

A New Age for Coal with CCSU

Opportunities for Flameless Pressurized Oxy-Combustion (FPO)

ADDRESSING EMISSIONS CHALLENGES & CARBON CAPTURE FOR COAL

Wyoming Infrastructure Authority

Energy & Technology Showcase,

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Agenda

- **FPO technology**
 - Description
 - Competitive advantage
- **DOE Project DE - FE0027771**
 - 50 MWth Pilot Plant
- **Commercial Possibilities**
 - Power Plant with Integral CO₂ Capture
 - Large Scale CHP with Integral CC
- **Connections to EOR in Southeastern Wyoming**

FPO technology

Philosophy and purpose

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

Proven technology



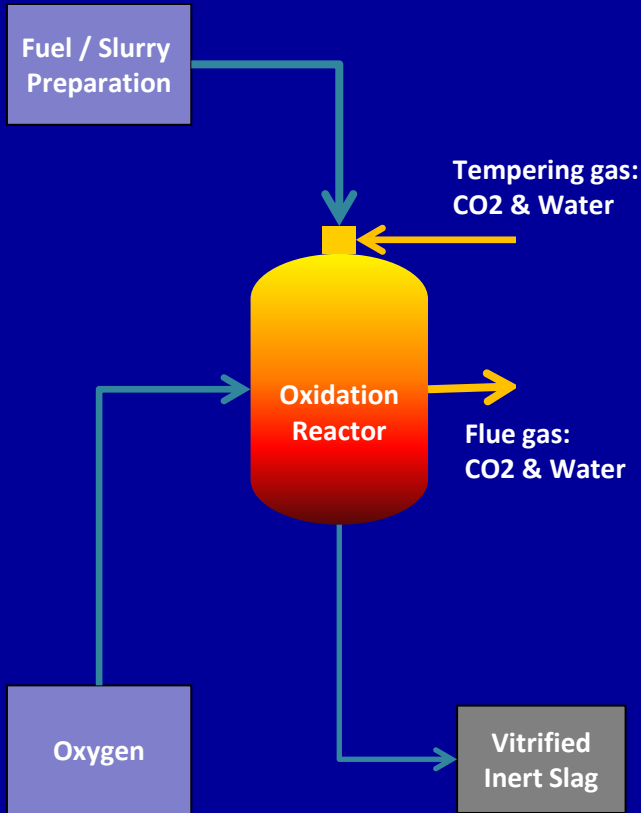
5 MWth Pilot Plant Unit started up in 2006 at Gioia del Colle R&D Centre, Italy



15 MWth Commercial Unit started up in 2011 in Singapore, and operated by Itea until 2013

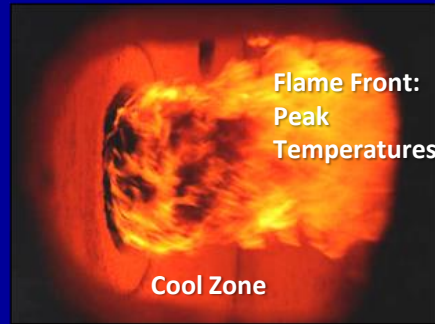
Joint ENEL-Itea detailed engineering study of 350 MWe coal fired plant

FPO versus traditional combustion processes



- Combustion using industrial oxygen in an atmosphere of CO₂ and water vapour

Traditional «flame» combustion:
"chaotic" / not locally controllable

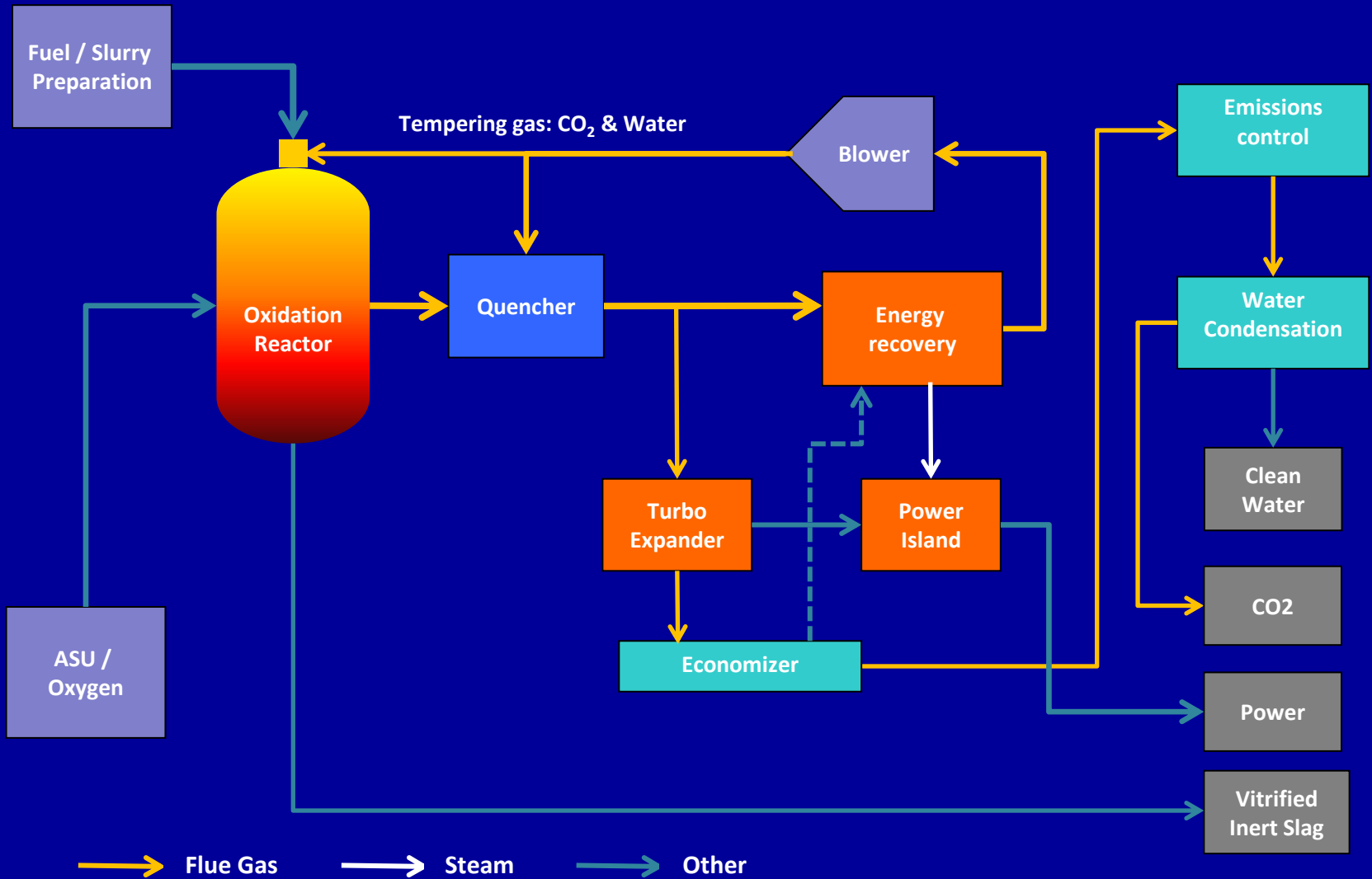


Itea «Flameless» combustion:
"mild" / controllable



- Complete oxidation: much lower TOC and zero soot at combustor exit
- Zero thermal NO_x: organic nitrogen converted to nitrogen gas
- Volume of flue gas reduced by ~ 85% so much lower cost of flue gas scrubbing
- No fly-ash: all Incombustibles end in zero carbon slag

FPO Process Scheme



Benefits of Itea FPO

Offers technology solution to increasingly onerous regulation

- Total combustion of coal and other brown fuels and wastes
- High energy recovery
- Emissions near zero:
 - No particulates (No soot or carbon compounds)
 - Negligible NO_x (Ozone precursor)
 - SO_x <10 mg/m³ after pressurized FGD
- No fly ash: Heavy metals and other incombustibles captured in non-leachable vitrified 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% alkaline ash
- Enables CO₂ capture (CC) on an economically viable basis
- Can address peaking by fast response: from 5% to 100% of capacity rate in <1/2 hour

Comparison of COE for PCC & FPO 550 MWe Coal-fired Plant

Parameter	Unit	SC no CC baseline	Post CC SC+Amine	Integral CC ITEA FPO
Power in LHV	MWth	1,345	1,880	1,520
Gross Power	MWe	580	661	723
Net Power	MWe	550	550	550
Efficiency	%	40.9%	29.3%	36.5%
Capital	€M	€936	€1,693	€1,690
CAPEX	€/kWe	€1,700	€3,078	€3,073
LCOE	€/MWh	€76	€133	€104
LCOE compared to baseline			175%	137%
LCOE compared to baseline with CC				78%

Close to 100% expected with Sub-bituminous coal with ~25% water content

Bituminous Coal LHV 26-27 MJ/kg , S <1%, High temperature melting ashes, low moisture content

350 MWe plant design from ENEL study was scaled to a 550 MWe capacity plant following proper scale-up coefficients, and compared to data made available by NETL for competing technologies. From the time of the study, the ASU data has been updated with commercially available vendor data for both Atmospheric and Pressurized Oxy-combustion. European location and costs; LCOE includes cost of coal @ €70-71/t, all the way through.

FPO - Development Path

Planned development

- 50 MWth pilot for coal power with CO₂ Capture – **Planning Project started**
leading to
- 500 MWth Unit for commercial coal power plant with Integral CO₂ Capture (CC)
and
- CHP projects from 50-500 MWth to supply steam, power and CO₂



DOE Project DE - FE0027771

Large Pilot Plant Planning - Completion September 30, 2018 by SwRI

Provides blueprint for 50 MWth Pilot Plant to...

- Enable scale up of FPO Core Process from 5 MWth to 50 MWth
- Provide clear understanding of scale-up rules required for commercial-scale unit
- Generate data for design of 500 MWth firing module for 550 MWe project
- Fire wide range of high-to-low rank coals and lignite over 3-year test program

Pilot Plant will be...

- CO₂ capture-ready but no CO₂ liquefaction required for test program
- Location with coal handling infrastructure, accessibility and visibility

50 MWth Pilot Plant

- Construction expected to start asap in 2019, should start operation by end-2020
- 3-year test program could proceed in parallel with engineering for 500 MWth unit

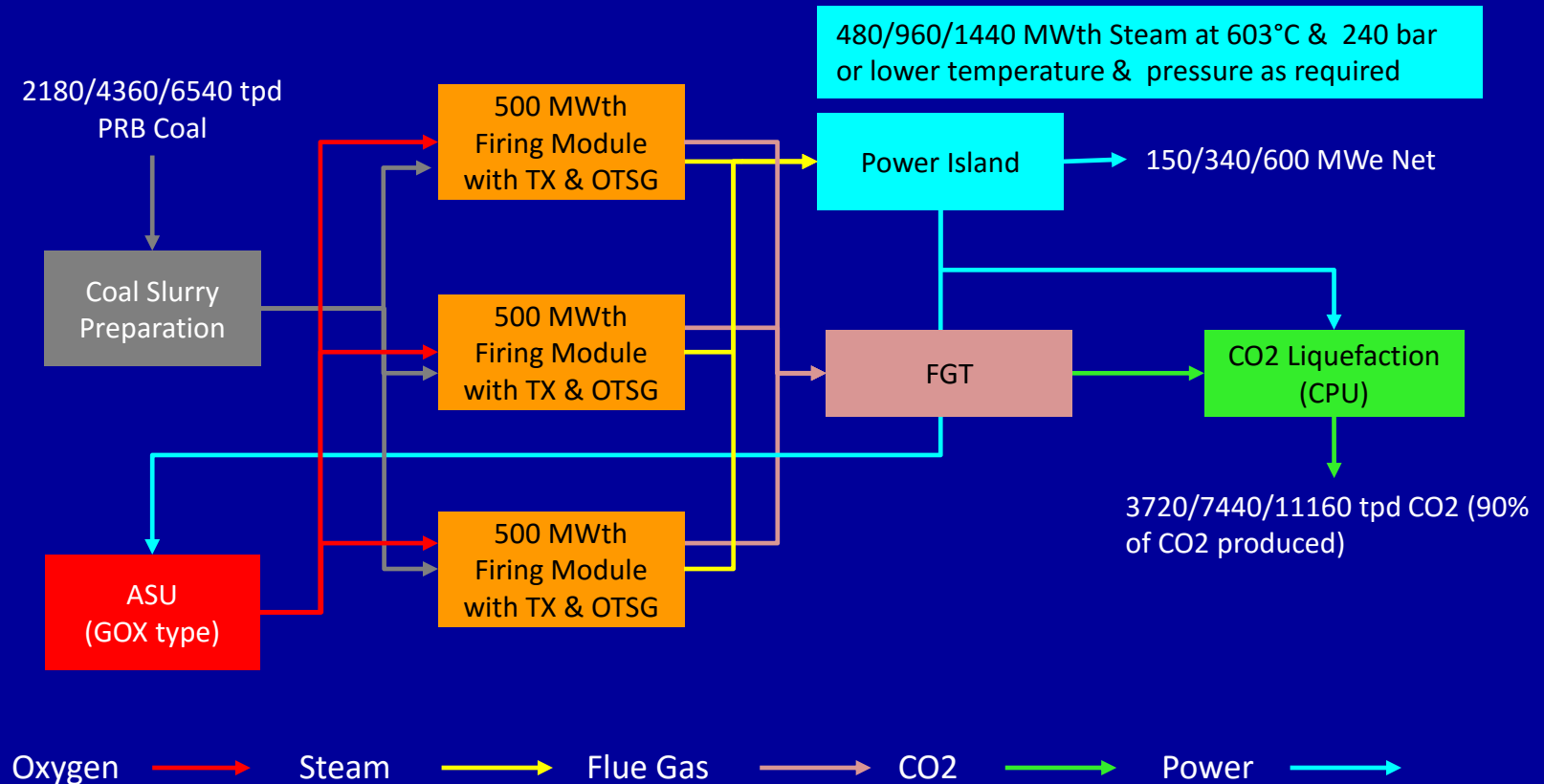
Test Program	Type of coal	Time span
Validation of Scale-up Parameters	PRB	6 mo
Duration Tests	PRB	12 mo
Flexible Fuel Capability	HV Illinois Appalachian Texas – Low & High Sodium Virgin Lignite Coal/Waste blends	18 mo (~3 mo each)

- Convert to commercial CHP unit after 3 years

Power Plant with Integral CC

500 MWth Firing Modules / up to 550 MWe FPO Coal Power Plant with Integral CC

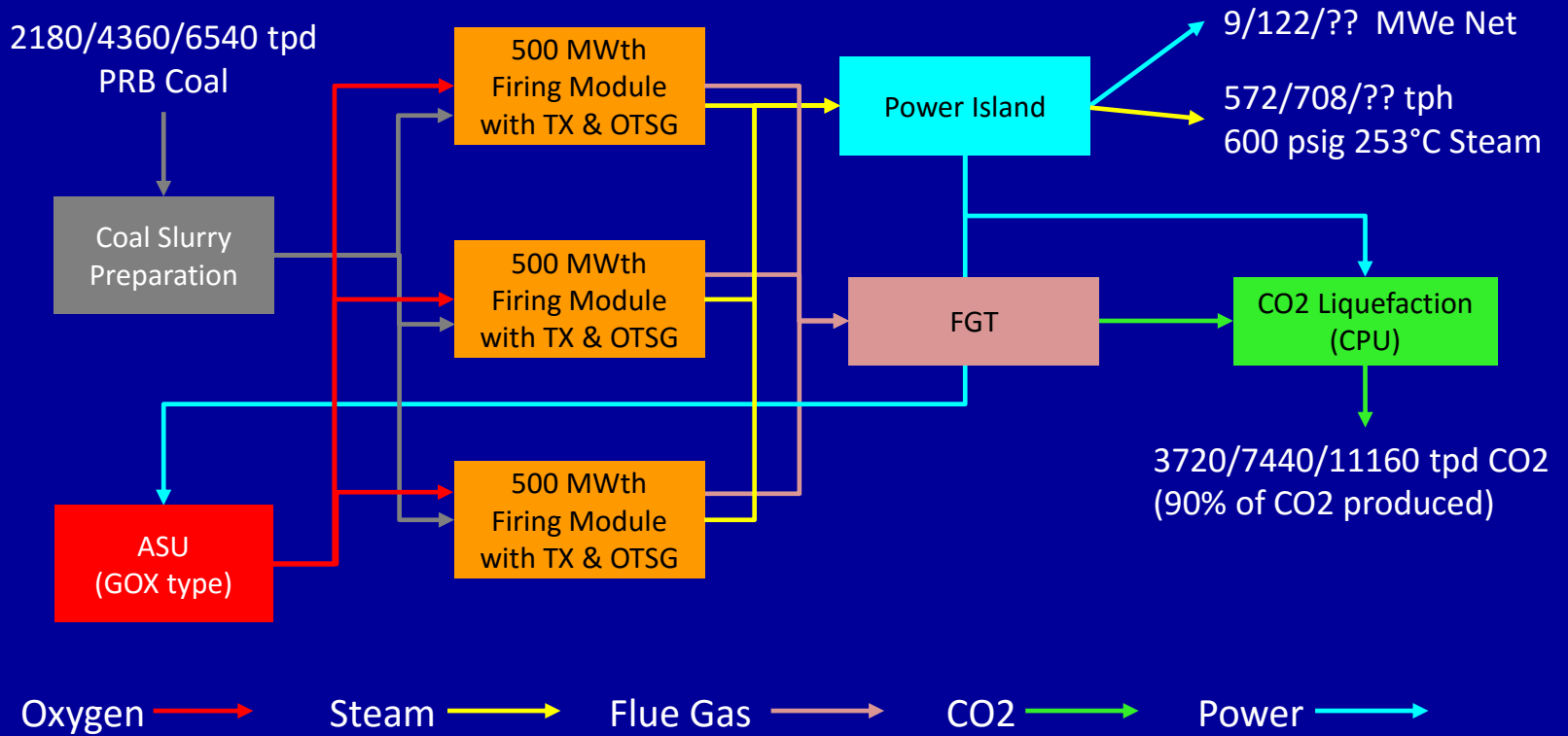
- Construction expected to start in 2022, for 2025 start-up
- Block diagram – flexible, expandable:



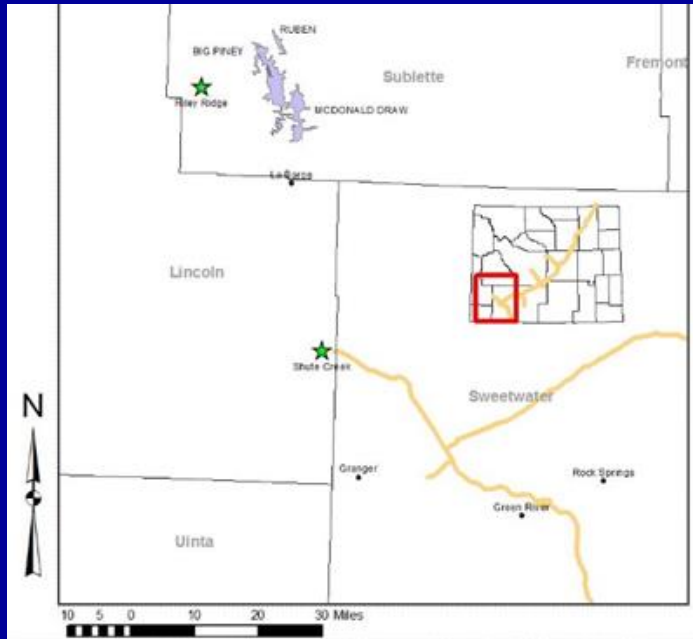
Large Scale CHP with Integral CC

Co-locate with high volume steam user

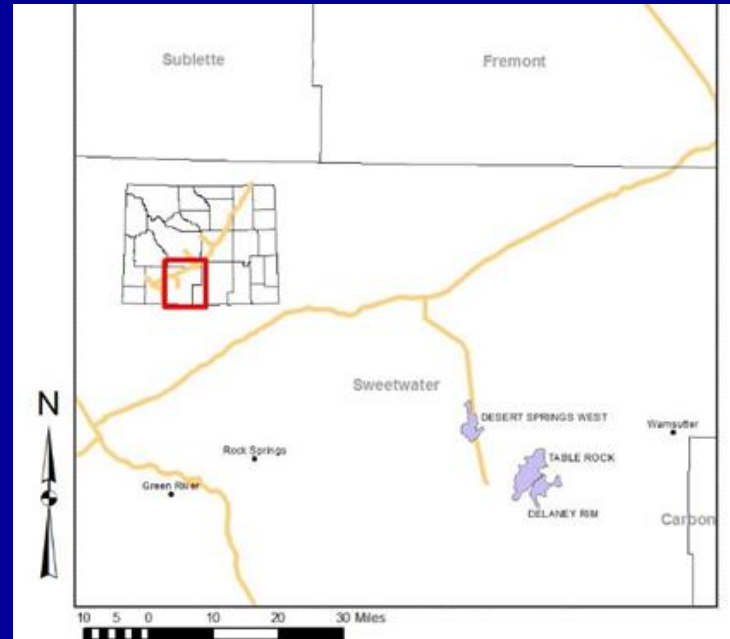
- 500 MWth Firing Modules / up to 1500 MWth FPO Coal CHP Plant with Integral CC



Connections to EOR in Southeastern Wyoming



LaBarge Area



Red Desert area.

A number of power plants are close to existing CO₂ pipeline infrastructure, which is close to high demand CO₂ oil field users

- Current cumulative production is ~20% of OOIP (oil in place)
- CO₂-EOR would likely mobilize an additional 15% of OOIP
- Recovery of 2 barrels of oil per ton of injected CO₂
- 3720-11160 tpd CO₂ available from scheme = 7.4-22.3 MBD oil

Wrap-up

Opportunities for FPO Technology

- Involvement in 50 MWth Pilot Plant test program
- Implementation of Commercial Power Plant with Integral CC could be staged
 - Single Module can produce 150 MWe + 3720 tpd CO₂
 - 3 Modules can produce 600 MWe + 11160 tpd CO₂
- Could Co-locate Large Scale CHP with high volume steam user
 - 2 Modules can produce 122 MWe + 708 tph 600 psig 253°C Steam + 7440 tpd CO₂
 - For efficiency, 3 Modules would require a machine (ST) which does not (yet) exist
- Gross oil revenues from EOR would be substantial