Particle Separator for Improved Flameless Pressurized Oxy-Combustion (FPO)

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Overview

Team Overview

Objectives

Background on the Technology

Project Update

Future Technology Steps

Conclusion

Project Team

Principal Investigator

Southwest Research Institute

Testing Partner

Itea, S.p.A.

Development and Analysis Partners

Electric Power Research Institute

GE Global Research

What are the objectives of the proposed project?

Select a design capable of separating FPO particles

Perform a detailed design and integration with test facility

Achieve particle removal with a low pressure loss

Evaluate material properties of particles and impact on separator surfaces

Assess economic potential of the separator technology

Background on FPO

Pressurized atmosphere of water and CO_2 under "volume expanded combustion"

- FPO combustion is more locally controllable with more uniform temperatures
- Pressurized firing with oxy-combustion also improves cycle efficiency

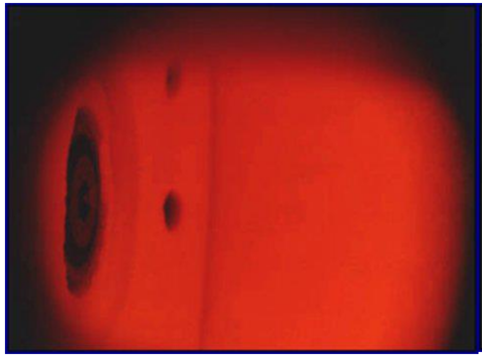
Chemical balance in combustion is near stoichiometric

- Achieved through CO_2 recycle, water, and oxygen balance control

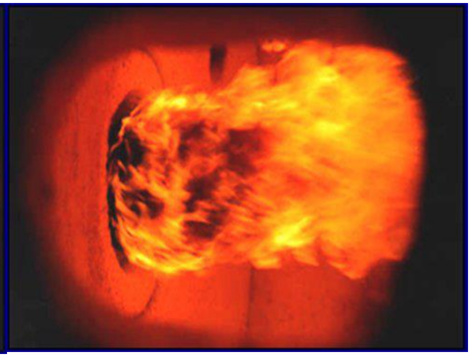
Almost zero carbon content in incombustible products

- Traditional: flying and falling ash particles
  - Must be filtered and collected from gas stream
- FPO: slag with near-zero carbon content
  - Drains out the bottom of the combustor
  - Particulate still exists in exhaust but at reduced quantities and sizes

Traditional Combustion with Flame Front

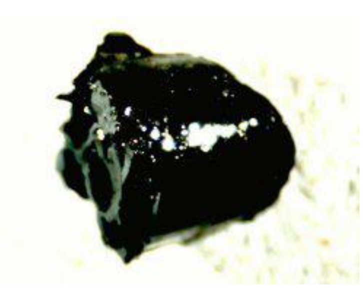


Flameless Pressurized Combustion



Traditional Combustor Products: Particulate

FPO Combustor Products: Near-zero carbon, neutral slag



What is the FPO Cycle?

Slurry of milled coal and water combusted under pressure

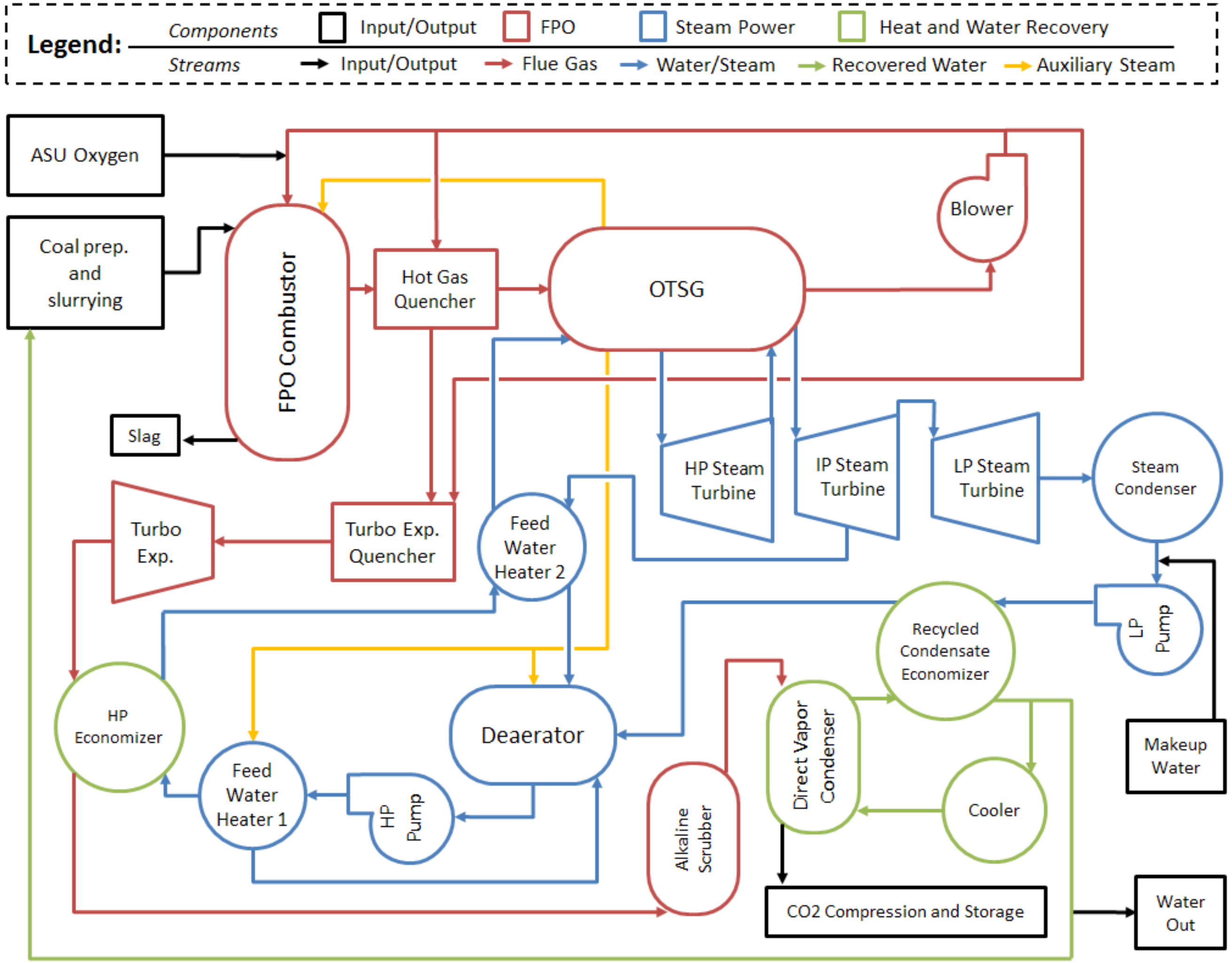
Hot combustor gas is quenched through mixing

Enters OTSG

Portion of flow leaves the process with energy before the OTSG and is expanded

A large percentage of combustion products are recycled

- Some recycled flow used for quenching
- The remainder of recycled flow is mixed with pressurized oxygen and injected into the combustor



What is the State of the Technology?

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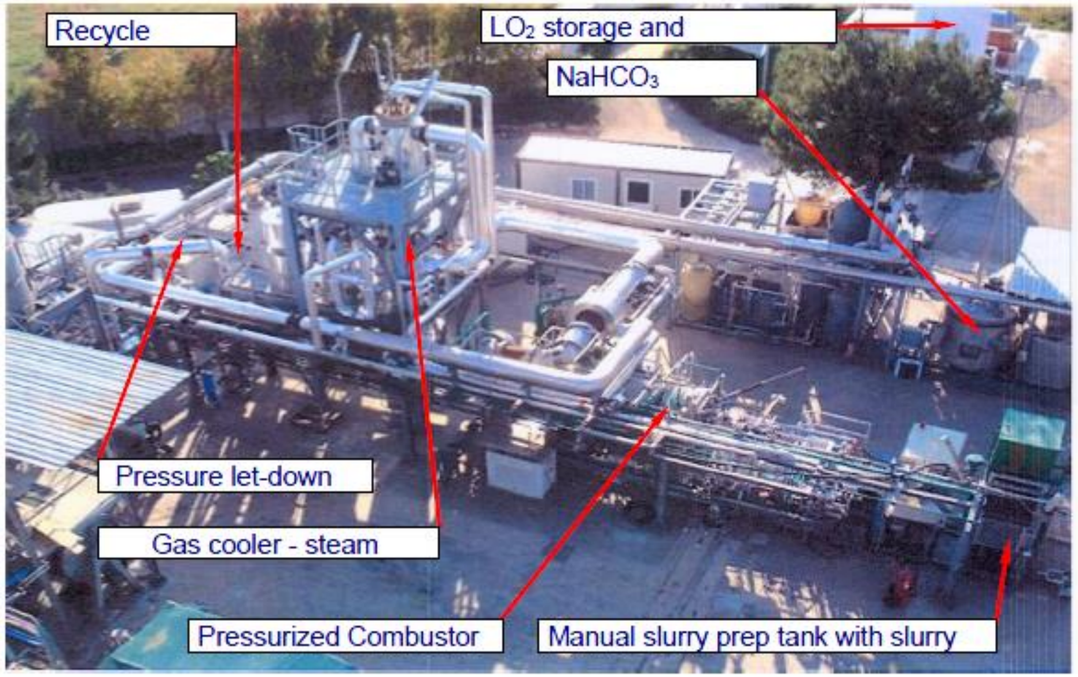
5 MWth plant in Italy

- Capable of 4 bar (58 psi) pressure
- Over 18,000 hours of testing experience
- Technology proven with high and low rank coals
- Test location for the particle separator



Techno-Economic assessment at the commercial scale

- In process under another DOE FPO development process
- Continued assessment will be developed by the same team at EPRI and SwRI

Why Particle Separation?

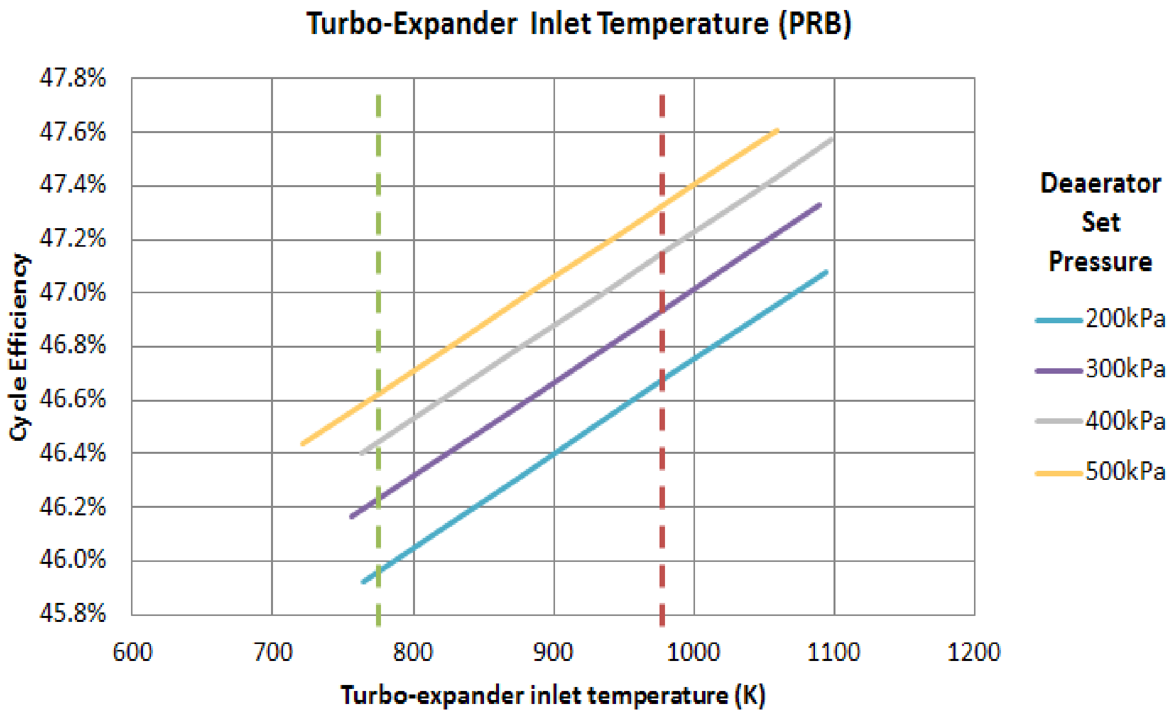
Demonstrated improved performance of pressurized cycle with recovered energy

Applicable to technologies other than FPO

Limits of the turbo-expander inlet temperature could be improved to the red line

- Requires demonstrated ability to withstand high temperatures

Goal to minimize pressure drop in order to maximized pressure ratio of expander



Project Status: Particle Separator Technology Selection

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Previous year work developed selection criteria and evaluated technologies

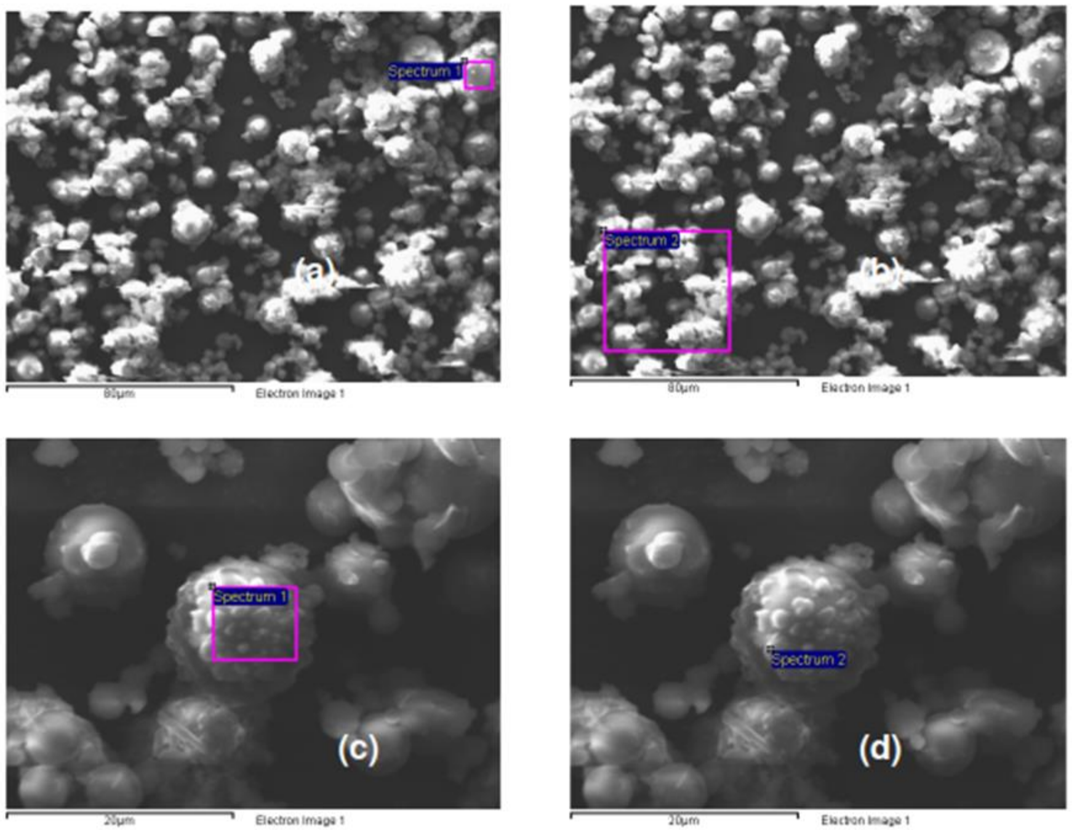
Large set of candidates that were narrowed to four based on capabilities

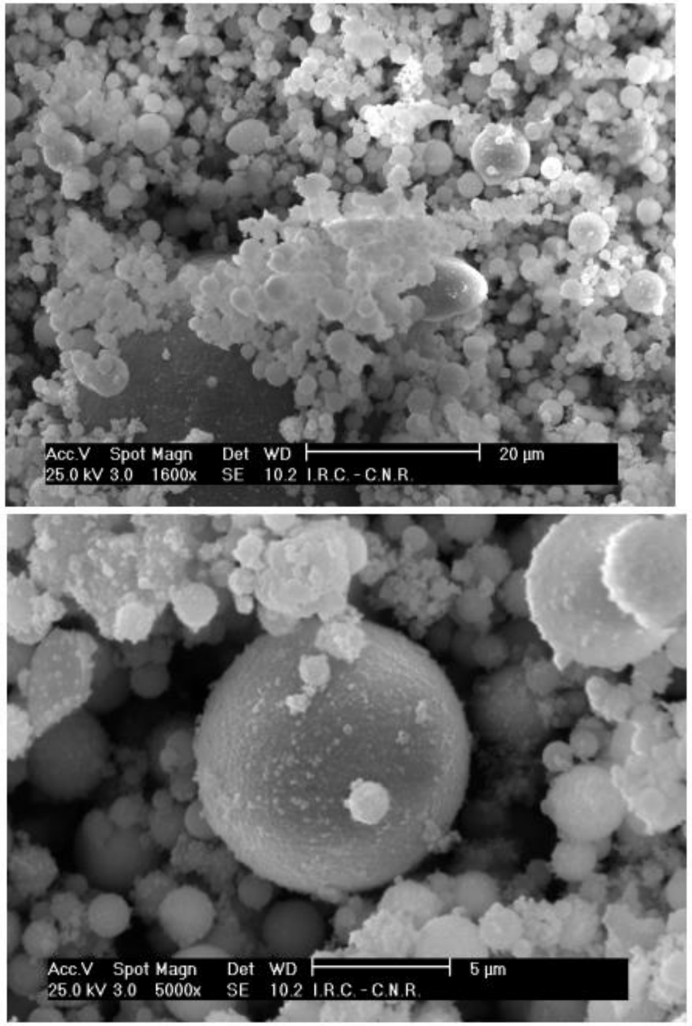
Cyclone and Ceramic barrier filter selected

- The two technologies are differing enough to merit further evaluation

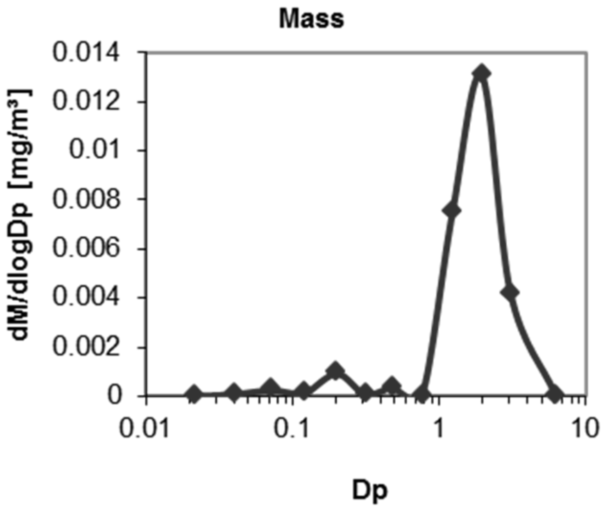
Category	Inertia Separator	Cyclone	Ceramic Barrier Filter	Electrostatic Precipitator
Program Goals	31	31	36	36
Physical Attributes	64	61	52	54
Operations	166	188	164	137
Environmental and Permitting	38	36	40	40
Business and Financing	57	59	53	40
Total	356	375	345	307

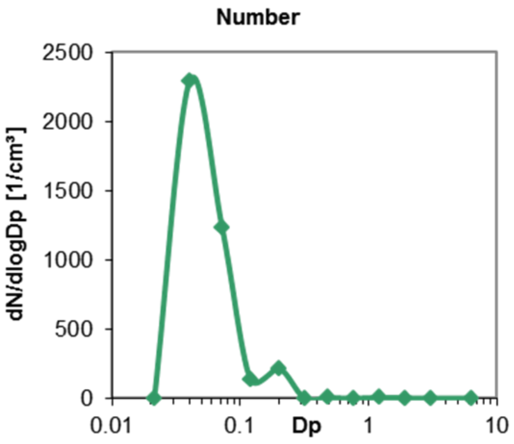
Project Status: Particle Properties





Project Status: Particle Properties





	a	b	c	d
	wt%	wt%	wt%	wt%
Na_2O	0.5	1.6	1.1	1.3
MgO	1.6	1.4	1.1	1.0
Al_2O_3	20.2	17.1	22.9	17.8
SiO_2	50.8	40.7	52.9	38.4
SO_3	4.2	16.6	7.6	20.7
K_2O	5.1	9.9	6.7	9.8
CaO	11.4	6.3	5.1	6.4
TiO_2	0.6	2.0	-	-
FeO	5.6	4.4	2.7	4
Cr_2O_3	-	-	-	1

Project Status: Flue Gas Properties

Pressure: 4.63 barg

Temperature: 500°C

Flue gas density: 3.45 kg/m^3

Flue gas flow rate: 0.45-0.9315 kg/s

Requirement of >90% removal at 0.9 µm

Gas Composition (% by mass)	
CO_2	89.239
H_2O	3.434
N_2	1.484
O_2	2.519
AR	3.296
NO	0.012
SO_2	0.011
HCl	0.001
CO	0.004

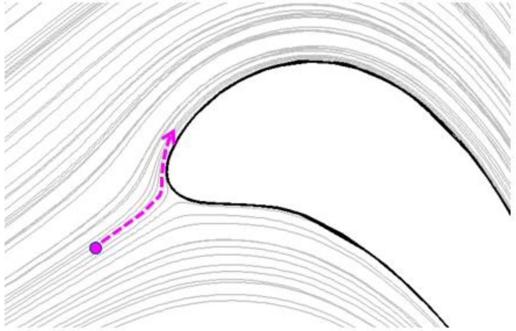
Project Status: Particle Size Removal Criteria Development

The Stokes Number indicates how well a particle moves along a local flow streamline within a suspending fluid

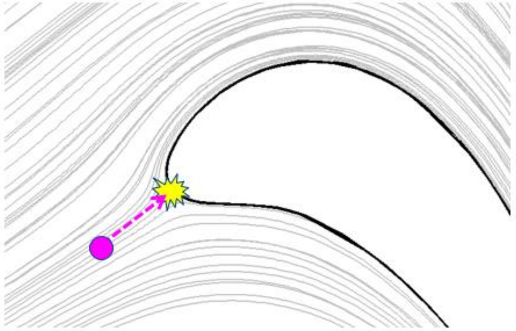
For a small Stokes Number (<<1) particles tend to follow a local streamline

For a large Stokes Number (>>1) particles travel like a ballistic object, and their trajectory crosses flow streamlines

$$\mathrm{Stk} = \frac{t_0\, u_0}{l_0} \qquad t_0 = \frac{\rho_p d_p^2}{18\mu_g}$$



Stokes Number << 1



Stokes Number >> 1

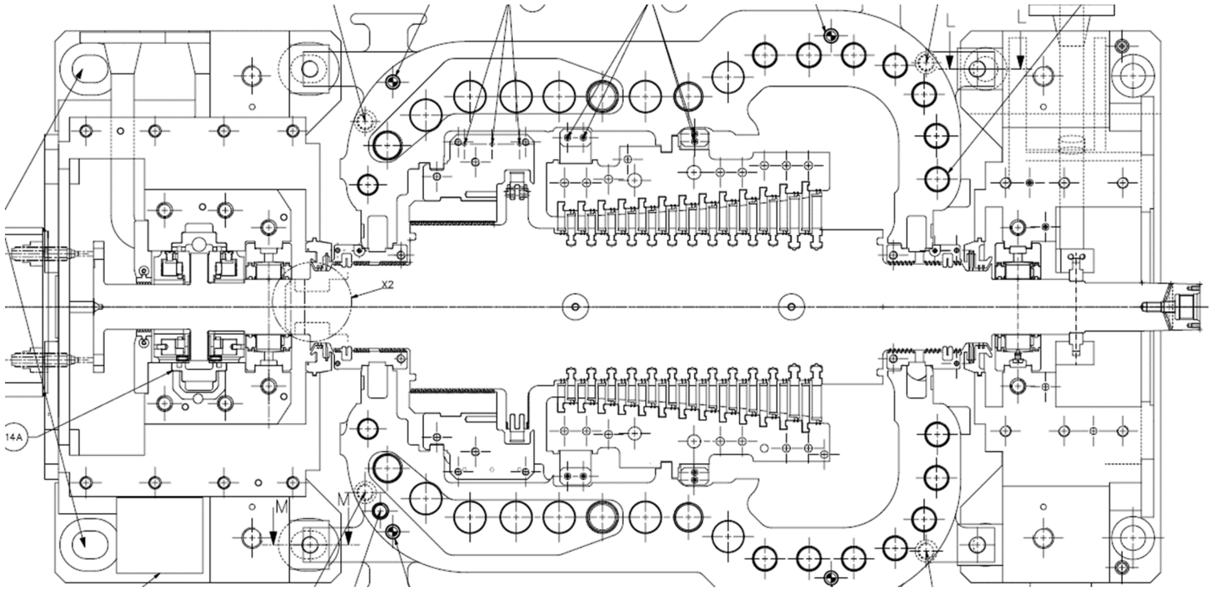
Project Status: Design of Commercial Turbo-expander

Baker Hughes/GE was contracted to develop a turbo-expander for FPO

Design based on Baker Hughes/GE line of flue gas expanders that are derived from modular reaction steam turbines

Custom design developed from the template to match FPO Commercial conditions

Scale based on Techno-economic analysis done under NETL projects



Project Status: Turbo-expander Flow Path

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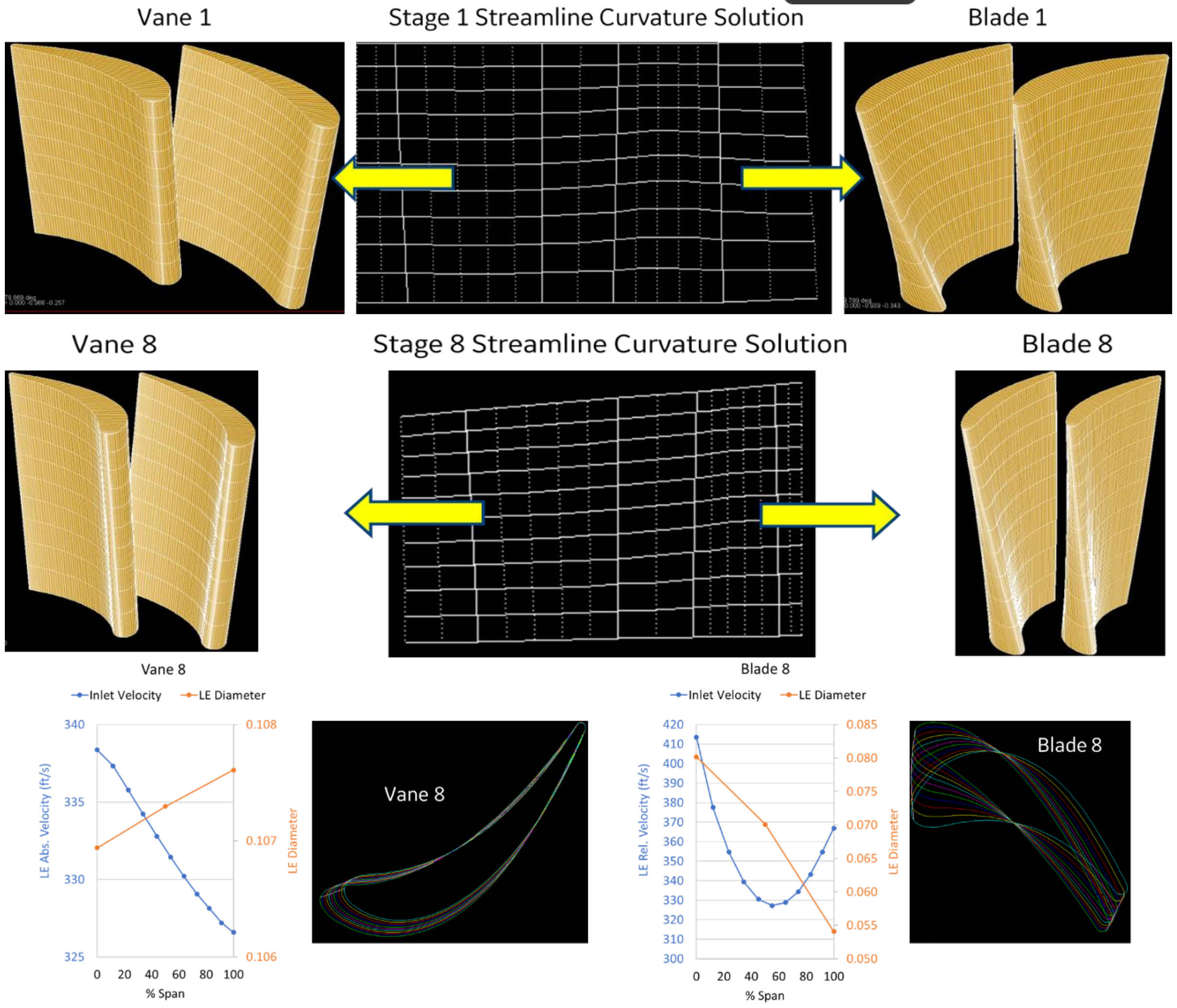
Custom design of rotating and stationary airfoils

GE's proprietary streamline curvature code used to determine flow path velocities

Stage 1 design between 169-220 ft/s

Stage 8 design between 326-415 ft/s



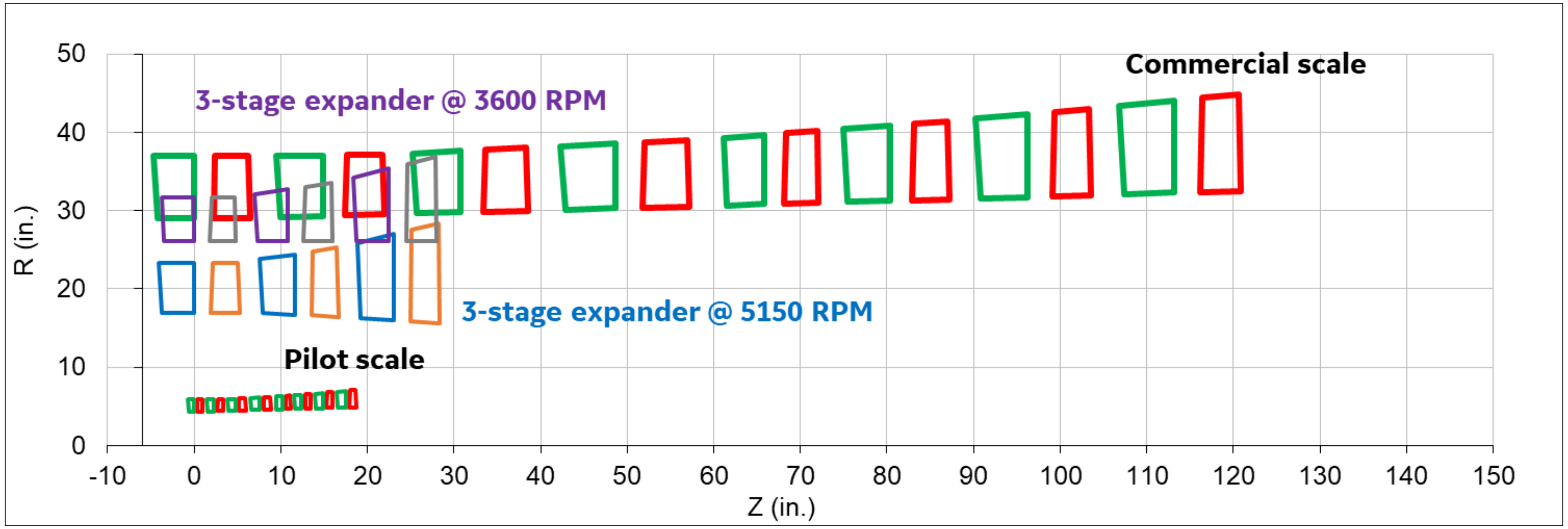
Project Status: Number of Turbo-expander Stages

Number of stages examined as a possible variable (3, 4, and 8)

Three stage expander at pilot scale may be more practical

Scale-up is more direct if number of stages are similar between pilot and commercial scales

Speed was varied between 3,600 rpm synchronous and 5,150 rpm



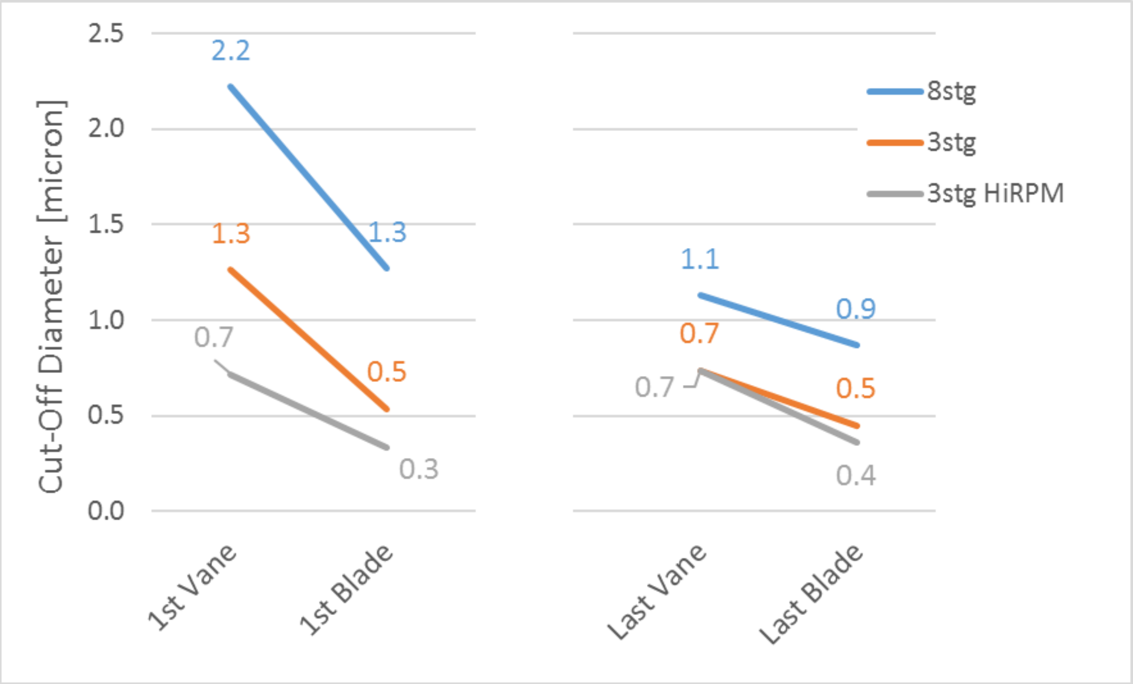
Project Status: Particle Size Cut-off

Recommended particle size cut-off based charted for each case

Highest velocities and highest chance for erosion generally in the last stage

8 stage configuration has least restrictive requirement

Requirement of removal of >90% of particles with diameter of 0.9 μm



Project Status: Cyclonic Separator Vendor

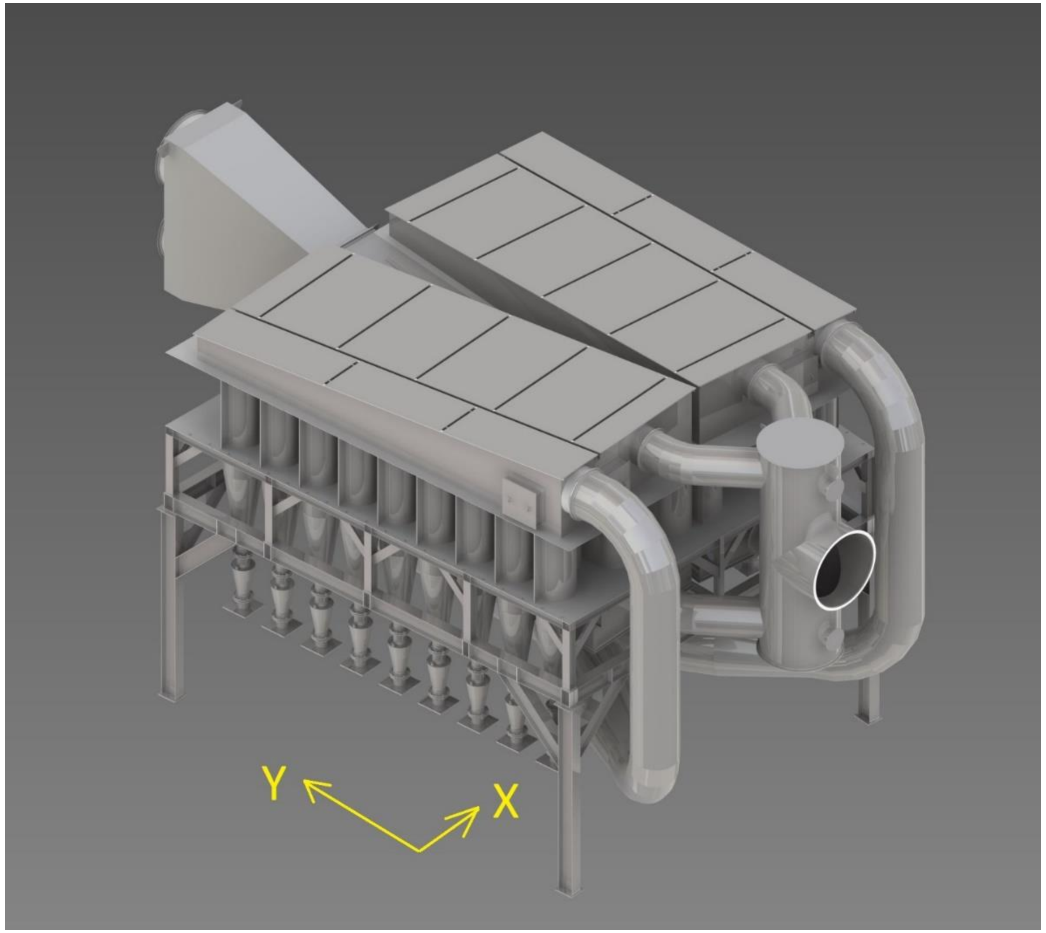
CORE Separator from Easom is being considered

Uses a concentrator followed by a reverse flow cyclone in a recycle loop

Design pressure drop of 14 kPa per system

Two systems will produce a 92% collection efficiency at 0.9 µm

Total pressure drop of 28 kPa



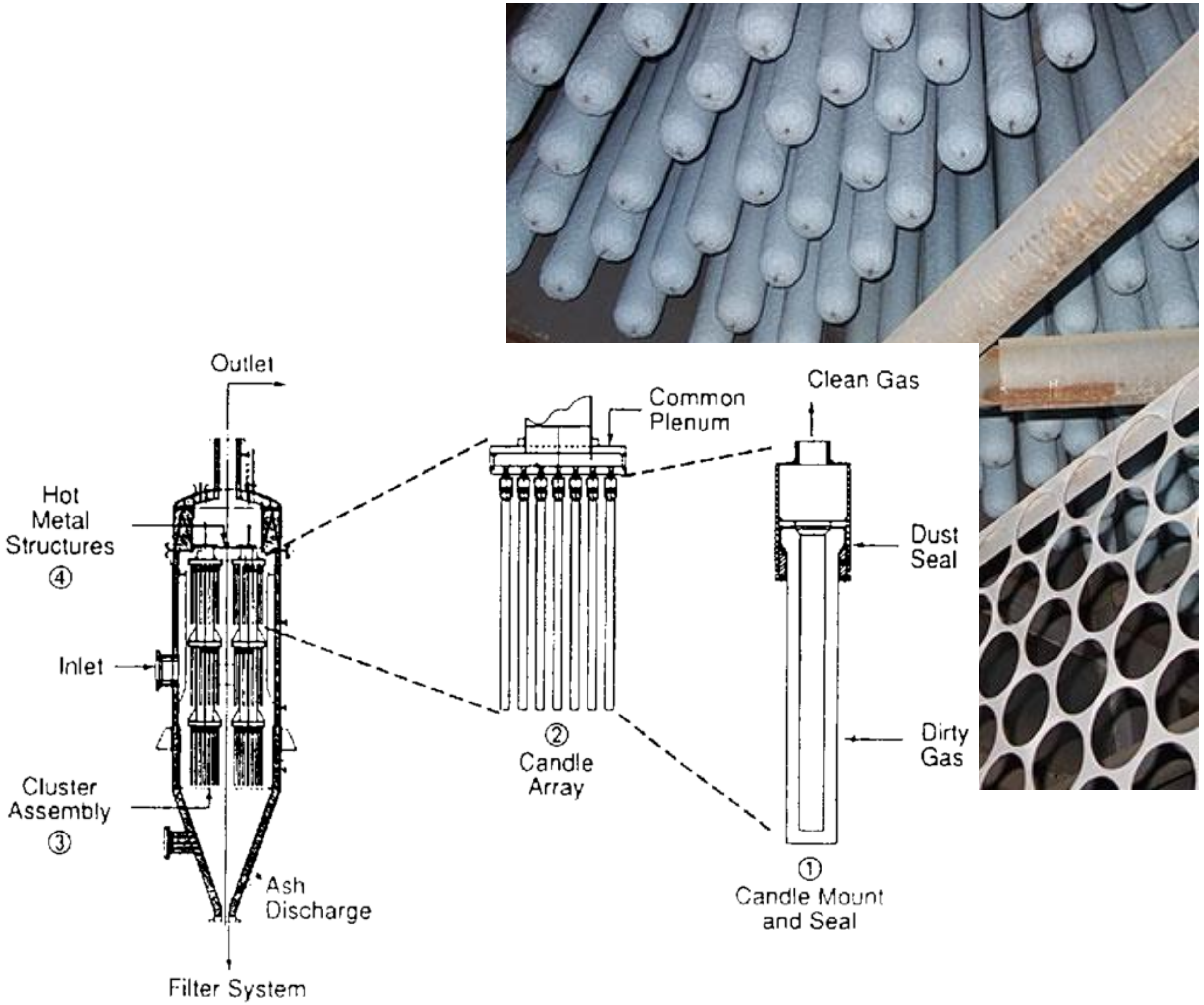
Project Status: Candle Filter Vendor

Ceramic material is preferred for good performance at design temperature of 500°C

Commercial demonstrations up to 899°C and 24.13 barg

- Commercial FPO operates at 11 barg

Boldrocchi was approached for a quote



Project Status: Test Setup

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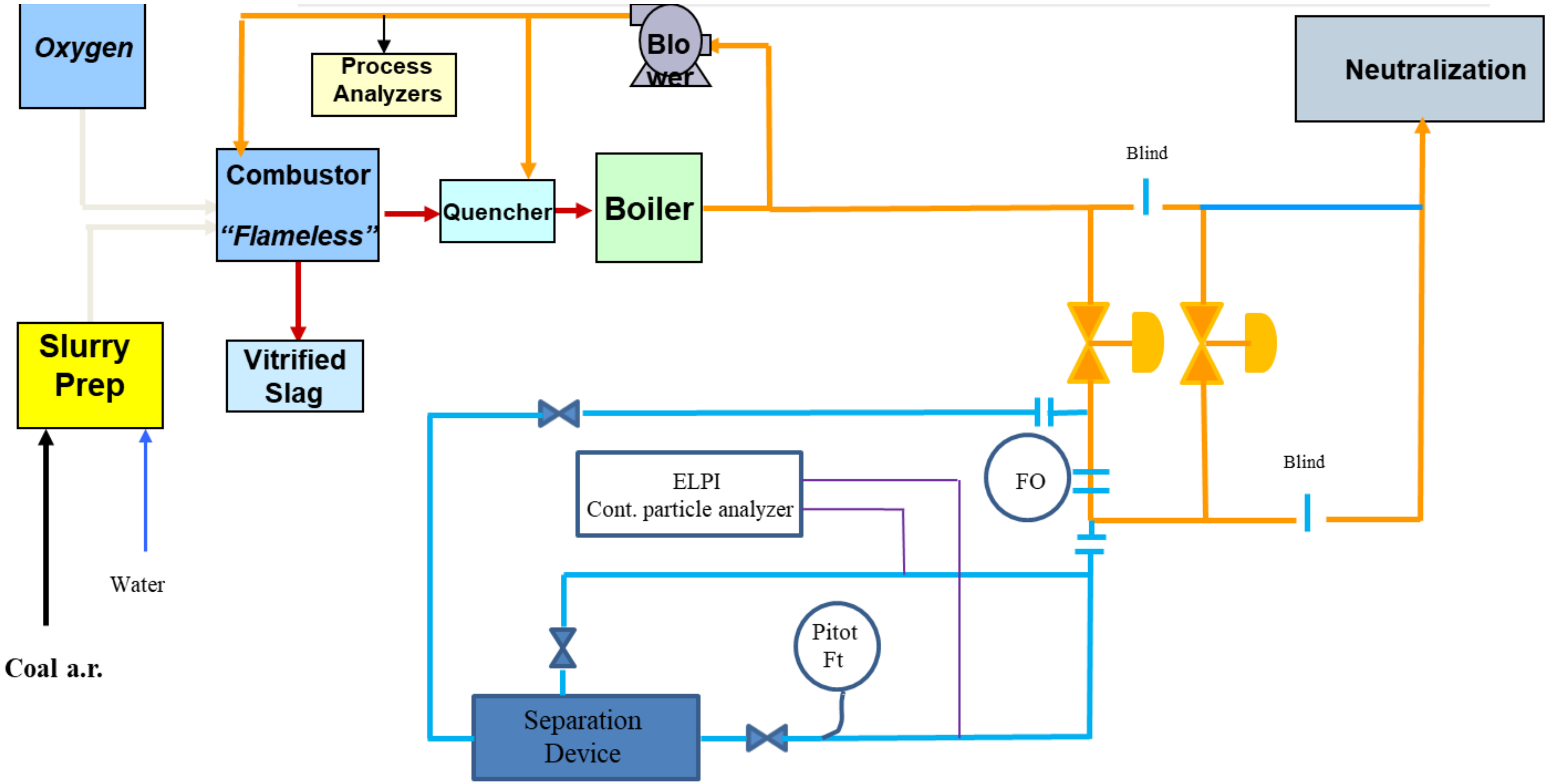

Project Status: Technological Challenges

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Cyclone

- Struggles at efficient separation for the particle range (1 to 3 µm)
- Efficiency drops below 10 µm

Filtration

- Alkaline sulfates present a challenge to filters
- Pre-coat treatment typically required with large amounts of additive
- Clogging could become a problem

Residual Particulate

- Particle morphology is not typically abrasive
- Evidence in centrifugal blower and gas lamination valve with 550 m/s velocities

Project Status: Challenges and Changes

Original Planned Test: Summer 2020 in Gioia del Colle, Italy

Coronavirus shut down all activity in Italy

Test facility in Italy is one-of-a-kind FPO pilot

Project extension being sought to accommodate future testing in Italy

Future Technology Steps: Market Report

OVERVIEW

PARTICLE SEPARATOR TECHNOLOGY SELECTION

- Operating Conditions
- Technologies Reviewed
- Identify Vendors

APPLICATIONS FOR HIGH-TEMPERATURE PARTICLE SEPARATION IN FOSSIL POWER PLANTS

- Integrated Gasification Combined Cycle (IGCC)
- Syngas Cleanup
- Fluidized Bed Combustion
- Circulating Fluidized Bed Combustion (CFBC)
- Waste-to-Energy Boilers
- Biomass Boilers

PERFORMANCE AND COST DATA

- Performance Data
- Capital and O&M Cost Data

SUMMARY

Conclusion

Particle Separation within FPO

Preferred Technologies Selected

Particle Removal Criteria Developed

Test Planned, but Delayed

Evaluation of Technology Implementation and Market Impact Underway

Conclusion

Thank You