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PARTICLE SEPARATOR FOR IMPROVED FLAMELESS PRESSURIZED OXY-COMBUSTION (FPO)

Acknowledgement and Disclaimer

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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

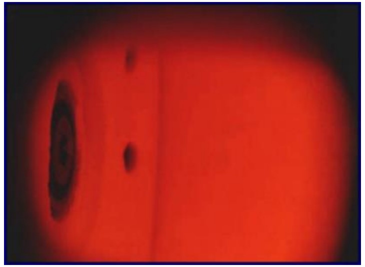
What are the objectives of the proposed project?

- 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

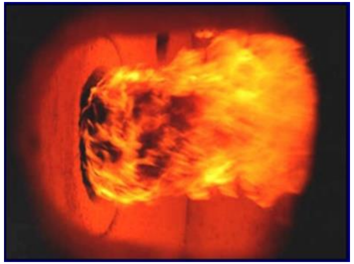
Background on FPO

- 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

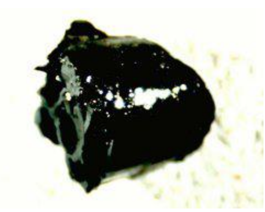


Flameless Pressurized Combustion



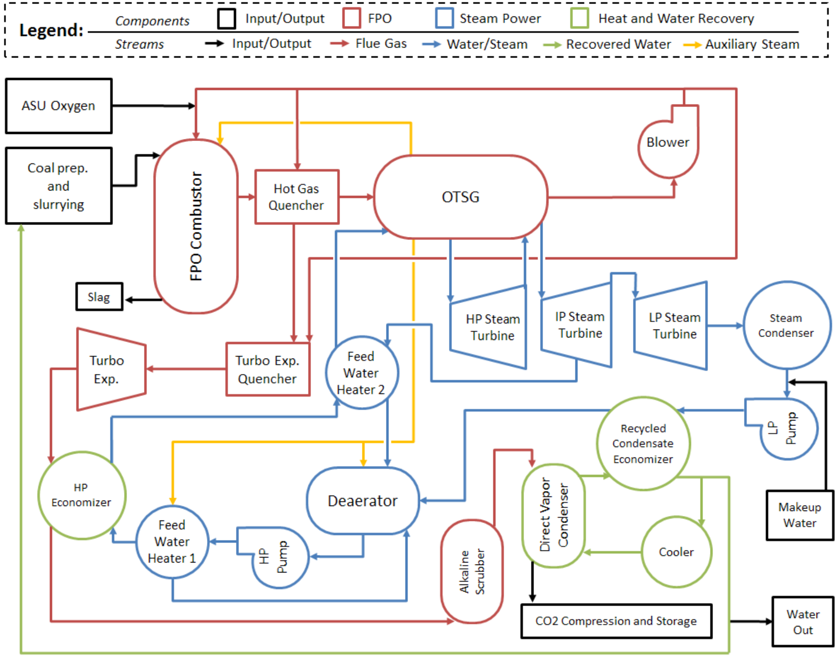
Traditional Combustor Products: Particulate

FPO Combustor Products: Near-zero carbon, neutral slag



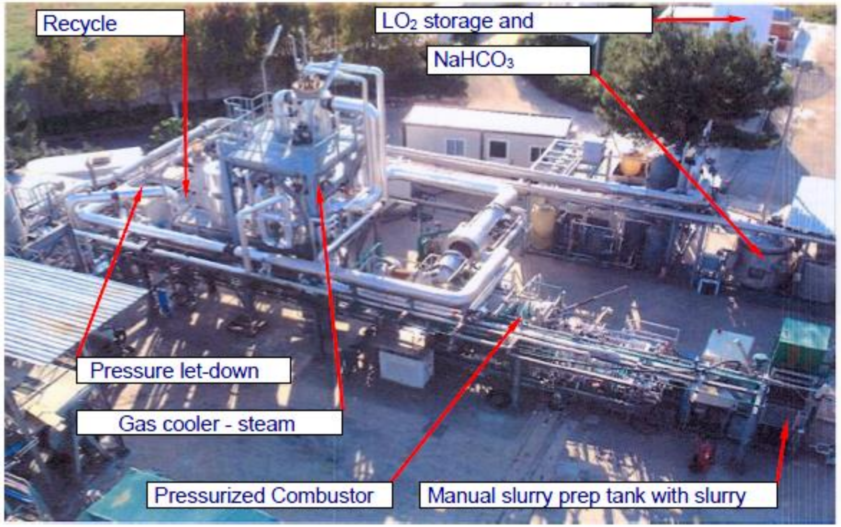
What is the FPO Cycle?

- 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



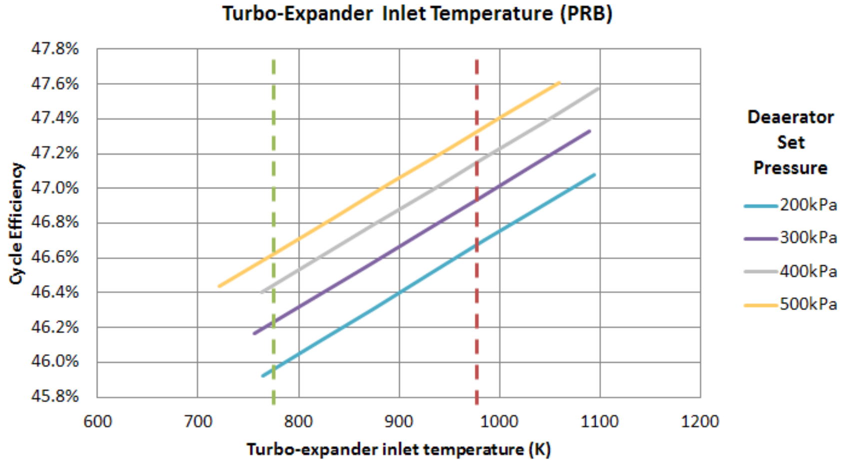
What is the State of the Technology?

- 5 MWth plant in Italy
  - Capable of 5 bar 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?

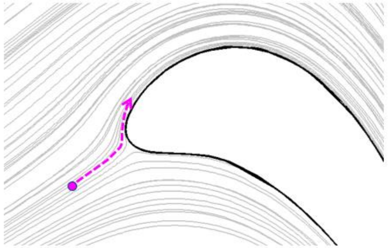
- Demonstrated improved performance of pressurized cycle with recovered energy
- Applicable to technologies other than FPO
- Limits of the turbo-expander inlet temperature could be improved to the red line
  - Requires demonstrated ability to withstand high temperatures
- Goal to minimize pressure drop in order to maximize pressure ratio of expander



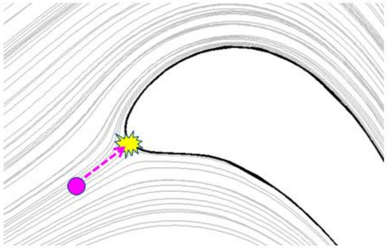
Project Status: Particle Erosion

- 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: Particle Properties

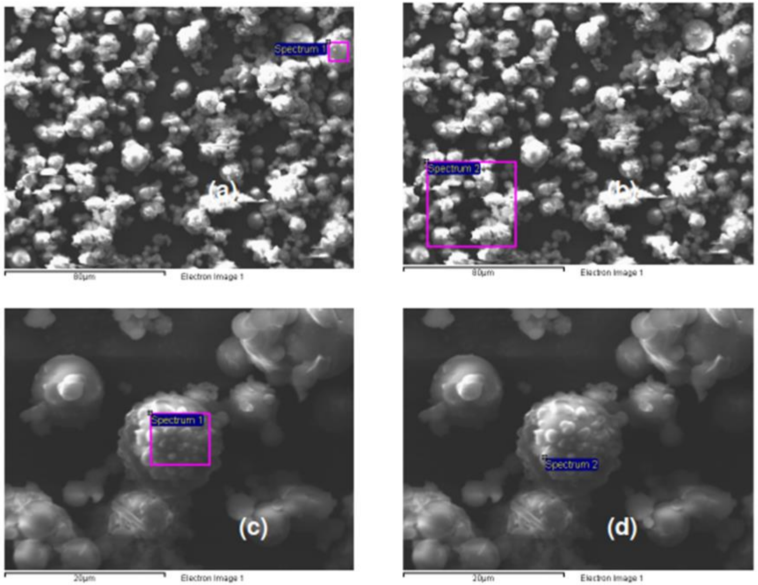
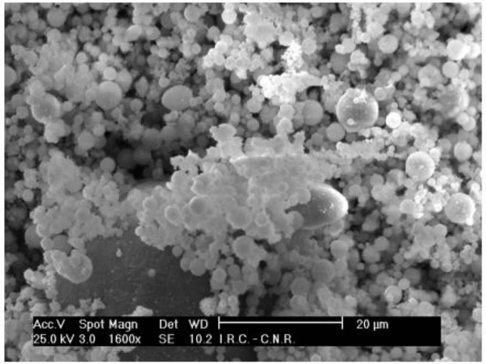
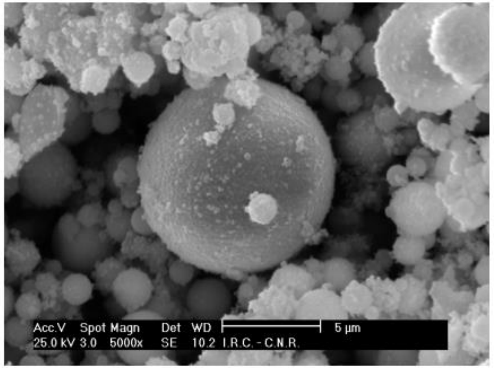
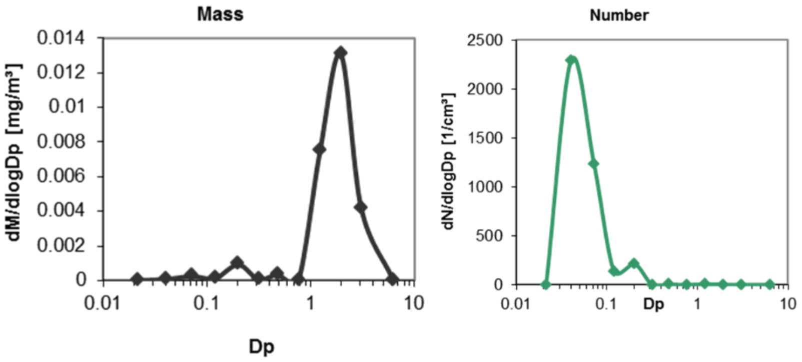


Figure 6.4 Dust collected in the downstream tube quencher, at the PTS sampling probe, at the end of the run. The corresponding EDXS results are reported in Table 6-6





Project Status: Particle Properties

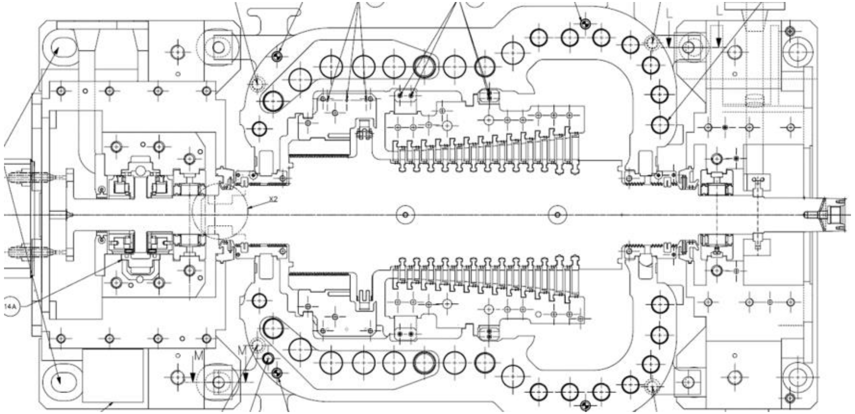


	a	b	c	d
	wt%	wt%	wt%	wt%
Na_2O	0.5	1.6	1.1	1.3
MgO	1.6	1.4	1.1	1.0
Al_2O_3	20.2	17.1	22.9	17.8
SiO_2	50.8	40.7	52.9	38.4
SO_3	4.2	16.6	7.6	20.7
K_2O	5.1	9.9	6.7	9.8
CaO	11.4	6.3	5.1	6.4
TiO_2	0.6	2.0	-	-
FeO	5.6	4.4	2.7	4
Cr_2O_3	-	-	-	1

Table 6-6 EXDS analysis results on a sample of dust collected in the downstream quencher tube, at the PTS sampling probe, at the end of the run. The letters (a-d) correspond to the areas delimited by the purple rectangles in Figure 6.4

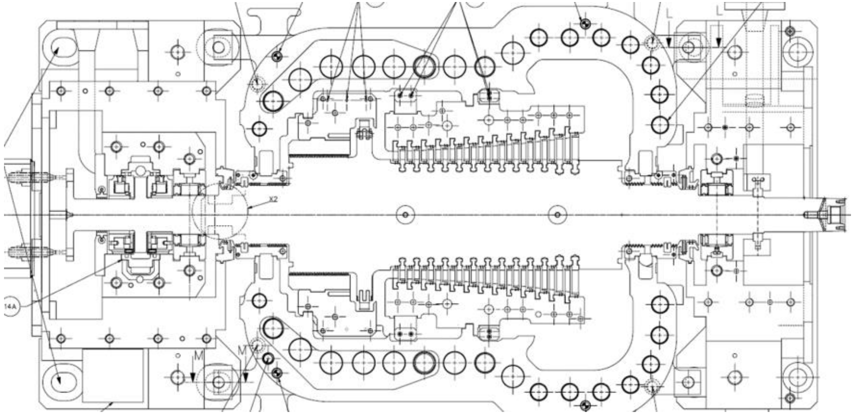
Project Status: Design of Commercial Turbo-expander

- 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



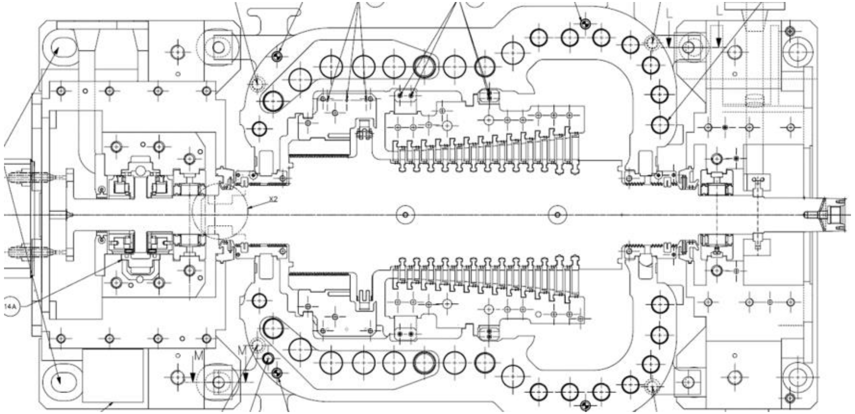
Project Status: Pilot Expander Particle Protection

- 25 MWth Pilot design expander by Baker Hughes/GE
- Pilot may install a separator based on the success of this project
- 975 kW shaft power
- 11,000 rpm
- 14 stages of expansion
- 14,400 kg/h of flue gas flow
- Inlet: 520°C and 12.2 bara
- Outlet 340°C and 2.47 bara



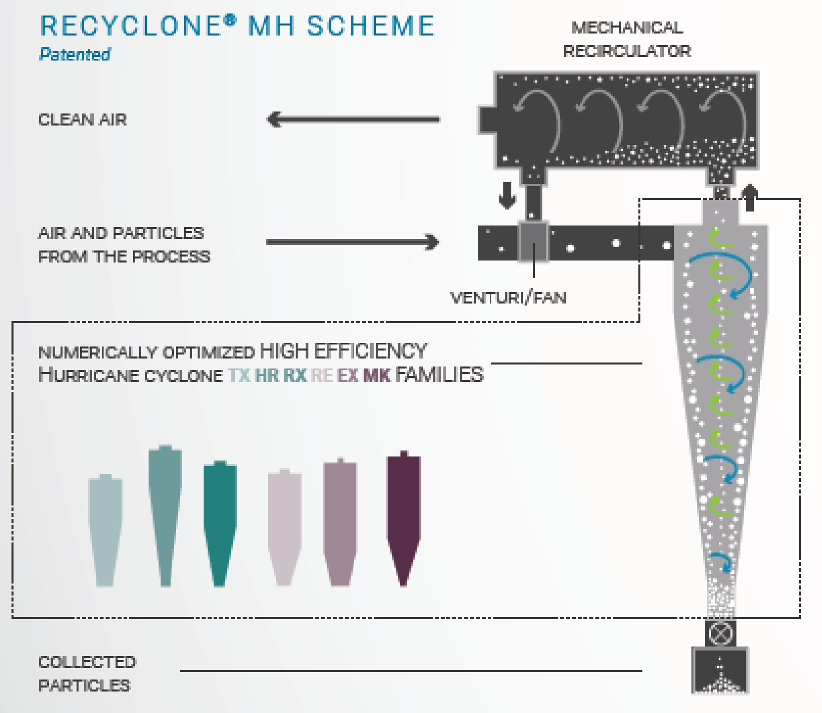
Project Status: Pilot Expander Particle Protection

- 25 MWth Pilot design expander by Baker Hughes/GE
- First stator airfoil: Inconel 718
- First rotor airfoil and stages 2 and 3: Stainless steel coated with chromium carbide for erosion resistance
- Stages 4 through 14: Stainless steel with no coating
- Coating is expensive and costly to replace



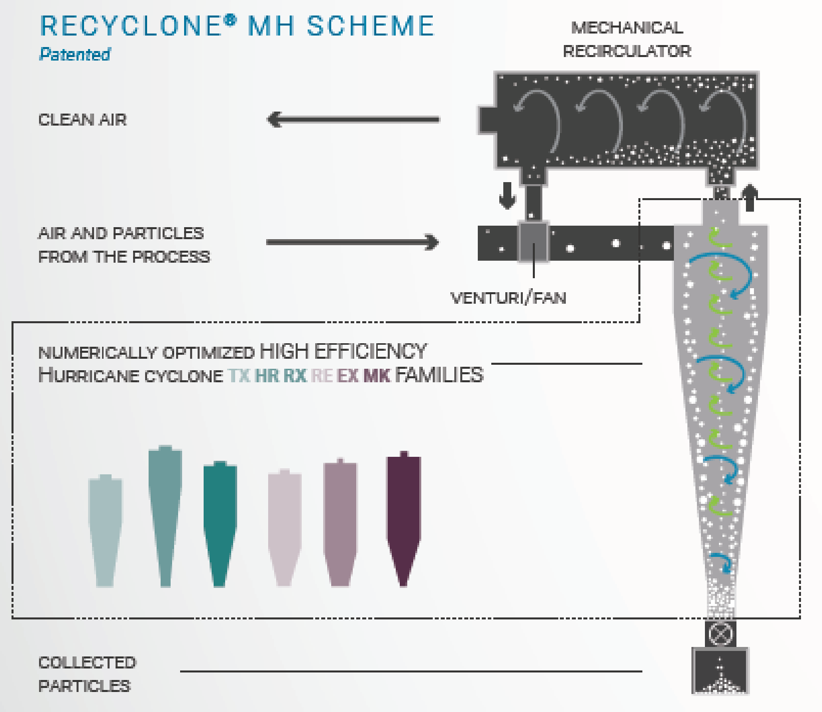
Project Status: Cyclonic Separator Vendor

- Advanced Cyclone Systems approached for their ReCyclone system in this application
- Electrostatic concentrator option not available due to the higher temperature of the flue gas
- No alloy restrictions, allowing high temperatures for the mechanical recirculator
- Typical pressure drop 150-230 mm w.g.
- Numerically optimized for the application



Project Status: Cyclonic Separator Modification

- Several proposed modifications to enable improved separation
- Allowance of up to 650°C
- Cooling of metal walls to protect metal and create cool fluid near wall
- Cool flue gas near wall creates a gradient of viscosity
- Lower viscosity near the wall could increase the stokes number and improve separation efficiency



Project Status: Flue Gas Test Conditions

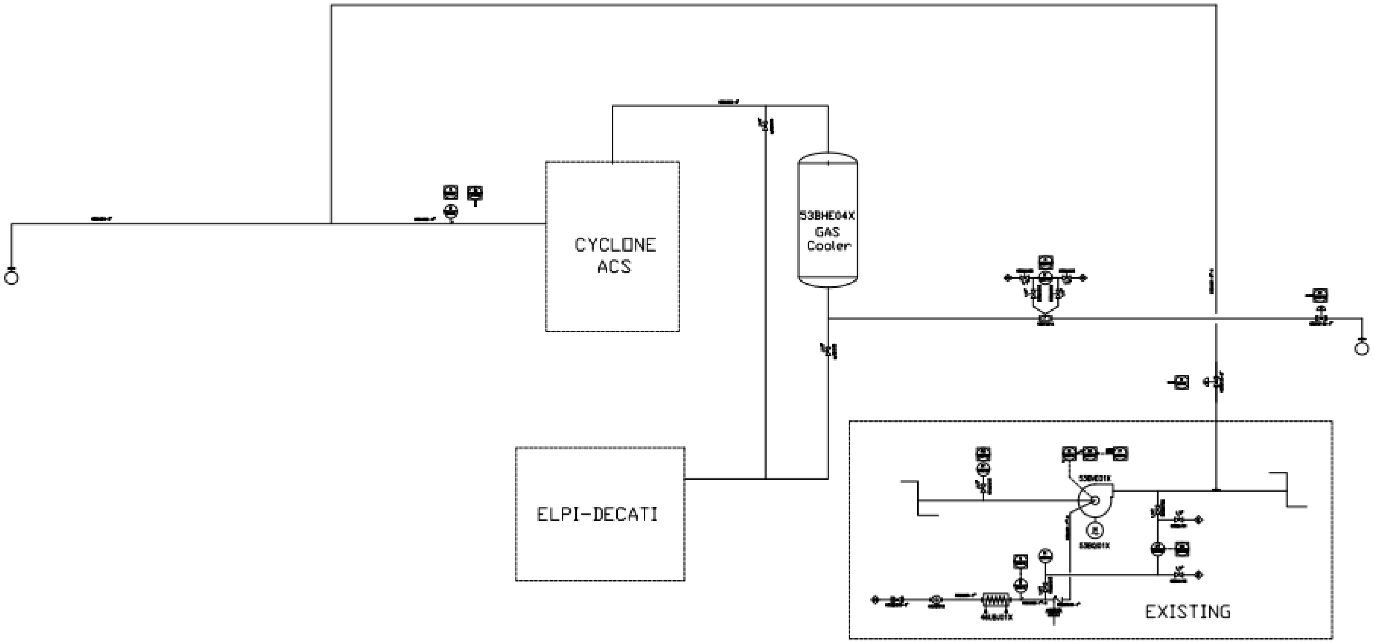
- Pressure: 3.10 to 4.48 barg
- Temperature: 500°C to 650°C
- Flue gas flow rate:
- Min: 141.6 N l/s
- Avg: 339.8 N l/s
- Max: 424.8 N l/s

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 Characterization

- Particle concentration: 70 to 120 mg/Nm^3
- Size (based on mean weight): 2-3 µm
- SEM character: round shape
- Particle Density: 2.24 g/cm^3

Project Status: Updated Test Setup

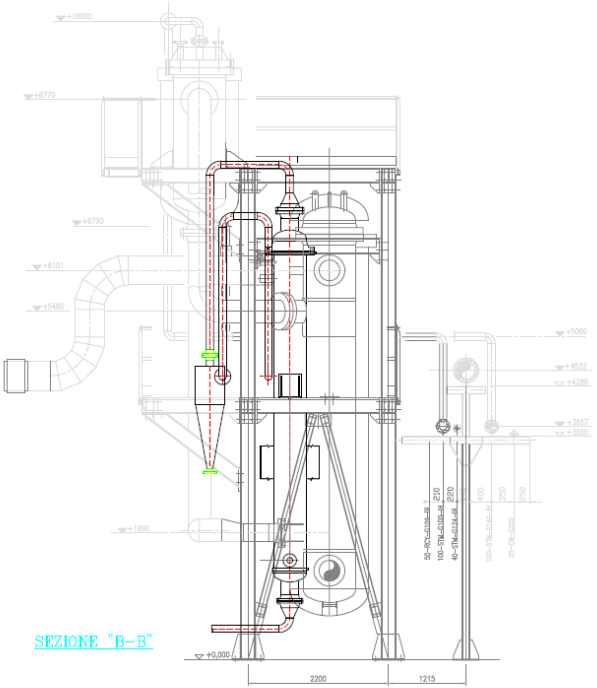


Project Status: Updated Test Setup

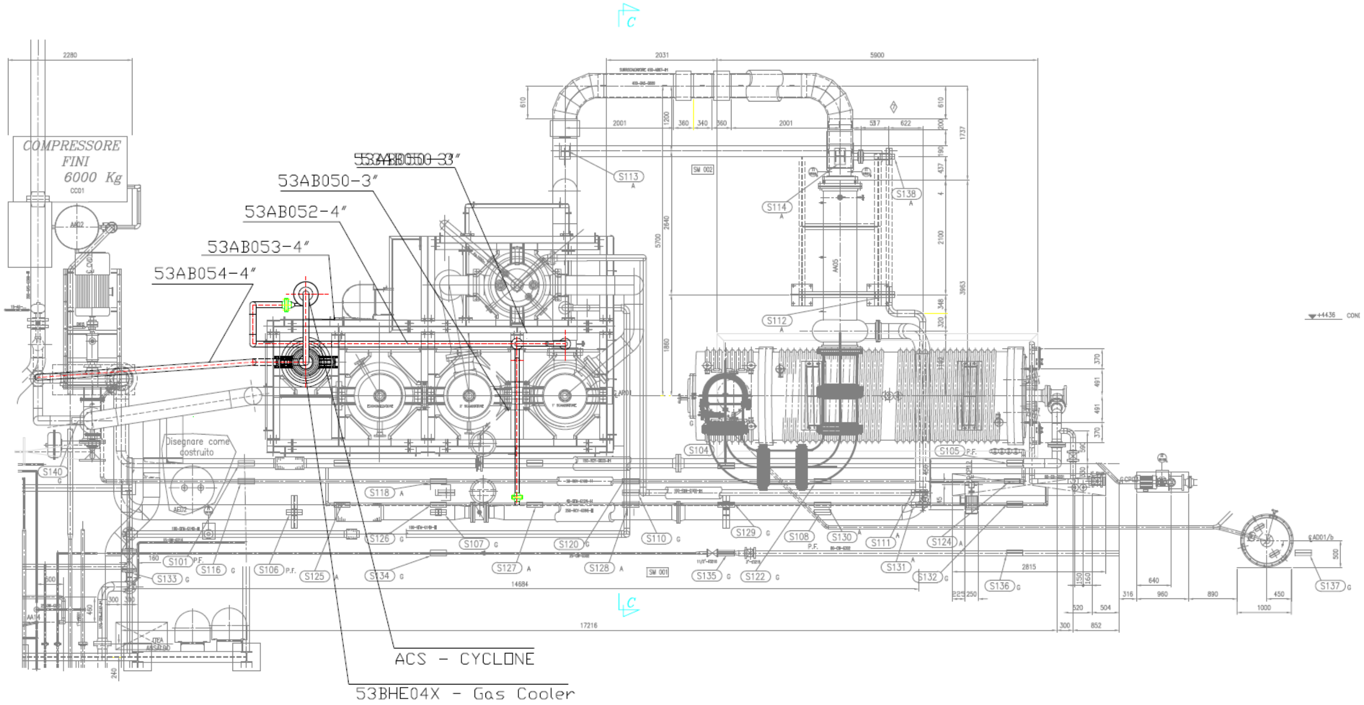
- Main flow rate: Metered and regulated by purge valve of pressure controller
- Admixed temperature control: Hot gas quencher outlet and blower outlet combine prior to cyclone
- Cooler for main flow
- Particle characterization: ELPI (electrical low pressure impactor) continuous analyzer by Dekati
- Return to FGD line

Project Status: Proposed Installation (Side)

- Piping from gas in boiler structure
- New structure to support cyclone, piping, cooler, etc …
- Cyclone with necessary valves
- Cooler with flue gas on shell side and warm feed water on tube side
- Pressure valves, instrumentation, etc…



Project Status: Proposed Installation (Top)



Project Status: Path Forward

- Original Planned Test: Summer 2020 in Gioia del Colle, Italy
- Coronavirus shut down all activity
- Test facility in Italy is one-of-a-kind FPO pilot
- Project extension granted
- New estimated time frame for test: Fall 2021
- Test campaign: 2 days of testing, 8 hours each day

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
- Vendor identified and engaged
- Test parameters developed
- Preliminary plan for pilot plant modifications
- Evaluation of Technology Implementation and Market Impact Underway

Thank You