Pre-Project Planning for a Flameless Pressurized Oxy-combustion (FPO) Pilot Plant

DOE National Energy Technology Laboratory
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Principal Investigator:
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Project Team: SwRI, ITEA, EPRI, GE Global Research, Jacobs, PRA

Project Summary

- 2 year project kicked-off in October 2016
- Response to FOA from DOE for Large Pilot Opportunities for Transformational Coal Technologies
  - Planning of a demonstration facility
  - Develop economic analysis and technology maturation pathway
- Targets
  - 90% CO_2 capture and compression to 2200 psig
  - Meet MATS and NSPS emission limits
  - Achieve COE reduction of 20%, matching PC development pathways

Project Team

Principal Investigator

Southwest Research Institute

Large Scope

Itea

Jacobs Engineering

Small Scope

Electric Power Research Institute

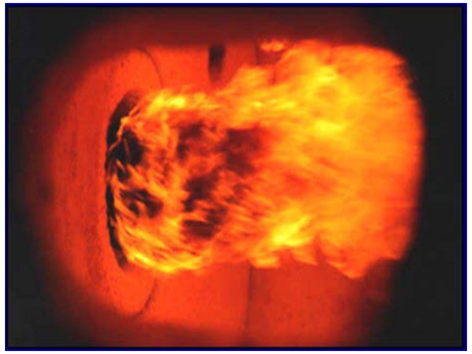
GE Global Research

Peter Reineck Associates

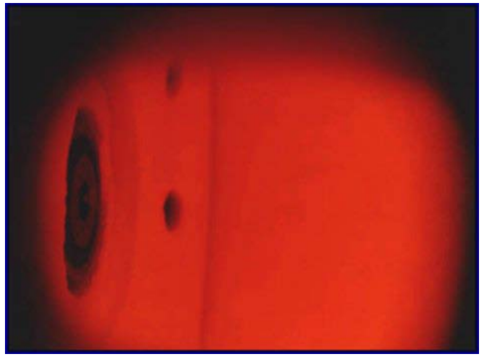
FPO Combustion Premise

- Pressurized atmosphere of water and CO_2 under “volume expanded combustion” avoids traditional flame fronts
  - FPO combustion is more locally controllable with more uniform temperatures
  - Pressurized firing also improves cycle efficiency
- Conversion of carbon to CO_2 is over 99%
  - Almost zero carbon content in incombustible products
  - Traditional: flying and falling ash particles
  - FPO: slag with near-zero carbon content and tiny particulate

Traditional Combustion with Flame Front

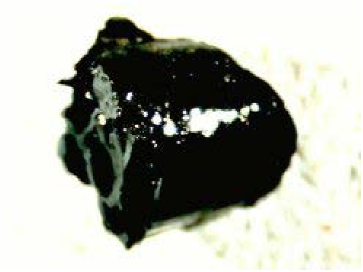


Flameless Pressurized Combustion

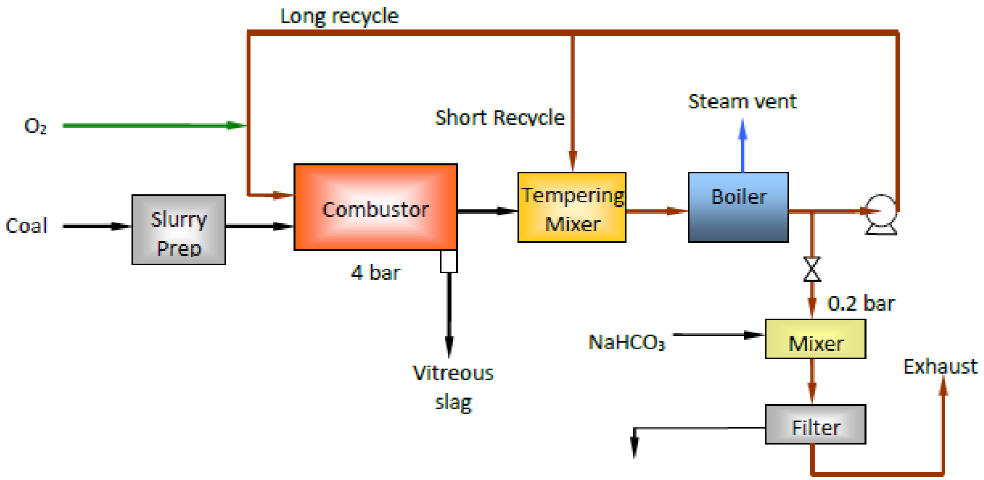


Traditional Combustor Products: Particulate

FPO Combustor Products: Near-zero carbon, neutral slag



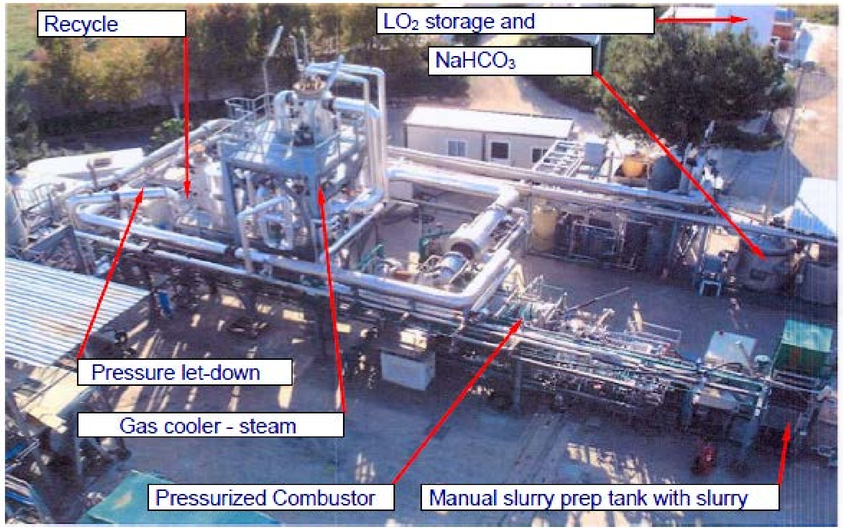
FPO Cycle Premise



- Slurry of milled coal and water combusted under pressure
- Hot combustor gas is quenched through mixing
- Enters Once-Through Steam Generator (OTSG)
- A large percentage of combustion products are recycled
  - Some recycled flow used for quenching before OTSG
  - The remainder of recycled flow is mixed with pressurized oxygen and injected into the combustor
- New iteration of cycle splits before boiler and includes turbo-expander

FPO 5 MWth Small Pilot

- 5 MWth plant in Italy
  - Capable of 4 bar (58 psi) pressure
  - Over 18,000 hours of testing experience
  - Technology proven with high and low rank coals



- Demonstrated advantages of FPO technology
  - NOx below detection limit due to oxygen separation
  - Highly reduced particulate emissions
  - Flue gas is mostly CO_2 and water, facilitating carbon capture
  - Flexible enough to burn low ranking coals

Project Tasks and Goals

- Choose a location to host the pilot facility (EPRI, PRA)
  - Should already have coal receiving and handling infrastructure available
  - Must meet local regulatory requirements

- Design and layout a 50 MWth pilot facility (SwRI, Itea, GE, Jacobs)
  - Includes engineering of coal slurrying, combustion loop, turbo-expander, and once-through steam generator
  - Produce plan drawings, P&ID, and detailed specifications of pilot plant equipment
  - Generate cost estimates at the AACE Class 4 estimate level

- Create a testing program that addresses knowledge gaps and advances FPO technology readiness level (EPRI, SwRI, Itea)

- Prove that FPO development path can meet DOE cost and emissions targets for transformational coal technologies with techno-economic assessment (EPRI, SwRI)

Site Selection Process

- Assess potential sites on merit with weighted grading criteria
- After an initial assessment, score each site for each set of criteria
- Add up scores and choose 3 candidate sites for detailed assessment
- Make on-site visits and perform an evaluation of capabilities
- Perform a review of final three sites and narrow down to primary and secondary selections

Item	Importance
Business and Financing	
Are the organization operating the host site and the host site itself financially stable?	Medium
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?	Low
Does the organization have a successful track record with doing DOE projects?	Low
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 (e.g., union labor agreements)?	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?	Low
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?	Low
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?	High
Physical Attributes	
Are there perceived construction risks / access issues?	Medium
Does the host site have the ability to use different coals?	Low
Does the site have a potential need for process steam?	Medium
Does the site have an existing air separation unit or excess oxygen?	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
Environmental, Permitting, and Safety	
Are there any other concerns with accessing / providing consumables?	Low
Are there any perceived health, safety, and environment issues?	High
Are there concerns around air permitting for the site?	Medium
Are there concerns around water permitting for the site?	Medium
Does the site have National Environmental Policy Act Environmental Assessment and Categorical Exclusion?	High
Operations	
Are there any noise restrictions at the site that could limit the hours of operation?	Low
Are there any security risks for the host site?	Medium
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?	Low
Does the site have existing staff to support the project through all phases?	Medium
Does the site have the ability to support full 24/7 operations?	High
Does the site location have weather-related or altitude concerns?	Low
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 organizations?	Medium
Is there a risk of changes in future operations of host site that could impact the test plan?	Low

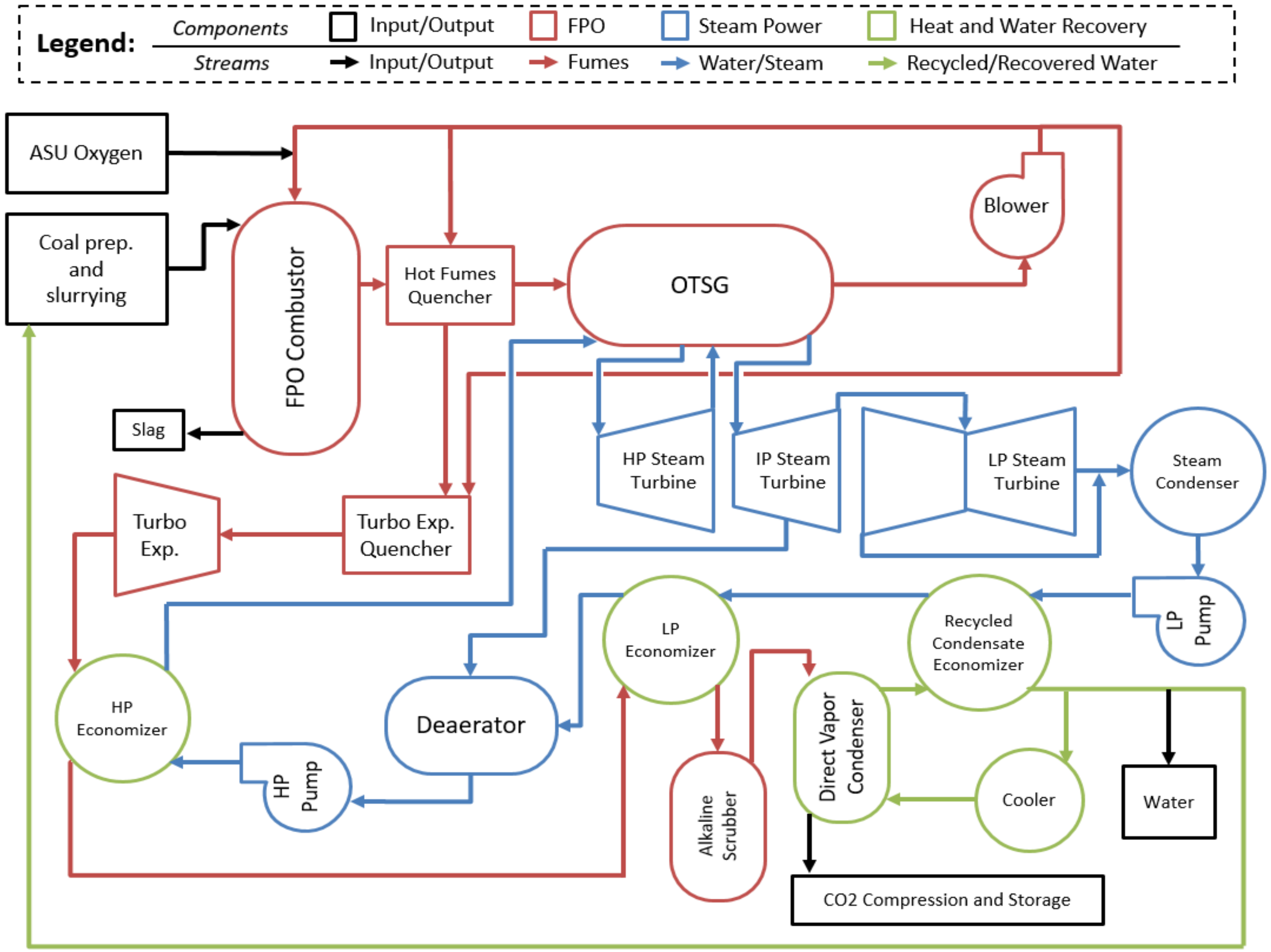
50 MWth Pilot Design

- Design Philosophy
  - 12 bar (174 psi) combustion loop
  - 50 MW of heat duty to the steam cycle and turbo-expander
  - Combustor exit temperature: 2510°F (1377°C)
  - OTSG inlet temperature: 1500°F (815°C)
  - Turbo-expander inlet temperature: 932°F - 1301°F (500°C - 705°C)

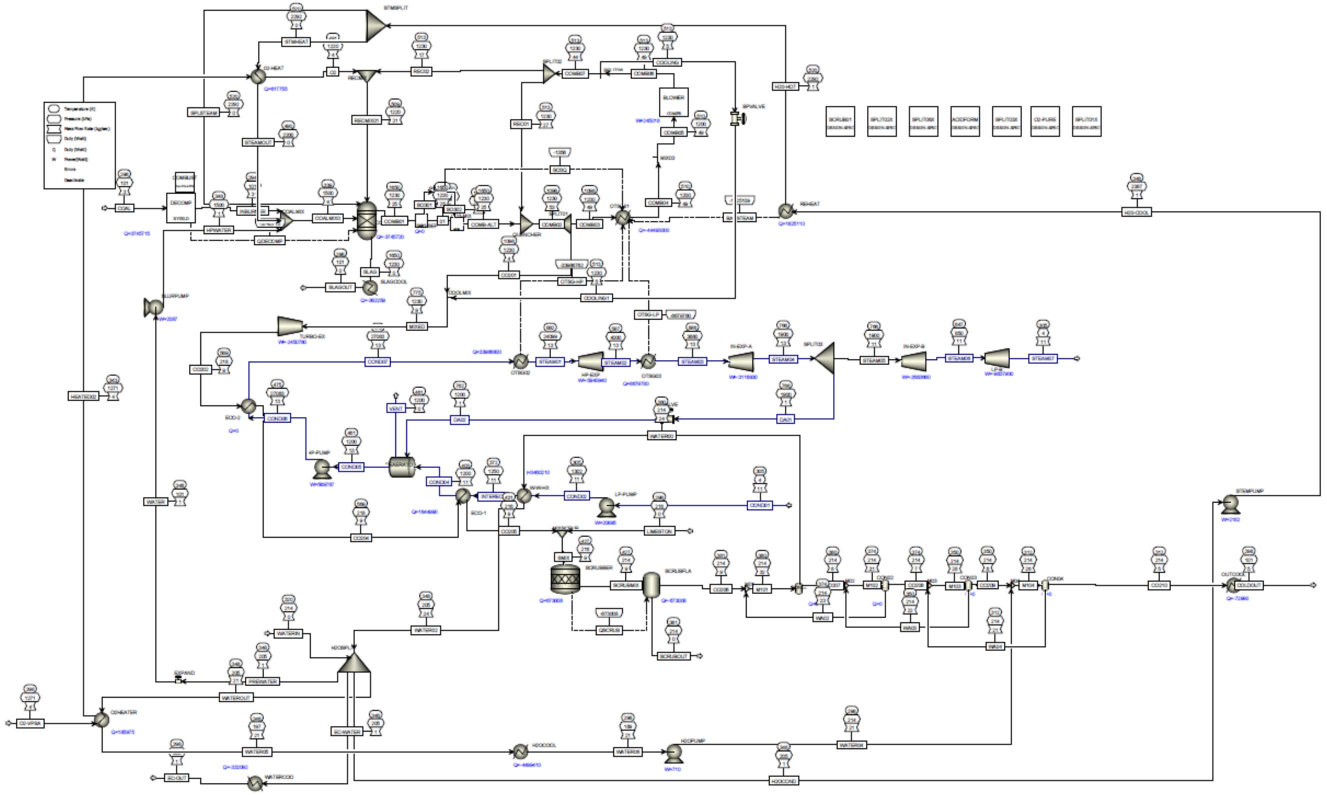
- Chosen Inputs
  - PRB coal as on-design, Illinois no.6 and ND-Lignite as off-design
  - Clean feed water for the steam generator
  - Oxygen at a minimum of 93% purity (requires ASU)

- Desired Outputs
  - Steam at customer required temperature and pressure
  - CO_2 at 95% purity
  - Produced water
  - Electric power from the turbines

Cycle Overview



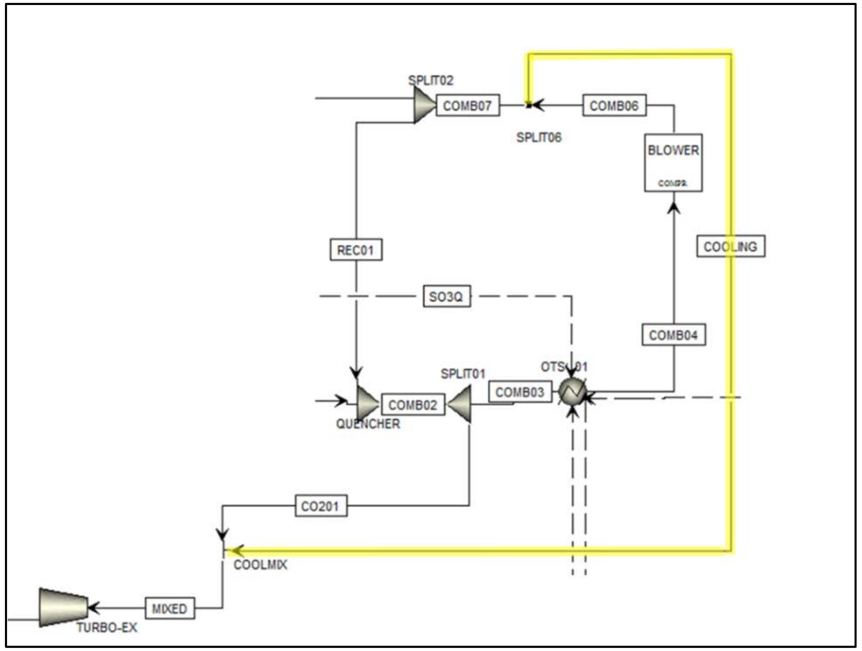
Aspen Plus Cycle Modelling

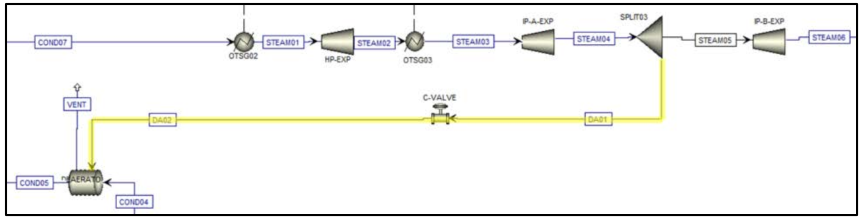


- Modelling of cycle performed in Aspen Plus v8.8
- Detailed stream mass, heat, and atom balances output by the model

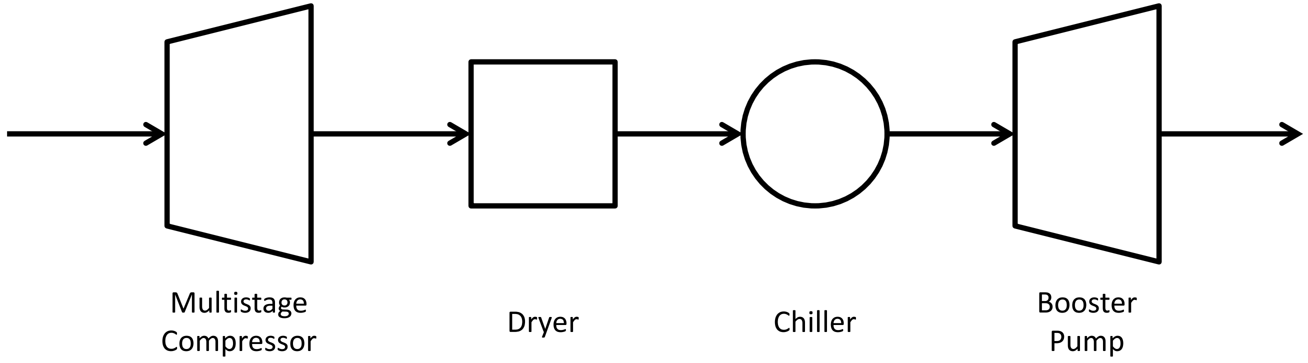
Valves and Plant Control

- Gas control valves and bypass lines provide plant flexibility
  - Low temperature gas only
  - Controls flow in long and short recycles
  - Controls temperature to turbo-expander
  - Dump valve after OTSG for emergency venting
- Valve for setting steam pressure to the deaerator
  - Flexibility for off-design and reduced flow conditions
- Steam governor control valve
- Test a wide range of coal ranks at an intermediate scale



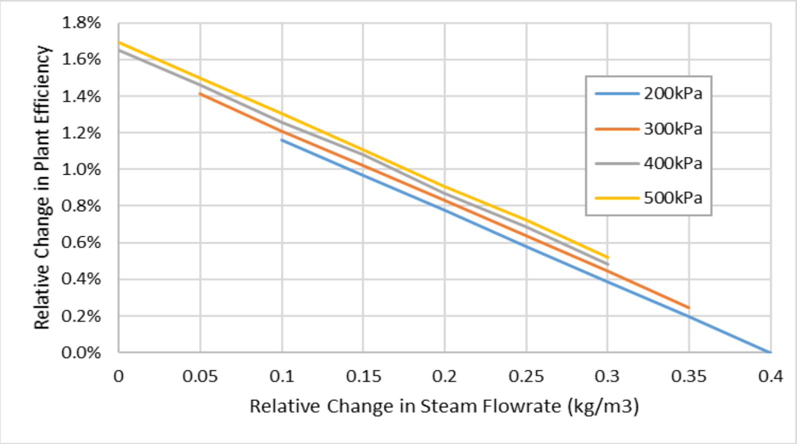


CO_2 Compression and Capture

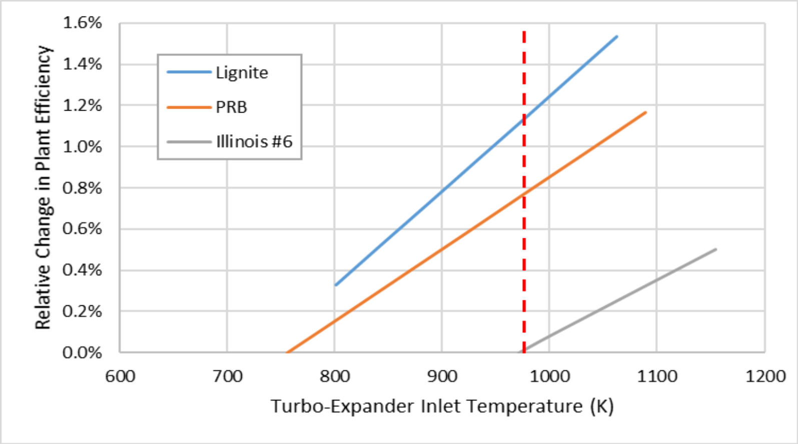


- Will only be included in the 50 MWth plant if required by the site
- Multistage compressor will allow for further water removal
- Condenser/chiller will vent incondensable gases
- Can produce CO_2 at commercial and EOR grade with O_2 at less than 1 ppm
  - Estimated to be 1.95 MWe parasitic power required for the 50 MWth plant (3.6% of as-is LHV coal heat input)

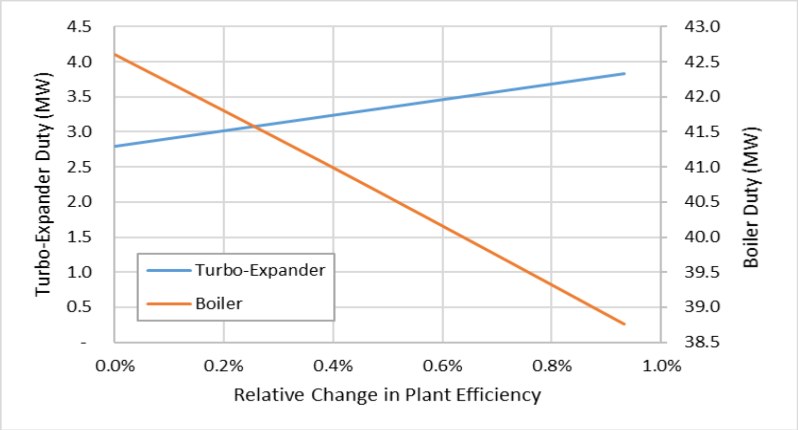
Cycle Optimization Studies



- Efficiency change for different deaerator set pressures



- Efficiency change for different coal types



- Efficiency improvement as duty is shifted to the turbo-expander

SwRI itea FLAMELESS TECHNOLOGY EPRI JACOBS GE

50 MWth Pilot Cycle Design Results

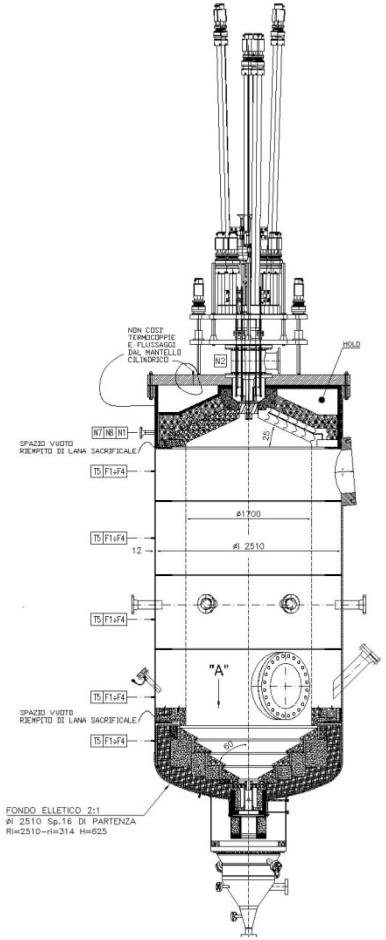
Performance Summary	
Total Gross Power MWe	**24.03**
Total Auxiliaries, MWe	**5.50**
Net Power, MWe	**18.53**
HHV Net Plant Efficiency, %	33.11
HHV Net Plant Heat Rate, kJ/kWh	10872
LHV Net Plant Efficiency, %	34.36
LHV Net Plant Heat Rate, kJ/kWh	10476
HHV Boiler Efficiency, %	90.21
LHV Boiler Efficiency, %	93.62
Steam Turbine Cycle Efficiency, %	47.59
Steam Turbine Heat Rate, kJ/kWh	7565
As-Received Coal Feed, kg/hr	10116
Limestone Feed, kg/hr	70
HHV Thermal Input, kWt	55,975
LHV Thermal Input, kWt	53,938
Excess Oxygen, % wt.	1.65

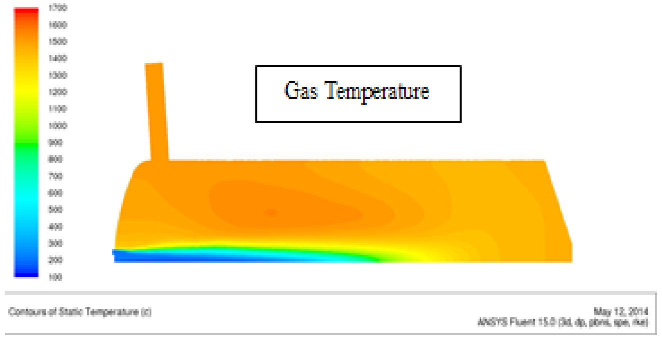
Power Summary	
Steam Turbine Power, MWe	**21.58**
Turbo-Expander Power, MWe	**2.45**
Total Gross Power, MWe	**24.03**
Auxiliary Load Summary	
Pulverizers, kWe	114.5
Slurry Pump, kWe	2.09
Vapor Condenser Cooler, kWe	150
Slag Cooler, kWe	36.5
Blower, kWe	245.0
Low Pressure Condensate Pump, kWe	20.9
High Pressure Condensate Pump, kWe	569.8
Vapor Condenser Pump, kWe	0.71
Service Steam Pump, kWe	2.18
Oxygen ASU, kWe	4353.5
Total Auxiliaries, MWe	**5.50**
Net Power, MWe	**18.53**

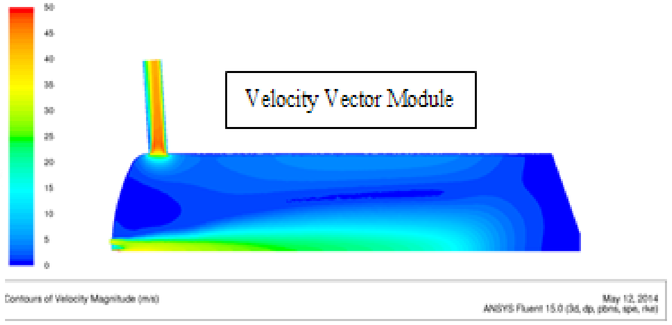
- Does not included estimated 1.95 MWe power draw by CCS
  - HHV net efficiency is 29.6% with CCS, LHV Net efficiency is 30.7%
  - Expected improvements with scale up to 550 MWe to efficiencies of 39.0% net LHV with CCS and 41.3% net LHV without CCS

Combustor Design

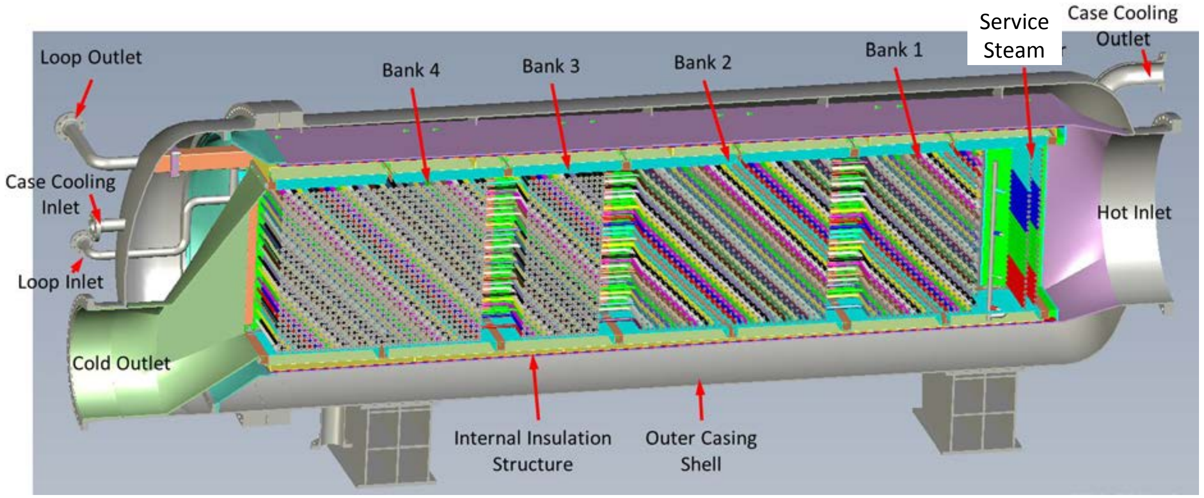
- Vertical design
  - Evolution from the horizontal combustor in the 5 MWth pilot
  - Refractory lined
- Expanded volume cone
  - Gas and slurry injected at top
  - Temperature and velocity tuned with CFD
  - Cone reaches to the bottom of the combustor before traveling back up the sides to the exit
- Flue gas quenching occurs immediately at exit







Once-Through Steam Generator (OTSG)



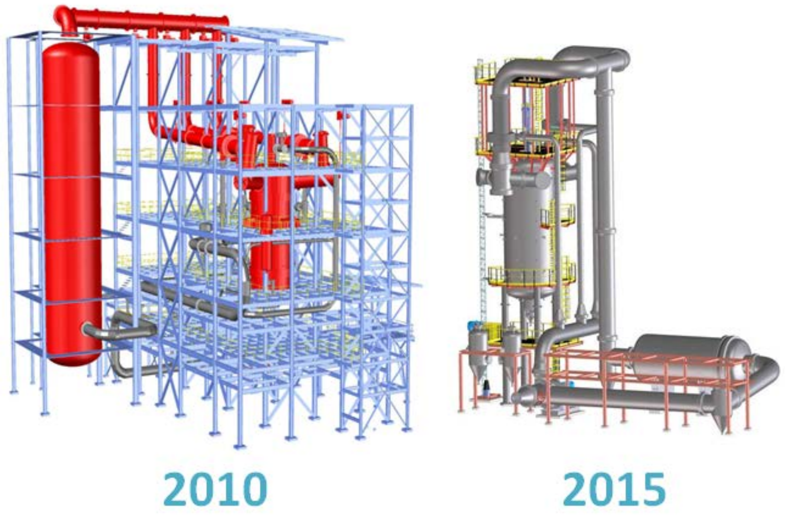
- Banks of finned tubes contained in a pressure vessel
  - Square duct supported and inserted into a circular pressure vessel
  - Between duct and pressure vessel is pressurized with cooler gas from the recycle blower
- Modular design can include multiple reheats
  - Banks can be assembled in different orders that optimize gas temperature profile
  - Fast startup and shutdown improves flexibility
- Size can improve ease of manufacturing and cost
  - Design of each OTSG could be kept small enough for off-site fabrication and transport
  - Multiple OTSG units may be needed, depending on plant scale

Technology Maturation

- Ongoing effort to mature the technology for a large demonstration plant
  - Reduced cost of support structure
  - Evolution of the OTSG design

- Address certain knowledge gaps through a large pilot
  - Scale-up of 5 MWth combustor
  - Once-through steam generator performance
  - Flue gas turbo-expander

- Test a wide range of coal ranks at large pilot scale
  - Demonstrate high efficiency even with high flue gas water content



Techno-Economic Assessment at Commercial Scale

- 350 MWe commercialization study already performed by ITEA with ENEL
  - Costed out earlier version of the system
  - Provided commercial scale material and energy balances
- Update existing commercial economic assessment with results from 50 MWth design efforts
  - Targeting a 500 MWe output to match DOE baseline studies
  - Add features and components not included in the 50 MWth pilot
  - Demonstrate a path to cost reduction goals

Parameter	**Unit**	**SCPC no CC Base Line**	**ITEA FPO / Integral CC Estimate**	**ITEA FPO / CCS-Ready Future Retrofit**
Power in LHV	MWth	1,345	1,410	1,410
Gross Power	MWe	580	695	695
Parasitic Power	MWe	30	145	113
Net Power	MWe	550	550	582
Efficiency % LHV	%	40.9%	39.0%	41.3%
Capital	$M	$869	$1,281	$1,243
CAPEX	$/kWe	$1,579	$2,328	$2,136
LCOE – **Bit. Coal**	$/MWh	$68	$78	$73
LCOE compared to Base Line			116%	108%
LCOE – **PRB Coal**	$/MWh	NA	$73	$68
LCOE compared to Base Line			108%	100%

Thank You