Enabling Staged Pressurized Oxy-Combustion (SPOC): Improving Flexibility and Performance at Reduced Cost

DE-FE0029087

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Acknowledgement and Disclaimer

Acknowledgement

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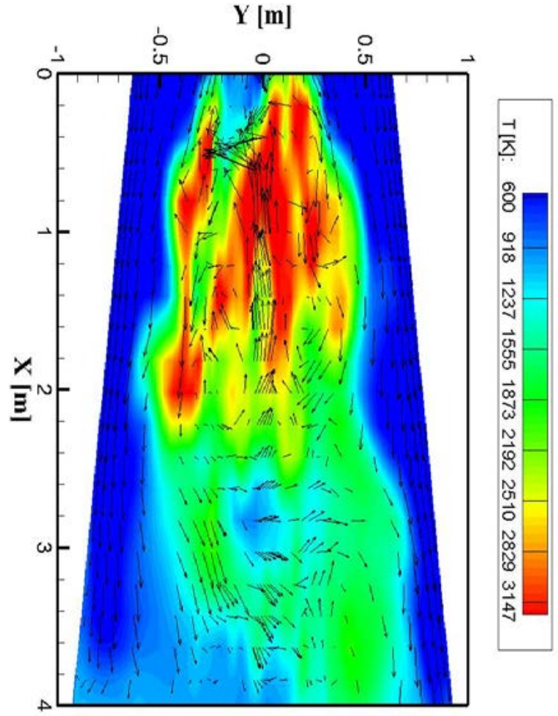
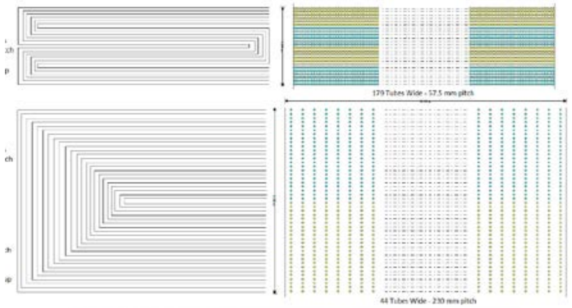
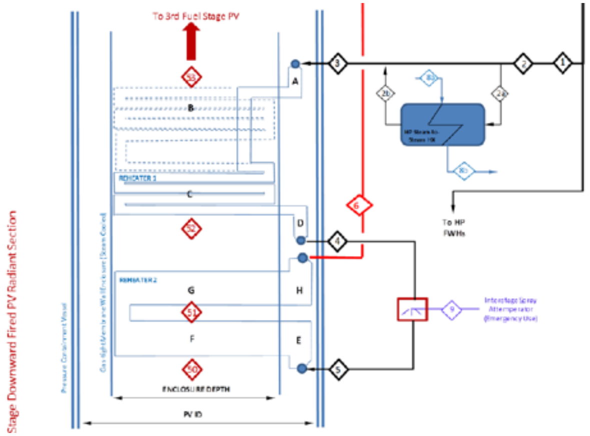
Agenda

- Project Overview
- Technology Background
- Technical Approach
- Progress
- Plans for Future Development
- Questions







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Project Overview

- Awarded October 2015, 24 month project
- $1,167m federal funding, $291,800 cost share (20%)
- EPRI are leading the project alongside Washington University in St. Louis, American Air Liquide and Doosan Babcock
- Objectives:
  - Update the design of the novel staged, pressurized oxy-combustion (SPOC) system by OEM review
  - Develop flexible design concepts utilizing the SPOC system and advanced oxygen supply strategies
  - Validate design tools through pilot plant testing

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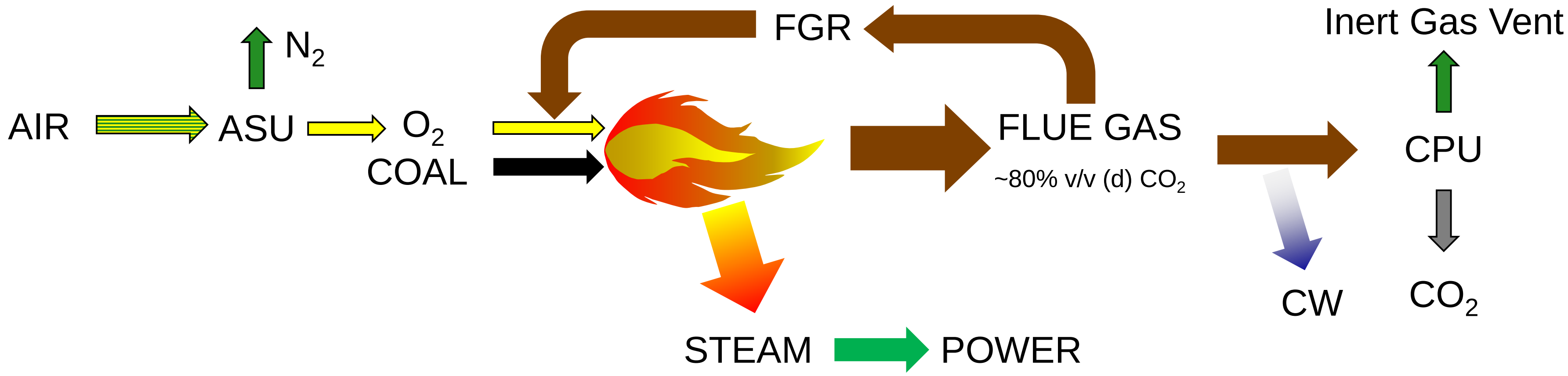
Technology Background – Oxy-Combustion

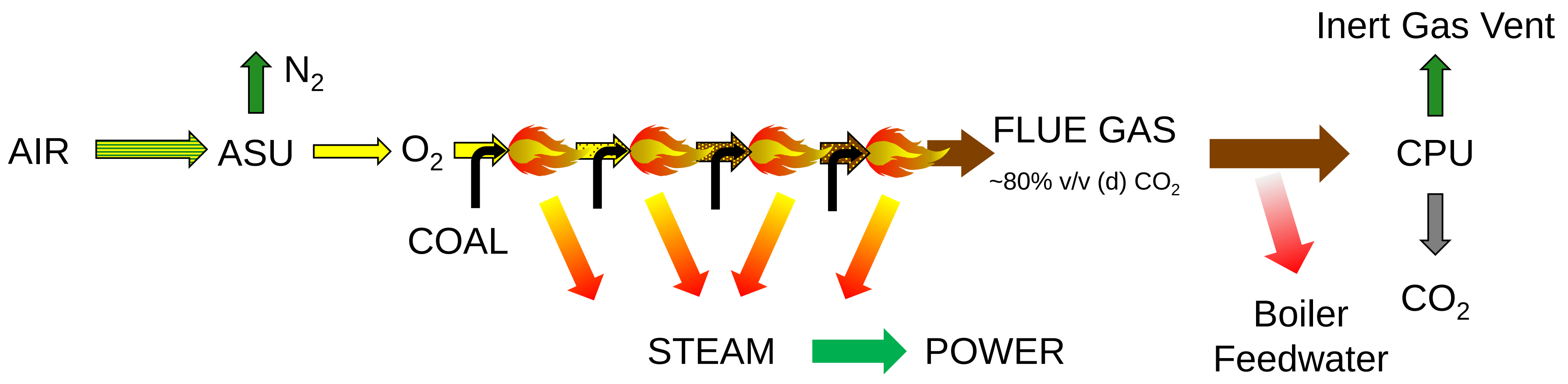
- Oxy-combustion technologies typically recycle a portion of the flue gas to reduce the peak temperatures and increase the resulting gas flow rate, making convective heat transfer easier
- The fan power needed for flue gas recycle (FGR) increases the overall auxiliary power
- Atmospheric oxy-combustion necessitates large furnace volumes and cannot utilize fuel moisture latent heat (low partial pressure of H_2O results in low-temperature condensation)



Boiler hardware arrangement similar to conventional air-fired boiler

Technology Background – Oxy-Combustion (cont.)

- **Staged Combustion –** most of the oxygen is added to 1st stage but fuel is restricted to deliver appropriate post-combustion temperatures; FGR and gas volume reduced
- **Pressurized Combustion –** reduces the size of the combustion system, eliminates air ingress, allows latent heat from moisture to be recovered at useful temperatures whilst delivering gases to the CPU at elevated pressure, enables easy SOx/NOx removal and restricts radiative heat flux by creating an optically dense medium; FGR is minimized

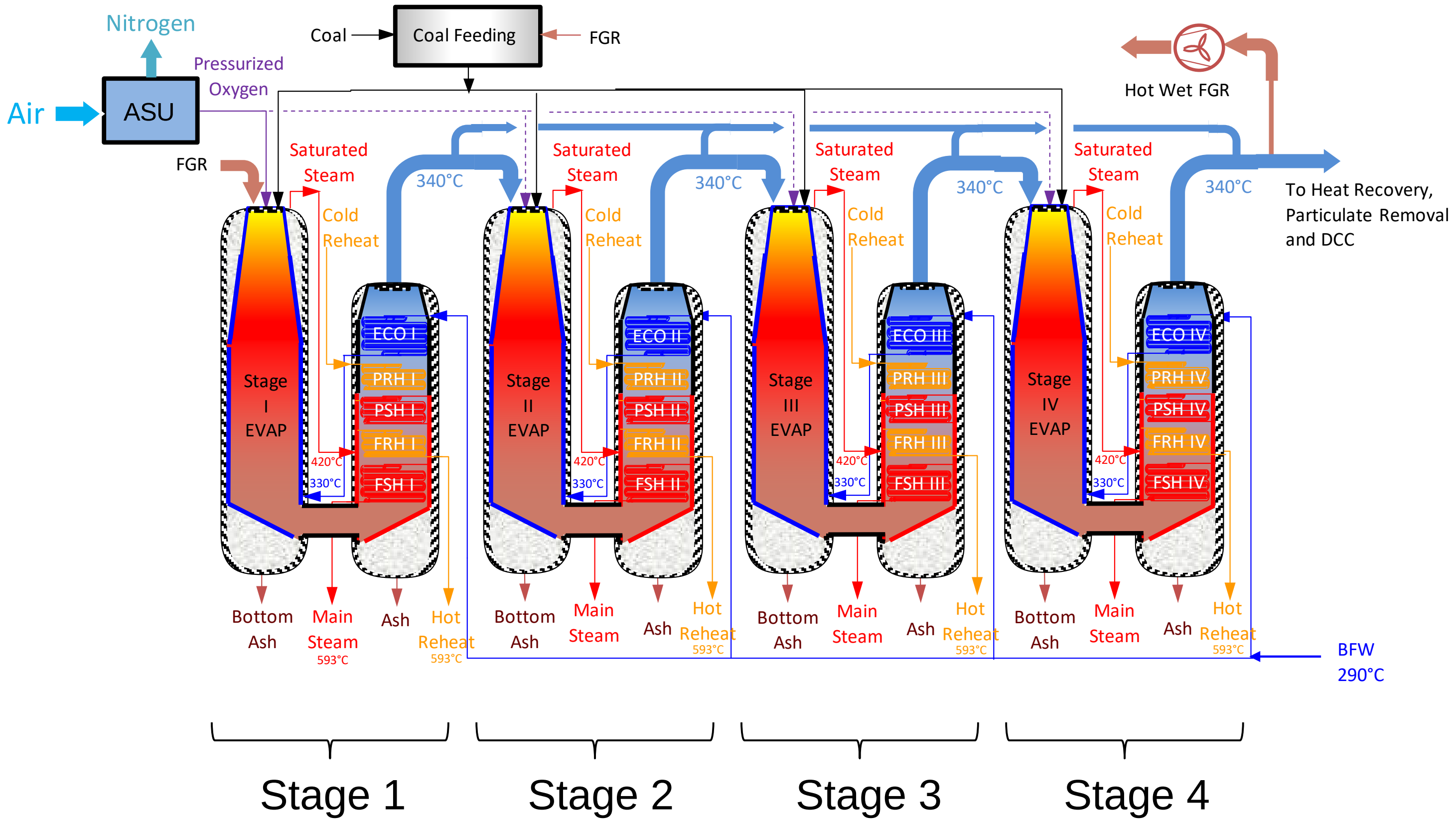


Compact boiler, enhanced convective heat transfer and lower CO_2 compression costs

Technology Background – SPOC

- What is “Staged Pressurized Oxy-Combustion” (SPOC)?

- Burn fuel incrementally to limit peak temperatures and heat flux levels
- Absorb heat sufficiently to allow next stage combustion
- Minimal need for FGR, hence low fan power requirements
- Operating pressure assures fuel moisture latent heat is captured into the steam cycle



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Technical Approach

Task	Description	Sub-tasks
Task 2	Concept review and configuration optimization	Design Basis Boiler OEM review of prior work Developed risk matrix Upgraded OEM boiler performance model for SPOC conditions Conducted heating surface sizing exercise for 550MWe scale Define boiler concept design, assess costs
Task 3	System integration with steam cycle	Model NETL baseline case B12A Assess heat recovery opportunities Auxiliary power of SPOC system
Task 4	Turndown and flexibility	Options for enhanced turndown Oxygen supply flexibility
Task 5	Combustor performance testing	Upgrade pilot plant for target pressure operation Carry out full load and part load testing to recommended conditions
Task 6	Economics	CAPEX assessment, OPEX and LCOE

Progress: Project Schedule

- Task 2 – SPOC concept review (complete)
- Tasks 3, 4 & 5 – Integration, flexibility and testing (ongoing)
- Task 6 – Economics (to be initiated)

Task Name	Start Date	End Date	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
			2016		2017												2018												2019			
Task 1.0: Project Management and Planning	**11/1/2016**	**10/31/2018**																														
Subtask 1.1: Project and Risk Management	11/1/2016	10/31/2018	M1																													
Subtask 1.2: Financial Reporting	11/1/2016	10/31/2018			Q			Q			Q			Q			Q			Q			Q									
Subtask 1.3: Project Reporting	11/1/2016	10/31/2018		K, M2					K, M2																							
Subtask 1.4: Technology Transfer/Exchange	11/1/2016	10/31/2018			Q			Q			Q			Q			Q			Q			Q									
Task 2.0: Concept Review and Configuration Optimization	**3/1/2017**	**3/31/2018**																														
Subtask 2.1: Design Basis Development	3/1/2017	4/31/2017				M3			M3																							
Subtask 2.2: SPOC Boiler Concept Review	4/1/2017	8/31/2017										S																				
Subtask 2.3: Definition of Optimized Arrangement for 550-MWe Scale	6/1/2017	3/31/2018																	M4			M4										
Task 3.0: Detailed Integration of SPOC with the Steam Cycle	**10/1/2017**	**8/31/2018**																														
Subtask 3.1: Steam Generator Performance	10/1/2017	3/31/2018																														
Subtask 3.2: CFD Modeling	12/1/2017	5/31/2018																														
Subtask 3.3: Steam Turbine Performance	3/1/2018	7/31/2018																														
Subtask 3.4: Oxygen Supply Energy Requirements	5/1/2018	8/31/2018																														
Task 4.0: Turndown and Flexibility	**1/1/2018**	**5/31/2018**																														
Subtask 4.1: Steam Generator Turndown	1/1/2018	5/31/2018																														
Subtask 4.2: Steam Generator Performance	1/1/2018	5/31/2018																														
Subtask 4.3: Oxygen Supply Flexibility	1/1/2018	5/31/2018																			S, M5			S, M5								
Task 5.0: Combustor Performance Testing	**12/1/2016**	**9/30/2018**																														
Subtask 5.1: Retrofit of 100-kWth Pressurized Oxy-Combustor	12/1/2016	4/30/2018															M6,D															
Subtask 5.2: Experimental Determination of Combustion Domains	5/1/2018	3/31/2018																														
Subtask 5.3: Measurement of Heat Flux, Composition, and Temperatures	8/1/2017	9/30/2018																														
Task 6.0: Economics	**5/1/2018**	**10/31/2018**																														
Subtask 6.1: SPOC System Total Overnight Capital	5/1/2018	7/31/2018																														
Subtask 6.2: ASU Overnight Capital	7/1/2018	9/30/2018																														
Subtask 6.3: COE Assessment	9/1/2018	10/31/2018																													F, M7	
			FY 2017											FY 2018												FY 2019						

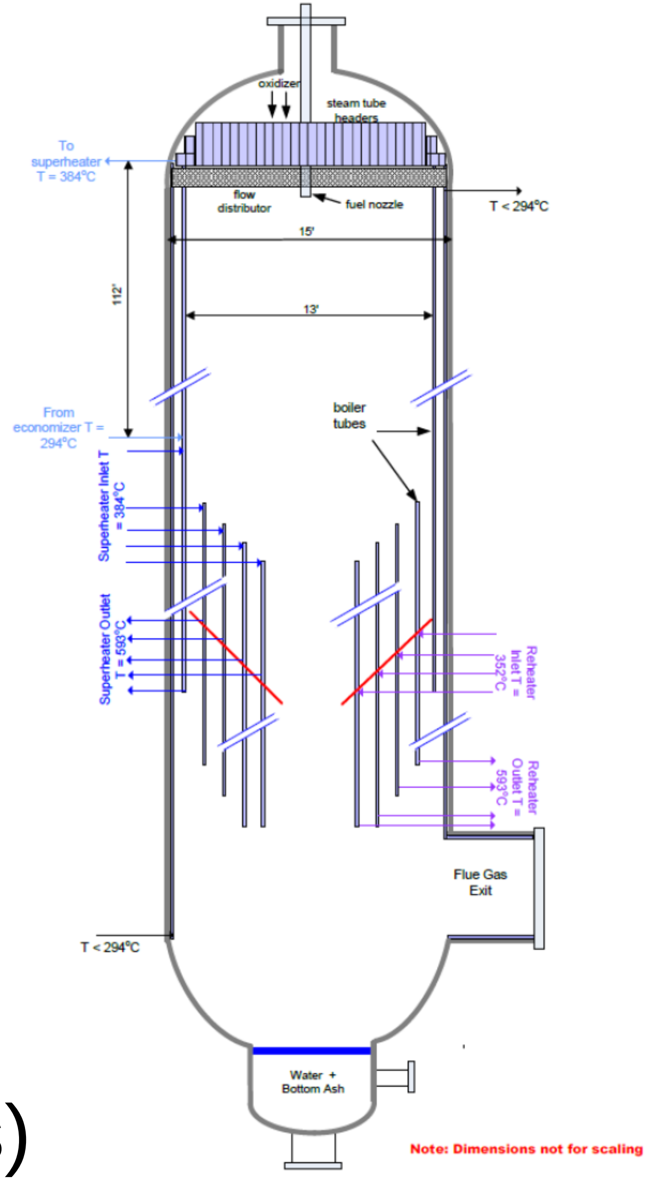
Boiler design activity minor delay due to workshop scheduling

Task 2 – OEM Concept Review

- The previously developed SPOC boiler concept was reviewed against OEM boiler design requirements

- Areas of particular focus were:
  - Layout
  - Vessel Arrangement and Sizing
  - Burner Design
  - Fuel Selection and Fuel Handling
  - Particulate Removal
  - Ash Management and Ash Handling

- Risk matrix developed (with potential mitigations)



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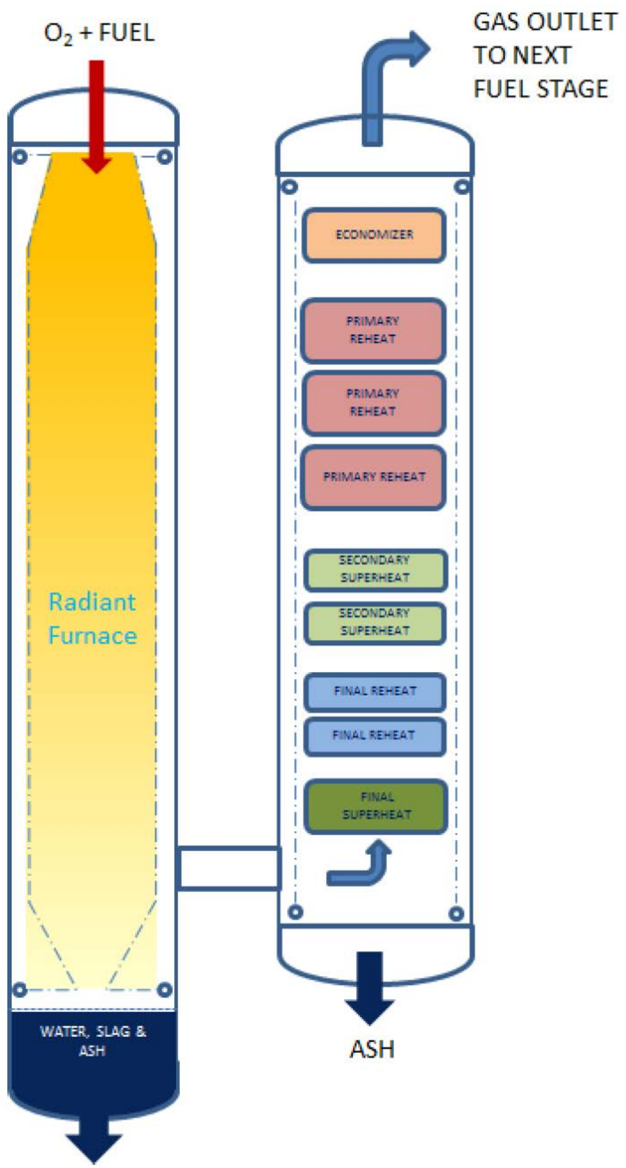
Task 2 – Risk Mitigation

- Revised design:
  - Combustor vessel with steam cooled walls and no heating surface in the gas path
  - Transition to upward flowing ‘convective’ sections – allowing for ash and slag management
  - Cross flow heat transfer, substantial heat transfer surface
- A workshop was held to develop the concept further



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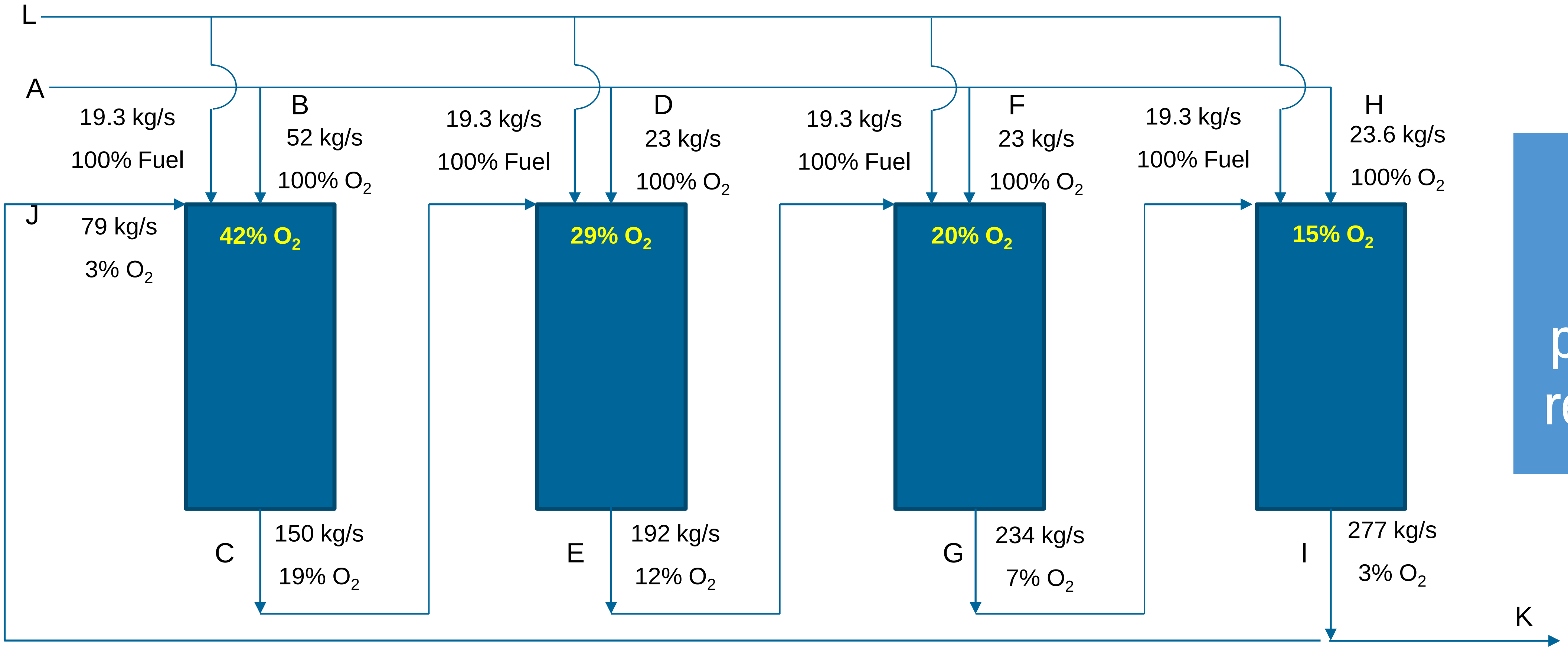
Task 2 – Original SPOC Concept



Each stage has unique performance requirements

	A	B	C	D	E	F	G	H	I	J	K
Total Flow (kg/s)	121.6	52	150	23	192	23	234	23.6	277	79	198
[O_2] (% v.)	100	100	17	100	10	100	6	100	3	3	3
[CO_2] (% v.)	0	0	48	0	52	0	54	0	56	56	56
[H_2O] (% v.)	0	0	35	0	38	0	40	0	41	41	41

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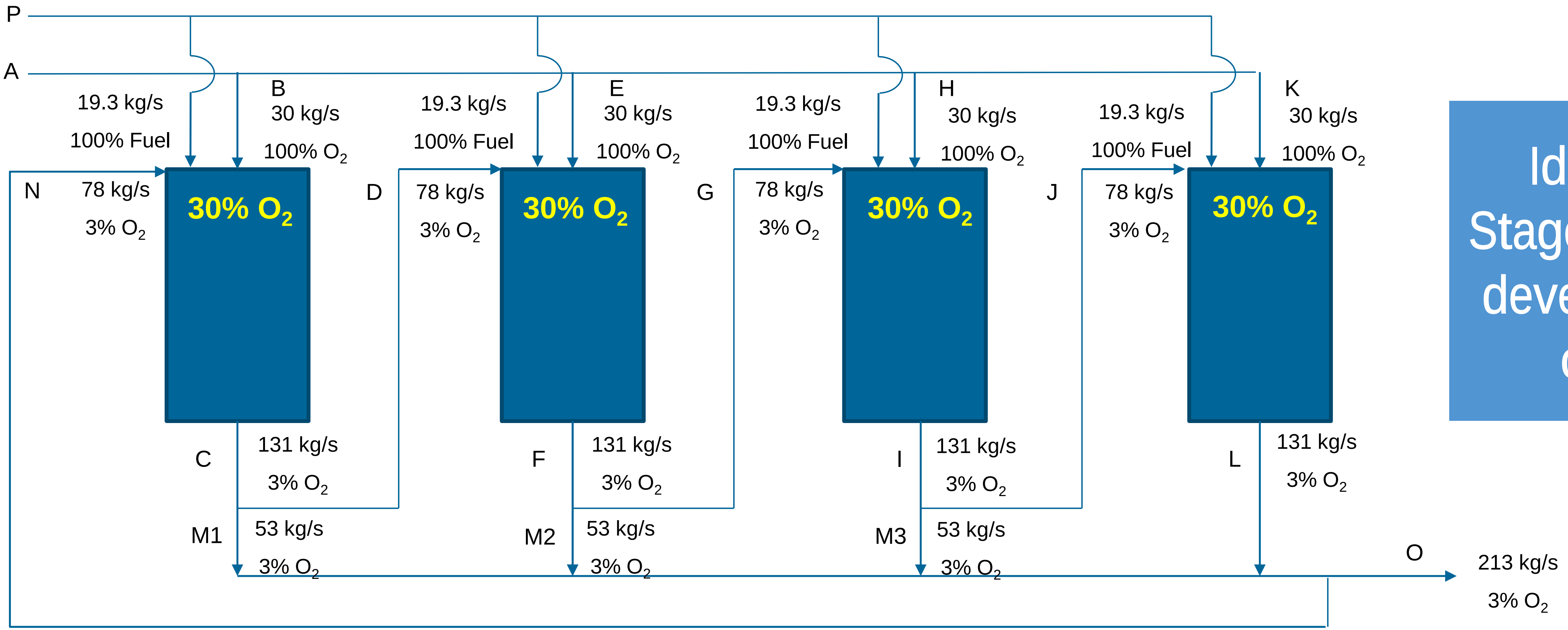
Task 2 – Revised SPOC Arrangement

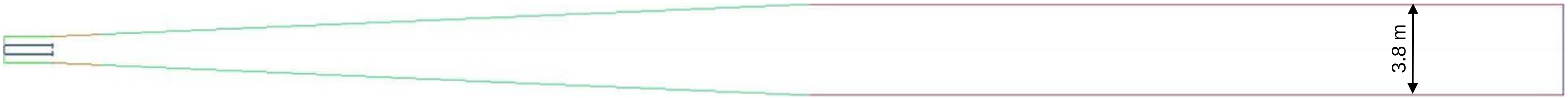


Identical Stages - lower development costs

	A	B	C	D	E	F	G	H	I	J	K	L	M1	M2	M3	N	O
Total Flow (kg/s)	122	30.4	131	77.8	30.4	131	77.8	30.4	131	77.8	30.4	131	53.2	53.2	53.2	53.2	213
$[O_2]$ (% v.)	100	100	3	3	100	3	3	100	3	3	100	3	3	3	3	3	3
$[CO_2]$ (% v.)	0	0	56	56	0	56	56	0	56	56	0	56	56	56	56	56	56
$[H_2O]$ (% v.)	0	0	41	41	0	41	41	0	41	41	0	41	41	41	41	41	41

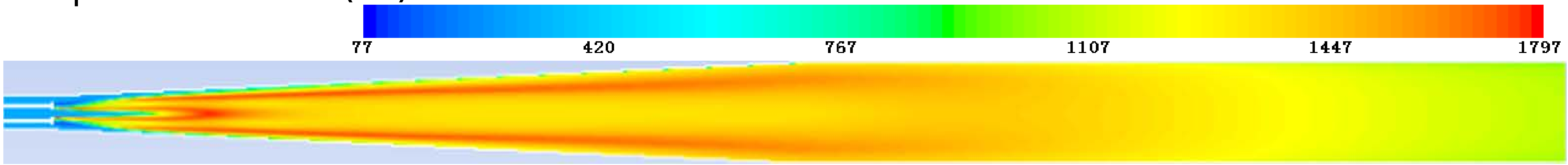
Task 2 – Combustion – Long conical design

- PRB coal; 385MW; 30%/70% of O_2/CO_2; Particle size: 40% 1.6~2.0 mm, 60% 10~200 µm.

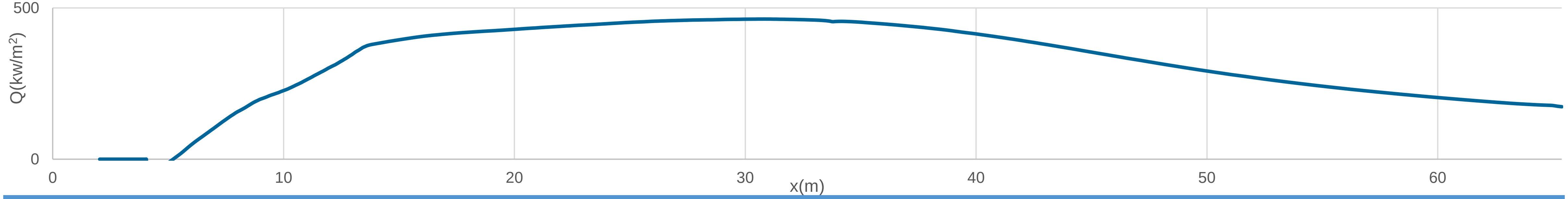


Drawing to scale

- Temperature contour (°C)



- Total surface heat flux (kW/m^2)



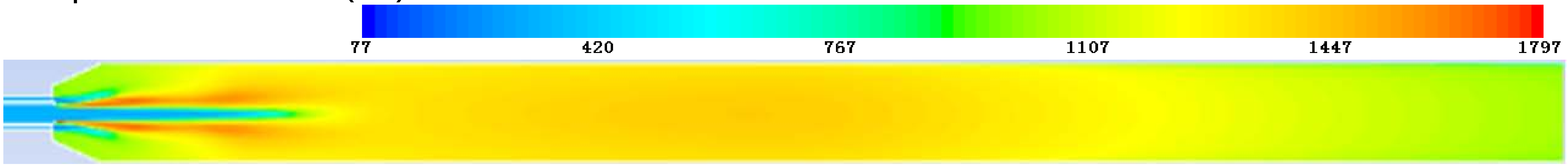
Complex furnace tube geometry needed in upper sections

2.3 – Combustion – Revised design

- Same conditions as previous case except particle size is 50% 1.4~1.8 mm, 50% 10~200 µm

Drawing to scale

- Temperature contour (°C)



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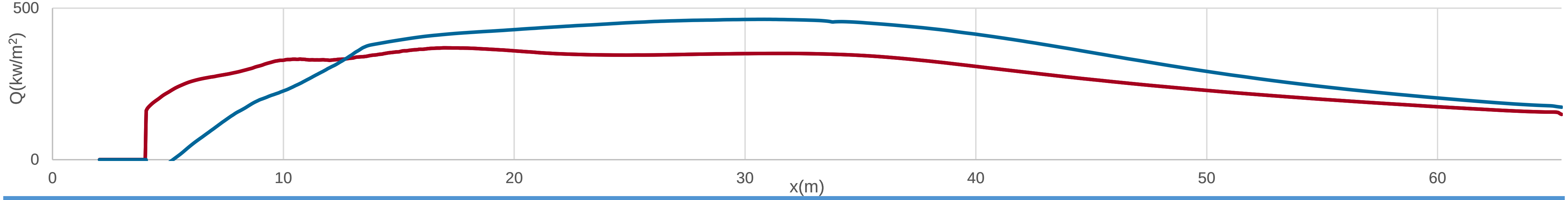

Simplified SPOC for reduced capital costs and lower peak heat flux

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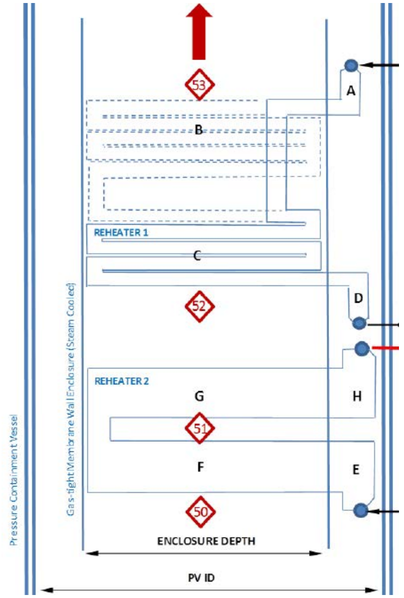
Task 2 – 550MWe Design

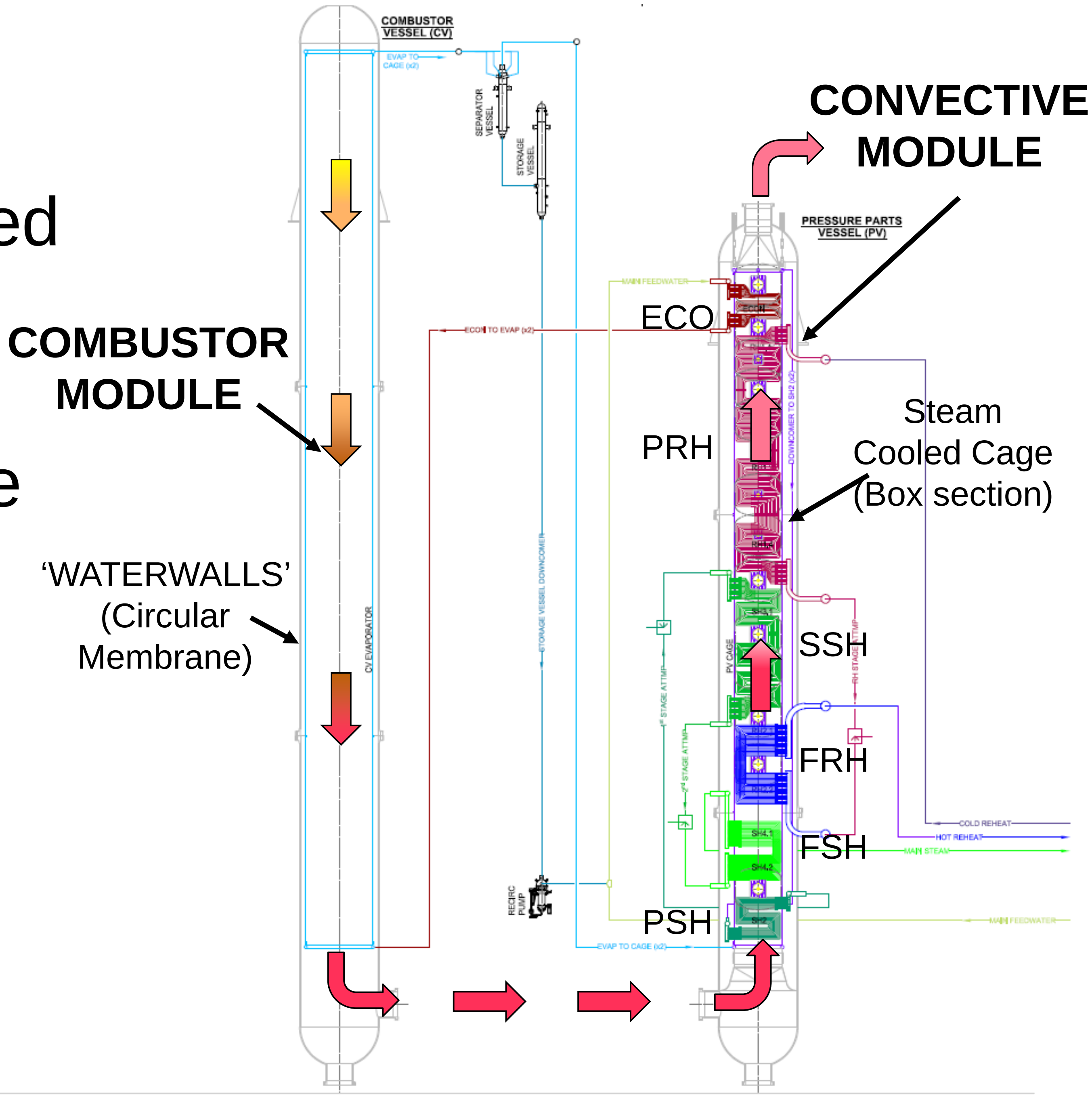


- Aim to reduce construction costs
- Single boiler design across all stages
- Modular and ground transportable
- Sequential gas bed concept
- Hot FGR ensures stage 1 identical to subsequent stages
- Steam/water equally shared across all stages
  - Mass flux / geometry / tube selection
  - Cage design, accommodation of headers/supplies/risers

Identical furnace and boiler stages reduces cost and complexity

Task 2 – Module Design

- Two pressure vessels needed for a single SPOC ‘stage’
- Combustor module cooled with evaporative surface due to high incident heat flux
- Direction change at base to aid furnace ash dropout
- Convective pass headers contained within PV cavities (minimize penetrations)



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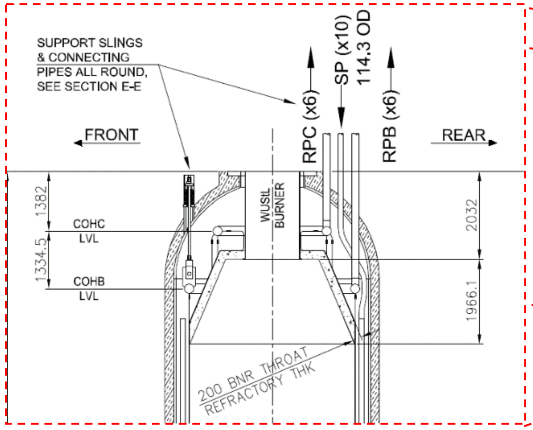
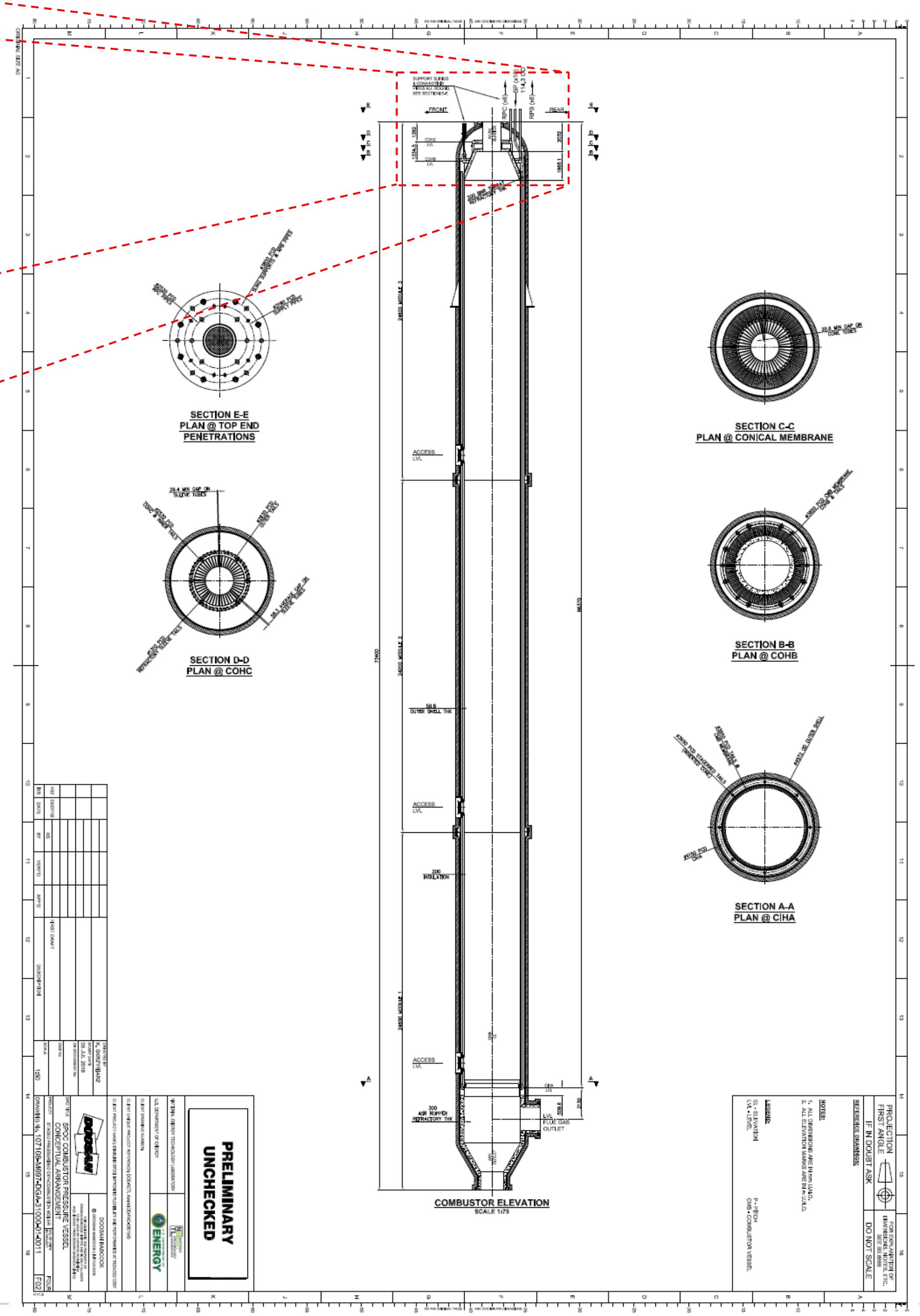
Task 2 – Combustor Module Concept

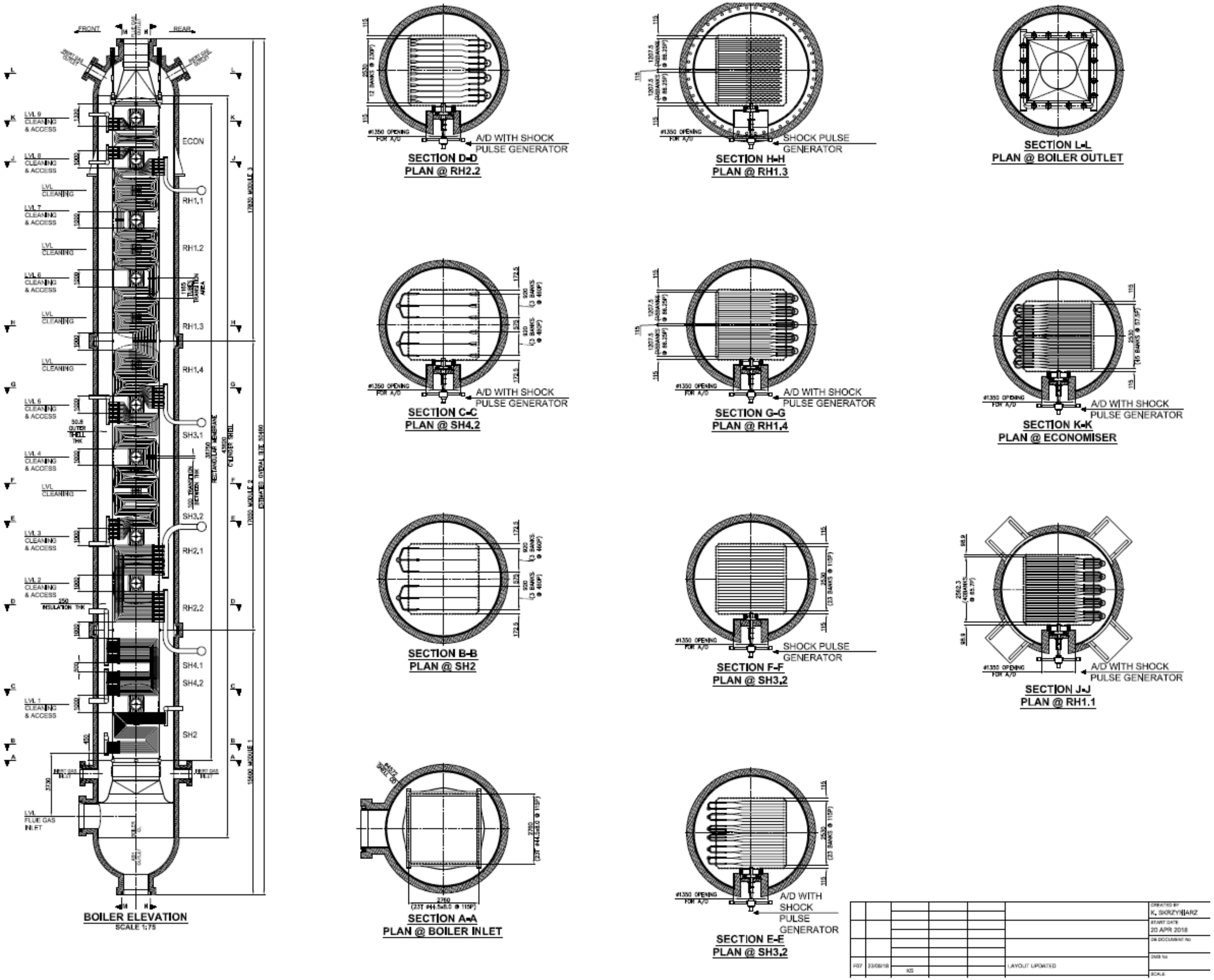




- Sized based on WUSTL combustion performance predictions
- Evaporator based on once-through, vertical tube membrane wall arrangement
- Top and bottom sections refractory lined

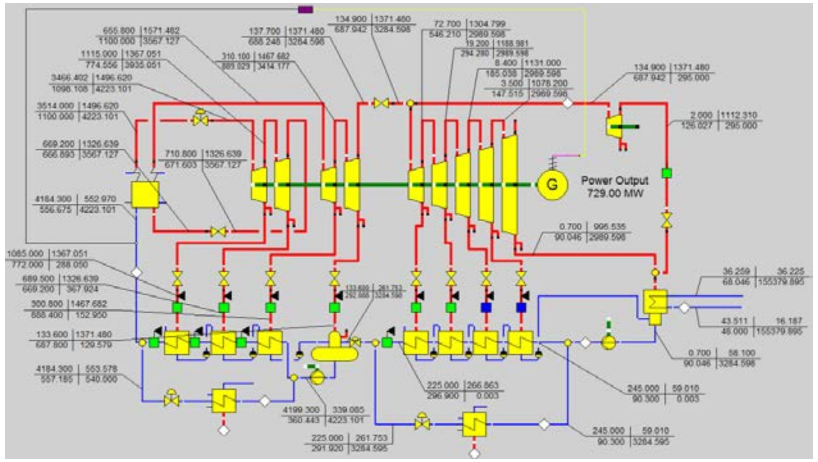
Task 2 – Convective Module Concept

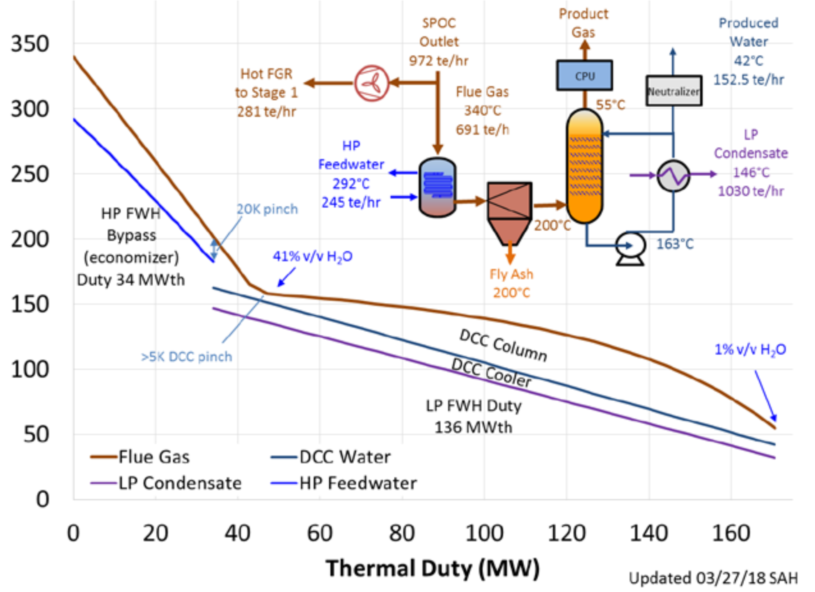
- Membrane walls, square profile
- Internal sub-headers
- Plenum at base to assist ash dropout
- Inert CO_2 gas added to cool pressure vessel
- In-situ cleaning



Task 3 – Integration with steam cycle

- NETL baseline case S12A modeled
- Assessment of heat recovery available
- 34 MWth available at sufficient temperature for HP feedwater bypass
- 136 MWth available at lower temperatures from DCC/acid gas removal column
- Corrosion resistant materials needed due to high acid dew point at pressure

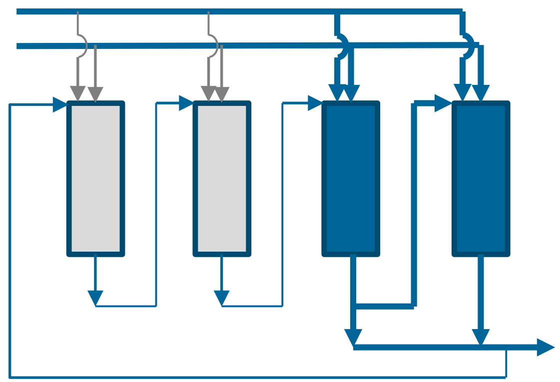




Low temperature heat available sufficient to eliminate LP feedwater heaters

Task 4 – Flexibility

- Stage Bypass Potential
  - at reduced firing rates on proceeding stages, full bypass of subsequent stages is possible with Concept 3 arrangement
  - NFPA-85 compliance, purge flow before stage restart
- Increased FGR at low load
  - Improved convective/radiative balancing
- Air Separation Unit
  - Storage of air inventory to allow MAC ‘deferment’
  - Reduced LOx storage, maintain 8 hour startup oxygen supply



Staged system delivers high turndown potential

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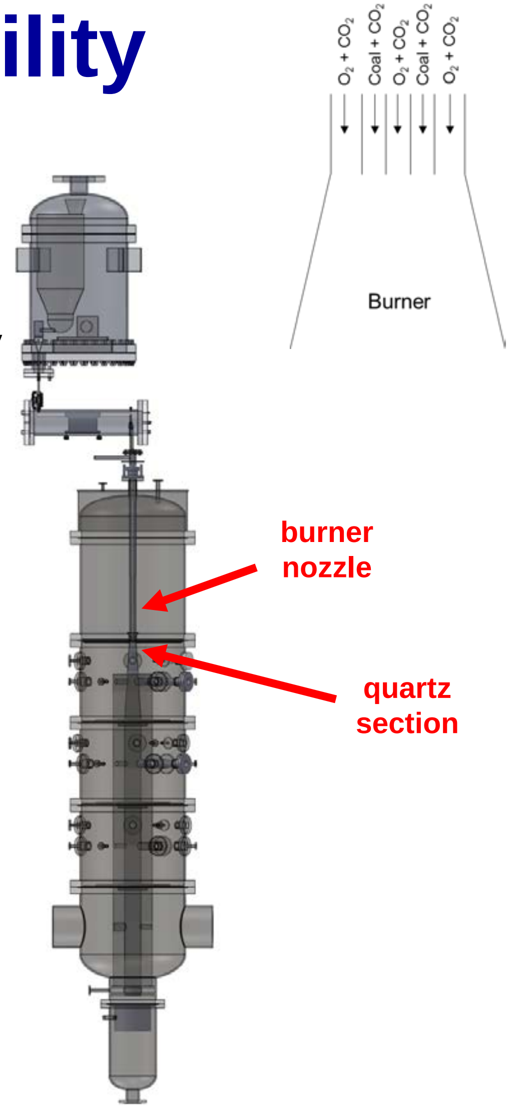
Task 5 – WUSTL Pressurized Combustion Facility

- Pressures up to 15 barg
- Thermal input up to 100 kW
- Solid and gaseous fuel testing capability
- Full view of near-burner (flame) region
- Diagnostics include:
  - Temperature profile
  - High Speed Camera
  - Heat Flux
  - Particle / gas sampling and ELPI, CEM
  - Laser transmission for soot/ash measurement
  - Fourier-transform infrared spectroscopy (FTIR)
- Ability to test multiple burners
  - Two types of burner configurations tested



Multiple load cases planned for numerical model validation

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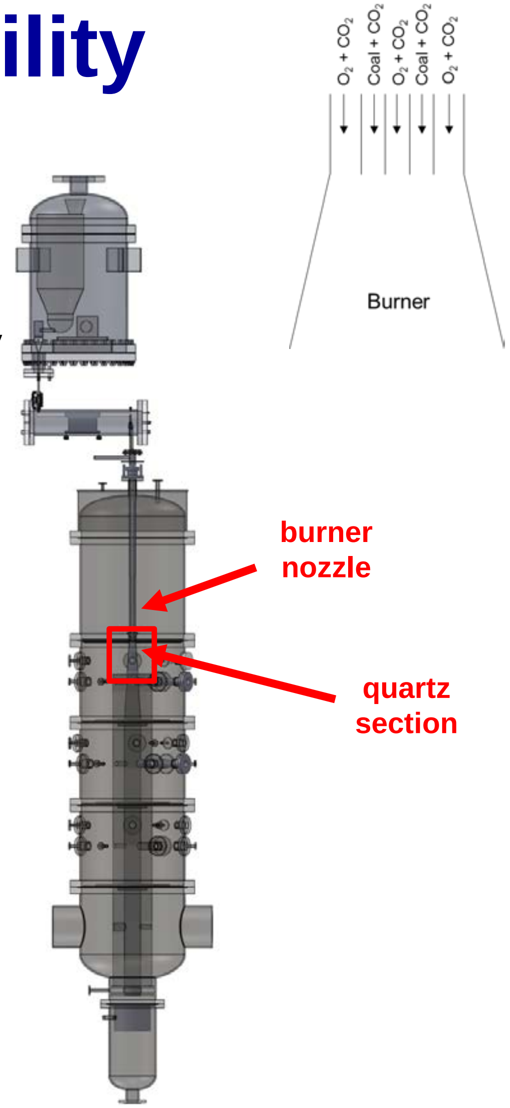

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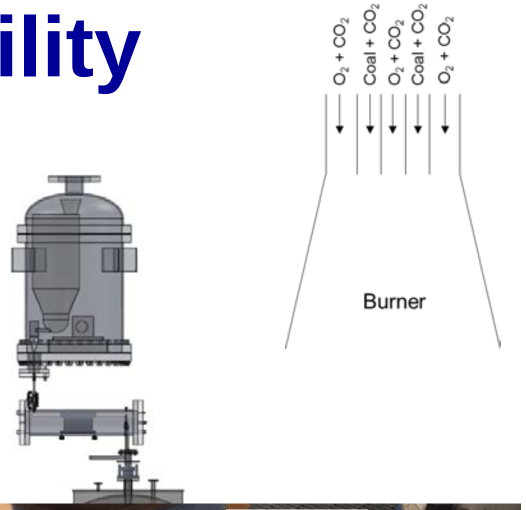

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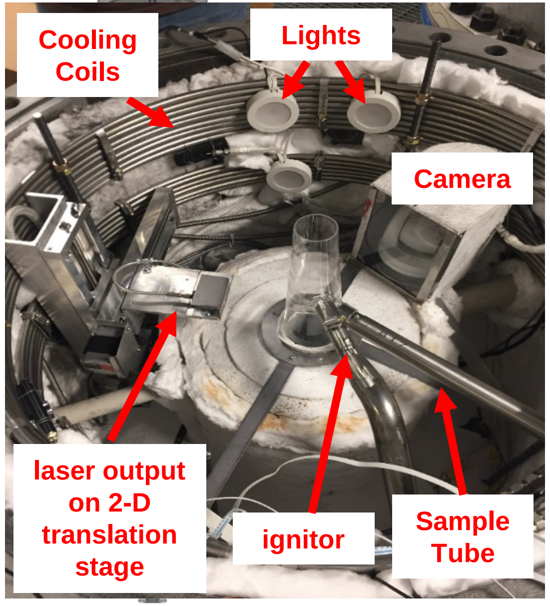


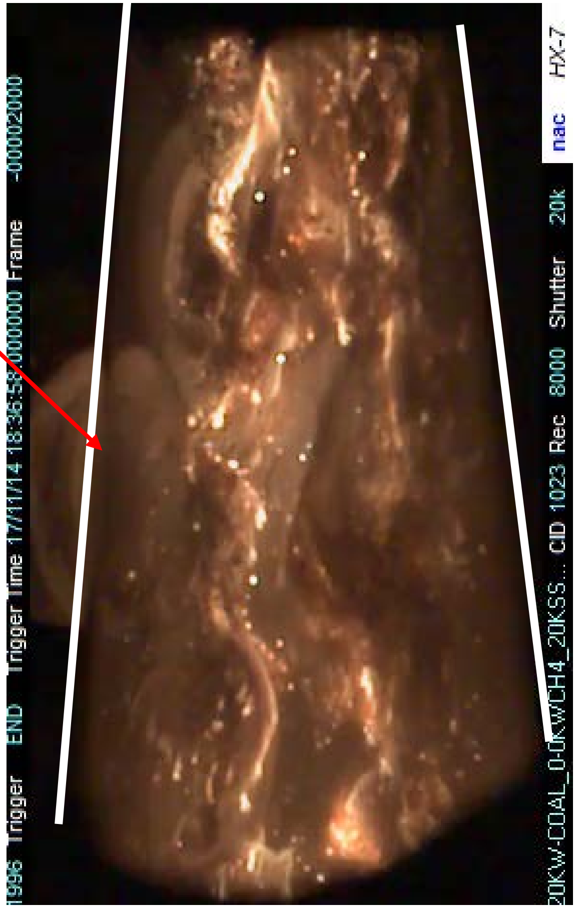
Multiple load cases planned for numerical model validation

Task 5 – Firing experience and validation

Experiments from 1 bar to 15 bar conducted at WUSTL show similar characteristics.

Video

Quartz wall



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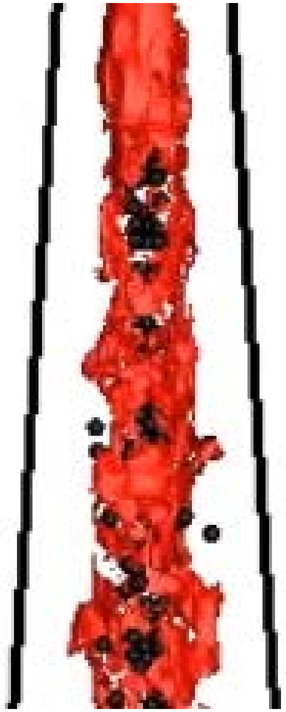

LES Simulation

Qualitative agreement between experiments and simulations achieved in terms of flame shape and flow field

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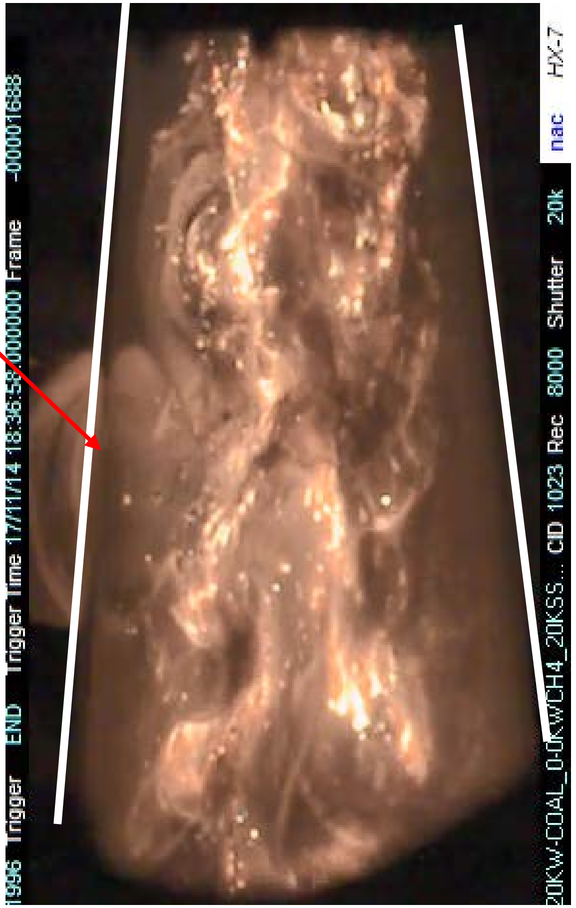

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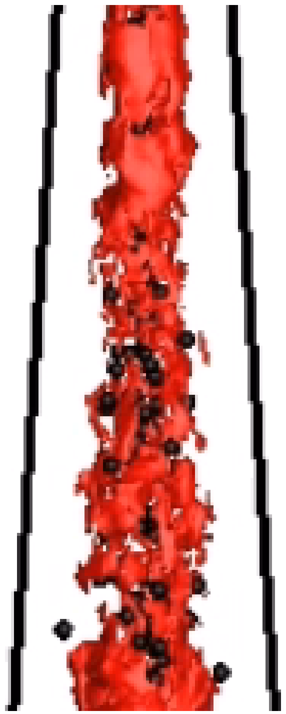

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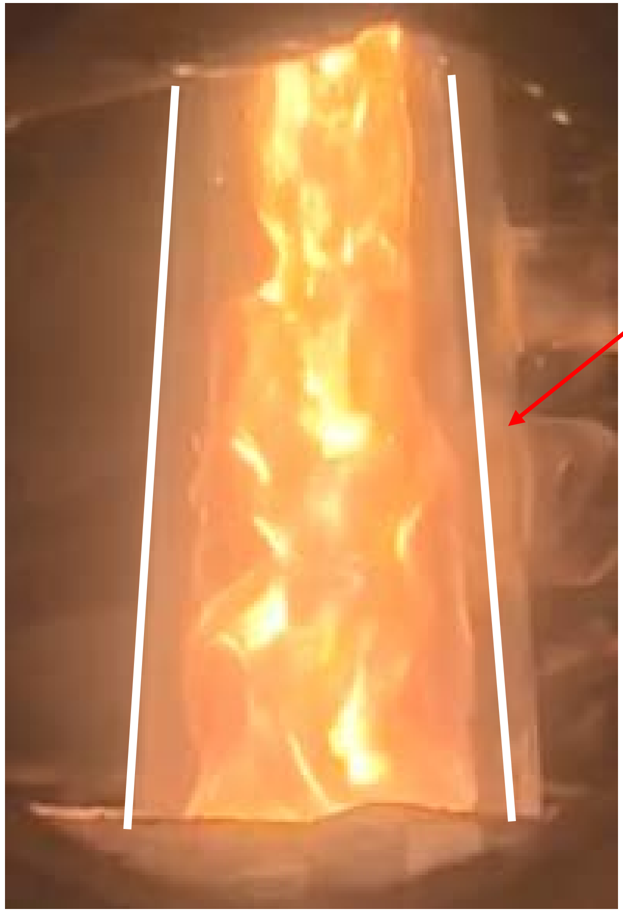

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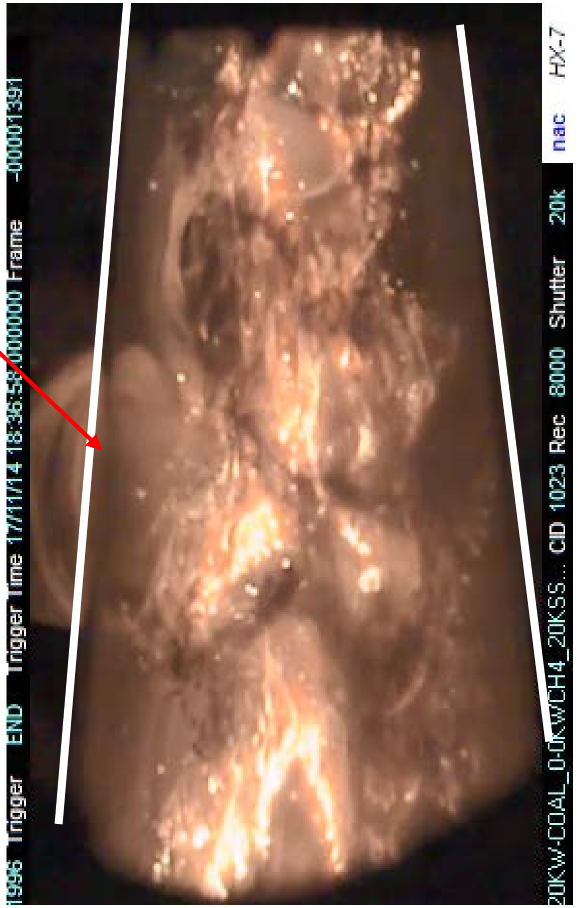

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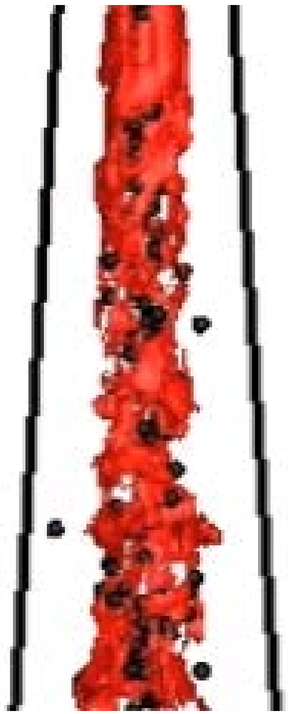

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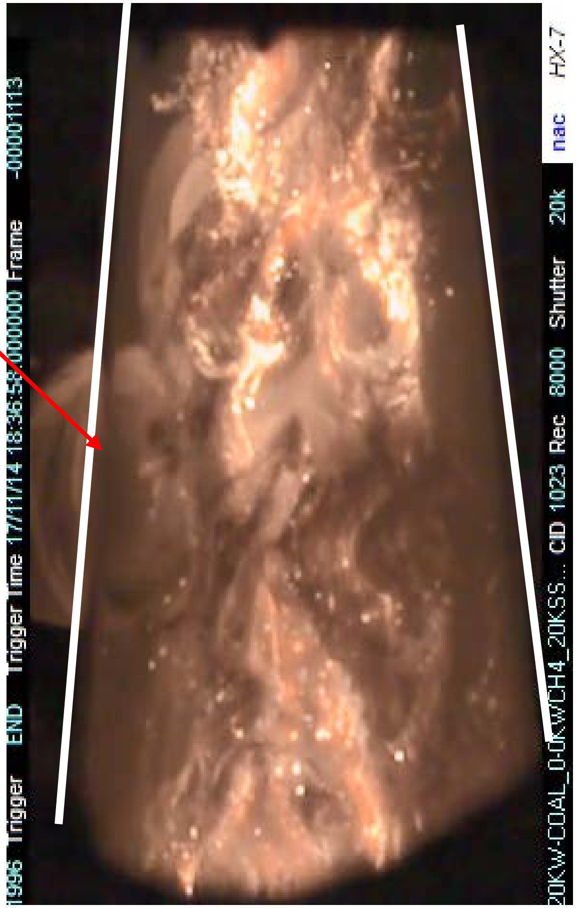

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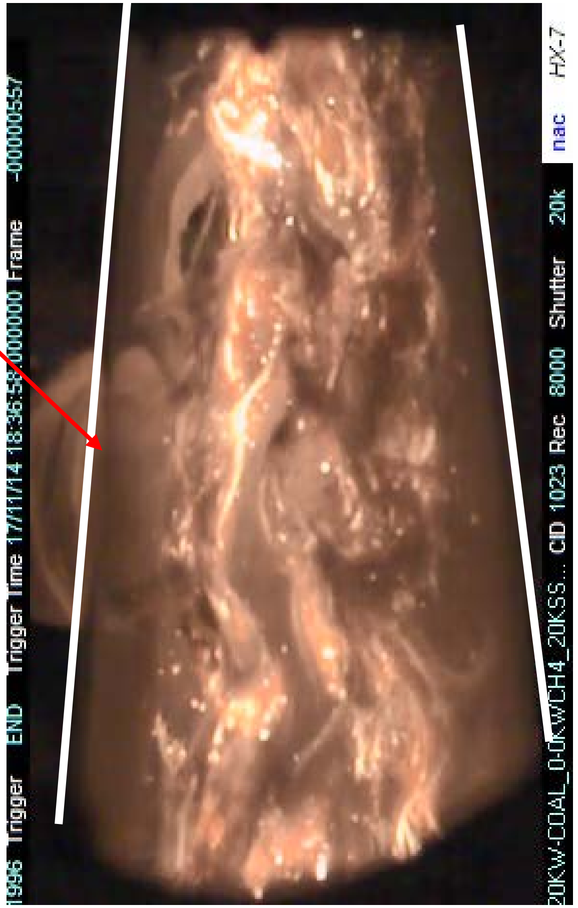

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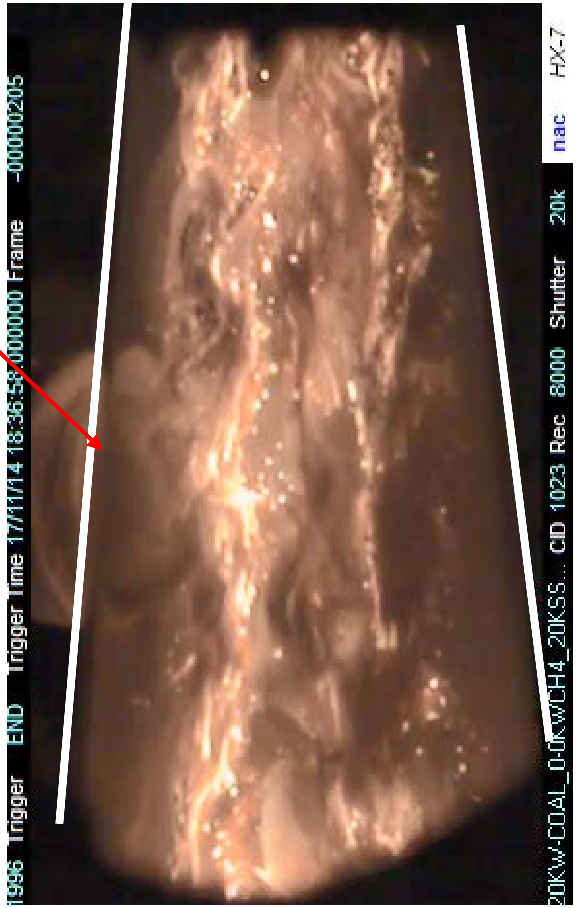
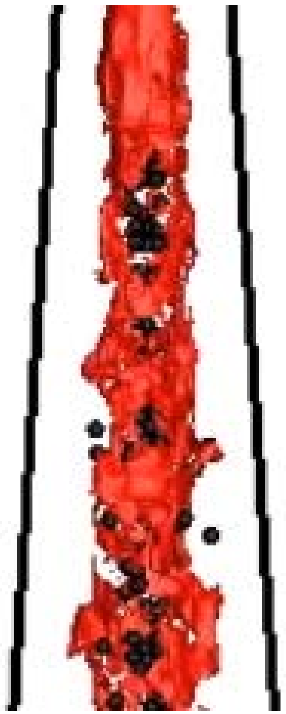


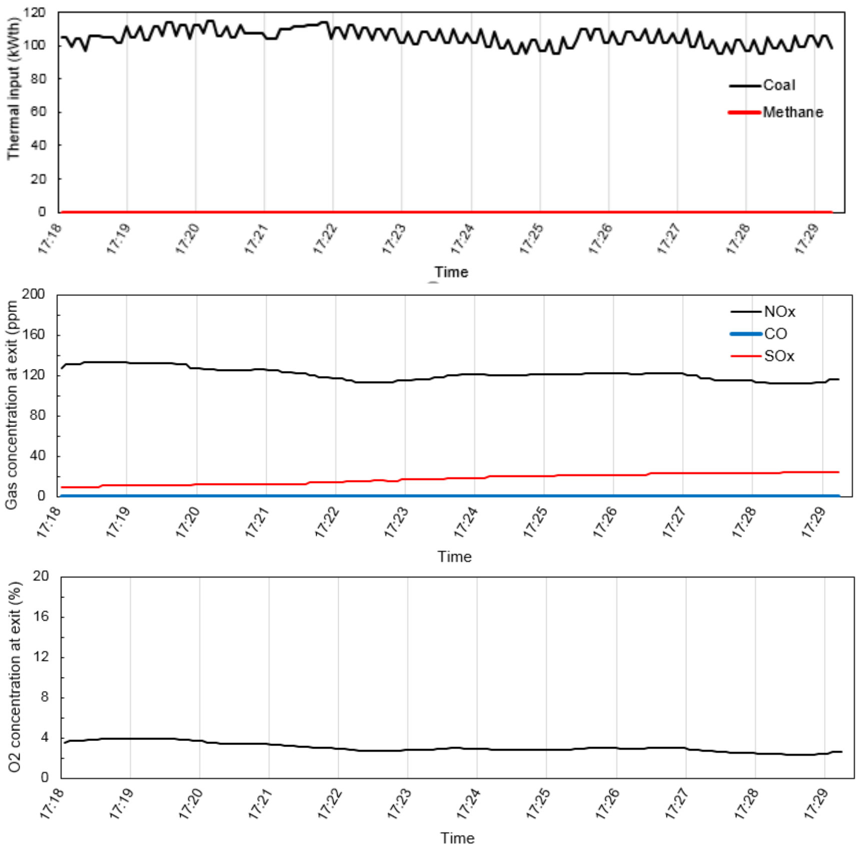
HS Camera Video



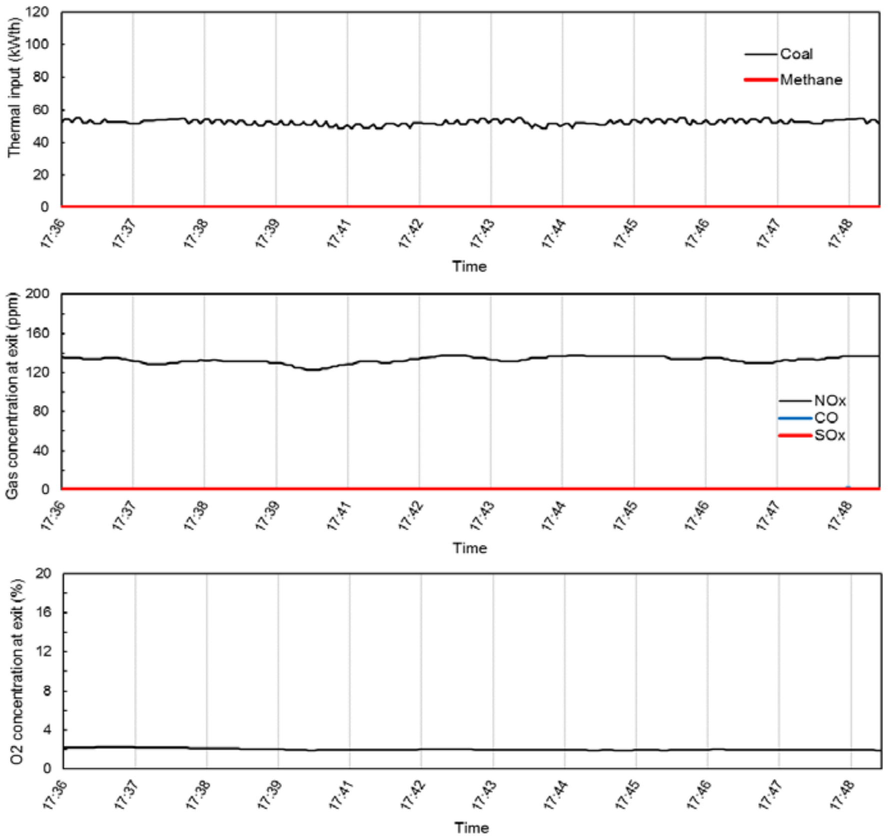
LES Simulation

Qualitative agreement between experiments and simulations achieved in terms of flame shape and flow field

Task 5 – Operation: 100% coal combustion at 15 bar

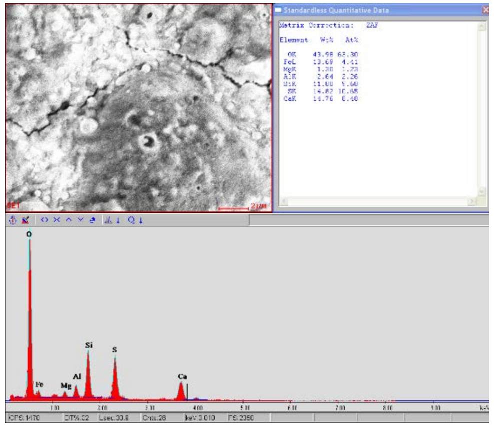


Full Load (100 kWth)



Part Load (50 kWth)

- Stable flame without methane support
- No CO and soot emission detected
- Complete burnout with 3% oxygen concentration



Ash analysis

Results used to validate CFD models for full scale application

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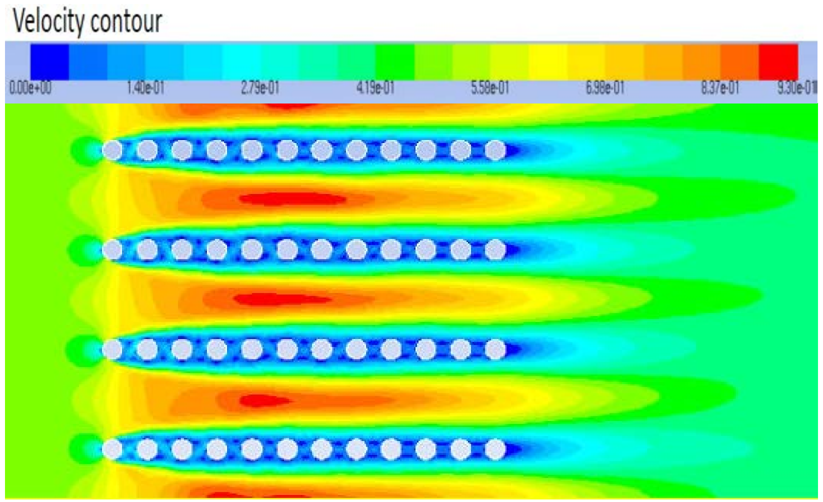
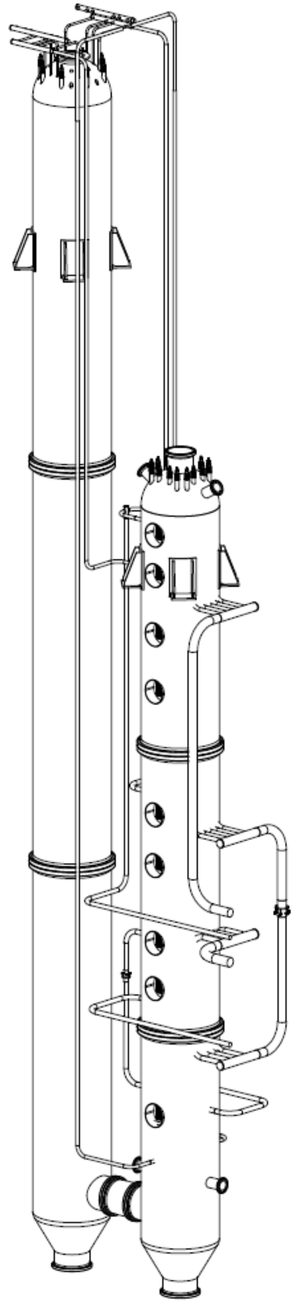
Plans for future development

- Validation of modeling from test results
- Reduction of ASU auxiliary power and thermal integration
- Flexibility opportunities for oxygen supply
- Cost analysis of 550MW concept design





Questions

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