Integrated Pollutant Removal: Modeling and Experimentation

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Goals

- Removal of all pollutants from a fossil fuel flue gas stream.
- Produce liquid CO_2 suitable for sequestration
- Power Generation Thermal efficiency above 33%
- Small incremental additional cost
- Use off-the-shelf technologies

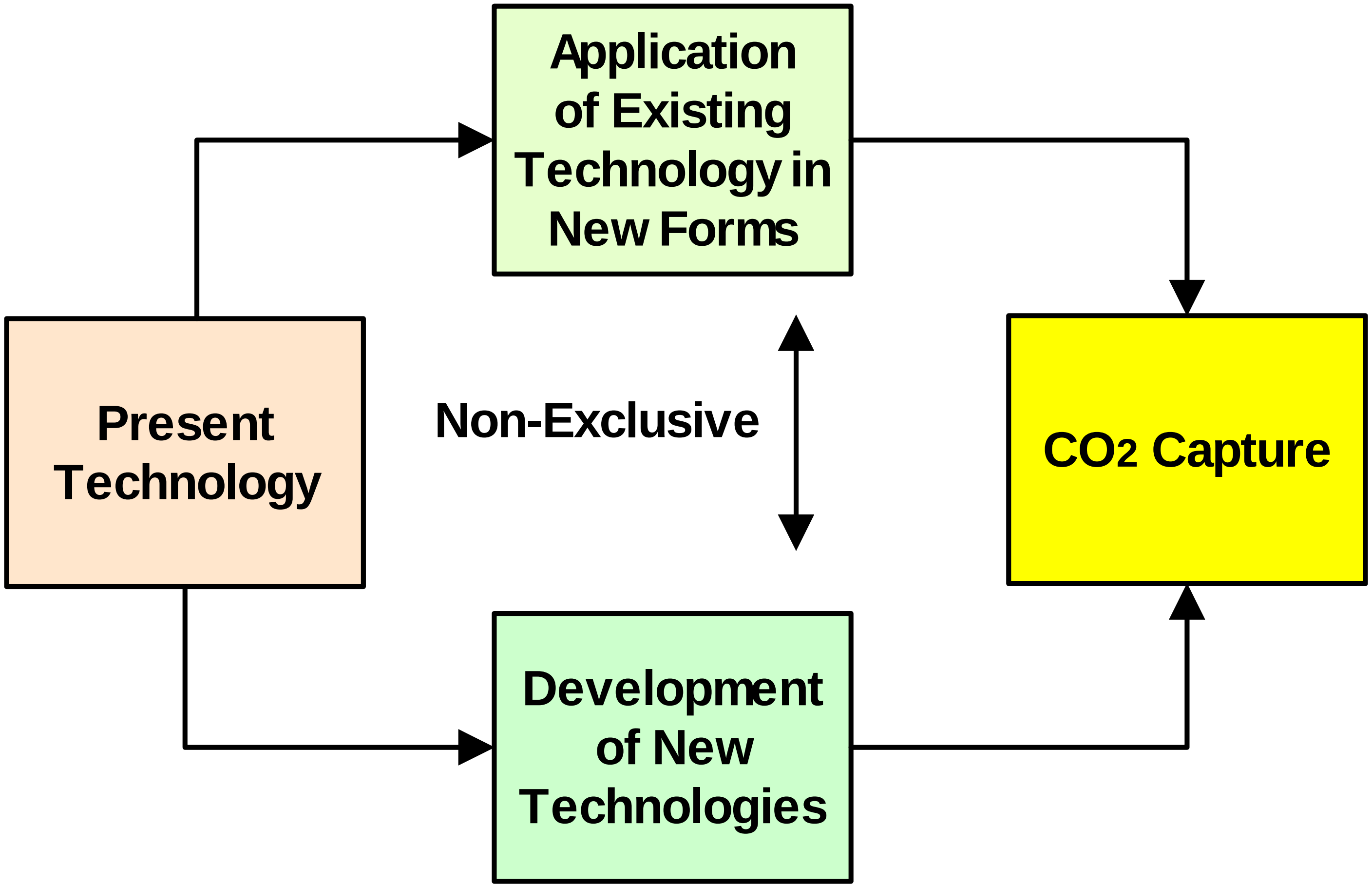
Background

- Project evolved from CO_2 sequestration research started in 2000
  - If we are going to sequester CO_2 we have to capture it economically
- Based on performance improvement principles used in power plant performance improvement program in Indonesia

Lesson Learned: Borrow Technologies From Other Industries!

- Petrochemical industry
- Chemical industry
- Petroleum refining industry

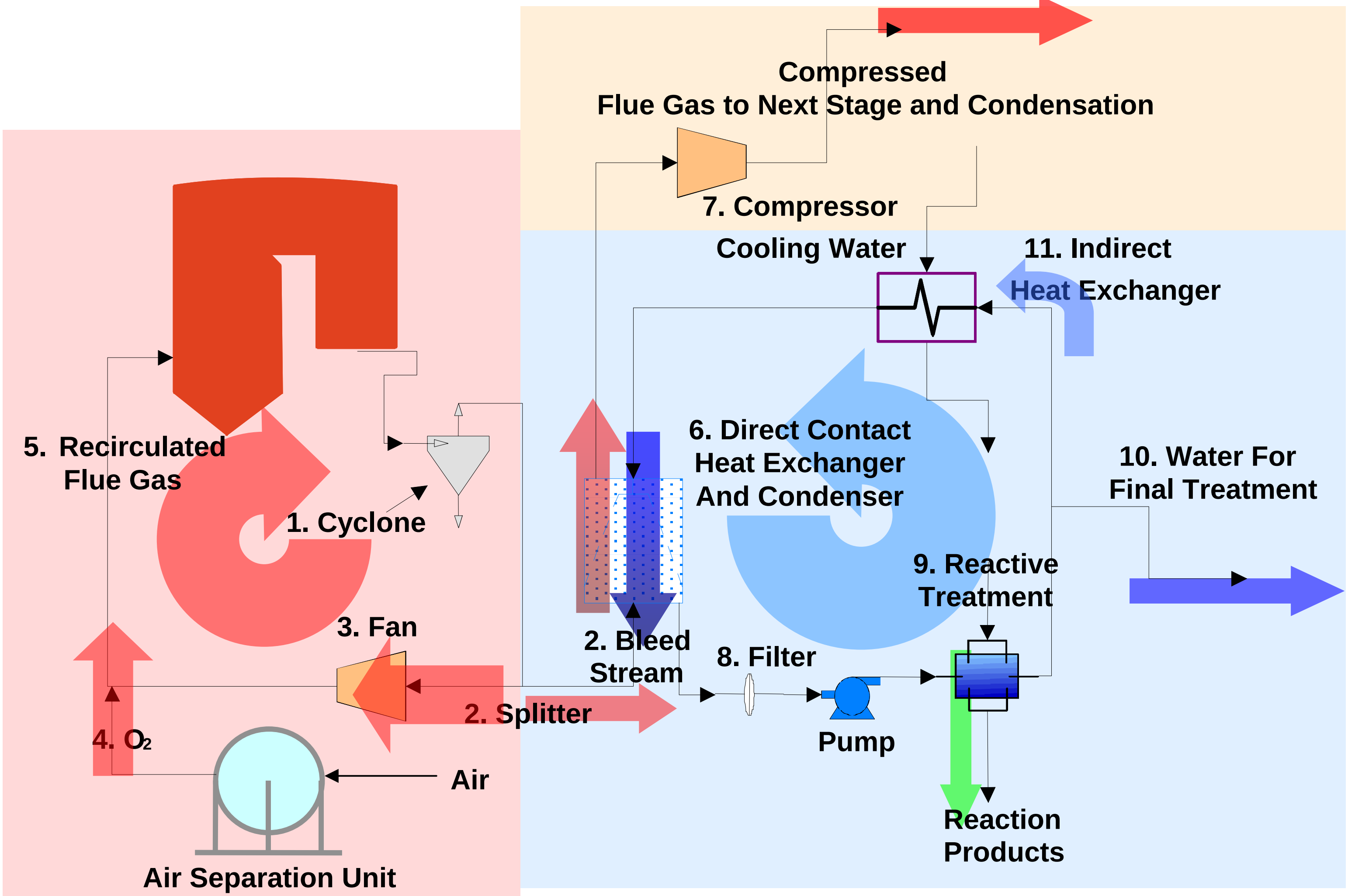
Two Paths to CO_2 Capture

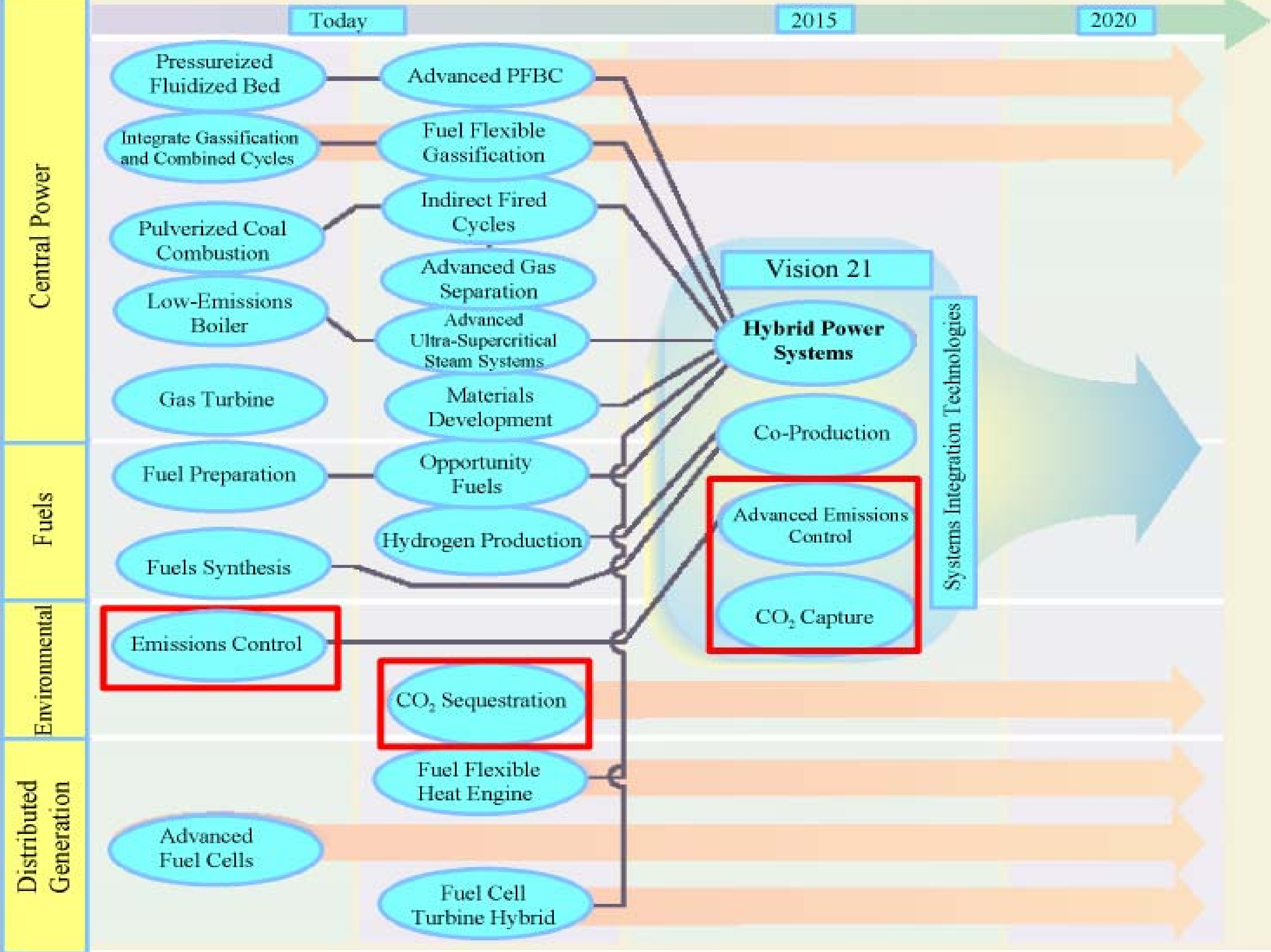


Conclusions

- There are no breakthroughs necessary to effectively remove CO_2 from denitrified flue gas (recirculating boilers, oxyfuel, etc)
  - **Technologies needed are routinely used in other industries.**
- 33% thermal efficiency plants can be built using existing technology. They can capture 99% of the CO_2 and other combustion product pollutants

Compression and Condensation



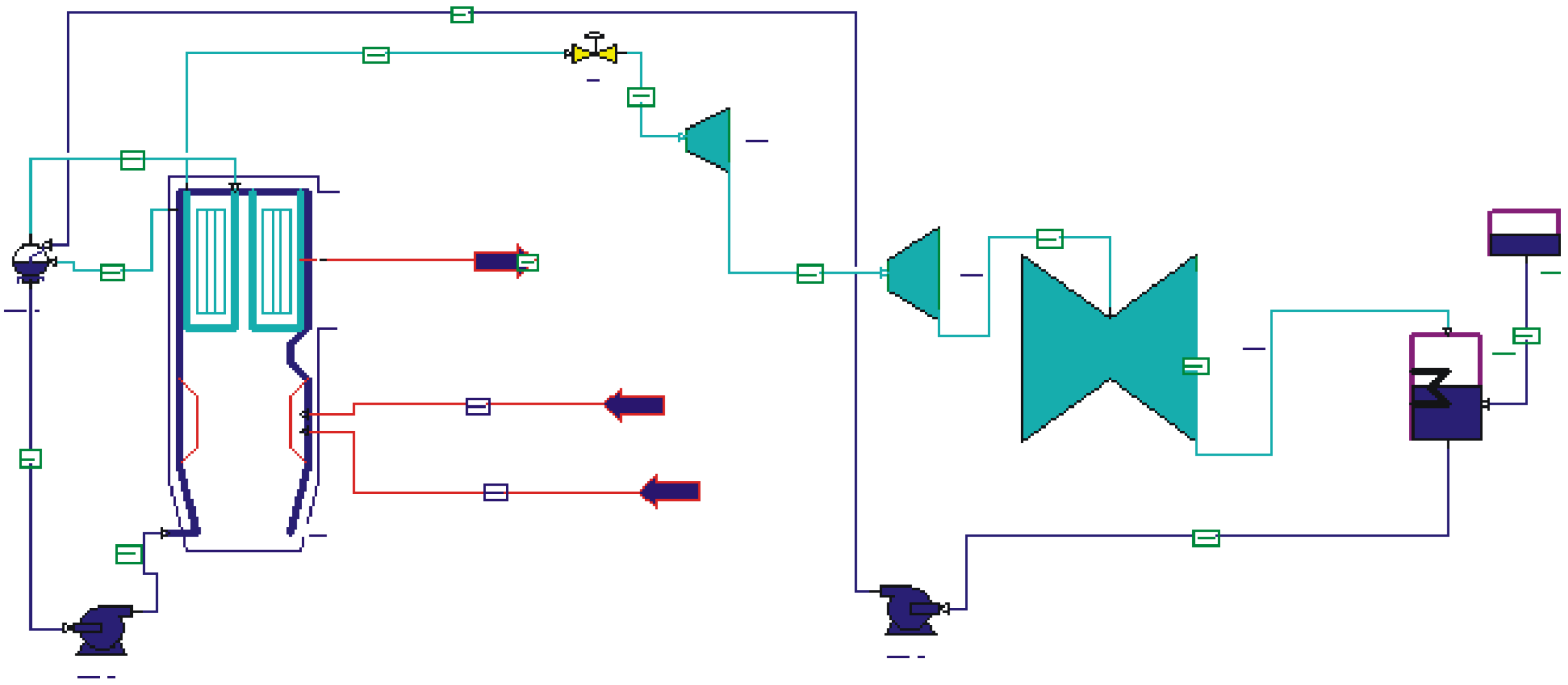


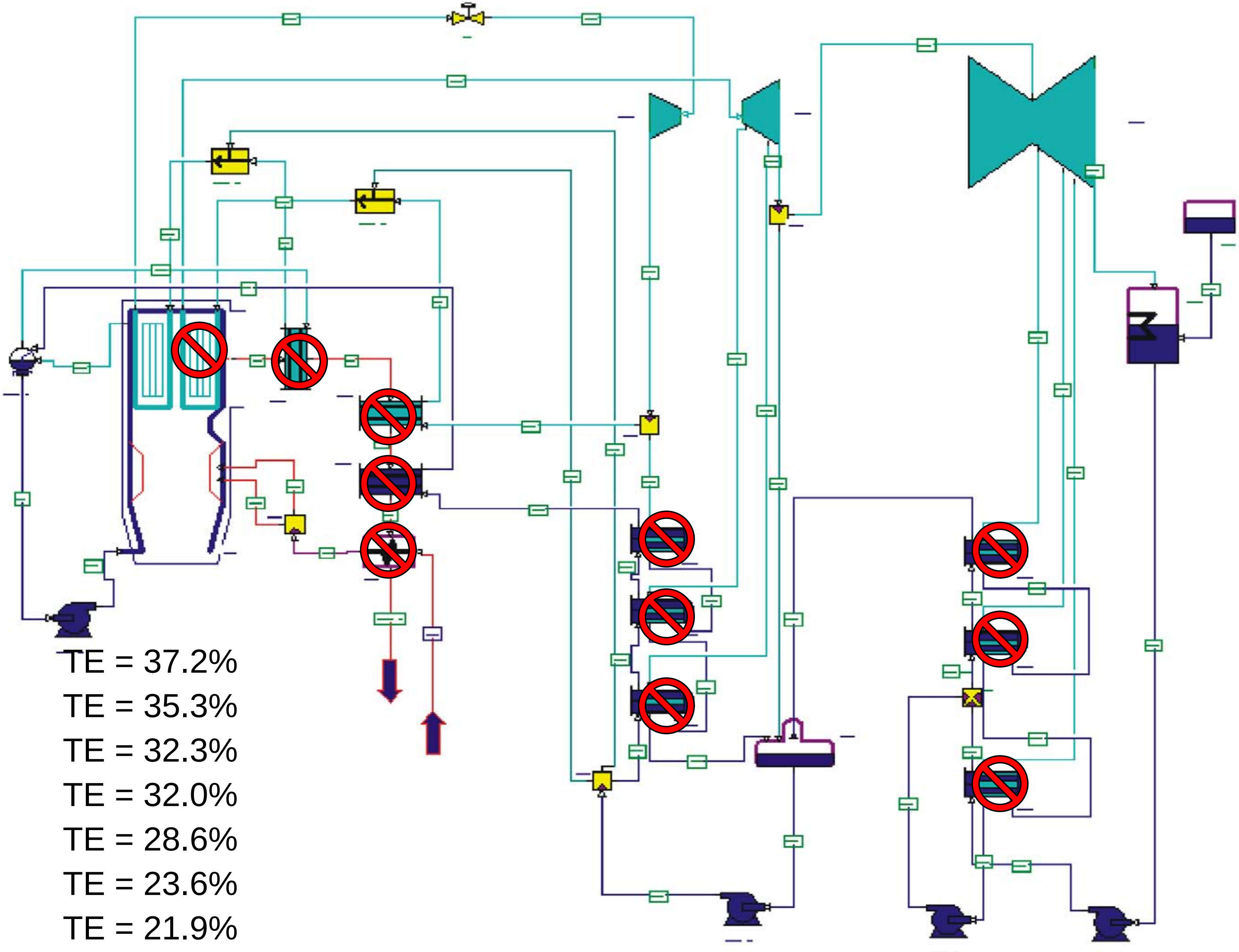
Today
2015
2020
Central Power
Fuels
Environmental
Distributed Generation
Pressureized Fluidized Bed
Advanced PFBC
Integrate Gassification and Combined Cycles
Fuel Flexible Gassification
Indirect Fired Cycles
Pulverized Coal Combustion
Advanced Gas Separation
Low-Emissions Boiler
Advanced Ultra-Supercritical Steam Systems
Gas Turbine
Materials Development
Vision 21
Hybrid Power Systems
Co-Production
Advanced Emissions Control
CO2 Capture
Systems Integration Technologies
Fuel Preparation
Opportunity Fuels
Hydrogen Production
Fuels Synthesis
Emissions Control
CO2 Sequestration
Fuel Flexible Heat Engine
Advanced Fuel Cells
Fuel Cell Turbine Hybrid

Energy Recovery and Conservation as Key Components in Low Emission Power Plants

- Estimates that do not consider energy recovery are pessimistic
- Existing plants are successful because they recover energy wherever possible
- Advances in power plant technology have included energy recovery

Power Plant Design





TE = 37.2%

TE = 35.3%

TE = 32.3%

TE = 32.0%

TE = 28.6%

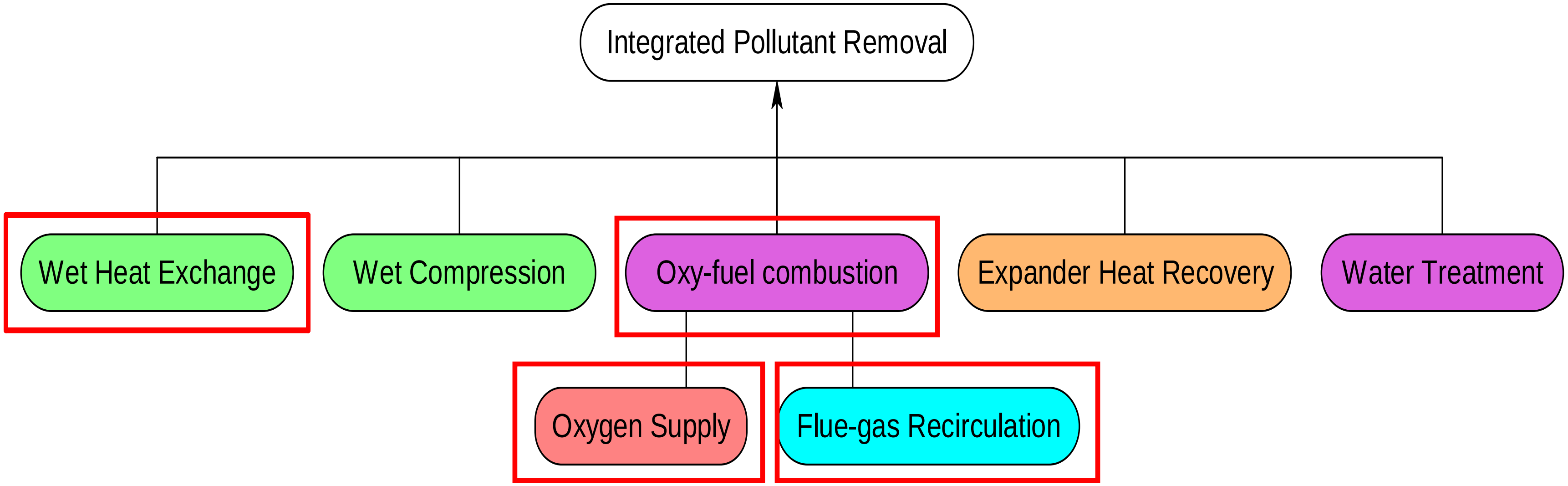
TE = 23.6%

TE = 21.9%

The Approach to Integrated Pollutant Removal

- Oxygen + flue-gas as combustion "air"
- Remove all pollutants and acid gases through compression and condensation
  - Remove coarse particulates and particle bound Hg (filtration)
  - Concentrate condensables and pollutant gases
  - Condense and remove H_2O and CO_2
    - Entrain particulates with fine particle bound Hg^{2+}
    - Dissolve and react SO_x, NO_x, Hg^{2+}
  - Decrease volume flow rate through compression and condensation
    - Increase relative volume of Hg^0
- Recover energy through heat transfer and expansion

Enabling Technologies



CRADA With Jupiter Oxygen (Cooperative Research and Development Agreement)

- Proven proprietary oxy-fuel system for aluminum melting
- Experience in oxygen production and burner technology
- Applying oxy-fuel to power generation
- Supplements IPR need for oxy-fuel system
- Gives a new dimension to heat transfer control with flexible oxygen content

Oxygen Costs For 400 MW Coal Plant

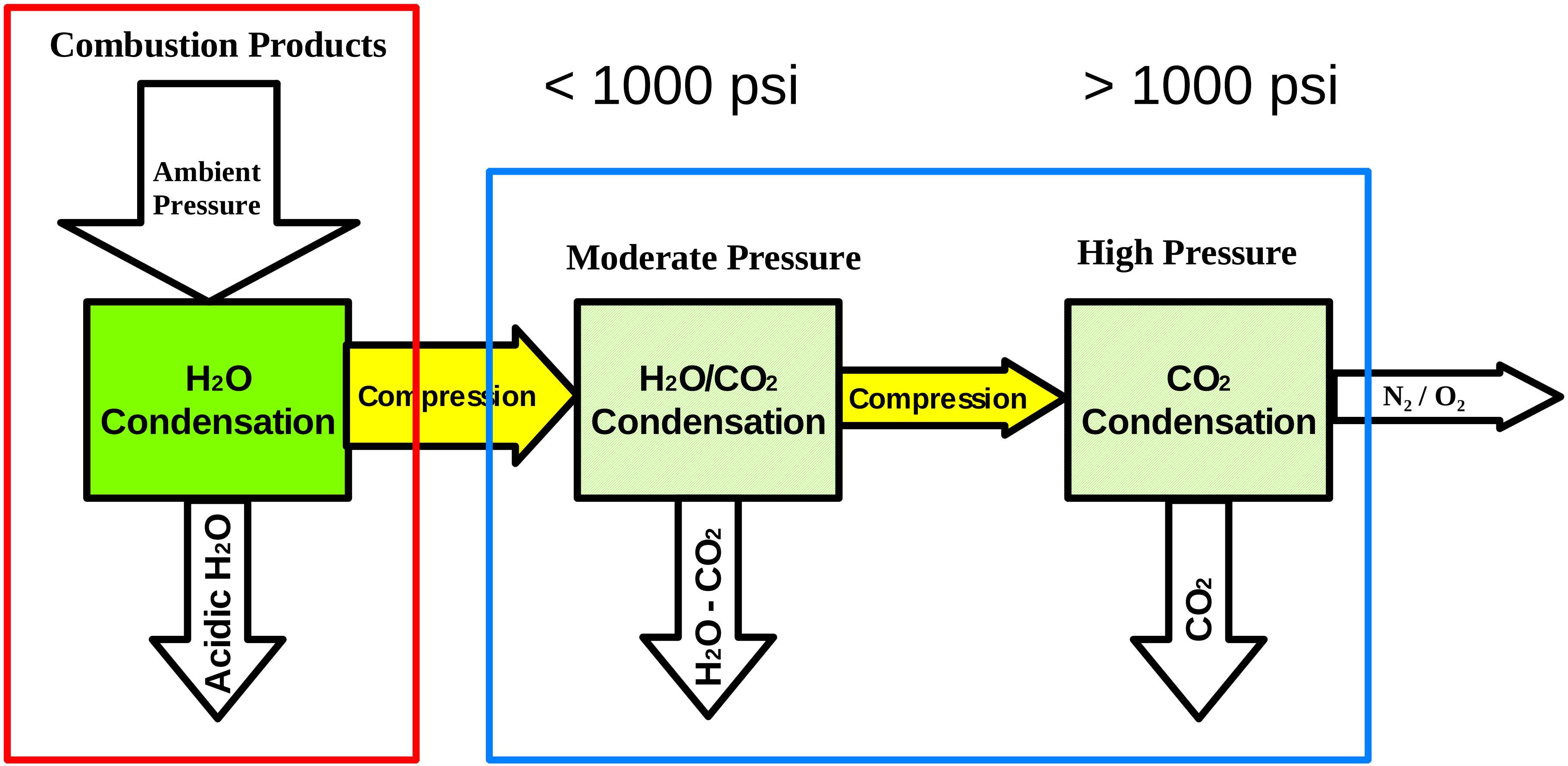
Capital cost: $160,000,000 ($20,000/ton/hr/day)

Power Required for Operation

- 250 kWh/ton (Cryogenic)=> 82.5 MW (Used in model*)
- 235 kWh/ton (Cryogenic) => 77.55 MW
- 147 kWh/ton (Ion Transport Membrane)=> 48.51 MW

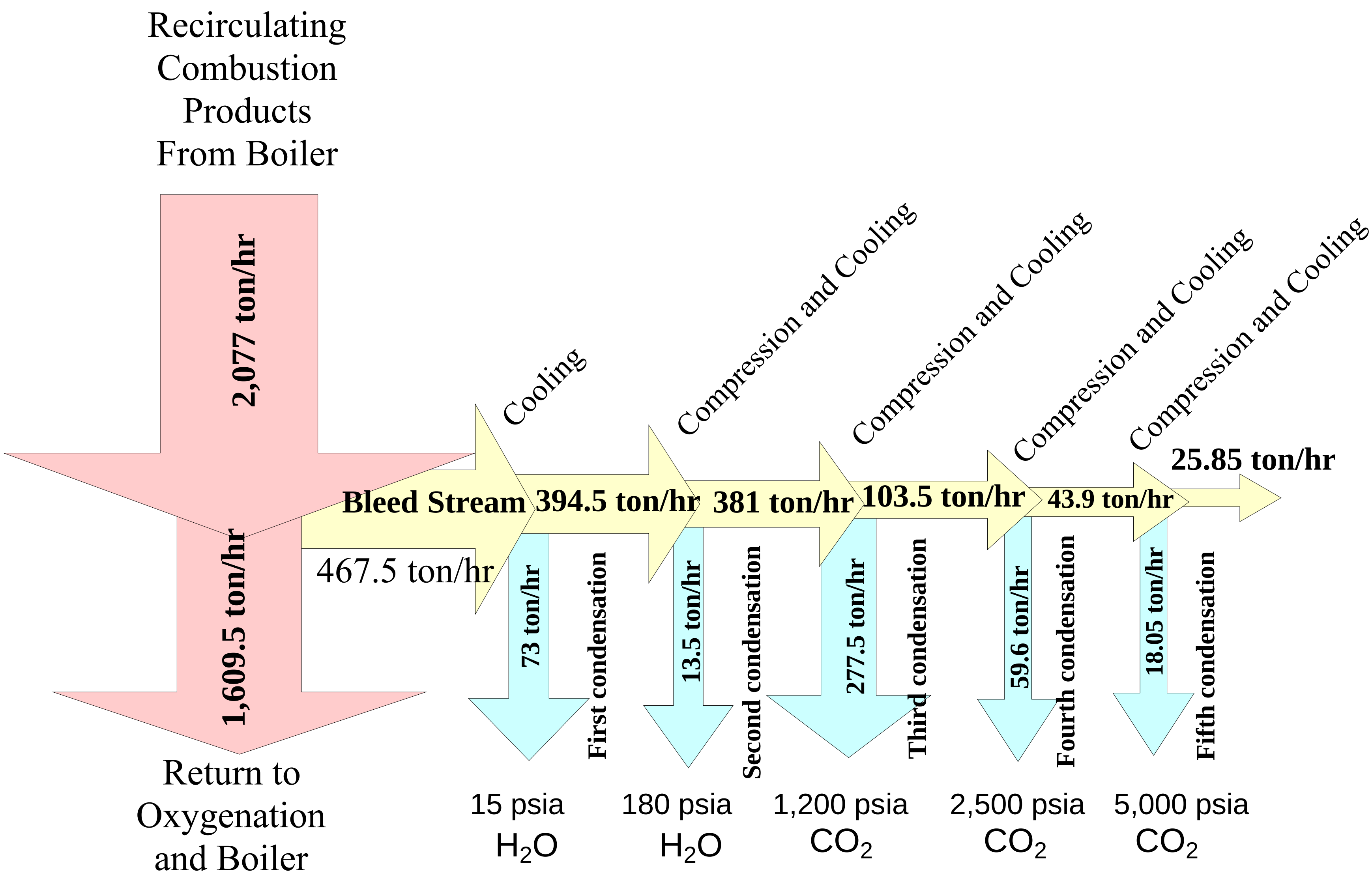
*330 ton/hr O_2
*153 ton/hr #6 Illinois Old Ben mine 26 coal

Three Stages Of Condensation In IPR

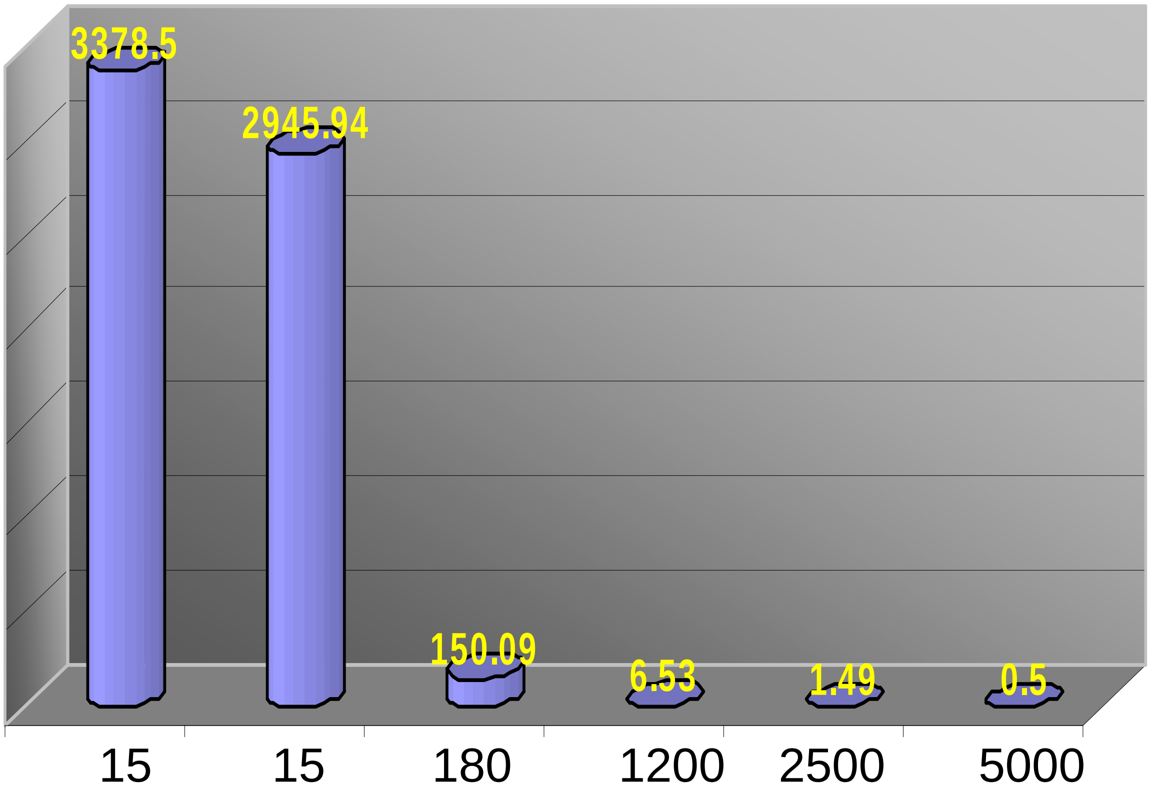


Ambient Pressure

Mass Flow Reduction

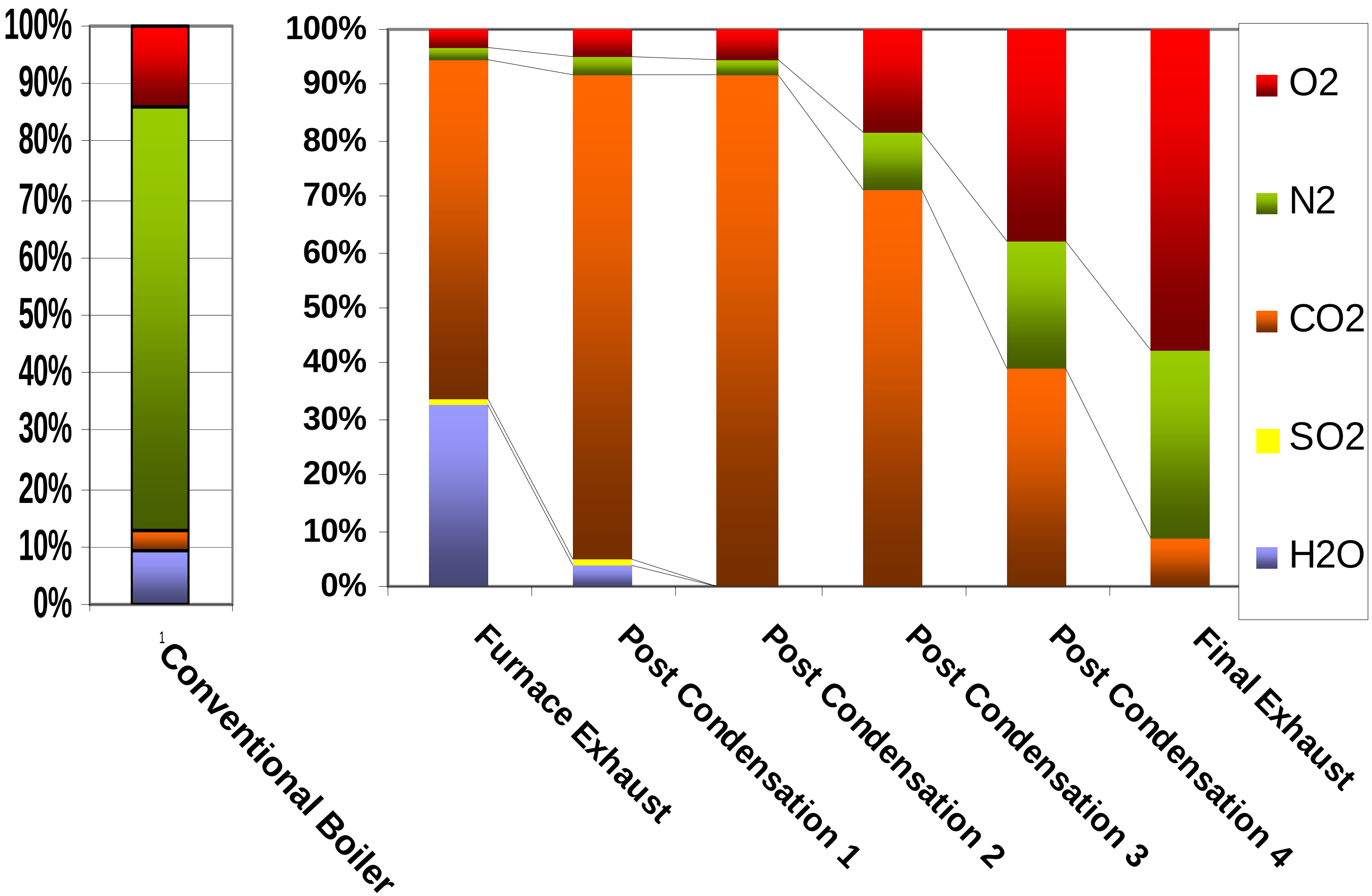


Volumetric Flow Rate (ft³/s)



Pressure (psia)

Progressive Composition of Exhaust



Flow Conditions (Conventional)

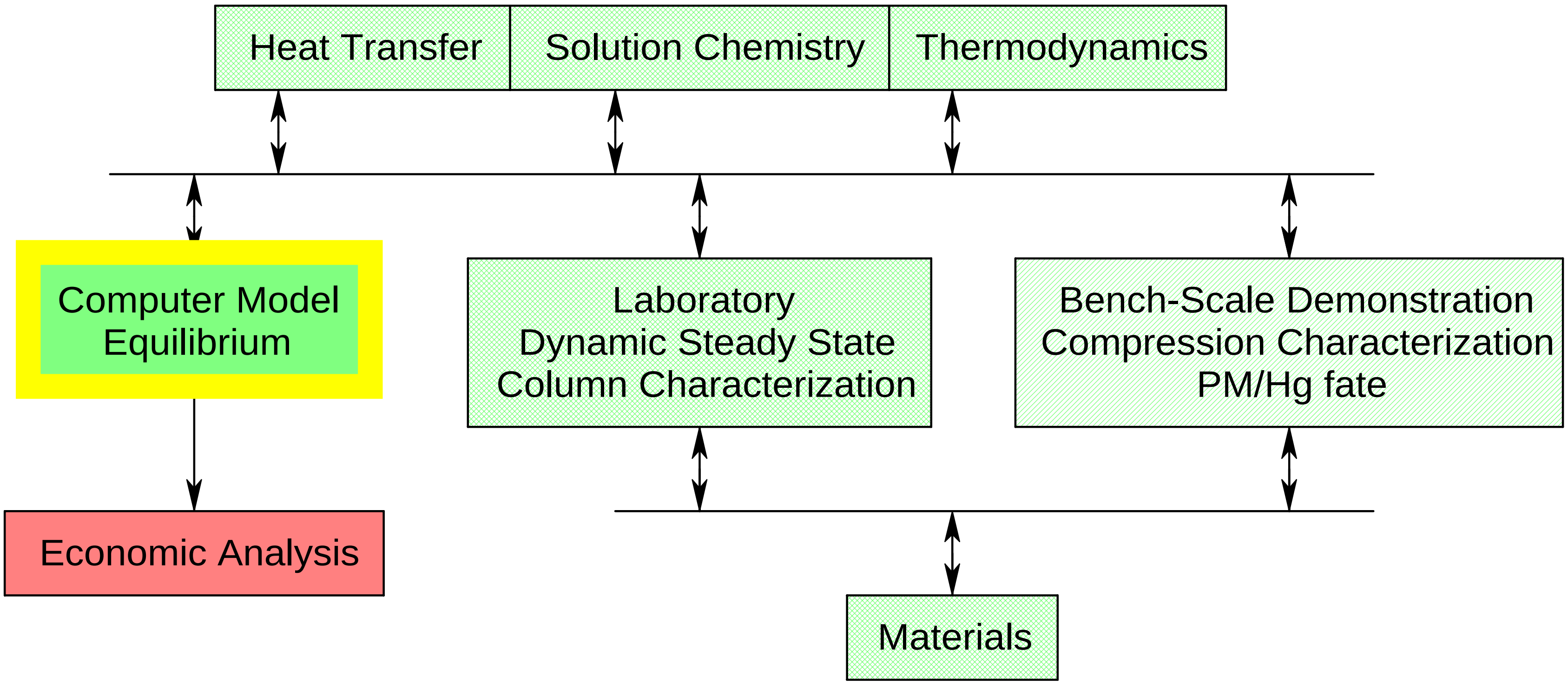
Comparison of combustion product flow rates			
	Conventional	Recirculating	Final Exhaust
Flow (lb/hr)	3,642,100	4,154,248	51,700

Ratio of conventional exhaust mass to condensed exhaust ≈ 70/1

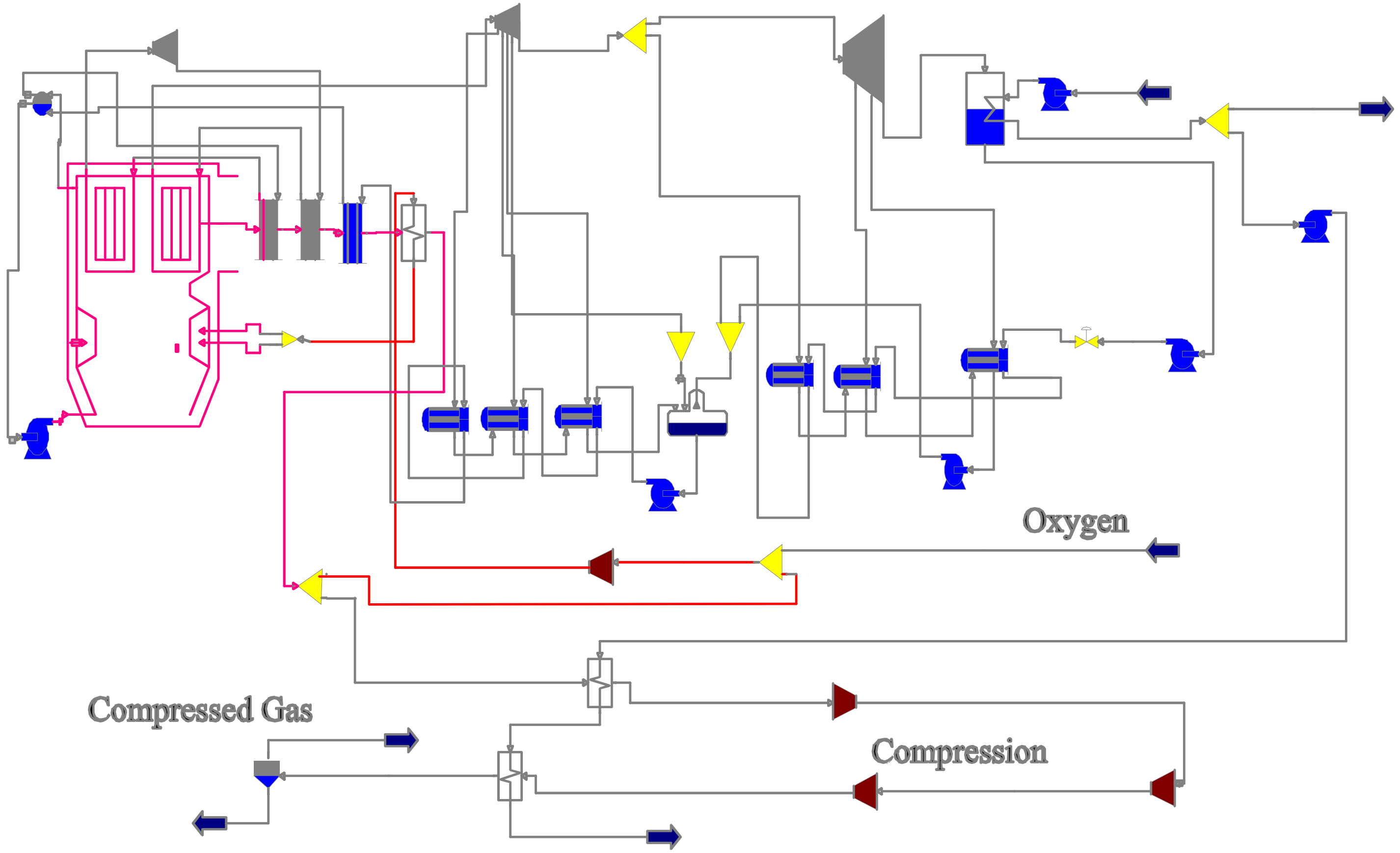
Ratio of high-pressure exhaust volume ≈ 31,000/1

Example Benefit: Elemental mercury at high volumetric concentration in final bleed stream, suitable for removal by conventional methods.

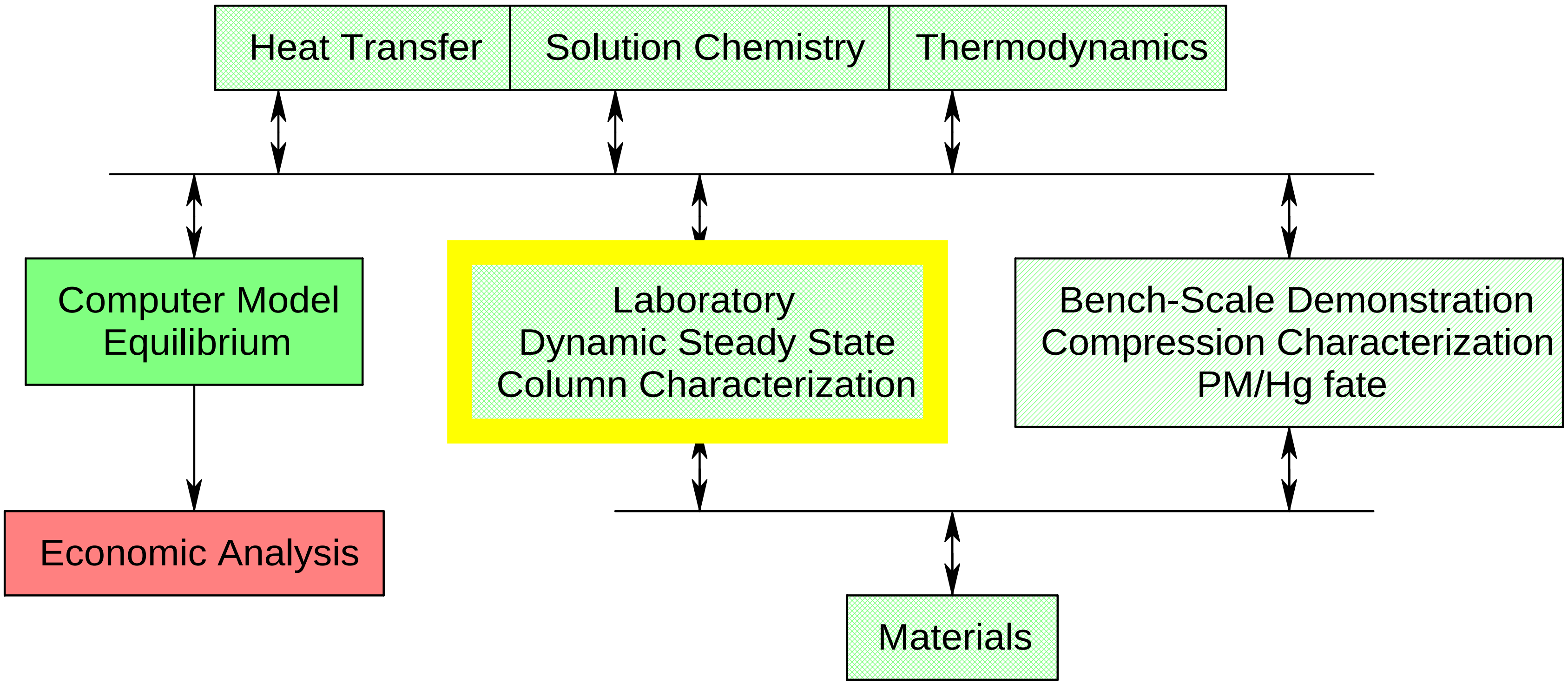
IPR Technical Approach



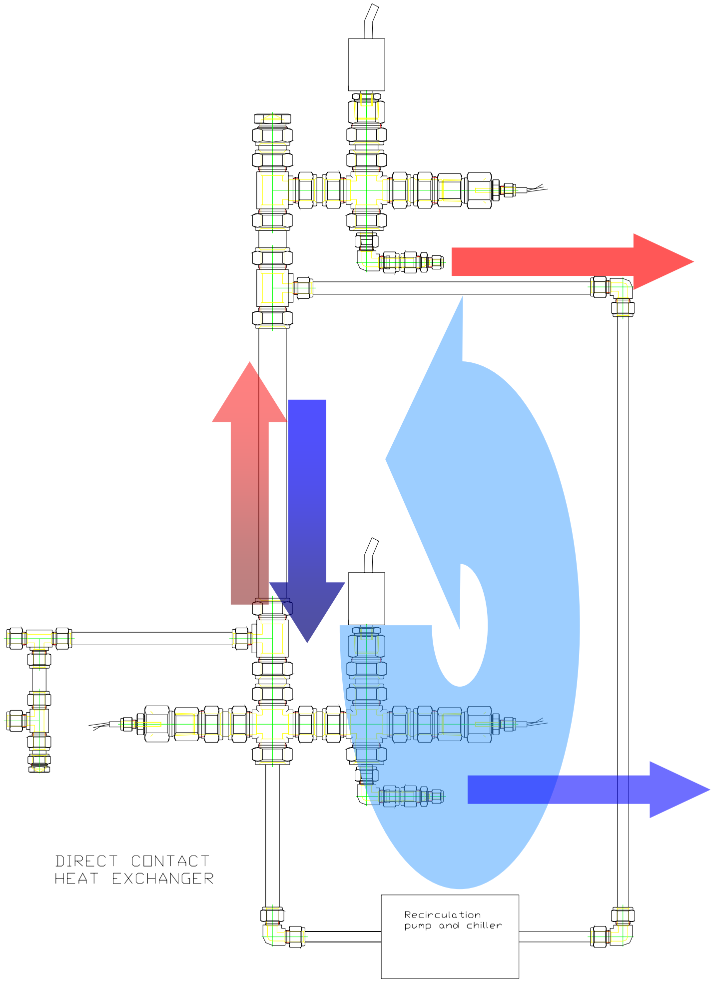
Parametric computer model of wet flue-gas heat exchanger

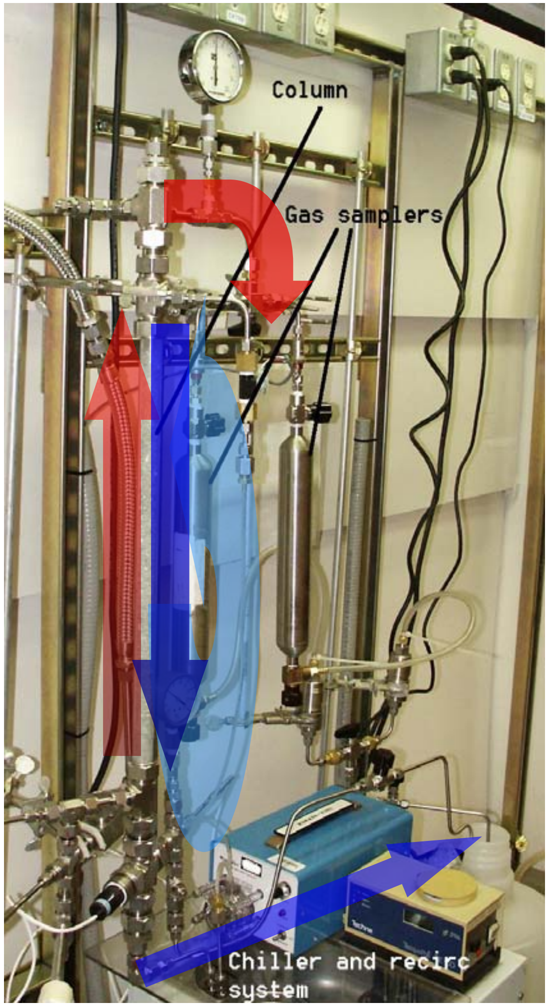


IPR Technical Approach



Laboratory Column Model

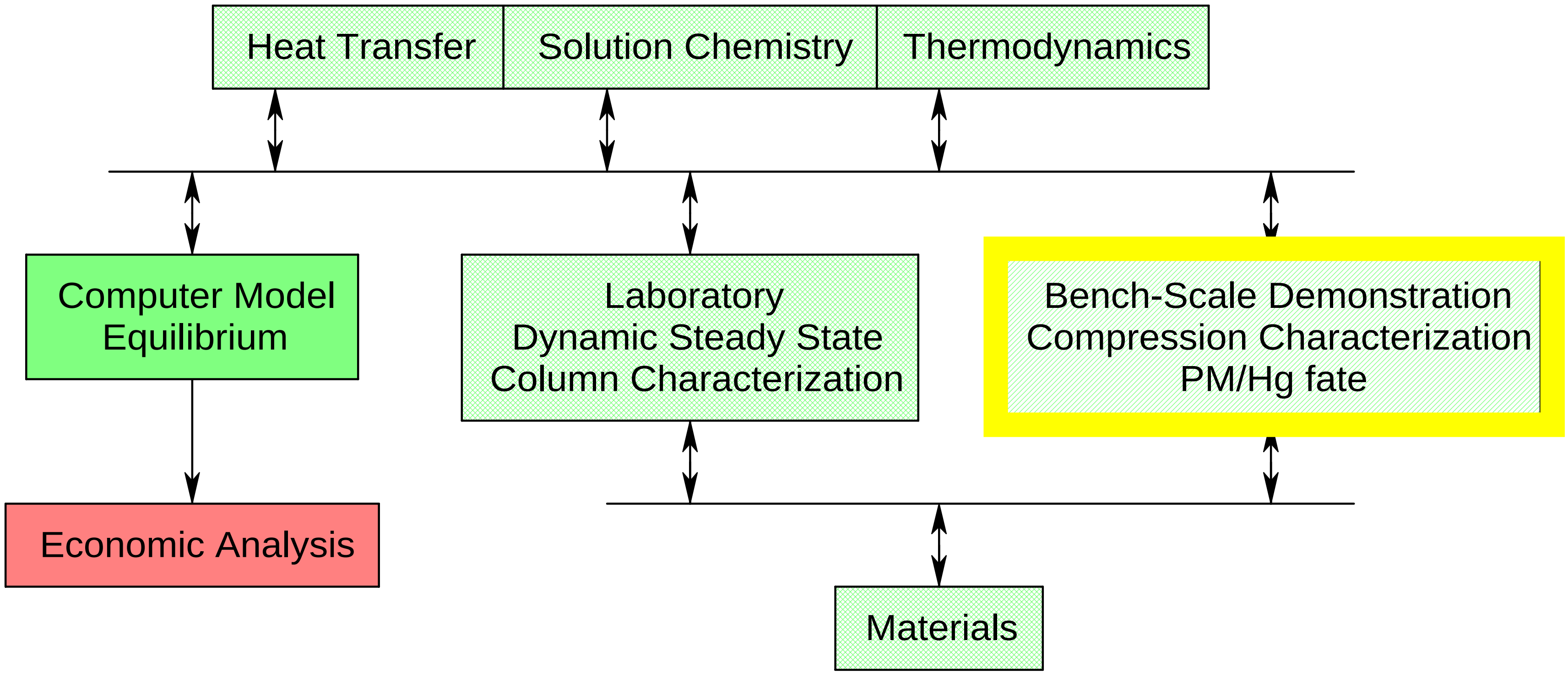




Hurdles To Effective Implementation

1. ~~Hybrid heat exchange~~
2. ~~Two phase compression~~
3. ~~Wastewater treatment~~
4. ~~Corrosion~~
5. ~~Leakage~~
6. Heat recovery
7. Advanced combustion designs
8. Detailed design and optimization
9. Cost of O_2 (capital, operational, energy)

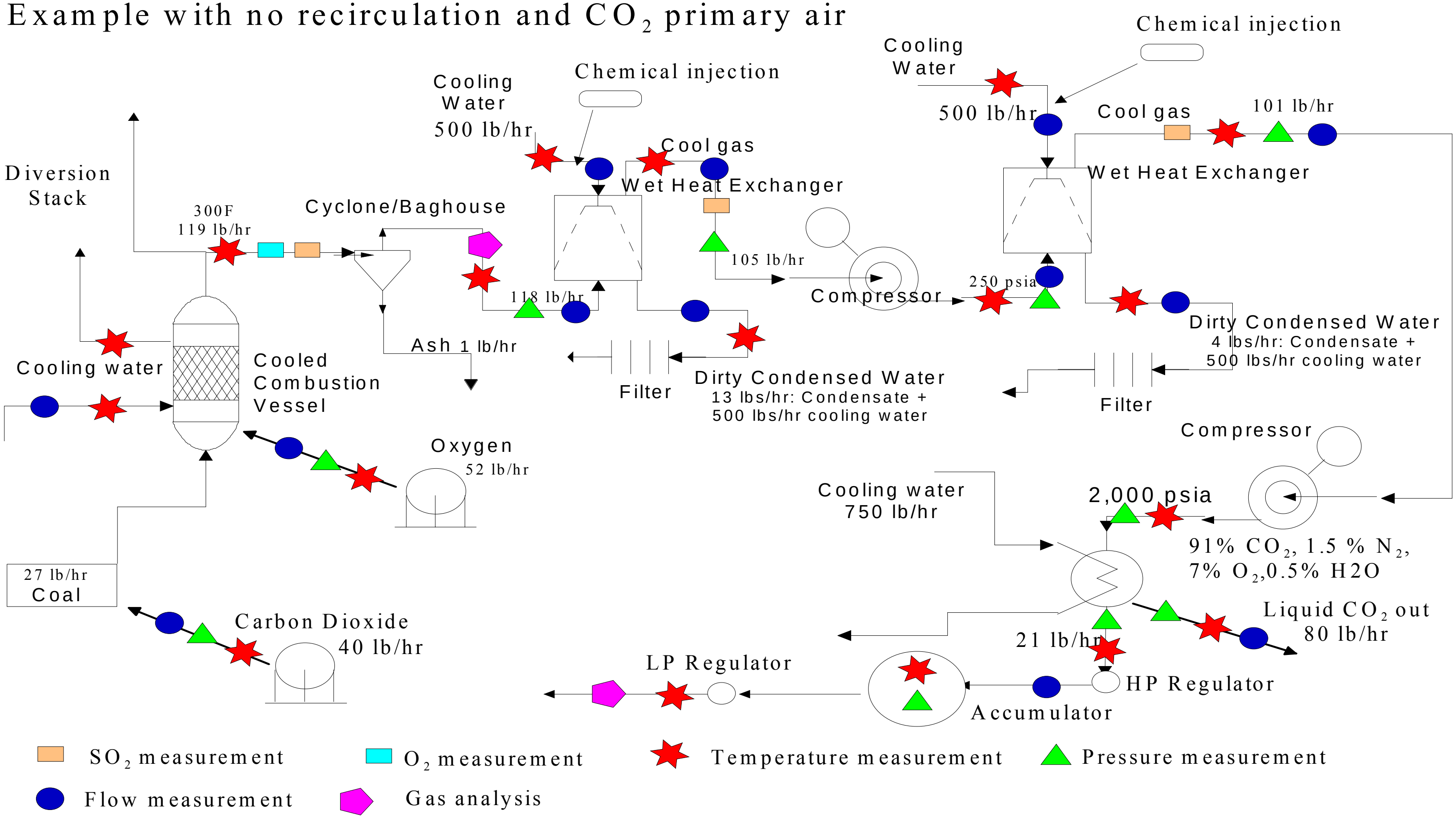
IPR Technical Approach



Bench-scale System Model

Based on Model BNCH12

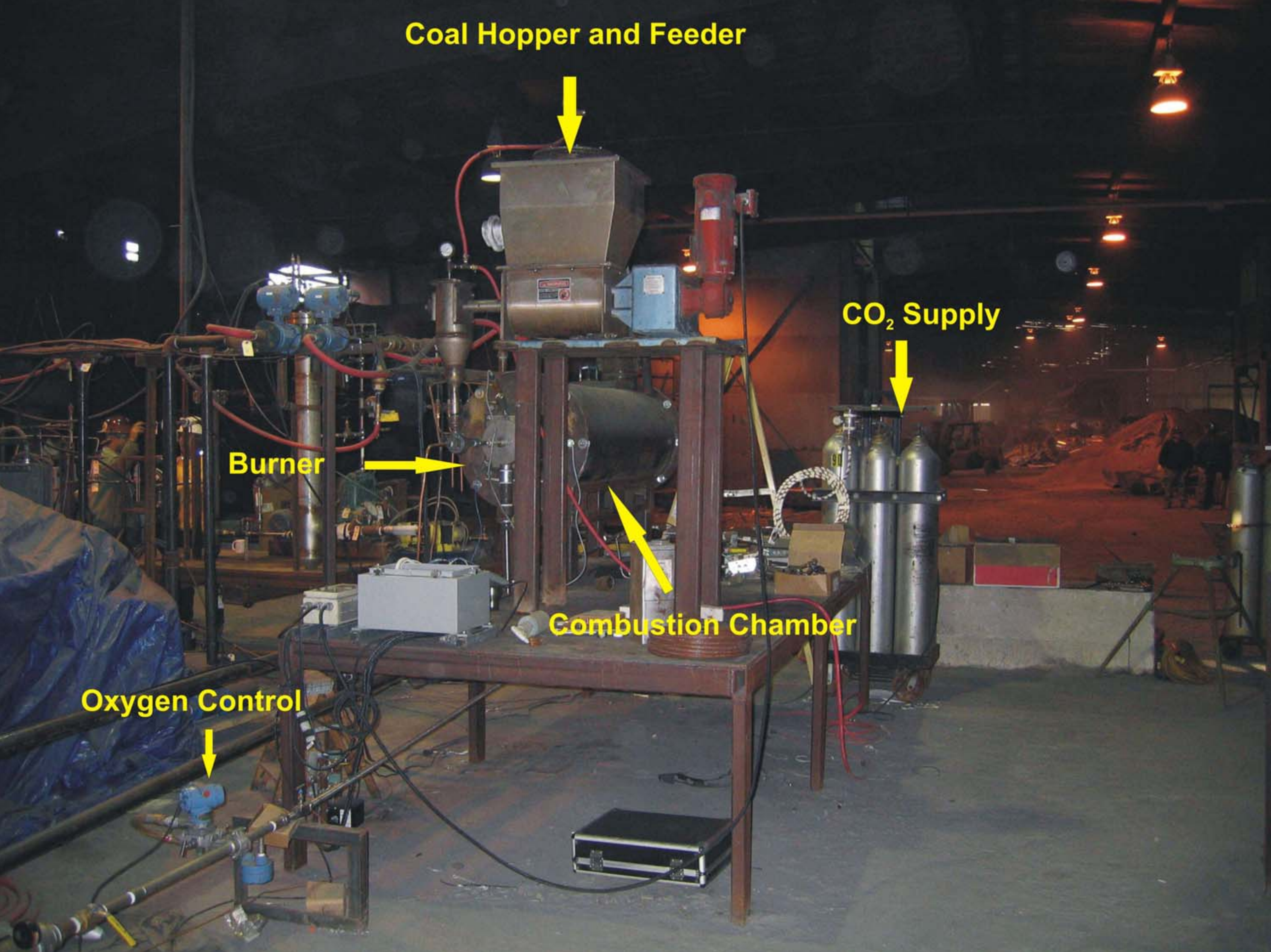
Example with no recirculation and CO_2 primary air

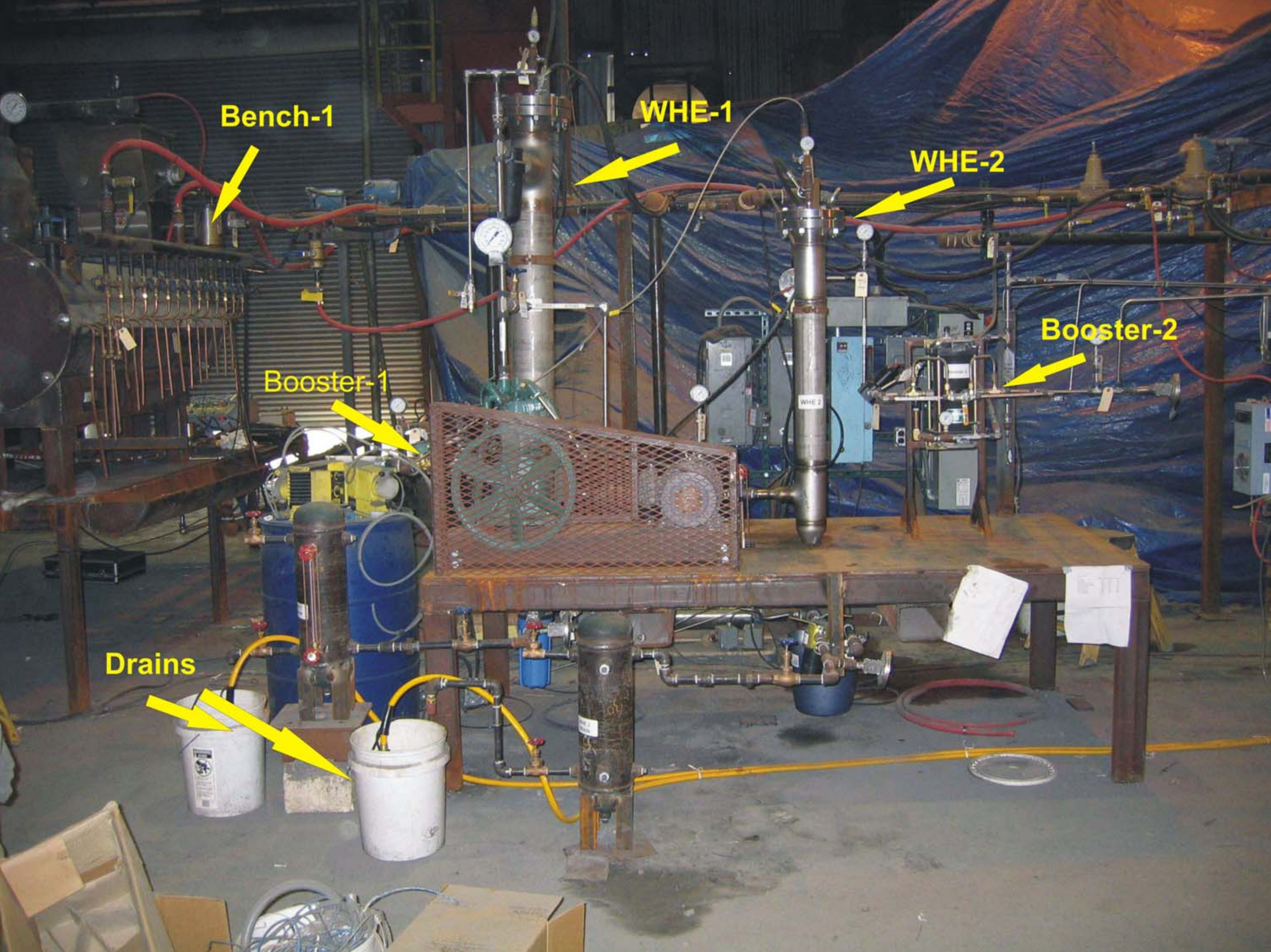


Junk Yard Wars Approach

Demonstration System

- Challenge from Jupiter 8/5/04
- Acceptance of challenge 8/22/04
  - Incremental approach
  - Off the shelf equipment
  - Primary air recirculation (oxy-fuel)
  - No applied heat recovery
- Beginning of detailed design 8/15/04
- Beginning of construction 8/30/04
- Successful operation 11/3/04


Coal Hopper and Feeder
CO_2 Supply
Burner
Combustion Chamber
Oxygen Control


Bench-1
WHE-1
WHE-2
Booster-2
Booster-1
Drains


WHE-3
Booster-3
Booster-4
Bench 2
Accumulator
Liquid CO_2
Collection Cylinder

Results

- > 99% of SO_2 removed
- All flue gas condensable at 1,500 psia
- Hg capture volume reduced as predicted
- All particulates removed from system

Thank you for your attention