

Improving Coal Power Economics: Retrofitting Flameless Pressurized Oxy- Combustion with Integral CO₂ Capture

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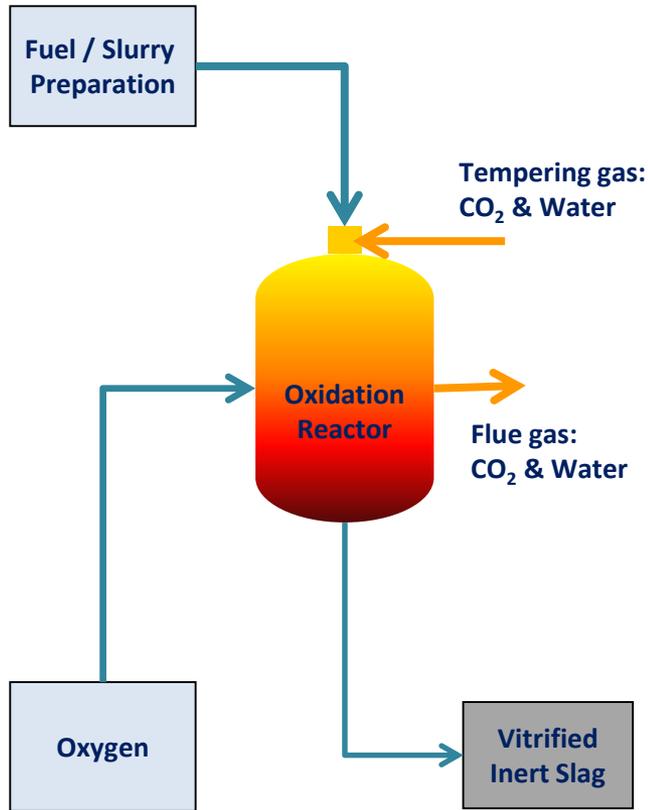
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Agenda

- **FPO technology**
 - Philosophy and performance vs. traditional combustion
 - Added value
 - Development path
- **Large Pilot Planning**
 - Update on DOE Project DE-FE0031580
 - Cycle diagram
 - Plan for commercial-scale cycle
- **LCOE for FPO with Integral CC**
 - Comparison with SCPC technology, with and without PCC
 - FPO firing PRB coal, New-Build and Retrofit
- **FPO Retrofitting**
- **Projected Output of New-Build and Retrofit Plants**
- **Outlook for Commercialization**

FPO versus traditional combustion processes



Philosophy and purpose

- Recover energy from low ranking coal and other brown fuels
- Enable CO₂ capture on an economically viable basis
- Minimize emissions of NO_x, particulates and heavy metals

Proven technology outperforms traditional combustion

- Flameless combustion using industrial oxygen in an atmosphere of CO₂ and water vapor
- Complete oxidation: low TOC & zero soot at combustor exit
- Zero thermal NO_x: organic nitrogen converted to N₂
- Flue gas volume reduced by ~ 85% minimizes scrubbing cost
- No fly-ash: all Incombustibles end in zero carbon slag

Added Value of Itea FPO

- **Accepts up to 65% water content:** fuels fired as slurry in water
- **Enables use of low-ranking coals** up to 40% ash, including alkaline ash
- **Enables CO₂ capture (CC)** on an economically viable basis
- **Addresses peaking by fast response:** from 5% to 100% capacity in <1/2 hr
- **Retrofittable** to supercritical and subcritical pulverized coal plants
- **Potential for Small Modular Power Plants** 80 to 350-MWe

FPO - Development Path

Planned development

- Large Pilot for coal power with CO₂ Capture – Planning Project started
leading to
- 240 to 500-MWth Modular Unit for commercial coal power plant with Integral CO₂ Capture (CC) – Retrofit or New-Build



Large Pilot Planning - Update

DOE funded planning projects

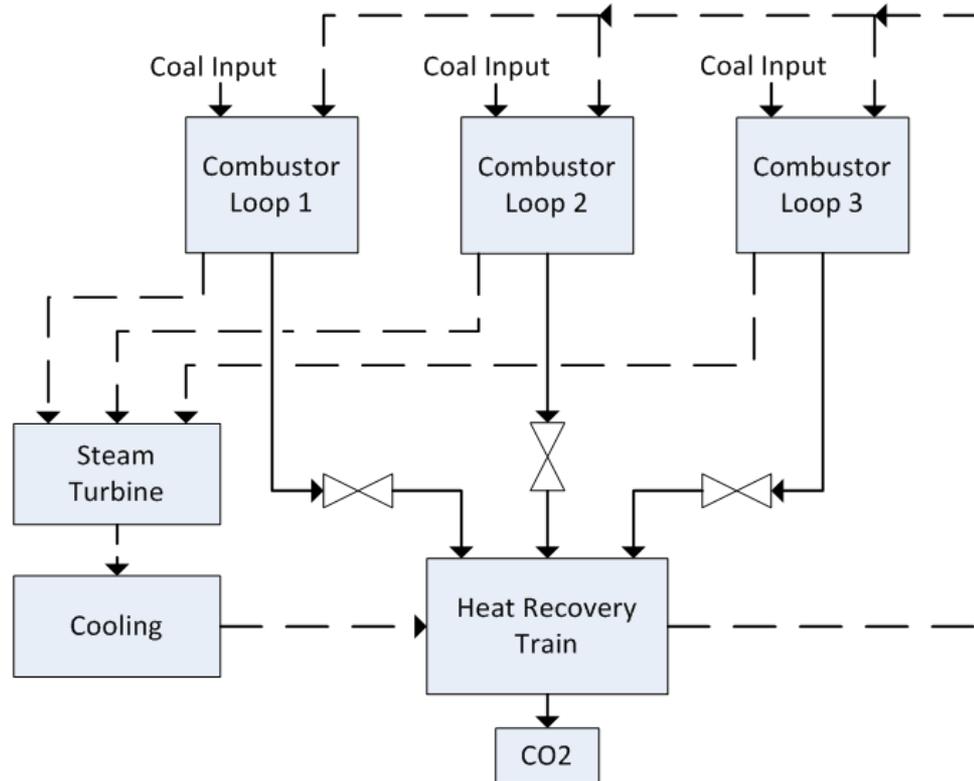
- **DE - FE0027771 - Completed early 2019**
- **DE-FE0031580 (Phase 1) - Started July 2018**
- Development of a Large Pilot as a scale up of 5-MWth pilot plant operating at Itea's Gioia del Colle R&D Centre, Italy since 2006
- Pre-FEED
- Cycle modeled in Aspen Plus
- Cycle design and optimization complete
- Near complete combustion shown with zero fly ash and high purity of CO₂
- Pilot will fire high- and low-rank coals over 2 year test program

Next step

- **Phase 2 FEED**

Plan for Commercial-Scale Cycle

- Combustor scaled from Large Pilot to 240 to 500-MWth
- 500-MWe with ASU and CO₂ Separation is possible with 3 X 500-MWth combustors
- Modular approach limits costs of combustor and steam generator
- Turbo-expander acts as control from pressurized loop to heat recovery and cleanup
- Potential CHP format could provide improved economics in favorable locations



Comparison of LCOE for SCPC, PCC and FPO 550-MWe

Parameter	Unit	PRB SCPC no CC Baseline (\$12A) updated to \$2018	PRB SCPC with PCC Baseline (\$12B) updated to \$2018	Projected n th -of-a-kind PRB FPO / Integral CC based on ITEA Projection
Power-in (LHV)	MWth	1,369	1,963	1,453
Gross Power	MWe	583	673	700
Parasitic Power	MWe	33	123	150
Net Power	MWe	550	550	550
Efficiency	% LHV	40.4%	28.0%	37.9%
Total Plant Cost	\$M	\$1,293	\$2,281	\$1,327
per kWe	\$/kWe	\$2,351	\$4,147	\$2,413
LCOE	\$/MWh	\$92.3	\$178.1	\$109.6
LCOE compared to S12A Baseline			193%	119%
LCOE compared to S12B Baseline				61.5%

Post CC Power-in high for reboiler steam cogen

FPO efficiency high due to heat recovery

Turbo-expander boosts FPO efficiency for PRB (and Lignite)

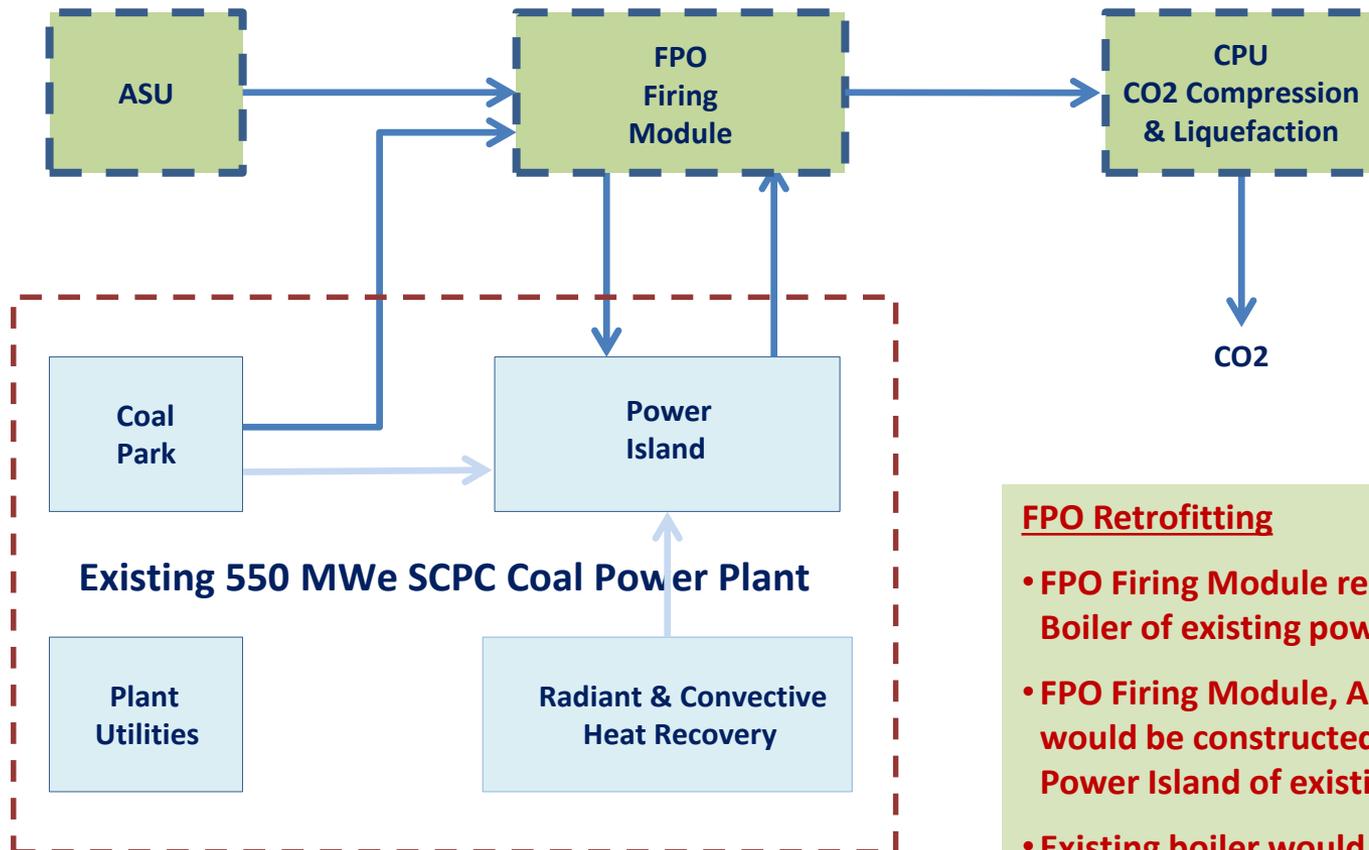
Affordable COE with CO2 Capture

- PRB Coal LHV 19.7 MJ/kg (8,486 Btu/lb), S 0.2%, 4.5% ash, 27% moisture
- Projected nth-of-a-kind based on 350-MWe ENEL detailed engineering study, scaled up to 550-MWe for Italy location. Used NETL methods for technology comparative studies
- For USA location capital cost, applied exchange rate of \$1.12/€1.00 throughout. For USA operating cost, applied exchange rate of \$1.12/€1.00 to Italian costs.

FPO Performance Firing PRB Coal, New-Build & Retrofit

Parameter	Unit	PRB SCPC no CC Baseline (\$12A) updated to \$2018	PRB SCPC with PCC Baseline (\$12B) updated to \$2018	Projected n th -of-a-kind FPO / Integral CC based on ITEA Projection	
				New Build	Retrofit
Power-in (LHV)	MWth	1,369	1,963	1,453	1,500
Gross Power	MWe	583	673	700	719
Parasitic Power	MWe	33	123	150	169
Net Power	MWe	550	550	550	550
Efficiency	% LHV	40.4%	28.0%	37.9%	36.7%
Total Plant Cost	\$M	\$1,293	\$2,281	\$1,327	\$736
per kWe	\$/kWe	\$2,351	\$4,147	\$2,413	\$1,338
LCOE	\$/MWh	\$92.3	\$178.1	\$109.6	\$83.5
LCOE compared to S12A Baseline			193%	119%	90.5%
LCOE compared to S12B Baseline				61.5%	46.9%

FPO Retrofitting



FPO Retrofitting

- FPO Firing Module replaces Boiler of existing power plant
- FPO Firing Module, ASU & CPU would be constructed next to Power Island of existing plant
- Existing boiler would be shut down and FPO Firing Module connected to Power Island

Retrofit FPO Plant with Integral CO2 Capture Firing PRB Coal (ITEA Prospect)

	CAPEX	Efficiency	Capacity	CO2
	(\$M)	(% LHV)	(MWe net)	(t/hr) [1]
Retrofit to Subcritical	\$760	31.5%	567	600
Retrofit to SCPC	\$736	36.7%	550	500

[1] Assumes capture of 90% of CO2 produced

Outlook for Commercialisation

FPO provides a pathway towards affordable, efficient, and clean coal power with integral CO₂ capture

With growth of renewables, U.S. market will need more load-following plants

- High availability based on standby at 5% capacity rate and coal storage on site
- FPO fast response to fluctuating demand
- FPO can operate as base load, daily cycling or renewable cycling response

CO₂

- FPO captures over 90% of CO₂ as clean stream ready for compression and liquefaction

Opportunities for FPO Technology

- Retrofitting FPO to coal plants in favourable locations provides solution for potentially stranded assets, reducing CO₂ emissions by 90% and increasing revenue by producing CO₂ and load-following.
- High efficiency and CO₂ capture firing low-ranking coals as-mined, without drying
- Potential for Small Modular Power Plants 80 to 350-MWe