equipment/materials; or management of radioactive wastes/materials?
□ No X Yes (describe)

The pilot plant would operate for a minimum of two years with continuous operation and monitoring. Following the demonstration term, MU would either continue to operate the sCO_2 system as a plant generation asset or decommission and remove it. Decommissioning costs have been excluded from the project plan, since the expectation is that MU would desire to continue plant operation.

3. Biological Resources

a. Identify any State or Federally listed endangered or threatened plant or animal species potentially affected by the proposed project.
□ None

Several mature hardwoods including cottonwood, sycamore, and hackberry are present within the M-K-T trail area and exhibit characteristics of potential summer roost habitat for federally-listed bat species (i.e., Indiana and northern long-eared bats). However, the pilot plant project should not include any tree clearing or impact the M-K-T Trail System in any way.

The installation of the proposed pilot plant within the existing, developed MU Power Plant footprint would not disrupt wetlands, floodplains, or other ecologically sensitive habitats. Because the pilot plant would be installed within an existing building, the pilot plant footprint would not impinge on vegetated, landscaped areas of the MU Power Plant. The only areas in the vicinity with unmanaged, native habitats and wildlife are along the M-K-T Trail System and Flat Branch Creek, roughly 500 to 600 feet from the proposed pilot plant. Pilot plant construction and operation would not be expected to impact the indigenous flora and fauna present along the M-K-T Trail System, including foraging or roosting habitat for threatened and endangered bat species.

Although not documented, external structures of the boiler room provide tall structures with views of the surrounding area that may be used transiently as perching structures by the state listed peregrine falcon. Disturbances to potential perching structures due to increased noise or vehicle activity during construction would be unlikely, and if they were to occur, temporary and very minor. Any falcons in the area would avoid the area and find suitable perches on nearby tall University buildings. Potential perching structures in the broader vicinity of the boiler room would not be impacted by pilot plant construction or operation.

b. Would any designated critical habitat be affected by the proposed project? X No □ Yes (describe)

c. Describe any impacts that construction would have on any other types of sensitive or unique habitats.
□ No planned construction □ No habitats □ None X Impact (describe)

Although not documented, external structures of the boiler room provide tall structures with views of the surrounding area that may be used transiently as perching structures by the state listed peregrine falcon. Disturbances to potential perching structures due to increased noise or vehicle activity during construction would be unlikely, and if they were to occur, temporary and very minor. Any falcons in the area would avoid the area and find suitable perches on nearby tall University buildings. Potential perching structures in the broader vicinity of the boiler room would not be impacted by pilot plant construction or operation.

d. Would any foreign substances/materials be introduced into ground or surface waters, soil, or other earth/geologic resource because of project activities? How would these foreign substances/materials affect the water, soil, biota, and geologic resources? X No □ Yes (describe)

U.S. DEPARTMENT OF ENERGY

ENVIRONMENTAL QUESTIONNAIRE

There are no surface waters within the proposed project site or the MU Power Plant site footprint. All excavations would occur within the MU Power Plant footprint. Since these excavations would occur on previously-disturbed grounds, geologic and soil conditions at the site would be minimally impacted by construction of the proposed pilot plant. Operation of the plant would not have impacts on subsurface conditions.

e. Would any migratory animal corridors be impacted or disrupted by the proposed project? X No □ Yes (describe)

Several migratory birds, such as warblers, may occur in habitats along the M-K-T Trail. The proposed project would not disturb these habitats.

4. Socioeconomic and Infrastructure Conditions

a. Would local socio-economic changes result from the proposed project? □ No X Yes (describe)

Project labor requirements include short-term jobs during the construction and engineering phase, and longer-term jobs during the operation phase of the project. Fabrication and installation of the pilot plant would be expected to last approximately 30 months. Construction would require a crew of approximately 30 workers and five construction managers, who would work intermittently during the construction period. Operation of the pilot plant would require approximately eight operators working 24 hours per day, seven days per week for the duration of operation. These positions would be filled by existing MU Power Plant staff, with the possibility of hiring a technician or two to supplement existing staff. Operations would be continuously, remotely monitored by MU staff, Echogen, and its collaborators. Successful demonstration of the sCO_2 process would attract visitors (researchers, energy industry professionals, DOE, interested members of the public, etc.) which could result in beneficial impacts to the local advanced energy industry. Successful demonstration could also encourage further development of sCO_2 technology locally and globally. Therefore, the pilot plant would benefit the local economy by needing relatively large numbers of local construction resources over the course of approximately two years. However, the operation of the pilot plant would not likely result in a substantial increase in the workforce from long-term, full-time jobs.

b. Would the proposed project generate increased traffic use of roads through local neighborhoods, urban or rural areas?
□ No X Yes (describe)

Construction of the proposed pilot plant would result in temporary, intermittent, and localized increased road traffic. Increased traffic would primarily be associated with movement of construction machinery, increased vehicle traffic for the approximately 35-person construction crew, and construction waste handling, trucking, and disposal. The increased traffic would occur intermittently over the course of the 30-month fabrication and installation period. Similar construction-related emissions would occur during the dismantling of the pilot plant, if MU decides to decommission the pilot plant after the demonstration term ends.

c. Would the proposed project require new transportation access (roads, rail, etc.)? Describe location, impacts, costs.
X No □ Yes (describe)

d. Would the proposed project create a significant increase in local energy usage? X No □ Yes (describe)

5. Historical/Cultural Resources

a. Describe any historical, archaeological, or cultural sites in the vicinity of the proposed project; note any sites included on the National Register of Historic Places. □ None

The oldest portion of the MU Power Plant was constructed in 1923 and is still in use at the southeast corner of the facility. Therefore, portions of the plant itself are historic. On campus, Francis Quad Historic District is bounded by Elm St, 9th St, Conley Ave & 6th St. Within that boundary there are 18 buildings of varying degree of architectural significance. The Historic District's focus is the open mall area with its iconic columns and accompanying buildings. The following is the list of buildings that make up the entire 18 building historic district: Chancellor's Residence, Engineering (original building), Geological Sciences, Hill Hall, Jesse Hall, McAlester Hall, Neff Addition, Neff Hall, Noyes Hall, Old Student

U.S. DEPARTMENT OF ENERGY

ENVIRONMENTAL QUESTIONNAIRE

Health, Parker Hall, Pickard, Sociology Building, Swallow Hall, Switzler Hall, Tate Hall, Townsend Hall, and Walter Williams Hall. No impacts are anticipated to the Historic District as the result of the new pilot plant.

The Columbia Cemetery, located approximately 300 feet from the west border of the MU Power Plant property, has been in use as a cemetery since 1820. This 33-acre cemetery contains many burials of prominent people associated with Missouri history, the University of Missouri, or the city of Columbia. It was listed on the National Register of Historic Places in 2007

b. Would construction or operational activities planned under the proposed project disturb any historical, archaeological, or cultural sites? □ No planned construction □ No historic sites □ Yes (describe) X No Impact (discuss)

The southeast portion of the MU Power Plant has been in operation since 1923 and is considered to be of historical value. Installation of the proposed pilot plant would take place within existing structures, which were constructed decades later and are not considered historically or culturally valuable. Therefore, the construction of the pilot plant would not require structural changes to historic portions of the plant. Additionally, the proposed pilot plant would not disrupt the industrial character of the site or surrounding area. Due to the distance from the project area of known historic resources, construction and operation of the pilot plant is not expected to have any impacts on historic buildings in the vicinity, such as the Historic District on the MU campus. The proposed project would not impact any archaeological sites, as none exist in the area.

c. Has the State Historic Preservation Office been contacted with regard to this project? X No □ Yes (describe)

d. Would the proposed project interfere with visual resources (e.g., eliminate scenic views) or alter the present landscape? X No □ Yes (describe)

The MU Power Plant has been generating power at the same location since 1923. The facility contributes to the visual landscape and fits in with the industrial aesthetic of the surrounding area. The larger buildings (including the boiler room) and stacks of the MU Power Plant can be seen from various surrounding properties, on and off of the University of Missouri campus, including the Francis Quadrangle two blocks to the east of the plant and the Columbia Cemetery to the west. There are no scenic vistas in the MU Power Plant viewshed.

e. Would the proposed project be located on or adjacent to tribal lands, lands considered to be sacred, or lands used for traditional purposes? Describe any known tribal sensitivities for the proposed project area.

No. There are no known tribal sensitivities for the proposed project area.

6. Atmospheric Conditions/Air Quality

a. Identify air quality conditions in the immediate vicinity of the proposed project with regard to attainment of National Ambient Air Quality Standards (NAAQS). This information is available under the Green Book Non-Attainment Areas for Criteria Pollutants located at http://www.epa.gov/air/oaqps/greenbk/astate.html

	Attainment	Non-Attainment
O_3 - 1 Hour	X	□
O_3 - 8 Hour	X	□
SO_x	X	□
PM - 2.5	X	□
PM - 10	X	□
CO	X	□
NO_2	X	□
Lead	X	□

U.S. DEPARTMENT OF ENERGY

ENVIRONMENTAL QUESTIONNAIRE

b. Would proposed project require issuance of new or modified local, state, or federal air permits to perform project related work and activities? □ No X Yes (describe)

A construction permit application has been submitted to the state of Missouri. A modification of the Title V Operating Permit will be needed before the expiration date.

c. Would the proposed project be in compliance with local and state air quality requirements? X Yes
If not, please explain.

d. Would the proposed project be classified as either a New Source or a major modification to an existing source?
□ No X Yes (describe)

The facility is an existing major Prevention of Significant Deterioration (PSD) source. Therefore, this project qualifies as a PSD modification, and a netting analysis must be made to determine if a significant net emissions increase will occur. As part of the draft permit (dated 12/9/2020) PSD Netting has been conducted using the past actuals of Boilers 7, 8 and 9 (EP7, EP8, EP9) from October 2012 to September 2014. The new multi-fuel process heater will be subject to New Source Performance Standard (NSPS) Db (40 CFR Part 60), as it is considered a steam generating unit that will commence construction after June 19,1984, and has a heat input capacity greater than 100 MMBtu/hr. Although steam is not generated, NSPS Db is applicable to any unit which "combusts any fuel" and "heats any heat transfer medium."

e. What types of air emissions, including fugitive emissions, would be anticipated from the proposed project, and what would be the maximum annual rate of emissions for the project?

The following table, based upon the draft permit (dated 12/9/2020), provides an emissions summary (in tons) for this project. The totals for project values are based upon an assumed maximum 2-years of operation.

	Maximum per Year	Total for Project
□ SO_x	222.59	445.18
□ NO_x	106.00	212
□ PM - 2.5	37.11	74.22
□ PM - 10	37.11	74.22
□ CO	83.87	167.74
□ CO_2	112,717.42	225,435.04
□ Lead	< 0.001	< 0.001
□ H_2S	None	None
□ Organic solvent vapors or other volatile organic compounds--List: 2.85 tons per year, total of 5.7 tons for two years of operation		
□ Hazardous air pollutants -- List: 6.72 tons per year, total of 13.44 tons for two years of operation		
□ Other -- List: HF 0.64 tons per year, total of 1.28 tons for two years of operation		
□ None		

f. Would any types of emission control or particulate collection devices be used?
□ No X Yes (describe, including collection efficiencies)

A baghouse, selective catalytic reduction system, and a dry scrubber will be used to control the particulate, NOx, and SO_2 emissions, respectively, from the fired heater. Particulate emissions (PM) are controlled by a high-temperature fabric filter baghouse, with a particle removal efficiency of greater than 99%. Per the permit, NOx emissions will be limited to 0.20

ENVIRONMENTAL QUESTIONNAIRE

lb/MMBtu heat input, based on a 30-day rolling average. Per the permit, SOx emissions will be limited to 0.20 lb/MMBtu heat input (or 92% reduction), based on a 30-day rolling average.

g. How would emissions be vented?

Emissions would be emitted via the existing stack.

7. Hydrologic Conditions/Water Quality

a. What nearby water bodies may be affected by the proposed project? Provide distance(s) from the project site.

It is not anticipated that there would be any change to groundwater or surface water quality or quantity due to the proposed pilot plant. No stream diversions or intrusions into streams, wetlands, or other surface waters would be required for construction and operation of the proposed pilot plant.

b. What sources would supply potable and process water for the proposed project?

Water supply for plant operations is provided by MU campus potable water supply wells with emergency backup water provided to MU by the City of Columbia. However, the MU Power Plant has not previously required water from the City wells.

c. Quantify the wastewater that would be generated by the proposed project.

		Gallons/day	Gallons/year
□	Non-contact cooling water	10,700	2,334,000
□	Process water		
□	Sanitary		
□	Other -- describe:		
□	None		

d. What would be the major components of <u>each</u> type of wastewater (e.g., coal fines)? □ No wastewater produced

The cooling tower discharge or blowdown is sent to the sanitary sewer system, and treated by the City of Columbia waste water treatment facility. The cooling tower water major components are listed in the following table, under the heading Main Cooling Tower.

U.S. DEPARTMENT OF ENERGY

ENVIRONMENTAL QUESTIONNAIRE

	SAMPLE ID	Main Cooling Tower
1	pH	8.3030
2	Conductivity (MMHS)	3,346.7
3	Free Halogen (PPM)	0.0400
4	P-Alkalinity (PPM)	
5	M-Alkalinity (PPM)	241.94
6	Calcium (PPM)	741.97
7	Magnesium (PPM)	662.13
8	Molybdenum (PPM)	0.0000
9	Zinc (PPM)	1.5410
10	Total Iron (PPM)	0.2910
11	Manganese (PPM)	0.0120
12	Copper (PPM)	0.0220
13	Aluminum (PPM)	0.0000
14	Silica (PPM)	48.300
15	Nickel (PPM)	0.0050
16	Vanadium (PPM)	0.7210
17	Sodium (PPM)	258.30
18	Potassium (PPM)	29.448
19	Chloride (PPM)	213.02
20	Bromide (PPM)	1.2190
21	Nitrite (PPM)	
22	Nitrate (PPM)	7.8380
23	Ammonia (PPM)	
24	Phosphonate (PPM)	1.3000 U
25	Ortho Phosphate (PPM)	3.9390
26	Total Phosphate (PPM)	6.9070
27	Fluorescent Tracer (PPB)	129.50
28	Sulfite (PPM)	
29	Sulfate (PPM)	1,475.3
30	Total Azole (PPM)	3.2150 B
31	Glycol (PPM)	
32	Glycol E/P (%)	
33	Turbidity (NTU)	2.74
34	Aerobic Bacteria (Cells/mL)	100
35	Primary Organism	Bacillus Specie
36	Secondary Organism	Pseudomonas Specie
37	DEAE (PPM)	
38	Morpholine (PPM)	
39	Cyclohexylamine (PPM)	
40	Boiler Polymer (PPM)	
41	ORP (mV)	343.00
42	Cycles (Magnesium/Well Water)	5.9

e. Identify the local treatment facility that would receive wastewater from the proposed project.

□ No discharges to local treatment facility

Wastewater would be received by:
Columbia Missouri Wastewater Treatment Plant
4900 Gillespie Bridge Rd.
Columbia, MO 65201

f. Describe how wastewater would be collected and treated. □ No wastewater produced

All wastewater would be collected via the public sewer system and treated by the local municipal wastewater treatment plant. There will be no on-site wastewater treatment.

U.S. DEPARTMENT OF ENERGY

ENVIRONMENTAL QUESTIONNAIRE

g. Would any run-off or leachates be produced from storage piles or waste disposal sites? X No □ Yes (describe source)

This proposed project would not necessitate the use of storage piles or other open materials storage areas from which runoff may be a concern. Coal at the plant is stored in silos; coal required for the pilot plant would not be expected to exceed silo storage capacity. Ash would continue to be disposed of offsite at an externally permitted disposal site; the permitted disposal site is equipped to mitigate leachates and runoff from ash storage.

h. Would project require issuance of new or modified water permits to perform project work or site development activities?
X No □ Yes (describe)

i. Where would wastewater effluents from the proposed project be discharged? □ No wastewater produced

All wastewater would be collected via the public sewer system and treated by the local municipal wastewater treatment plant.

j. Would the proposed project be permitted to discharge effluents into an existing body of water?
X No □ Yes (describe water use and effluent impact)

k. Would a new or modified National Pollutant Discharge Elimination System (NPDES) permit be required?
X No □ Yes (describe)

The site currently has an exclusion from NPDES Stormwater Permitting (expires April 2022), so no NPDES permit is required. A combined permit is in place with the county, which needs to be renewed every 5 years.

l. Would the proposed project adversely affect the quality or movement of groundwater? X No □ Yes (describe)

It is not anticipated that there would be any change to groundwater or surface water quality or quantity due to the proposed pilot plant.

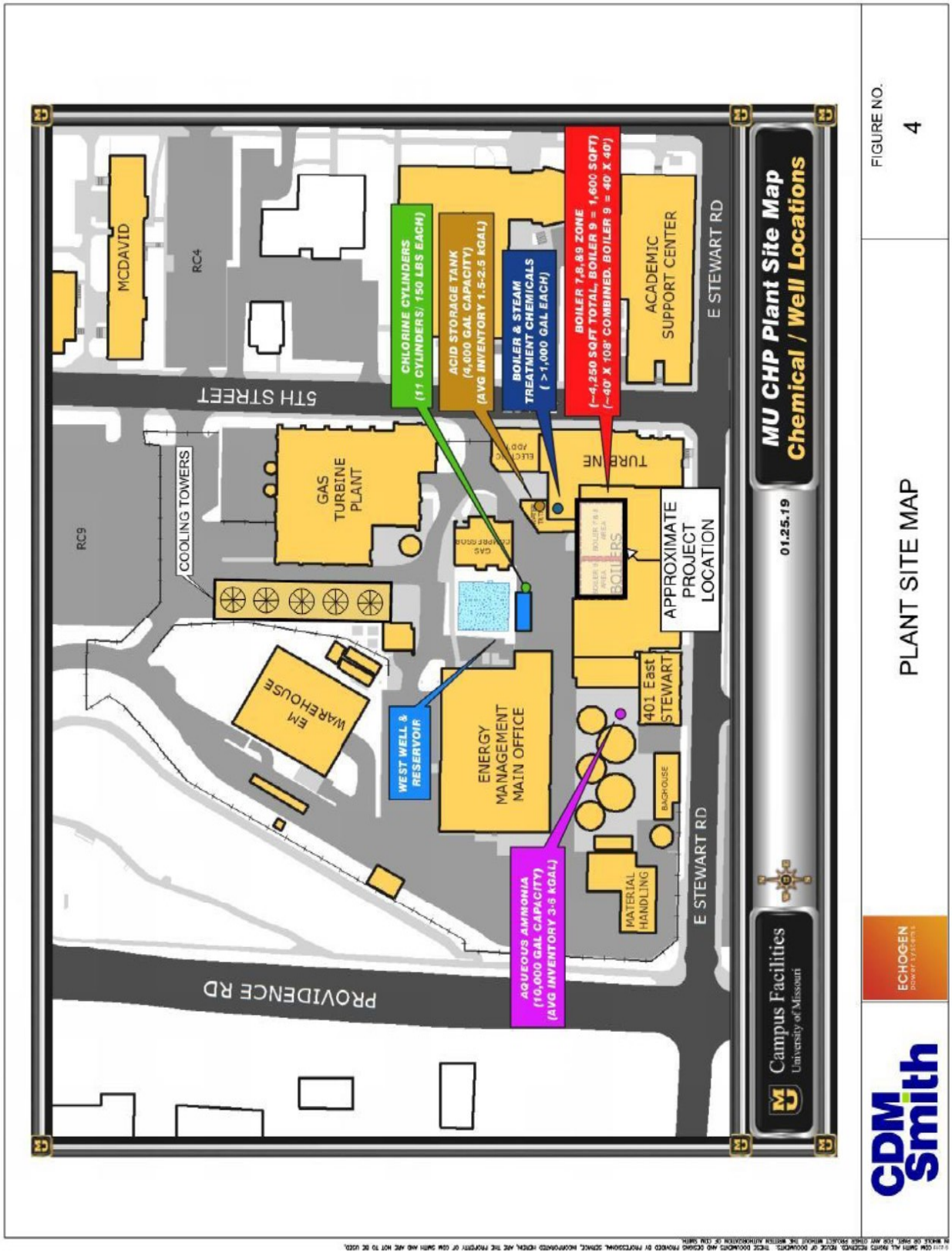
m. Would the proposed project require issuance of an Underground Injection Control (UIC) permit?
X No □ Yes (describe)

n. Would the proposed project be located in or near a wellhead protection area, drinking water protection area, or above a sole source aquifer or underground source of drinking water (USDW)?
□ No X Yes (describe)

A potable water supply well and underground potable water supply reservoir are located within the MU Power Plant property in the area north of the boiler room (Figure 4). There are four additional potable water supply wells on the University of Missouri campus outside of the power plant.

U.S. DEPARTMENT OF ENERGY

ENVIRONMENTAL QUESTIONNAIRE



U.S. DEPARTMENT OF ENERGY

ENVIRONMENTAL QUESTIONNAIRE

8. Solid and Hazardous Wastes

a. Identify and estimate wastes that would be generated from the project. Solid wastes are defined as any solid, liquid, semi-solid, or contained gaseous material that is discarded, has served its intended purpose, or is a manufacturing or mining by-product (See EPA Municipal Solid Waste and Municipal Solid Waste by State). The table below includes an estimate of the solid waste produced by, and attributable to, the pilot facility during operation.

	Annual Quantity
□ **Municipal solid waste (e.g., paper, plastic, etc.)**	28.8 cubic yards
□ **Coal or coal by-products (coal ash)**	3,800 tons
□ **Other -- Identify: (scrubber byproduct)**	1,660 tons
□ **Hazardous waste – Identify:**	
□ **None**	

The demolition of the existing boilers will result in additional one-time generation of solid waste. The quantity of demolition waste has not been estimated, but is expected to include asbestos, fiberglass insulation, steel, copper, concrete, coal ash residues, and ordinary rubbish.

b. Would project require issuance of new or modified solid waste and/or hazardous waste related permits to perform project work activities? X No □ Yes (explain)

The types, quantities, and characteristics of waste products produced at the pilot plant would be similar to those produced at the existing power plant. The primary solid waste products associated with the pilot plant are ash (including fly ash and bottom ash) and spent lime/carbon byproduct from the scrubber. The scrubber byproduct would be disposed of with the ash. The projected quantity of ash and lime production is approximately 5,460 tons annually. No additional waste disposal measures or infrastructure would be required to accommodate the pilot plant.

c. How and where would solid waste disposal be accomplished?

□ None generated

□ On-site (identify and describe location)

X Off-site (identify location and describe facility and treatment)

The coal ash produced at the location (including bottom ash and fly ash) is considered a Coal Combustion Byproduct (CCB), and is returned via truck to the coal supplier, Knight Hawk Coal facilities, located in Illinois. Knight Hawk Coal has Illinois Department of Natural Resources (IDNR) permits that allow them to dispose of the ash in specific areas that have been approved. While it is understood that the generated ash qualifies as beneficial use ash, their permit only allows them to landfill the material in designated areas of their operations, i.e. filling surface mined pits, etc. The generated ash is considered a CCB, which means coal combustion waste when used beneficially in any of several specified ways.

Asbestos-containing solid waste would be transported via truck to the City of Columbia Sanitary Landfill, which is permitted to accept asbestos materials.

d. How would wastes for disposal be transported?

Systems for storing and handling toxic/hazardous substances, including waste products, would be largely unchanged by pilot plant operation. Ash would continue to be handled according to plant safety guidelines and would be disposed of off-site by Knight Hawk Coal, located in Illinois. Scrubber byproduct would be disposed of together with ash. Due in part to scrubber byproduct disposal, the quantity of solid waste produced at the pilot plant would be slightly greater than quantity of ash produced by equivalent operation of the existing boilers. Solid waste handling and disposal would be manageable via existing in solid waste handling infrastructure.

U.S. DEPARTMENT OF ENERGY

ENVIRONMENTAL QUESTIONNAIRE

e. Describe hazardous wastes that would be generated, treated, handled, or stored under this project. Hazardous waste information can be found at EPA Hazardous Waste website. □ None

Asbestos will be handled during demolition of the existing boiler casings.

f. How would hazardous or toxic waste be collected and stored? □ None used or produced

Asbestos waste from the demolition will be handled in compliance with EPA, OSHA & MDNR regulations.

g. If hazardous wastes would require off-site disposal, have arrangements been made with a certified TSD (Treatment, Storage, and Disposal) facility?

□ Not required X Arrangements not yet made □ Arrangements made with a certified TSD facility (identify)

While specific arrangements have not yet been made, the City of Columbia Sanitary Landfill is permitted to accept asbestos-containing solid waste materials, which are expected to be generated as part of the removal of the existing boiler units.

9. Health/Safety Factors

a. Identify hazardous or toxic materials that would be used in the proposed project.

□ None X Hazardous or toxic materials that would be used (identify):

The proposed project would use Ammonium Hydroxide, Calcium Hydroxide and Carbon Dioxide. The AQCS will use the existing aqueous ammonia storage and forwarding system. Ammonium Hydroxide (19% Aqueous Ammonia) would be used in the proposed project. The AQCS will also use the existing hydrated lime storage and transport system, including Calcium Hydroxide – Hydrated Lime/Hydrate. The existing cooling tower will be used for this project. Materials used in connection with the cooling tower water treatment are as follows:

- Nalco 3DT199
- Nalco 3DT222
- Nalco H-550
- TowerBrom 960
- Sulfuric Acid

b. Describe the potential impacts of this project's hazardous materials on human health and the environment.

□ None

Ammonium Hydroxide (19% Aqueous Ammonia): May displace oxygen and cause rapid suffocation. Causes severe skin burns and eye damage. May cause respiratory irritation. Very toxic to aquatic life.

Calcium Hydroxide (Hydrated Lime): Causes skin irritation. Causes serious eye irritation. May cause respiratory irritation

Carbon Dioxide: Can cause rapid suffocation. May cause dizziness and drowsiness. Can increase respiration and heart rate. May cause nervous system damage. May cause frostbite

Nalco 3DT199: Causes eye damage. Causes skin burns. May cause irritation during inhalation. Ingestion may cause burns in digestive tract. Toxic to aquatic life with long lasting effects.

Nalco 3DT222: Causes severe skin burns and eye damage. May cause irritation during inhalation. Ingestion may cause burns in digestive tract. Toxic to aquatic life with long lasting effects.

Nalco H-550: Toxic if swallowed. Harmful in contact with skin or if inhaled. Causes severe skin burns and eye damage. May cause an allergic skin reaction. Causes serious eye damage. May cause allergy or asthma symptoms or breathing difficulties if inhaled. May cause respiratory irritation. Harmful to aquatic life.

U.S. DEPARTMENT OF ENERGY

ENVIRONMENTAL QUESTIONNAIRE

TowerBrom 960: Harmful if swallowed, in contact with skin or if inhaled. Causes skin irritation. Causes serious eye damage. Very toxic to aquatic life with long lasting effects.

Sulfuric Acid: Fatal if inhaled. Causes severe skin burns and eye damage. May cause cancer. Causes damage to organs. Harmful to aquatic life.

c. Would there be any special physical hazards or health risks associated with the project? □ No X Yes (describe)

The proposed project would pose normal physical hazards or health risks to the plant employees associated operation of a standard power plant, such as burns from coal and hot piping, pinch dangers from rotating equipment, exposure to high energy fluid and equipment with high pressures and temperatures, falls from elevated platforms, as well as general slips, trips and falls. Additionally, the proposed project involves potential exposure to hazardous materials, such as Ammonium Hydroxide, Calcium Hydroxide, Carbon Dioxide, and cooling tower chemicals. The health risks associated with Carbon Dioxide are being studied with dispersion modeling.

d. Does a worker safety program exist at the location of the proposed project? □ No X Yes (describe)

The MU Power Plant property is surrounded by a fence to prohibit public access. The proposed pilot plant project site is not accessible to the general public. In addition to personal protective equipment (PPE) specified by safety data sheets (SDSs) for chemical handling, hard hats and safety glasses are required to be worn by employees and visitors throughout most of the MU Power Plant, including the proposed project site. Any workers entering the site during construction and operation of the pilot plant would be provided ear protection, as required by OSHA regulations. The facility is smoke-free and requires visitors to check-in and be escorted within the plant property. All plant employees receive chemical worker training.

e. Would additional safety training be necessary for any new laboratory, equipment, or processes involved with the project?
□ No X Yes (describe)

Operation of the pilot plant would require use of CO_2 as the process fluid. CO_2 is minimally toxic, odorless, chemically inert, and nonflammable. However, the sCO_2 system operates using CO_2 at elevated pressures and temperatures; if a CO_2 leak occurs, the compressed CO_2 may quickly expand and displace oxygen in the local atmosphere, creating an asphyxiation hazard for workers in the area. The asphyxiation hazard risk would be monitored using a system of CO_2 sensors and proper ventilation controls would be in place to mitigate hazards in the event of a CO_2 leak. Evacuation and emergency response protocols would be developed to define emergency response actions. Employees would receive appropriate training to work under these potentially hazardous conditions and would adhere to all applicable OSHA guidelines.

f. Describe any increases in ambient noise levels to the public from construction and operational activities.
□ None X Increase in ambient noise level (describe)

Ambient noise at and around the MU Power Plant may be temporarily elevated during construction due to increased vehicle traffic and operation of construction equipment. Construction activities would be restricted to working hours to mitigate noise concerns. Operation of the plant is subject to a university-imposed 85 dB background noise limit. Any workers entering the site during construction and operation of the pilot plant would be provided hearing protection, as required by OSHA regulations. Currently, ambient noise from traffic is generally louder than plant activities at the fence line, and noise is not a major safety concern at the MU Power Plant. Noise at the fence line is not expected to increase from current levels due to operation of the pilot plant. Pedestrians on nearby sidewalks, passing vehicle traffic, and nearby residential and commercial areas are not expected to experience increases in ambient noise.

g. Would project construction result in the removal of natural or other barriers that act as noise screens?
□ No construction planned □ No X Yes (describe)

During construction of the proposed pilot project, the roof of the building would be temporarily removed to facilitate installation of new equipment. The roof serves as a barrier to noise traveling vertically. However, neither the old steam

boilers, nor the new pilot plant would be operational during the time the roof is removed. The roof will be replaced prior to pilot plant operation.

h. Would hearing protection be required for workers? □ No X Yes (describe)

Any workers entering the site during construction and operation of the pilot plant would be provided hearing protection, as required by OSHA regulations. This would be a continuation of the current active safety plan for the MU Power Plant facility.

10. Environmental Restoration and/or Waste Management

a. Would the proposed project include CERCLA removals or similar actions under RCRA or other authorities?

X No □ Yes (describe)

b. Would the proposed project include siting, construction, and operation of temporary pilot-scale waste collection and treatment facilities or pilot-scale waste stabilization and containment facilities? X No □ Yes (describe)

c. Would the proposed project involve operations of environmental monitoring and control systems?
□ No X Yes (describe)

Continuous emissions monitoring systems (CEMS) will be installed, operated and maintained to allow monitoring of permitted emissions (including SO_X and NO_X) to verify compliance with applicable permits. CEMS will be used to monitor SO_2 emission and a circulating dry scrubber will be used to control SO_2 emissions. A catalytic reduction system will be used to control NO_X emissions. Stack testing will be used to verify that CO emissions are in compliance with applicable permits. Nitrogen oxide (NO_X) emissions will be controlled using selective catalytic reduction (SCR) as specified in the permit application. The compliance with applicable permits for opacity limits will be monitored via the use of CEMS to measure particulate matter (PM) emissions and/or the use of continuous opacity monitoring system (COMS) for measuring the opacity of emissions discharged to the atmosphere. A baghouse will be used to control PM emissions.

d. Would the proposed project involve siting, construction, operation, or decommissioning of a facility for storing packaged hazardous waste for 90 days or less? X No □ Yes (describe)

There will be no new facility for storing packaged hazardous waste for 90 days or less.

E. REGULATORY COMPLIANCE

1. For the following laws, describe any existing permits, new or modified permits, manifests, responsible authorities or agencies, contacts, etc., that would be required for the proposed project

a. Resource Conservation and Recovery Act (RCRA): X None □ New Required □ Modification Required
Describe:

b. Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA):
X None □ New Required □ Modification Required
Describe:

c. Toxic Substance Control Act (TSCA): X None □ New Required □ Modification Required
Describe:

U.S. DEPARTMENT OF ENERGY

ENVIRONMENTAL QUESTIONNAIRE

d.	Clean Water Act (CWA): Describe:	X	None	□	New Required	□	Modification Required
e.	Underground Storage Tank Control Program (UST): Describe:	X	None	□	New Required	□	Modification Required
f.	Underground Injection Control Program (UIC): Describe:	X	None	□	New Required	□	Modification Required
g.	Clean Air Act (CAA): Describe: The permit application was submitted to MDNR. (See Section II.D.6.)	□	None	□	New Required	X	Modification Required
h.	Endangered Species Act (ESA): Describe:	X	None	□	New Required	□	Modification Required
i.	Floodplains and Wetlands Regulations: Describe:	X	None	□	New Required	□	Modification Required
j.	Fish and Wildlife Coordination Act (FWCA): Describe:	X	None	□	New Required	□	Modification Required
k.	National Historic Preservation Act (NHPA): Describe:	X	None	□	New Required	□	Modification Required
l.	Coastal Zone Management Act (CZMA): Describe:	X	None	□	New Required	□	Modification Required

2. Identify any other environmental laws and regulations (Federal, state, and local) for which compliance would be necessary for this project, and describe the permits, manifests, and contacts that would be required.

None.

F. DESCRIBE ANY ISSUES THAT WOULD GENERATE PUBLIC CONTROVERSY REGARDING THE PROPOSED PROJECT. □ None

Some members of the local community may voice opposition to the potential for the proposed project to support continued use of fossil fuels. The proposed technology has the ability to support multiple fuel types (e.g. coal, natural gas

ENVIRONMENTAL QUESTIONNAIRE

and biomass). While public education has not been explicitly included on the project plan, some level of public outreach and education may be considered to explain the benefits of the technology and the ability to support multiple fuel types.

The temporary road closures that would accompany the construction phase of the proposed project may present an inconvenience to the local community.

G. WOULD THE PROPOSED PROJECT PRODUCE ADDITIONAL DEVELOPMENT, OR ARE OTHER MAJOR DEVELOPMENTS PLANNED OR UNDERWAY, IN THE PROJECT AREA?

X No □ Yes (describe)

There exists the potential for general maintenance and repair work to be performed in the proposed project area. Any such work could be done in parallel with the proposed project and is not expected to have any impact upon the activities or schedule of the proposed project.

H. SUMMARIZE THE SIGNIFICANT IMPACTS THAT WOULD RESULT FROM THE PROPOSED PROJECT.

X None (provide supporting detail) □ Significant impacts (describe)

Based upon the preliminary review of the proposed project scope and plans, it is anticipated that there would be no significant adverse environmental consequences, and that there would be no significant impacts from the proposed project.

I. PROVIDE A DESCRIPTION OF HOW THE PROJECT WOULD BE DECOMMISSIONED, INCLUDING THE DISPOSITION OF EQUIPMENT AND MATERIALS.

The proposed project execution plan does not include a decommissioning phase. Assuming that the DOE elects to abandon the equipment in place, it is anticipated that the project equipment would remain in place for continued operation by the university, after the end of the proposed testing program.

III. CERTIFICATION BY PROPOSER

I hereby certify that the information provided herein is current, accurate, and complete as of the date shown immediately below.

Signature: _____ Date (mm/dd/yyyy): _____

Typed Name: _____

Title: _____

Organization: _____

IV. REVIEW AND APPROVAL BY DOE

I hereby certify that I have reviewed the information provided in this questionnaire, have determined that all questions have been appropriately answered, and judge the responses to be consistent with the efforts proposed.

DOE Project Manager

Signature: _____ Date (mm/dd/yyyy): _____

Typed Name: _____