FINAL TECHNICAL REPORT

- United States Department of Energy
- Award # EE0002856
- Project Title: Beowawe Bottoming Binary Unit
- Principal Investigator:
    - Dale McDonald
      Senior Engineering Manager
      (646) 829-3944
      dmcdonald@terra-genpower.com
- Submitting Official:
    - Vitaly Lee
      Vice President, Business Management
      (646) 829-3955
      vlee@tgpnyc.com
- Submission Date: 01/04/2013
- DUNS Number: 967623120
- Recipient:
    - Beowawe Binary, LLC
      9590 Prototype Ct. Ste. 200
      Reno, NV 89512
- Grant Period: December 2009-December 2013
- Reporting Period End Date: 12/31/2012

Executive Summary

This binary plant is the first high-output refrigeration based waste heat recovery cycle in the industry. Its working fluid is environmentally friendly and as such, the permits that would be required with a butane based cycle are not necessary. The unit is modularized, meaning that the unit's individual skids were assembled in another location and were shipped via truck to the plant site. This project proves the technical feasibility of using low temperature brine

The development of the unit led to the realization of low temperature, high output, and environmentally friendly heat recovery systems through domestic research and engineering.

The project generates additional renewable energy for Nevada, resulting in cleaner air and reduced carbon dioxide emissions. Royalty and tax payments to governmental agencies will increase, resulting in reduced financial pressure on local entities. The major components of the unit were sourced from American companies, resulting in increased economic activity throughout the country.

Accomplishments

Project Objectives:

Perform a study to determine the technical and economic feasibility of a power generation expansion at the existing Beowawe Geothermal Power Plant utilizing binary technology that derives its heat source from the existing low pressure, low temperature (205F) brine that is currently injected into the geothermal reservoir.

Obtain the necessary permits related to the expansion, including water rights for anew fresh water well that will provide makeup water for the new cooling system.

Engineer, procure, construct, test, and commission a 1,853 kW electric (MWe) binary plant.

Operate and maintain the new binary plant, providing non-proprietary data to the NGDS and DOE GTP for a minimum of two years.

Accomplishments Under Objectives:

- The Binary Unit Generated 10,002 MWh at an availability factor of 94.1% in 2011, and generated a net 9545 MWh at an availability of 95.90% (adjusted for binary-only related outages) in 2012. The lower production in 2012 was due to an extended outage of the main steam plant.
- Condenser fouling due to debris in the cooling tower basin led to diminished production. The condenser was cleaned and the unit returned to normal operation.
- The unit has undergone various logic and wiring changes to allow the cooling tower fans to operate in reverse. Periodic reversal of the flow direction is necessary to de-ice the tower under freezing conditions.
- Various changes have been made to the HMI programming to increase performance tracking and monitoring abilities.
- Adverse operating conditions which have led to the release of refrigerant have been successfully addressed with the addition of a recovery and storage system.
- With a clean condenser, the plant performs at or above what is guaranteed by the performance curves.

Opportunities for Training and Professional Development

- The construction of the plant led to the creation of two permanent positions within the company- a plant engineer and a plant operator.
- Twenty-four jobs were created during the design, planning, and construction phases of the project.
- The binary plant gives the steam plant operations personnel the opportunity to operate a binary plant, which has become mainstream within the geothermal industry.

Results Disseminated to Communities of Interest

- Operating data and maintenance expenses are reported on a monthly basis to the DOE's Low Temperature Team.
- The binary team plans make a presentation regarding the unit at the 2012 GRC.

Products

Nothing to Report

Participants and Other Collaborating Organizations

Nothing to Report

Special Reporting Requirements

Changes/Problems

Neither the project objectives nor the approach have been changed throughout the duration of the project. At this time, the focus of the operations and engineering team is to optimize the unit in terms of thermal efficiency and reliability.

Paper submitted for Oral Presentation at the GRC Annual Meeting, October 23-26, 2011, Town & Country Resort & Conference Center, San Diego, California.

Title: **A NEW HIGH EFFICINCY BINARY EXPANDER DESIGN: LOW TEMPERATURE GEOTHERMAL APPLICATION BOTTOMING BEOWAWE GEOTHERMAL FLASH PLANT**

Author: **Halley K. Dickey, TAS Energy, Inc.**
Address: 6110 Cullen Blvd.
Houston, TX 77021
Phone: 909-838-6235
E-mail: HDickey@TAS.com

Author(s): **Greg Forsha, Mike Forsha, Bob Linden; Barber-Nichols Inc.**
Address: 6325 West 55th Avenue
Arvada, CO 80002
Phone: 303-421-8111
E-mail: (GForsha, MForsha, RLinden)@Barber-Nichols.com

TEXT

A NEW HIGH EFFICINCY BINARY EXPANDER DESIGN: LOW TEMPERATURE GEOTHERMAL APPLICATION BOTTOMING BEOWAWE GEOTHERMAL FLASH PLANT

Halley K. Dickey
TAS Energy, Inc.
6110 Cullen Blvd., Houston, TX 77021
E-mail: HDickey@TAS.com

Greg Forsha, Mike Forsha, Bob Linden
Barber-Nichols Inc.
6325 West 55th Avenue Arvada, CO 80002
E-mail: (GForsha, MForsha, RLinden)@Barber-Nichols.com

Keywords
Turbo-expander, ORC cycle, low-temperature geothermal, bottoming cycle, Beowawe

ABSTRACT

Through the development of a range of new high efficiency binary expanders applied to the Organic Rankine Cycle, lower than traditionally thought of as "commercially viable resource temperatures" can now be utilized for geothermal and waste heat applications. Generally not considered viable for utility scale deployment, the project demonstrates the technical and economic feasibility of electricity generation from nonconventional geothermal resources of 205°F, utilizing the first commercial use of a low temperature bottoming cycle at a geothermal flash power plant.

In May of 2009, the U.S. Department of Energy's (DOE) Geothermal Technologies Program (GTP) issued a Funding Opportunity Announcement (DE-FOA-0000109) to promote the development and commercial application of energy production from Low-Temperature Geothermal Fluids, between 150-300° Fahrenheit. Terra-Gen Power, LLC successfully received an award to demonstrate the technical and economic feasibility of geothermal energy production from these non-conventional geothermal resources.

This paper intends to highlight; 1) the successful development of a new design axial turbine family for geothermal and waste heat applications, applied to 2) the successful utilization of a low temperature resource in a commercial utility power sale setting, and finally 3) the successful demonstration of flash bottoming binary cycle technology.

Introduction to a New ORC Turbine Family

In conjunction with Barber Nichols Inc (BNI), TAS has successfully developed an axial turbine – gearbox family for ORC applications. The turbine design is focused mainly on geothermal and waste heat applications using R134a and R245fa and as the primary working fluid, to cover gross power output from 500 kW – 5.0 MW output with temperatures from 200 – 500°F (97 - 260°C) designed to work with both water cooled and air cooled heat rejection.

The Design Challenge

The first step in achieving the desired result was to identify and establish the key design goals and current market limitations / barriers:

- Recognition that a customized one off approach to equipment design is not aligned with the majority of market needs, and
- At these low power levels, high turbine-gearbox costs (on a $/kW basis) can challenge plant economics.
- Develop a family of pre-engineered turbines with suitable modularity to allow use of common parts as the general architecture, with a
- Market changing design with a result that would improve the customer value proposition; by both reducing lead-time, and maximizing NPV.
- Design objective was to minimize production unit cost while maintaining high reliability and good performance.
- Achieve the widest application (ORC fluid selection, source temperature and output range) using a minimum number of configurations.

The Design Process

Design for manufacturability and assembly (DFM/DFA) is the classic method for creating good product design via reduced part count, simplified manufacturing techniques, and standardize parts and materials with the ultimate goal of developing a quality product at the lowest cost while saving time. The primary advantage of the design for assembly (DFA) methodology is that it ensures a good design early in the design process further reducing the detailed design effort and cost. DFM/DFA methodology was used throughout the process:

- The design is simple with a low parts count See Figure 1
- Different turbine configurations use most of the same parts w/ different trims
- Simple castings incorporate key design features
- The small size of the turbines allows the use of low cost radially split housings
- Two piece turbine plenum/bearing housing design provides effective, low cost thermal isolation between turbine inlet stream and seal and bearing assemblies
- The need for piping expansion joints is minimized with a strong, stiff plenum that will handle piping stress loads in excess of API requirements
- Rotor blades are Electro-Chemically Milled (ECM) on the rotor disk and the shroud is electron beam welded to produce a low cost, robust rotor
- Turbine speeds are limited to enable the use of manufacturer's standard industrial (pre-engineered) gearboxes, reducing cost and lead time
- Turbine thrust is limited to enable use of off-the-shelf rolling element bearings
    - Bearing scheduled maintenance interval is 2 years
    - Ball bearings limit shaft deflections and improve seal life
    - Turbine thrust bearing capacity eliminates the need for thrust bearings in the gearbox which improves gearbox efficiency to greater than 98%
    - Turbine bearing lube oil demand is minimized, favorably impacting oil sump and pump size

[*Insert Figure 1: Turbine Design Concept*]

- Figure 2 shows CFD results for the turbine flow path:
  - The design achieves high performance with a high stage loading (to reduce the number of stages) and limits reaction to maintain low thrust
  - Resulting blades and vanes can be manufactured with cost effective ECM and flank milling processes respectively
- The design facilitates rapid field maintenance:
  - Access to turbine internals only requires removal of piping spool piece
  - Turbine rotors are slip-fit and locked to the shaft with tapered locking devices to allow rapid removal / replacement without the need for heat
  - The shaft/bearing/seal subassemblies are interchangeable and a preassembled spare can be stocked at a service center to eliminate the need for a complete field disassembly

[*Insert Figure 2: Turbine Flow Path CFD Results*]

The Results

The results speak for themselves. Figure 1 shows the basic design concept for the axial flow turbine family. The power range is covered with two cast turbine plenums – one for low flows and one for high flows. The temperature range is covered with a single-stage or two-stage turbine; a single-stage for lower to moderate temperatures, and two-stage for higher temperatures. Figure 1 shows single-stage configuration. The second stage is simply mounted on the shaft extension.

The single stage unit is expected to be applied to lower temperature applications, mostly geothermal in the 200-350°F range, where there is a lower enthalpy drop and R134a is the preferred refrigerant. The range of output is expected to be in the 2.5 to 5MW range which represents the lower end of the geothermal applications. See Figure 3.

[*Insert Figure 3: Manufactured Turbine in the TAS Shop*]

All configurations use the same shaft-bearing-rotor assembly. A symmetric design allows for either direction of rotation and application in dual drive configurations. This provides for a standard design having the same skid foot print for all applications throughout the entire 500kW – 5.0MW range, applicable to geothermal, solar thermal, and waste heat recovery to power, with either R134a or R245fa..

Cost Effective Low Temperature Design - Health and Safety Benefits

This application utilizes R134a, an environmentally friendly working fluid that is well known and proven. The thermodynamic properties of R134a provide the highest practical cycle efficiency given the low temperature of the resource. Further, the high molecular weight allows for a smaller number of turbine stages to reduce cost of the power turbine equipment.

The safety and environmental impact of the TAS equipment provides a significant advance in binary cycle power plants over the working fluids used in isopentane (flammable and explosive) and ammonia (toxic) cycle technologies.

R-134a is non-flammable, unlike conventional hydrocarbon-based binary systems that use pentanes, butanes, propanes, or their derivatives. Consequently, no fire protection system is required, with a resultant capital reduction.

R-134a is non-toxic and non-corrosive, unlike the ammonia which is proposed for use in some high-efficiency binary power cycles. R-134a eliminates a safety hazard for plant personnel, reduces or eliminates permitting costs and delays with state and federal agencies, and the concerns of those communities adjacent to large ammonia-using facilities.

The elimination of safety and environmental hazard leads directly to capital cost and operating cost reductions:

- R134a is not listed by or subject to the State of Nevada, Division of Environmental Protection, Chemical Accident Prevention Program (CAPP) - Permitting Requirements, eliminating cost and time delays.
- R134a is non-flammable. This eliminates the need for the fire protection system which is required for the use of hydrocarbon based binary power plants. As a result, insurance costs will be less since the plant has no flammable materials.
- As of January 2009, all employees working in facilities with flammable fluids are required to be provided with and wear non-flammable cover garments.
- R134a is non-toxic and non-corrosive, unlike the ammonia which is proposed for use in other high-efficiency binary power cycles. R-134a eliminates a safety hazard for plant personnel, permitting costs and delays with state and federal agencies, and the concerns of those communities adjacent to facilities with a large ammonia inventory.
- The overall higher environmental and safety benefits of the R134a have a benefit beyond the reduced capital cost and permitting effort. With no flammability and no toxicity, the prospect of reduced staffing is presented.
- For a simple process design with few rotating components, the potential for reduced staffing and cost savings is a reality.

DOE Low Temperature Project Application

In May of 2009, the U.S. Department of Energy's (DOE) Geothermal Technologies Program (GTP) issued a Funding Opportunity Announcement (DE-FOA-0000109) to promote the development and commercial application of energy production from Low-Temperature Geothermal Fluids, between 150-300° Fahrenheit. Terra-Gen Power, LLC successfully received an award to demonstrate the technical and economic feasibility of geothermal energy production from these non-conventional geothermal resources at their operating geothermal flash plant at Beowawe, near Battle Mountain, NV.

The FOA provided for the demonstration of the technical and economic feasibility of electricity generation from nonconventional geothermal resources of 205°F using the first commercial use of a low temperature bottoming cycle at a geothermal power plant, with an inlet temperature of less than 300°F. The proposed two-year project supports the DOE Geothermal Technology Program's goal of promoting the development and commercial application of energy production from low-temperature geothermal fluids, i.e., between 150°F and 300°F. The successful award was based on Terra-Gen Power's ability to:

- Perform a study to determine the technical and economic feasibility of a power generation expansion at the existing Beowawe Geothermal Power Plant utilizing binary technology which derives its heat source from the existing low pressure, low-temperature (205°F) brine, which is currently injected into the geothermal reservoir.
- Obtain the necessary permits related to the expansion, including water rights for a new fresh water well which will provide makeup water for the new cooling system.
- Engineer, procure, construct, test, and commission a 2.5 megawatt electric (MWe) binary plant.
- Operate and maintain the new binary plant, providing nonproprietary data to the National Geothermal Data System (NGDS) and the Department of Energy Geothermal Technologies Program (DOE GTP) for a minimum of two years.

[*Insert Figure 4: Beowawe Modular Plant Design*]

Benefits and Outcomes:

- Proving the technical and economic feasibility of utilizing the available unused heat to generate additional electric power from a binary power plant from the low-temperature brine at the Beowawe Geothermal Power Plant.
- Providing non-proprietary data to the NGDS and DOE for two years.
- Increased economic benefits in terms of job creation, income generation, and increased tax and royalty payments.
- Decreased greenhouse gas (GHG) emissions.

Impacts:

- Innovative application new to low temp geothermal, potentially adding 10% additional power.
- Good economics in high price region.

Beowawe Flash Plant

Located in Eureka County, NV, the Beowawe geothermal power station is owned by Terra-Gen Power, LLC. The geothermal area at Beowawe Geysers straddles the Eureka-Lander County line in Whirlwind Valley, about 10 km west of the small community of Beowawe, Nevada. It is one of the largest geothermal fields in Nevada with some of the highest reported subsurface temperatures in the state (reservoir temperatures of 213-216°C), making it an ideal area for the development and production of geothermal power.

The Beowawe flash power plant came on line in 1985, producing 16.7 MW from a 200°C resource. During the first year of plant operation, injection of spent brine outside of the Beowawe reservoir caused the reservoir pressure to reduce, which allowed cold ground water to flow into and cool the geothermal reservoir. The cold water inflow stabilized the reservoir pressure but over eight years it reduced the temperatures of the production wells by as much as 21C. A large new production well was drilled, which temporarily restored full plant output but accelerated the decline in reservoir pressure, causing a reduction in the power plant output. The problem was resolved over the next two years, and full production resumed.

In 2005, Sierra Pacific Power Company signed a 20-year contract to purchase geothermal power from Beowawe Power. Operated by Caithness Operating Company, the Beowawe plant will supply Sierra Pacific 17.7 MWe in January 2006.

- The Beowawe plant has experienced resource decline over its life and had a reduced output, well below the design output.
- The engineer, procure, construct, test, and commission of a new advanced design 2.5 MWe gross binary plant was completed by Terra-Gen Power, LLC. See Figures 2, thru 6.

[*Insert Figure 5: Beowawe Modular Skids in shop*]

- The plant was constructed through the end of 2010, and commission in January of 2011.
- The turbine is over-performing and exceeding the performance guarantee, currently producing in excess of 2.0 MWe.

[*Insert Figure 6: Beowawe Modular Bottoming Plant operating in field*]

Summary

This paper demonstrates how this project application benefits the geothermal industry worldwide by:

- Proving the technical and economic feasibility of utilizing typically available unused flash tank brine heat to generate additional electric power.
- Delivering increased economic benefits in terms of job creation, income generation, and increased tax and royalty payments.
- Decreasing greenhouse gas (GHG) emissions.
- Demonstrating how this innovative application can potentially add 15% additional power to a geothermal flash plant.
- Still delivering good economics even in high price region.
- Introducing a new market changing expander design that is now currently available as a standardized commercial product with performance guarantees, and offers the ability to improve a customer value proposition by reducing lead-time and maximizing NPV.
- Substantiating the commercial viability and utility use of low temperature heat sources from below 200°F on up.
- Establishes that rapidly deployable commercical technology is available to be applied to bottom cycle existing flash plants and low temperature, lowere enthalpy resources.
- Establishes the BNI design allowing geothermal and low heat applications up to 5.0 MW with a geared axial expander.

- Yields a flexible design capable of operating on R134a from extremely low temperatures to 350°F or higher, which is also capable of switching to R245fa above beyond the capabilities of R 134a, without any change in manufacturing design.
- Employs an innovative application of existing technology using a novel configuration and a new application. Consequently, a large efficiency improvement is accomplished with minimal technology risk.
- Results in a 15% increase in efficiency over existing binary geothermal power plants (on a power plant only basis), and thereby reduces the barrier to application, as well as a 20% reservoir capacity increase (MW of installed capacity for the same total fluid extraction) compared to existing geothermal binary power plants when the geothermal fluid pump parasitic loads are subtracted from the plant net output.
- May allow daily operations with fewer staff, enabling small geothermal resources to meet economic hurdles, obtain financing for development, and be added to total installed U.S. geothermal capacity.
- Shortens the time and risk to construct a power plant by 3 – 6 months, resulting in reduced financing costs during construction, and provides earlier commercial operations, all of which improve risked NPV.
- Employs proven manufacturing approach of prefabrication packaging allows 90% of the total plant construction inside the controlled environment of the TAS Energy Houston factory.
- Modularization of the packages results in rapid field assembly and the ability to match standard modules to various reservoir sizes.
- Has high U.S. content and opens a path toward export of the technology to globalize low to moderate temperature renewable resources.

FIGURES

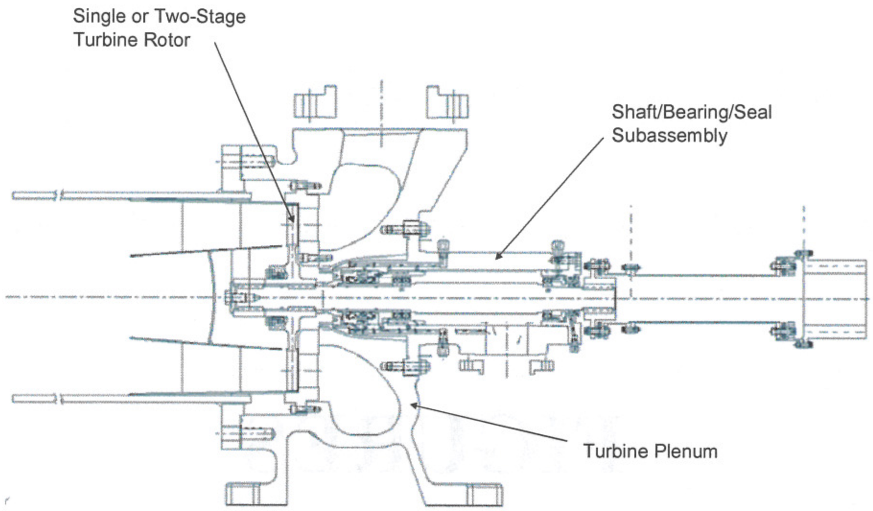


Figure 1: Turbine Design Concept

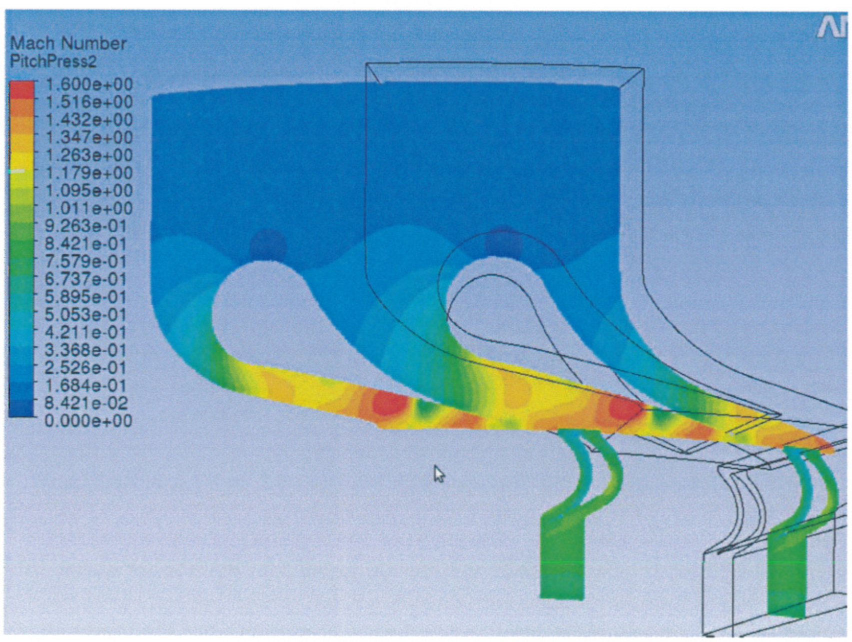


Figure 2: Turbine Flow Path CFD Results

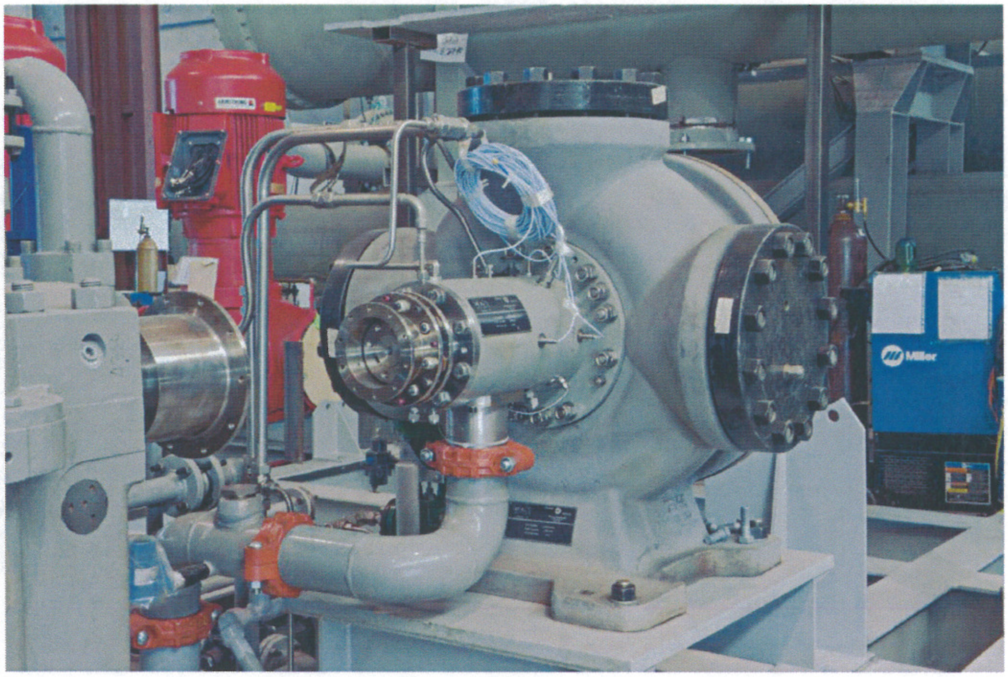


Figure 3: Manufactured Turbine in the TAS Shop

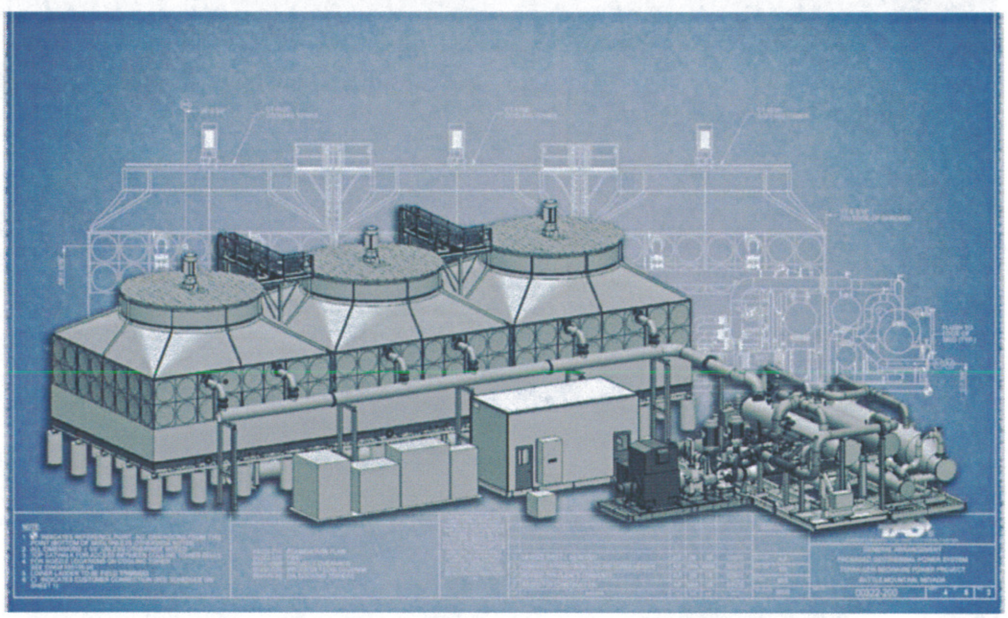
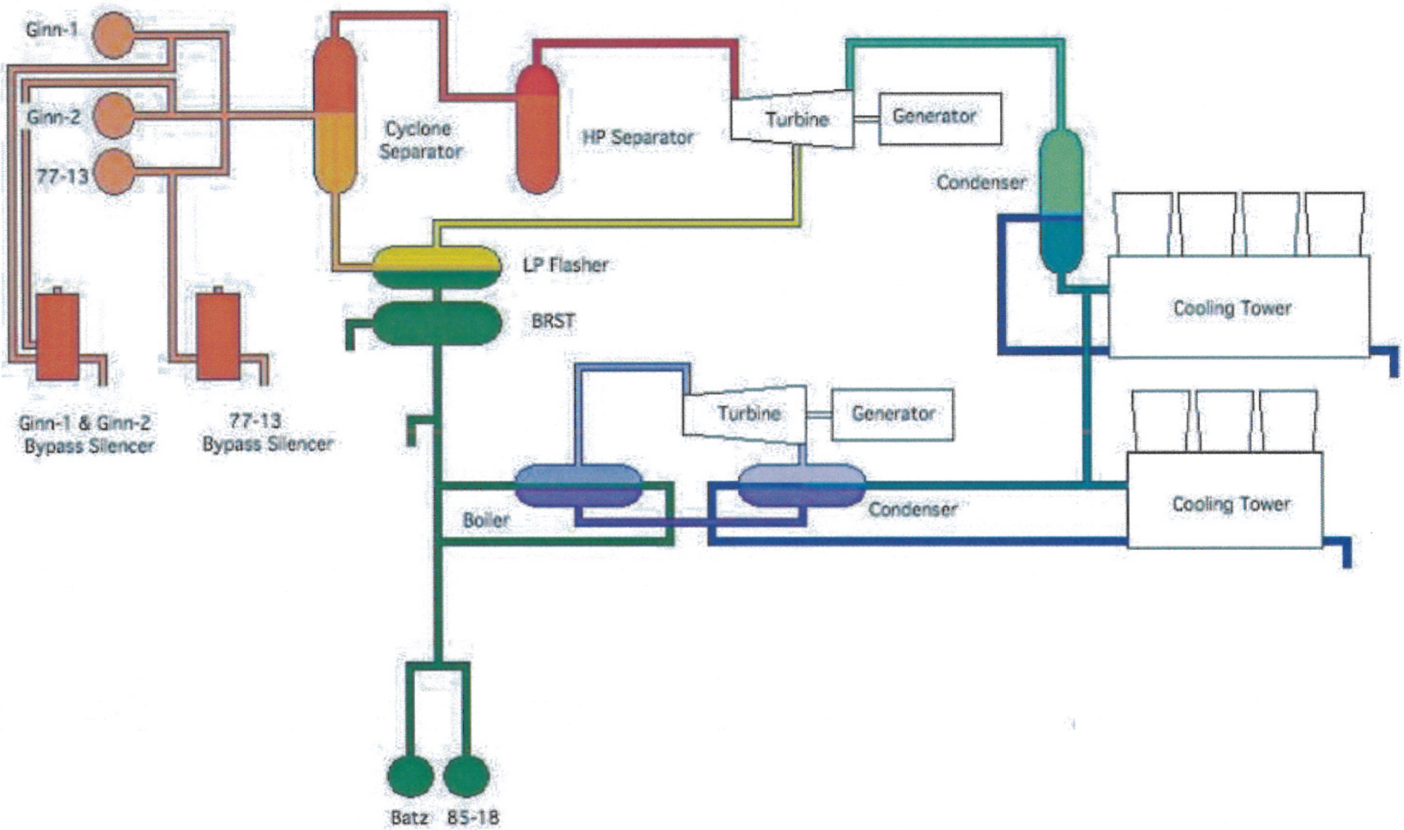


Figure 4: Beowawe Modular Plant Design

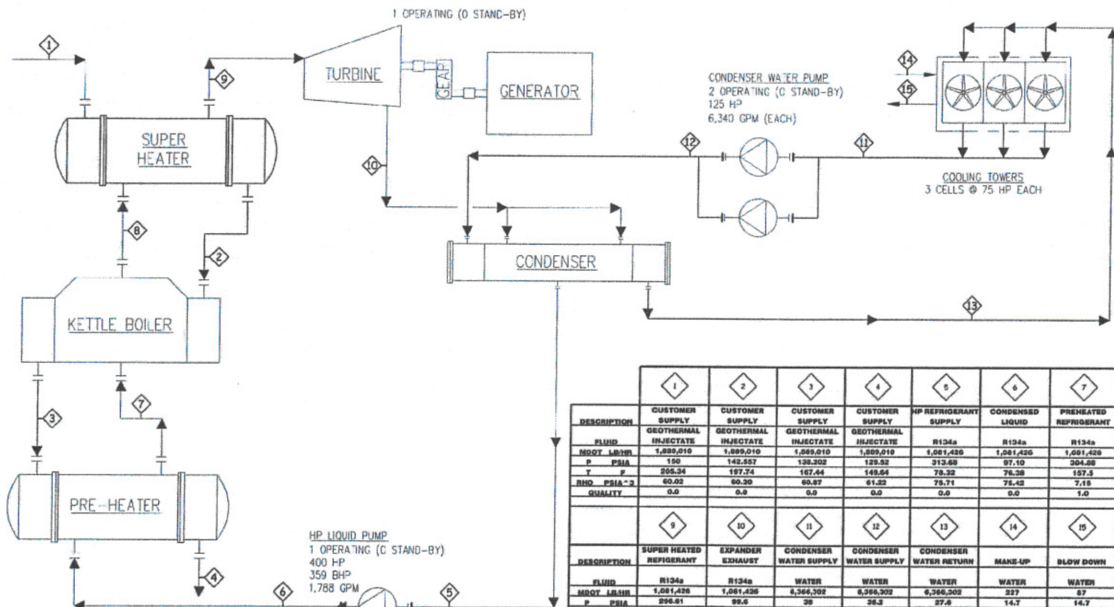
Figure 5: Beowawe Modular Skids in shop

Figure 6: Beowawe Modular Bottoming Plant operating in field


Ginn-1
Ginn-2
77-13
Cyclone Separator
HP Separator
Turbine
Generator
Condenser
LP Flasher
BRST
Cooling Tower
Ginn-1 & Ginn-2 Bypass Silencer
77-13 Bypass Silencer
Turbine
Generator
Boiler
Condenser
Cooling Tower
Batz
85-18

T:\Project Management\Projects\00322 Beowawe\08.0 Engineering\08.01 Drawings\08.01.02 Drawings Working\000 PFD\00322-010-01.dwg, 1/21/2010 1:29:39 PM

DWG NO. 00322-010 SHT 1 OF 1



	1	2	3	4	5	6	7	8
DESCRIPTION	CUSTOMER SUPPLY	CUSTOMER SUPPLY	CUSTOMER SUPPLY	CUSTOMER SUPPLY	HP REFRIGERANT SUPPLY	CONDENSED LIQUID	PREHEATED REFRIGERANT	VAPORIZED REFRIGERANT
FLUID	GEOTHERMAL INJECTATE	GEOTHERMAL INJECTATE	GEOTHERMAL INJECTATE	GEOTHERMAL INJECTATE	R134a	R134a	R134a	R134a
MDOT LB/HR	1,889,010	1,889,010	1,889,010	1,889,010	1,081,426	1,081,426	1,081,426	1,081,426
P PSIA	150	142.557	138.202	129.52	313.68	97.10	304.88	304.38
T F	205.34	197.74	167.44	149.64	78.32	76.38	157.5	157.5
RHO PSIA^3	60.02	60.30	60.87	61.22	75.71	75.42	7.15	7.13
QUALITY	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0

	9	10	11	12	13	14	15
DESCRIPTION	SUPER HEATED REFIGERANT	EXPANDER EXHAUST	CONDENSER WATER SUPPLY	CONDENSER WATER SUPPLY	CONDENSER WATER RETURN	MAKE-UP	BLOW DOWN
FLUID	R134a	R134a	WATER	WATER	WATER	WATER	WATER
MDOT LB/HR	1,081,426	1,081,426	6,366,302	6,366,302	6,366,302	227	87
P PSIA	296.61	99.6	38	36.2	27.6	14.7	14.7
T F	196	125.6	59.4	59.4	74.4	50	74.4
RHO PSIA^3	5.62	1.82	62.37	62.37	62.27	62.41	62.27
QUALITY	1.0	1.0	0.0	0.0	0.0	0.0	0.0

Sent 1.21.10 R/ Customer
Transmittal # 00322-3

NOTES:

REFERENCE DRAWINGS

PROPERTY OF TURBINE AIR SYSTEMS

DO NOT SCALE DRAWING

REV	DESCRIPTION	BY	CHK	APP	DATE
A	ISSUED FOR REVIEW	MEK	DAB	DB	01/21/10

TAS
6110 CULLEN BLVD. HOUSTON, TX 77021
PHONE: (713) 877-8700 FAX: (713) 440-8892

DRAWN BY: MEK	DATE: 01/20/10	CUST. P.O. NO: 0810C28-200
CHECKED BY: DAB	DATE: 01/20/10	SCALE: N.T.S.
APPROVED BY: DB	DATE: 1/21/10	SITE: BEOWAWE
PROJ. MGR:		TAS JOB NO: 00322

PROCESS FLOW DIAGRAM
GEOTHERMAL POWER SYSTEM
TERRA-GEN BEOWAWE POWER PROJECT
BATTLE MOUNTAIN, NEVADA

DWG. NO. 00322-010 SHEET 1 OF 1 REV. A

Exhibit B
Project Conditions and Scope of Supply

1.0 Project Description

The Advanced Heat Recovery (AHR) System developed and manufactured by Turbine Air Systems Ltd. (TAS) is a packaged solution for generating electrical power from various heat sources.

The proposed technology is a closed looped organic Rankine cycle. The cycle is a vapor power cycle with refrigerant (an organic fluid) instead of water/steam as the working fluid. Functionally it resembles the steam cycle power plant: a pump increases the pressure of condensed liquid refrigerant; the high pressure liquid is pre-heated via a recuperator exchanger; the liquid refrigerant is then vaporized in an evaporator (or waste heat recovery exchanger / WHRU) by extracting waste heat from the heat source; the high-pressure refrigerant vapor expands in a turbo expander and generator, producing power; and finally the low-pressure vapor leaving the turbine is de-superheated through the recuperator shell & tube heat exchanger and condensed via a condenser before being sent back to the pump to restart the cycle. The TAS AHR System utilizes an environmentally-friendly organic working fluid.

Location:

Geographical	Battle Mountain, NV
Average annual dry bulb temperature	Sub-freezing to 110.0°F
Cooling tower temperatures	57.0, 62.0, 67.0, 70.0, and 72.5°F
Altitude	~ 5000 ft above sea level
Corrosion potential	High desert
Hazard potential	Safe area
Dust potential	None considered
Design wind velocity	80mph / 35.8 m/s
Protection	NEMA 4 for weather exposed items
Seismic	Zone 4

Source energy:

Primary process	Geothermal injectate – from low pressure separator
Heat stream	Geothermal ground fluids
Temperature	205°F (customer supplied)
Temperature downstream of AHR	140°F
Flow	3900 GPM maximum (customer supplied)
Maximum source side pressure	150 PSIG - from low pressure separator

AHR heat rejection (HR):

Media	Cooling tower available at site – options as requested
Rating condition for AHR output	45°F Wet bulb (customer supplied)

Electrical Output:

TAS System Net output	1,931kW expected at design of 45°F wet bulb **(guaranteed 1,853kW)**

2.0 Major Equipment Description

The AHR module will consists of multi section heavy duty structural steel equipment skid with packaged turbo-generator set, cooling tower modules, heat exchangers, high pressure liquid refrigerant pump, medium and low voltage switchgear, enclosure for sound noise reduction, ANSI B31 piping, valves, pumps, PLC system controls, factory installed and pre-wired.

The AHR equipment skid is prefabricated to the maximum extent possible such that field installation consists of only setting the AHR skid on a prepared foundation, , connecting the condensate heat source, utility services and control interfaces.

The AHR system uses an Allen Bradley Programmable Logic Controller (PLC). The PLC interfaces with a graphical touch screen Human Machine Interface (HMI) terminal located on the face of the control panel in the motor control center (MCC) section of the module. This system is used to automatically safely start, stop and control the system under steady state / changing conditions, provide a visual indication of operating status, alarms, faults and monitor protective devices associated within the AHR process.

The system is prefabricated, under an ISO 9001:2000 quality management system, to the maximum extent possible such that field installation consists of setting the package on your prepared foundations, connecting utility services, control interfaces and connection to the plant condenser water supply / return.

Advanced Heat Recovery Module (1 Total)

Design type	Pre packaged skid, partial weather enclosure
Controls	Allen-Bradley PLC
Corrosion protection	TAS standard industrial paint system
Weather protection	NEMA 4 weather exposed, otherwise NEMA 3R
Electrical hazard protection	Safe area
Sound power level (L_w)	85 dbA re 10^{-12}W

Package Module Comprising:

Turbo Expander (1 per module)

Manufacturer	TAS – BNI Design
Design code	API 611 style
Expander type	Axial-single stage
Speed	TBA RPM to 1825 RPM output
Materials of construction	Pressure casing Cast steel
Drive type	via speed reduction gearbox

Generator (1 per module)

Design code	NEMA
Type	Synchronous
Speed	1825 RPM
Enclosure	TEFC
Maximum output	3,000kW

High Pressure Liquid Pumps (1 per module)

Type	Multistage centrifugal
Capacity	1 x 100%
Speed	3550 RPM
Shaft seal type	Mechanical, oil buffered
Motor	400 HP, 480V, 3PH, 60Hz

Evaporator – Geothermal Condensate - heat transfer to refrigerant

Design code	ASME
Type	Shell & Tube TEMA Class C Preheater and Evaporator
Tube material	Carbon steel
Shell and balance of equipment	Carbon steel

Condenser, refrigerant to cooling tower water

Design code	ASME
Type	Shell & tube exchanger
TEMA	Class C
Tube material	Carbon steel
Balance of equipment	Carbon steel

Cooling Water Pumps

Type	Single stage centrifugal
Capacity	1 x 100%
Speed	3625 RPM
Shaft seal type	Mechanical
Motor	300 HP each, 480V, 3PH, 60Hz

Cooling Tower Array - Base

Type	Induced draft
Fill type	PVC
Number of cells	3
Fan motor x number / type	Total 3 fans (1 per cell) x 75 hp each / TEFC

Packaged ORC Skid Structural Features

Modular, suitable for outdoors installation, with the following design features:

- Structural steel members: ASTM A572 runners minimum, perimeter and intermediate.
- Retractable lifting trunnions: (4) per module; accord w/ ASME B30.20 - field placement / mobility.
- Jack bolts (1) per anchor bolt hole - each longitudinal structural steel skid member.
- Flooring - Electrical room: $^{3}/_{16}$" (4.8 mm) min diamond plate - epoxy grade paint
- Flooring, equipment skid – open design with grating for maintenance and operator access
- Piping: Fabricated to ANSI B31 standards (B31.1 power / B31.5 refrigeration) includes valves, low point drains, insulation on hot surfaces and ¼" stainless steel instrumentation tubing
- Controls: For motor starters / electrical equipment, operator interface via control panel
- Grounding: (2) grounding bosses on skids, opposite ends
- Regional design capable: Seismic, high wind, arctic

3.0 Electrical & Utility Requirements

Electrical

	Quantity	Requirements	Notes
Electrical Generator:	One	3,000kW, 4160V	Single Expander to generator
Electrical Loads:	One	400HP, 480 volts	Liquid refrigerant pump motors
	One	300HP, 480 volts	Cooling water pump motors
	Three	75 HP, 480 volts	Cooling tower fan motors
	One	20 HP, 480 volts	Air Compressor motor (intermittent)
	Two	2 HP, 480 volts	Ventilation fan motors
	One	1.5kW, 120 volts	System controls and PLC
Control system:			UPS power is not required

Utilities	Supplied by	Requirements	Notes
Instrument Air	TAS	Usage < 5 scfm	80 min - 175 max psig - 40°F dew point
Cooling tower water	Customer	Usage ~2% flow	~ 274 GPM
Water drain	Customer	Bleed	68 GPM Cooling tower blow down
Chemical treatment	Customer	As needed	Customer supplies water management

Renewable Energy Systems

NEW HIGH EFFICIENCY EXPANDER DESIGN: LOW TEMP GEOTHERMAL APPLICATION BOTTOMING BEOWAWE FLASH PLANT

2011 GRC Annual Meeting

San Diego, California

October 25, 2011

TAS

economic. clean. energy.

introduction

- TAS - Barber-Nichols, Inc. (BNI) has developed a range of new high efficiency ORC expanders: 500 kW – 5.0 MW
- Substantiated commercial viability of utility scale low temperature heat sources from below 200°F
- DOE Funding Opportunity demonstration at Terra-Gen Power's Beowawe Geothermal Flash Plant
- Utilizing unused flash tank brine heat to generate additional electric power – 2.5 MW Gross.
- Improved financial performance:
  - Adding 15% additional power to a geothermal flash plant
  - Delivering improved economics even in high price regions
  - Decreasing greenhouse gas (GHG) emissions.

proven approach

- R134a (or R 245fa) - well known - proven environmentally friendly working fluid
- Highest practical cycle efficiency given the low temperature of the resource
- Improved safety and environmental impact - non-flammable - non-explosive - non-toxic
- 15% increase in efficiency over existing binary technology
- Reduces the barrier to application
- Increases reservoir capacity by 20% (MW of installed capacity for the same total fluid extraction) - compared to existing pumped geothermal binary power plants

flexible approach

- Shortens time and risk to construct - 3 – 6 months
  - De-risk and improve NPV
  - Reduced financing costs during construction
  - Earlier commercial operations = early revenue
- Proven manufactured prefabrication packaging
  - Allows 90% of the total plant construction inside the controlled environment
  - Modularization of the packages results in rapid field assembly
  - Ability to match standard modules to various reservoir sizes
- High U.S. content opens a path toward technology export - globalize low to moderate temperatures

a new ORC turbine family

- Recognition - "one-off" - not aligned with the market needs
- At these low power levels, high turbine-gearbox costs (on a $/kW basis) can challenge plant economics
- Develop "family of pre-engineered turbines"
  - Highest possible efficiency
  - With suitable modularity
  - Common parts count as the general architecture
- Market changing design
  - Improving customer value proposition
  - Reducing lead-time
  - Maximizing NPV
- Minimize production cost – maintain reliability & performance.
- Widest application - fluid selection, source temp - output - minimum number of configurations.

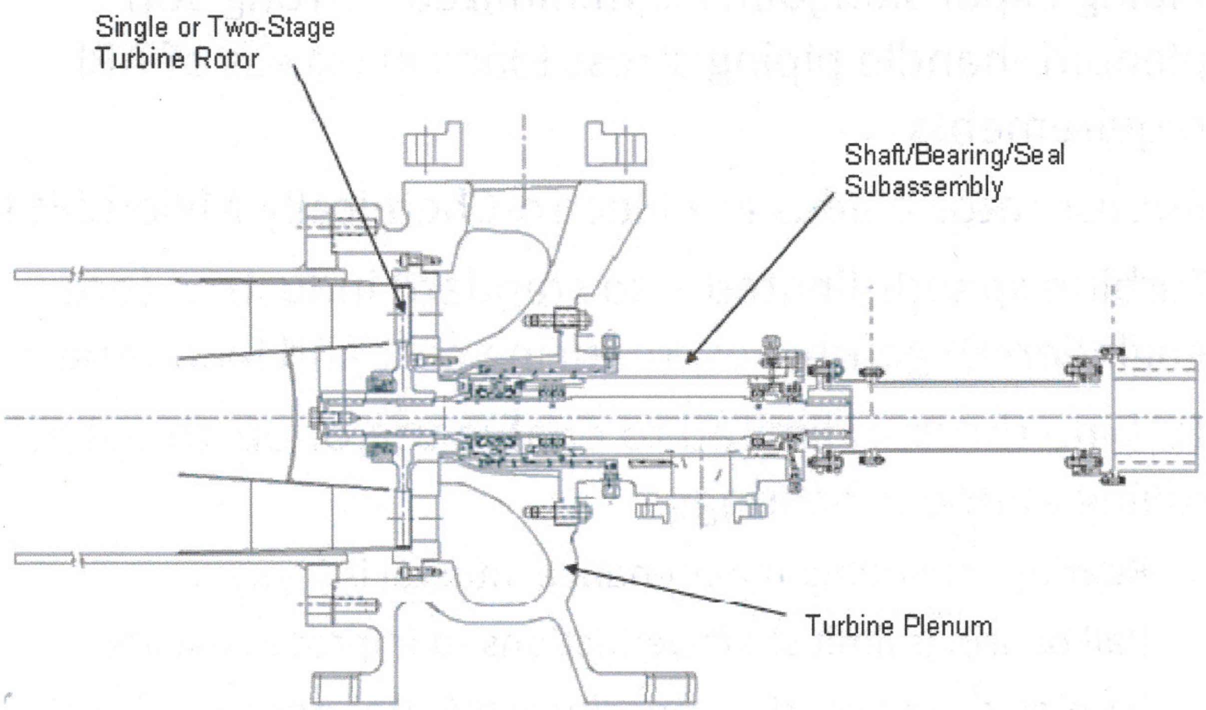
design process

- Design for manufacturability and assembly (DFM/DFA)
  - Reduced part count, simplified manufacturing techniques, and standardize parts and materials
  - Developing a quality product at the lowest cost while saving time.
- Different turbine configurations use most of the same parts w/ different trims
- Simple castings incorporate key design features
- The small size of the turbines allows the use of low cost radially split housings
- Two piece turbine plenum/bearing housing design provides effective, low cost thermal isolation between turbine inlet stream and seal and bearing assemblies

design process

- Piping expansion joints is minimized - strong stiff plenum -handle piping stress loads in excess of API requirements
- Robust rotor blades are Electro-Chemically Milled (ECM)
- Turbine speeds limited – so standard industrial (pre-engineered) gearboxes, reducing cost and lead time
- Turbine thrust is limited to enable use of off-the-shelf rolling element bearings
  - Bearing scheduled maintenance interval is 2 years
  - Ball bearings limit shaft deflections -d improve seal life
  - Turbine thrust bearing capacity eliminates need for thrust bearings in the gearbox -gearbox efficiency > 98%

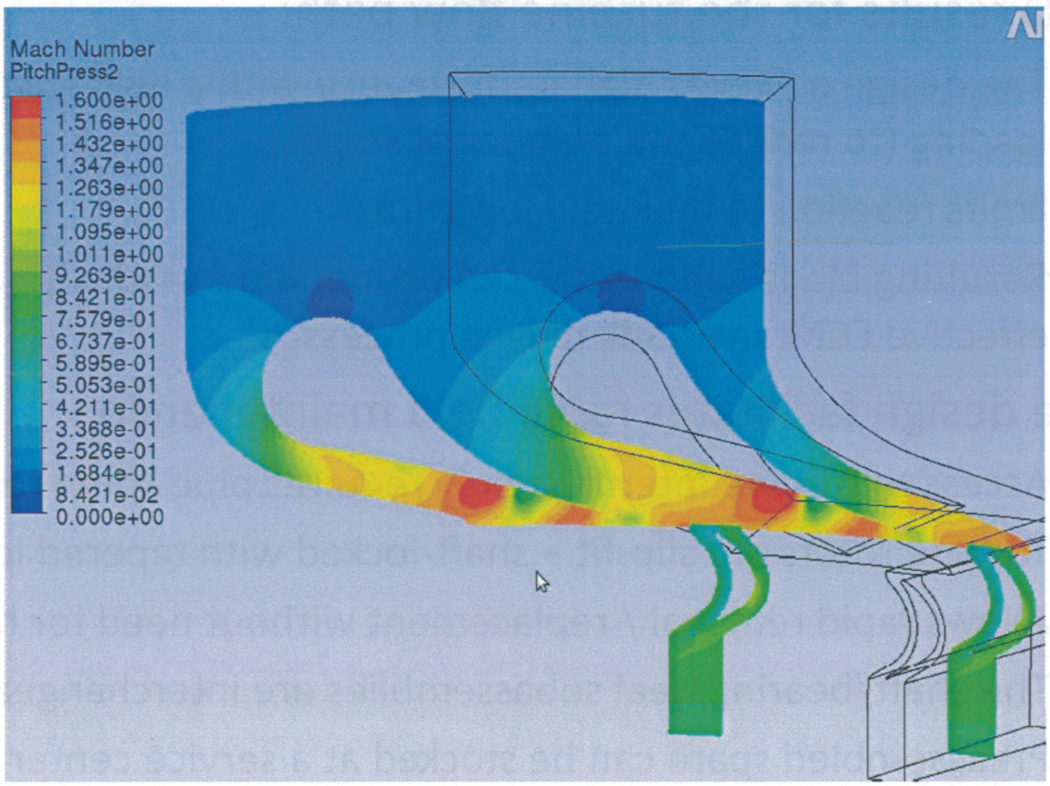
turbine design cutaway



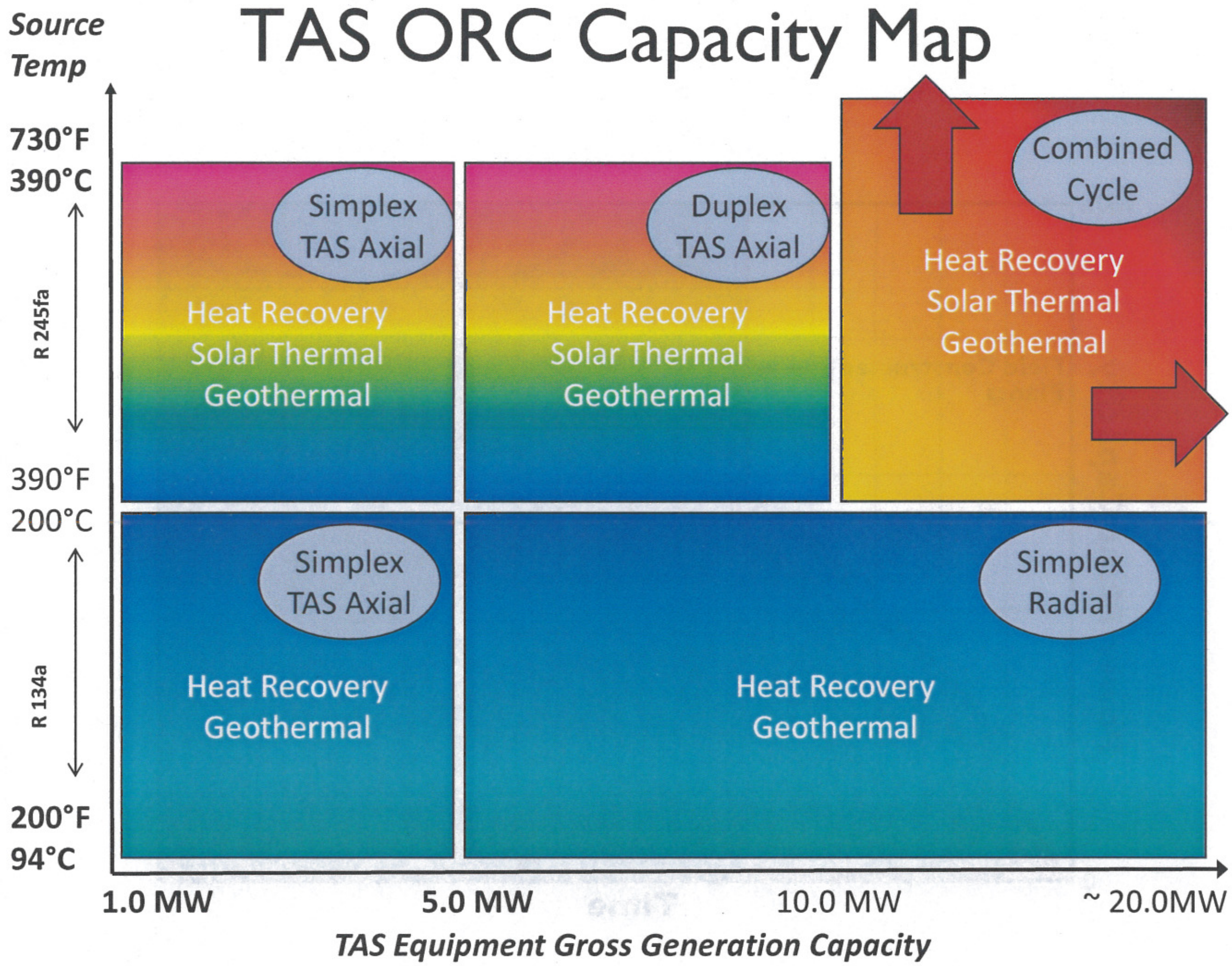
design result

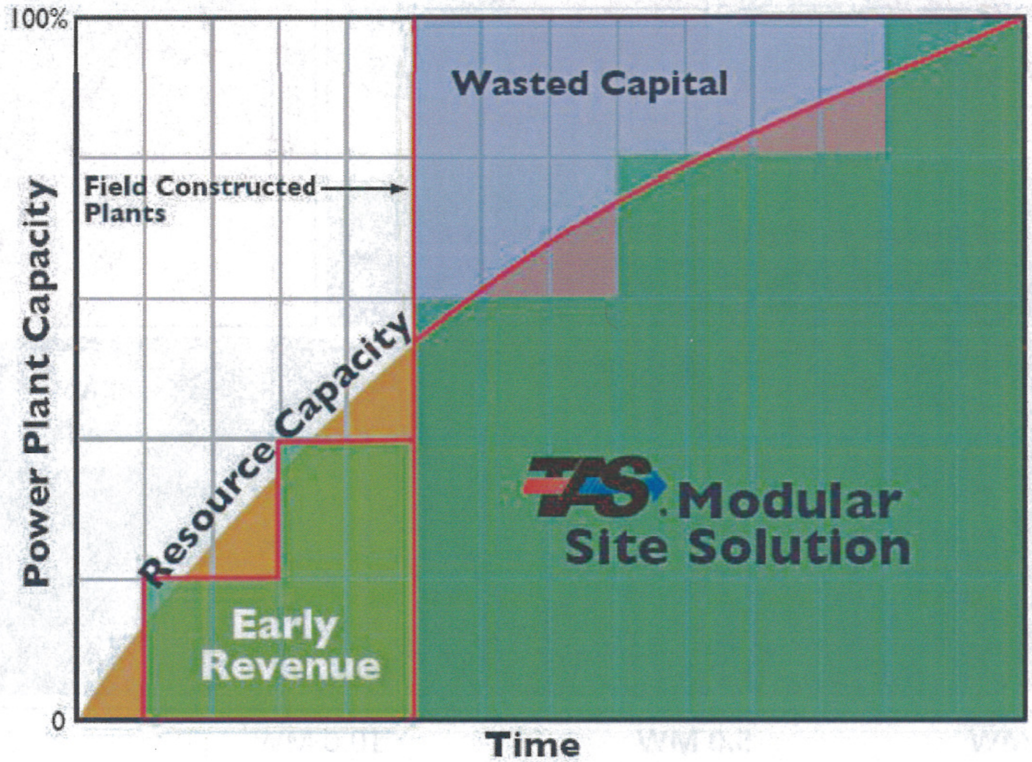
- CFD results for the turbine flow path:
  - The design achieves high performance with a high stage loading (to reduce the number of stages)
  - limits reaction to maintain low thrust
  - Resulting blades and vanes can be manufactured with cost effective ECM and flank milling processes
- The design facilitates rapid field maintenance:
  - Access to turbine internals- only requires pipe spool removal
  - Turbine rotors are slip-fit – shaft-locked with tapered locking
  - Allows rapid removal / replacement without need for heat
  - The shaft/bearing/seal subassemblies are interchangeable
  - Preassembled spare can be stocked at a service center

design result



TAS ORC Capacity Map

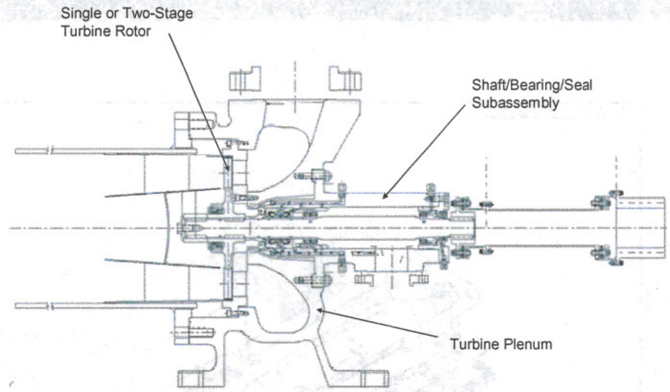


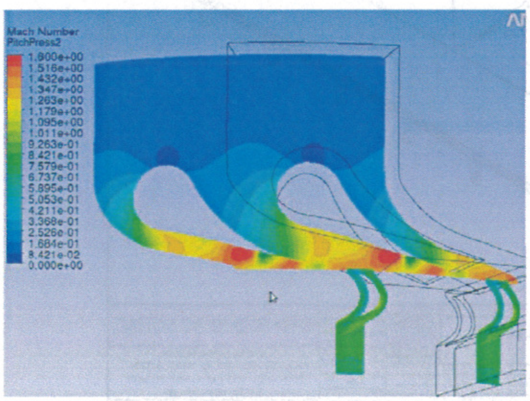

100%
0
Power Plant Capacity
Time
Wasted Capital
Field Constructed Plants
Resource Capacity
Early Revenue
TAS Modular Site Solution

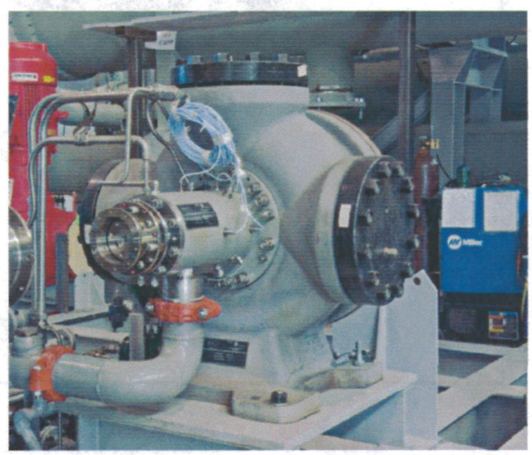
TAS Turbo-Expander Development

GEA
GEOTHERMAL ENERGY ASSOCIATION

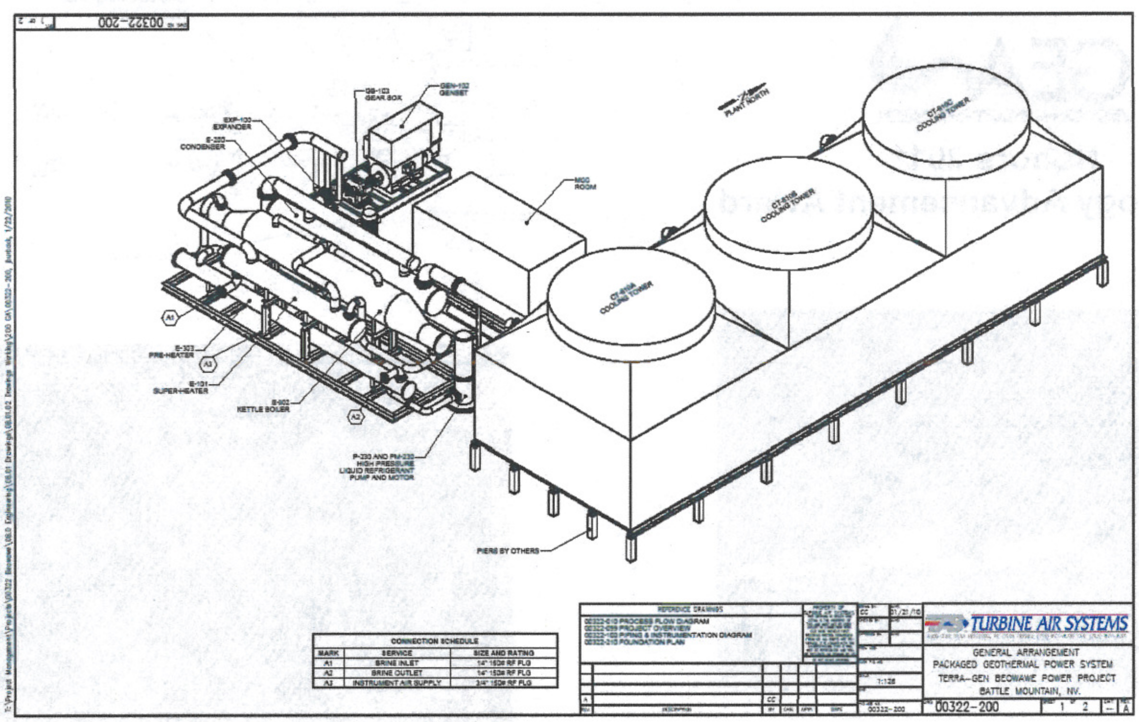
Honors 2011
Technology Advancement Award





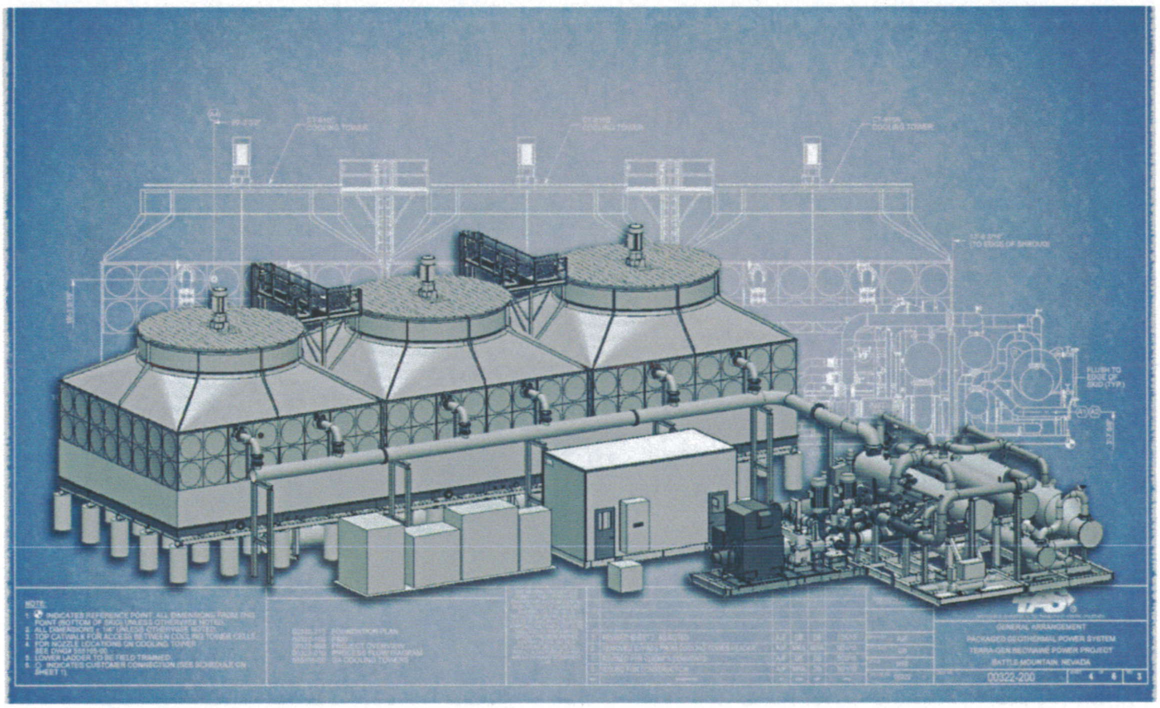


www.tas.com



205°F – Subcritical Cycle - Nominal 2.5 MW's

economic. clean. energy.



205°F – Subcritical Cycle - Nominal 2.5 MW's

economic. clean. energy.

205°F – Subcritical Cycle - Nominal 2.5 MW's

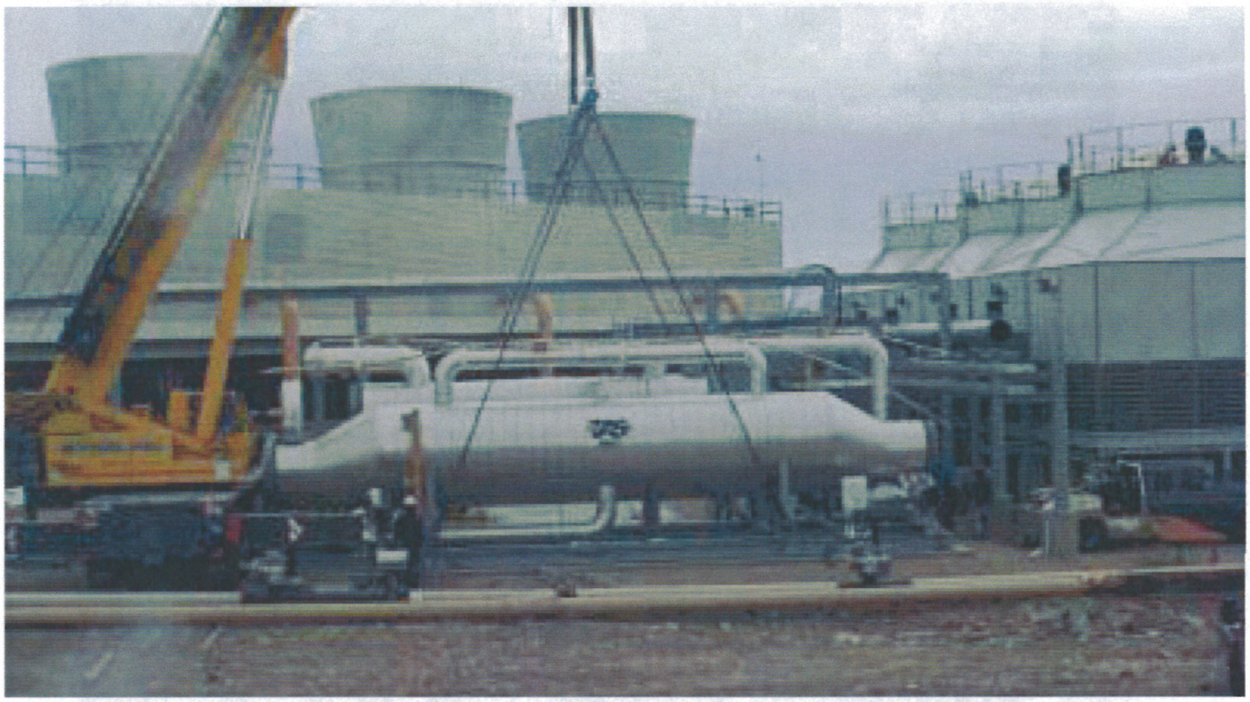
205°F – Subcritical Cycle - Nominal 2.5 MW's

205°F – Subcritical Cycle - Nominal 2.5 MW's

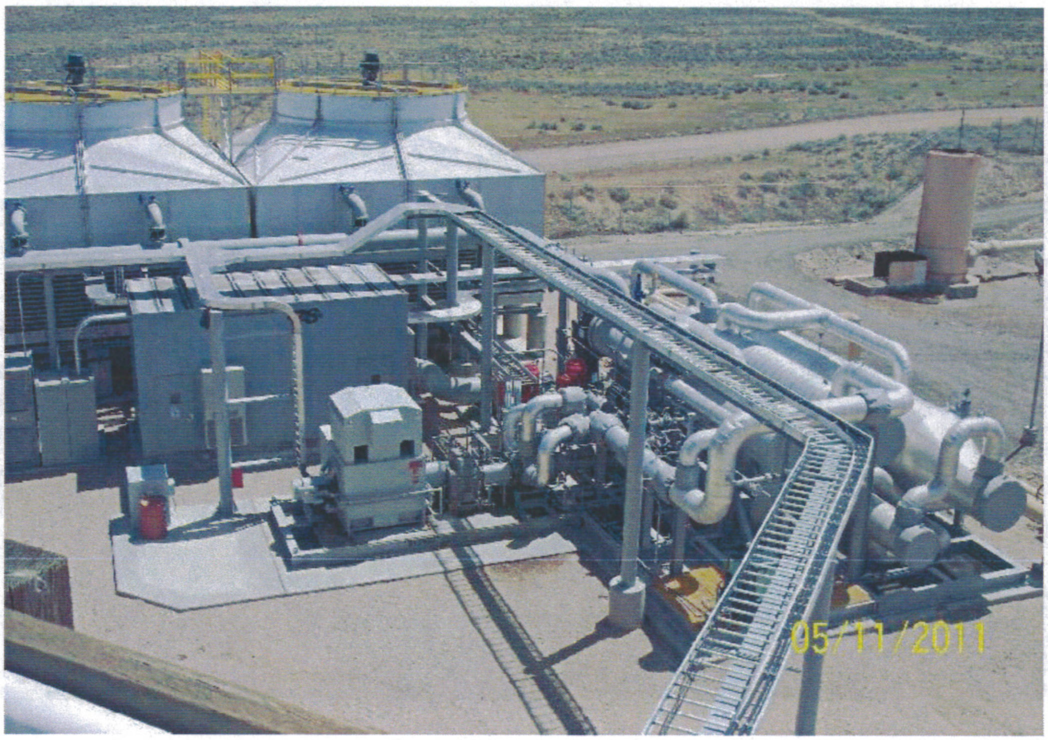
TAS
economic. clean. energy.

205°F – Subcritical Cycle - Nominal 2.5 MW's

205°F – Subcritical Cycle - Nominal 2.5 MW's



205°F – Subcritical Cycle - Nominal 2.5 MW's



205°F – Subcritical Cycle - Nominal 2.5 MW's

end game results

- Increased low temp cycle efficiency without complicated or expensive field erected plants
- Reduction in operation and maintenance costs.
- Much more environmentally friendly plant – environmentally benign – non- flammable R-134a or R-245fa - for low to high temp
- Simple to install – operate - maintain
- High efficiency - robust performance – low cost
- Unparalleled flexibility

Thank You!

Halley Dickey
713-877-8700 main
909-838-6235 cellular
hdickey@tas.com
www.tas.com

TAS®
economic. clean. energy.