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

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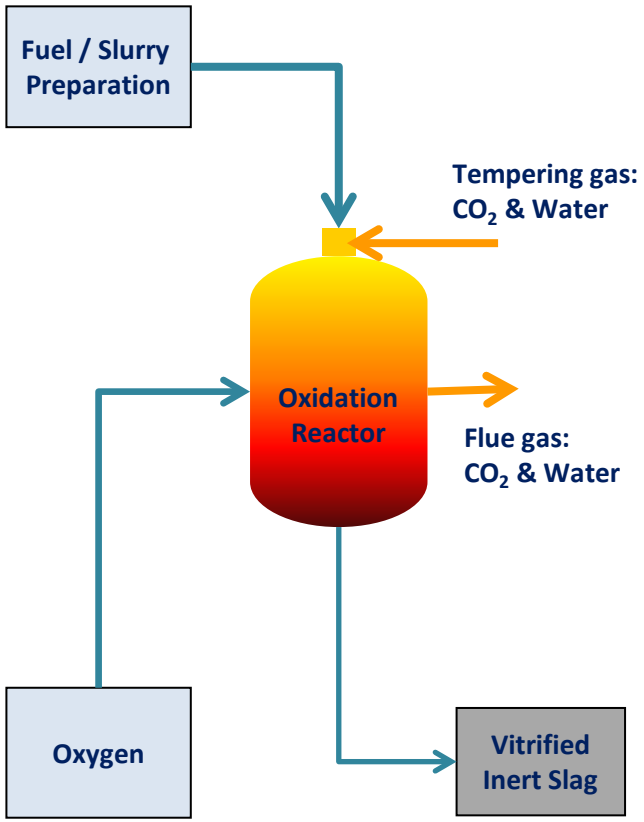
Agenda

- **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 CO_2 capture on an economically viable basis
- Minimize emissions of NOx, particulates and heavy metals

Proven technology outperforms traditional combustion

- Flameless combustion using industrial oxygen in an atmosphere of CO_2 and water vapor
- Complete oxidation: low TOC & zero soot at combustor exit
- Zero thermal NOx: organic nitrogen converted to N_2
- 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 CO_2 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 CO_2 Capture – Planning Project started

  leading to

- 240 to 500-MWth Modular Unit for commercial coal power plant with Integral CO_2 Capture (CC) – Retrofit or New-Build

Large Pilot Planning - Update

DOE funded planning projects

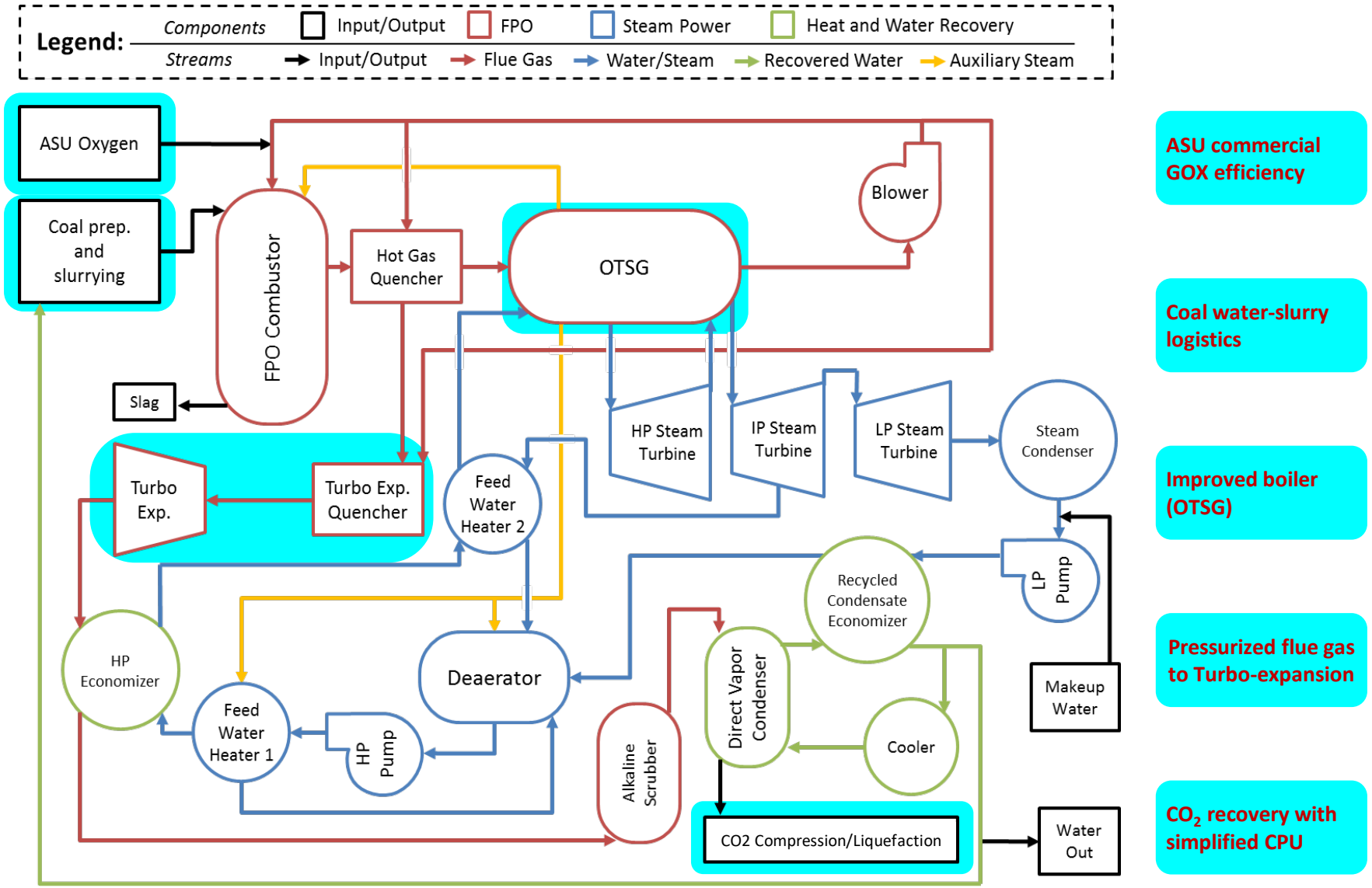
- **DE - FE0027771 - Completed early 2019**
- **DE-FE0031580 (Phase 1) - Started July 2018**

- 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**

FPO Commercial Application– Cycle Diagram



ASU commercial GOX efficiency

Coal water-slurry logistics

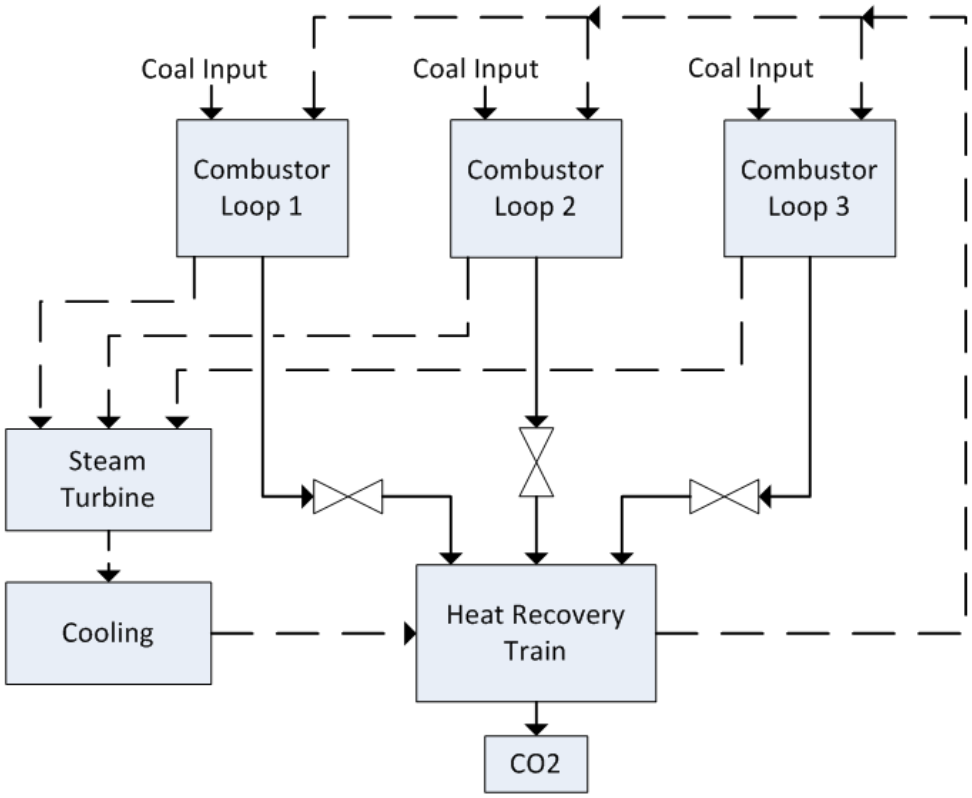
Improved boiler (OTSG)

Pressurized flue gas to Turbo-expansion

CO_2 recovery with simplified CPU

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 (S12A) updated to $2018	PRB SCPC with PCC Baseline (S12B) updated to $2018	Projected nth-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)

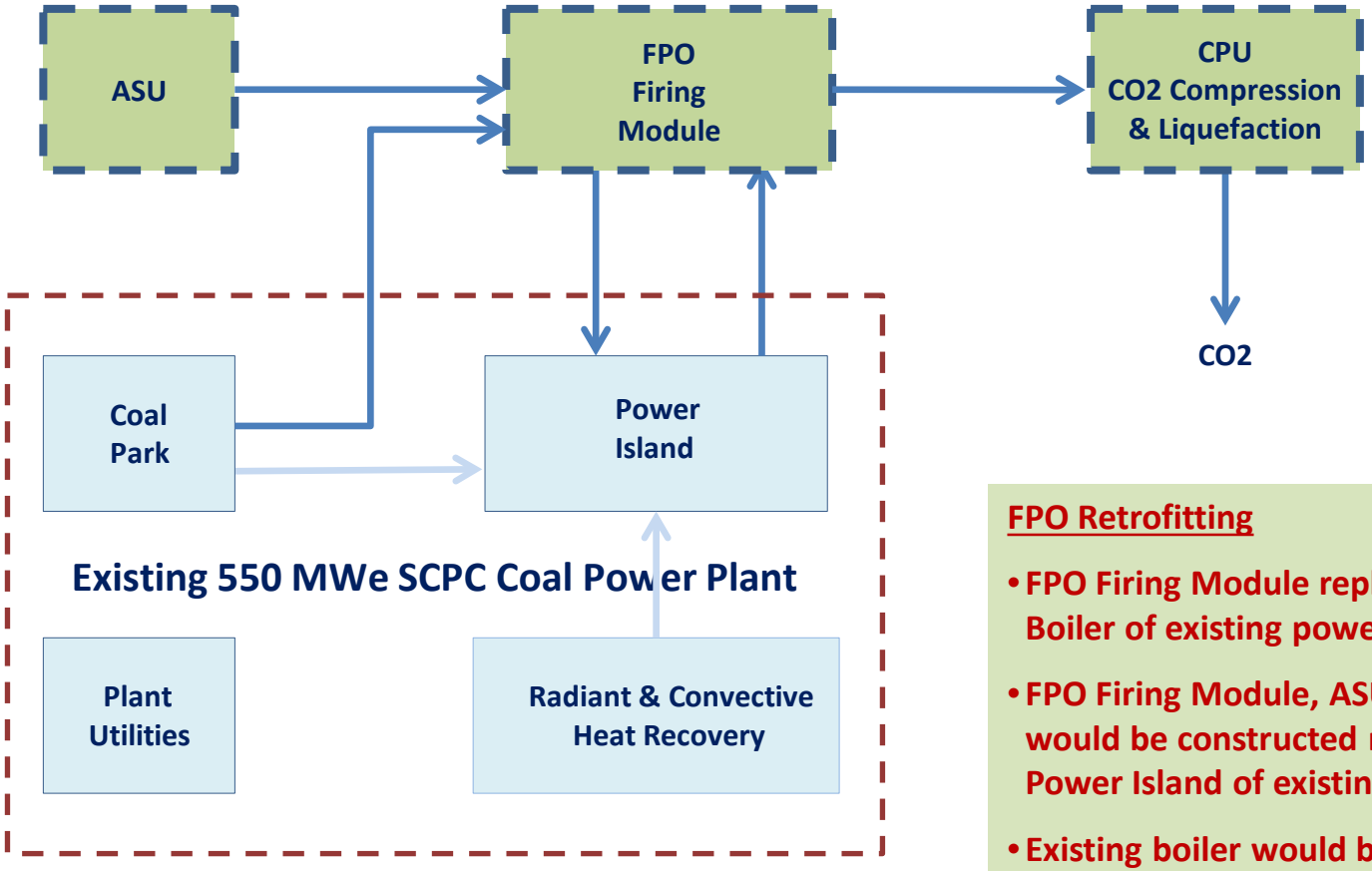
Affordable COE with CO2 Capture

- 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 (S12A) updated to $2018	PRB SCPC with PCC Baseline (S12B) updated to $2018	Projected nth-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