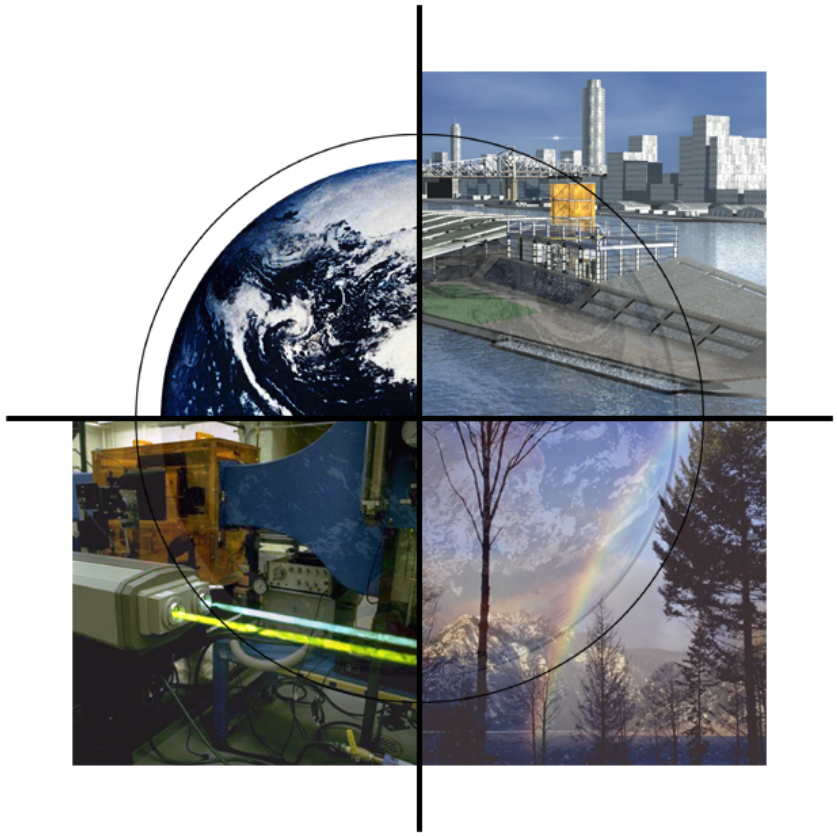
Gasification Technologies



Advanced Technology Options for FutureGen

Pittsburgh, PA
March 30, 2006

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Gasification Technology Roadmap

Challenges

Optimization of Coal Use with
- *Zero emissions*
- *High efficiency*
- *Low cost plants*

for production of
- *Electric power*
- *Fuels*
- *Chemicals*
- *Hydrogen*

Reduction of Power Plant Pollutants (NOx, SOx, Hg, As, Cd, Se, PM)

Reduction of CO_2 Emissions

Maintain Low Cost of Electricity to the Public through diversified mix of indigenous fuels

R&D Pathways

By 2010
- Transport/Compact gasifiers
- Advanced materials & instrumentation
- Dry feed pump
- Warm gas cleaning (all contaminants including Hg)
- 7FB gas turbines
- ITM oxygen
- 85 % capacity factor
- 98 % carbon conversion

By 2020:
All of 2010 improvements
Plus:
- Chemical looping gasifiers
- Hydrogen gas turbines
- SOFC topping cycle
- 90 % capacity factor
- CO_2 capture & sequestration

Targets

By 2010
- Efficiency 45-50% (HHV
- Capital $1000/kW[1]

By 2012
- Increase COE < 10% w/CO_2 capture

By 2020
- Efficiency 50-60% (HHV)
- Capital $900-1000/kW
- Targets for Plants w/o Carbon Capture

[1]cost in 2002 $

Key Activity
Cost and Performance Targets

- **Gasification**
  - >5% reduction in capital cost of IGCC
  - $1-2M reduction in annual O&M costs
  - 2-4 point gain in thermal efficiency
  - >5 point improvement in plant availability
- **Gas Cleaning**
  - $60-80/kWe reduction in capital cost
  - >1 point gain in thermal efficiency
  - Near-zero emissions of all contaminants (SOx, NOx, Hg, As, Se, Cd)
- **Air Separation**
  - $75-100/kWe reduction in capital cost
  - >1 point increase in thermal efficiency
- **Hydrogen/Carbon Dioxide Separation**
  - <10% increase in cost of electricity
  - >25% reduction in cost of hydrogen ($5.89/MMBtu by 2015)

Gasification Technology Options for FutureGen

	Gasifier	Oxygen Supply	Gas Cleanup	H_2 / CO_2 Gas Separations
Baseline	Entrained, Slagging -GE Energy -CP E-Gas -Shell	Cryogenic	Ambient and cold -Rectisol -Selexol	Conventional -Selexol -PSA
Advanced Options	Transport Compact - Rocketdyne	Ion Transport Membranes	Warm gas cleaning - RTI sorbents	H_2 membranes CO_2 reverse-selective CO_2 hydrates
Basis	CCPI Orlando R&D Demos	APCI 150 TPD Demonstration	Pilot testing at Eastman 50 MWe testing TBD	Tests at PSDF/ Eastman
Reason	Lower cost Use of LRC Improved efficiency	Lower cost and better integration Higher efficiency	Higher efficiency Cleaner syngas Lower cost	Higher yield H_2 Reduction of CO_2 emissions

PSDF Accomplishments Summary

- **Transport reactor:** 8,300 hours of operation in gasification mode; Gasification operations routine, reliable, and automatically controlled with adequate quality.
- **Fuel Diversity:** Bituminous, sub-bituminous, and lignite coals.
- **Coal feed and ash removal subsystems:** Coal feed operation routine and reliable; Lower cost alternative coal feed and ash removal system part of development program.
- **Advanced particulate control:** Experienced <0.1 ppm emissions
- **Filter safe guard device:** Developed
- **Syngas cleanup:** Ultra-low emission levels for S, N, and Cl achieved.
- **Syngas cooler:** Routine and reliable.
- **Sensors/Logic:** Improvements made.
- **Solid Oxide Fuel Cell:** First operation on coal-derived gas.
- **Piloted Syngas Burner:** Successful operation on syngas with heating value as low as 48 Btu/scf.

Future Test Opportunities for Transport Gasifier

- **Future Test Program at PSDF**
  - Additional testing of alternative coal feedstocks, particularly high sodium lignite
  - Test Stamet advanced coal feed pump
  - Test advanced materials and instrumentation
  - Integrate with novel CO_2/H_2 separation technologies
  - Evaluate fuel cell tolerance to contaminants
- **CCPI Demonstration**
  - Testing at one-half scale in 280 MWe IGCC demonstration in FL
- **Why FutureGen?**
  - Oxygen vs. air at Orlando
  - Full-scale vs. half scale at Orlando
  - Integration with advanced technologies at FutureGen
  - More diverse coal feed testing at FutureGen vs Orlando

Compact Gasifier
Key Design Features and Advantages

- **Compact plug flow gasifier --** 90% size reduction, factory fabrication, low capital cost, and easy maintainability
- **Rapid-mix injector and dry pumped feed system –** 99% carbon conversion, 82% to 85% cold gas efficiency (HHV), and low oxygen consumption
- **Long-life components (cooled refractory liner and injector) –** 99% gasifier availability without redundant units
- **Fuel flexibility (lower operating cost) –** Gasify all ranks of coal, petroleum coke, refinery residuals, oil sands, stranded natural gas, biomass, and combustible wastes
- **Product flexibility --** High pressure operation enables cost competitive production of liquid fuels, hydrogen, and chemicals as well as electricity
- **Ideal for hydrogen production and carbon sequestration –** 70% plant efficiency (HHV) with 90% carbon capture

Compact Gasifier Performance Comparisons (Parsons)

	Case 1 Compact	Case 2 GE	Case 3 Compact	Case 4 Shell
Gross Power (MW_e)	706	758	715	734
Auxiliary Load (MW_e)	101	123	101	110
Net Power Output (MW_e)	605	635	614	624
Thermal Input (MW_{th})	1,430	1,620	1,430	1,490
Net Plant Heat Rate (Btu/kWhr)	8,080	8,700	7,960	8,130
Net Plant Efficiency, HHV	42.2%	39.2%	42.9%	42.0%
Total Plant Cost ($/kW)	1,385	1,532	1,211	1,519
Levelized Cost of Electricity ($/MW)	48.9	53.4	44.6	52.8

85% Capacity Factor Assumed for Levelized Cost of Electricity calculations

Cost and Performance Comparisons (Parsons)

	Radiant / Quench Case 1 vs. Case 2	Convective Case 3 vs. Case 4
Δ Cold Gas Efficiency (HHV Basis)	9%	4%
Δ Net Power, MWe	(30)	(10)
Δ Thermal Input, MW_{th}	(190)	(60)
Δ Net Plant Heat Rate (HHV), Btu/kWh	(620)	(170)
Δ Total Plant Cost, $x1000	($99,720)	n/a
Δ Cost per kW, $/kW	($147)	(308)
Δ Levelized (10 year) Busbar COE, $/MWh	(4.5)	(8.2)
Δ Levelized (10 year) Busbar COE, %	(8.4%)	(15.5%)

85% Capacity Factor Assumed for Levelized Cost of Electricity calculations

Why Oxygen Separation Membrane Technology is Important

- **In an IGCC plant, the air separation unit**
  - Accounts for ~15% of the plant capital cost
  - Consumes ~ 10% of the gross power output
- **Reducing capital cost and increasing efficiency of ASU**
  - Improve economic viability of IGCC,
  - Stimulate commercial deployment.
- **Systems studies of membrane technologies have shown significant potential**
  - Increased net MWe
  - IGCC plant efficiency
  - Major decreased cost of oxygen production,
  - Overall decrease in Cost of Electricity (COE)

Membrane Air Separation Advantages

Air Products

	ITM Oxygen	Cryo ASU	Δ %
IGCC Net Power (MWe)	438	409	+7
Net IGCC Efficiency (% LHV) (% HHV)	41.8 40.4	40.9 39.5	+2
Oxygen Power Req't (kWh/ton)	147	235	- 37
Oxygen Plant Size (sTPD)	3,200	3,040	+5
Oxygen Plant Cost ($/sTPD)	13,000	20,132	- 35
Total IGCC Cost ($,000)	447,000	448,000	-----
IGCC Specific Cost ($/kW)	1,020	1,094	- 7

IGCC plant cost reduced 7%, plant efficiency increase 2% with >35% cost and energy savings in oxygen production

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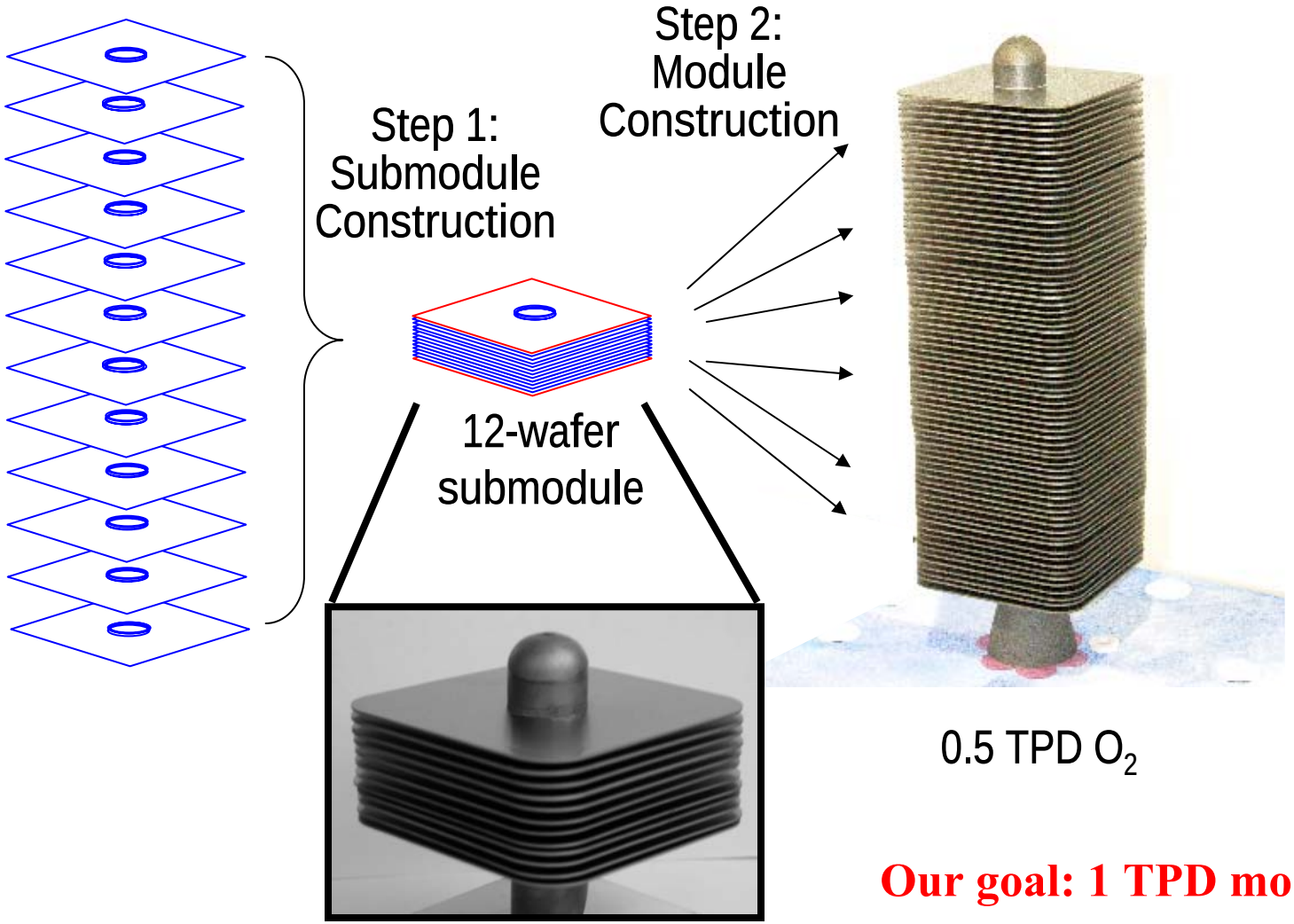
Commercial-Scale ITM Oxygen Modules Have Been Fabricated



Our goal: 1 TPD modules

Courtesy of Air Products

Ion Transport Membranes (ITM)

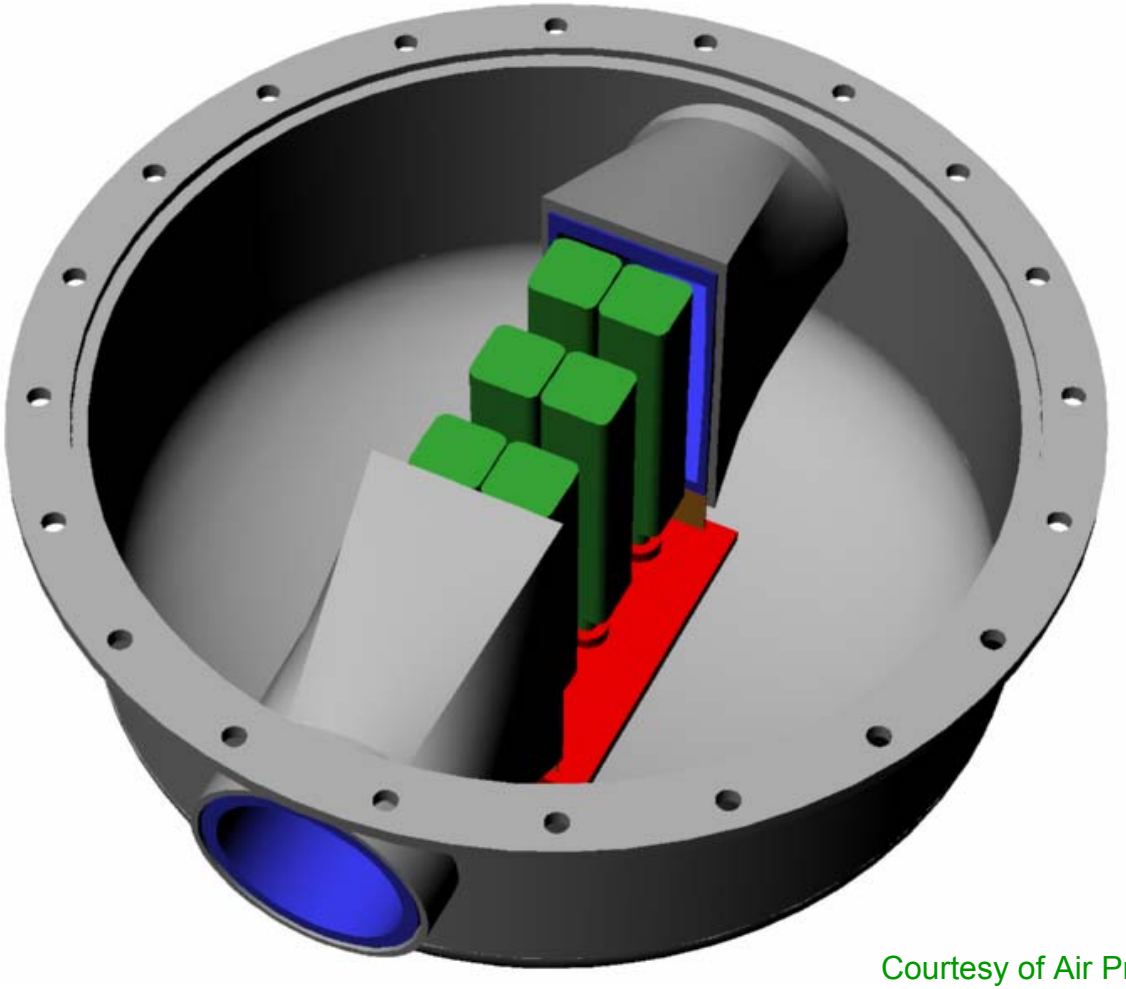
Air Separations

- **Commercial-scale Ion Transport Membranes (ITM) modules successfully tested at APCI's Sparrows Point industrial gas plant in January 2006 at design operation conditions producing >95% purity oxygen**
- **Negotiating scale-up to 150 tpd to begin in FY 2007**
- **ITM expected to reduce cost of ASU >30% and IGCC total >7%**

Subscale Engineering Prototype ITM Test unit at APCI's Sparrows Point gas plant

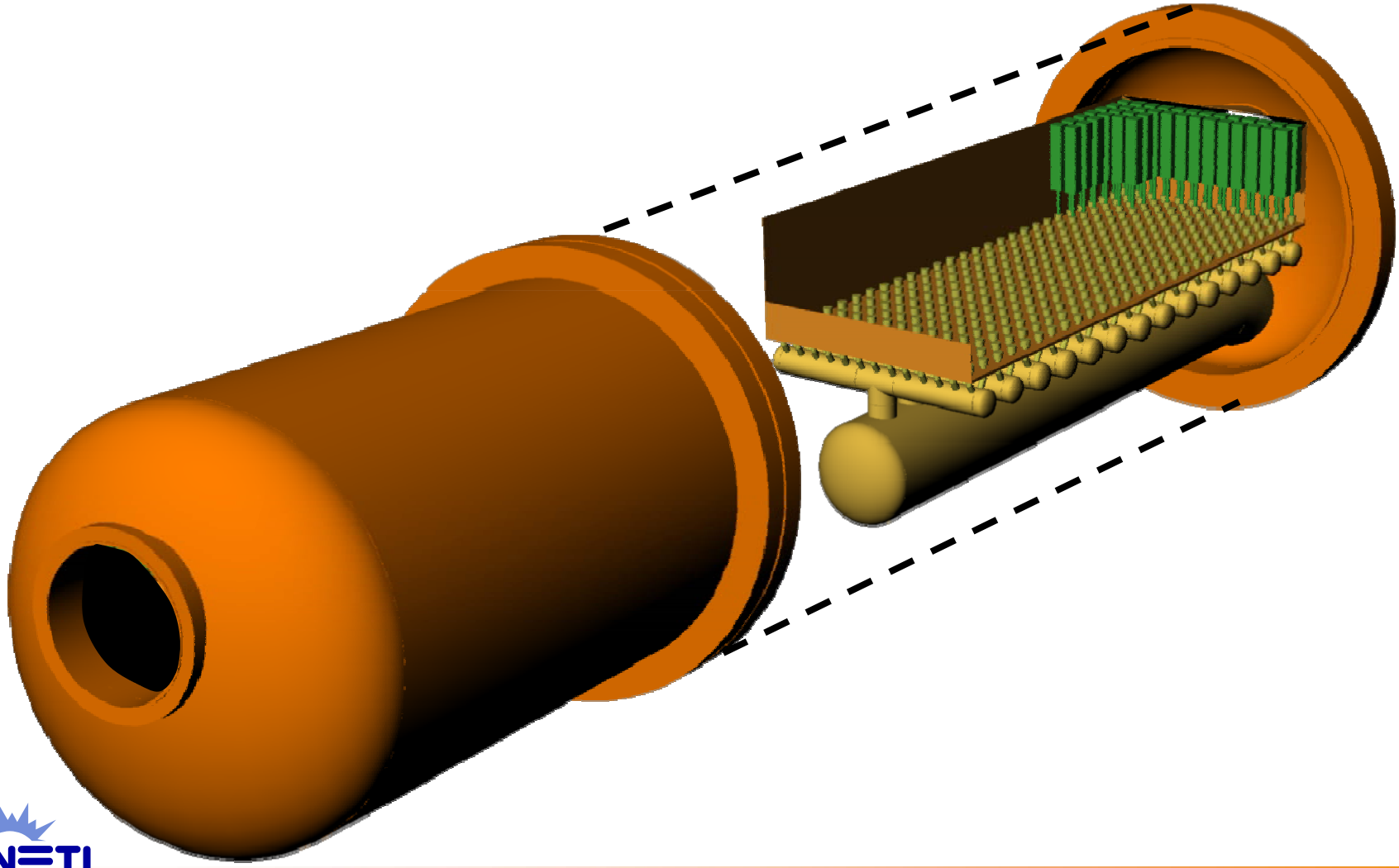
Test membrane modules
FY06 – 5 TPD
FY08 – 150 TPD
Offer commercial air separation modules
Post- FY09 demos of IGCC & FutureGen

Commercial ITM Oxygen Vessel Concept



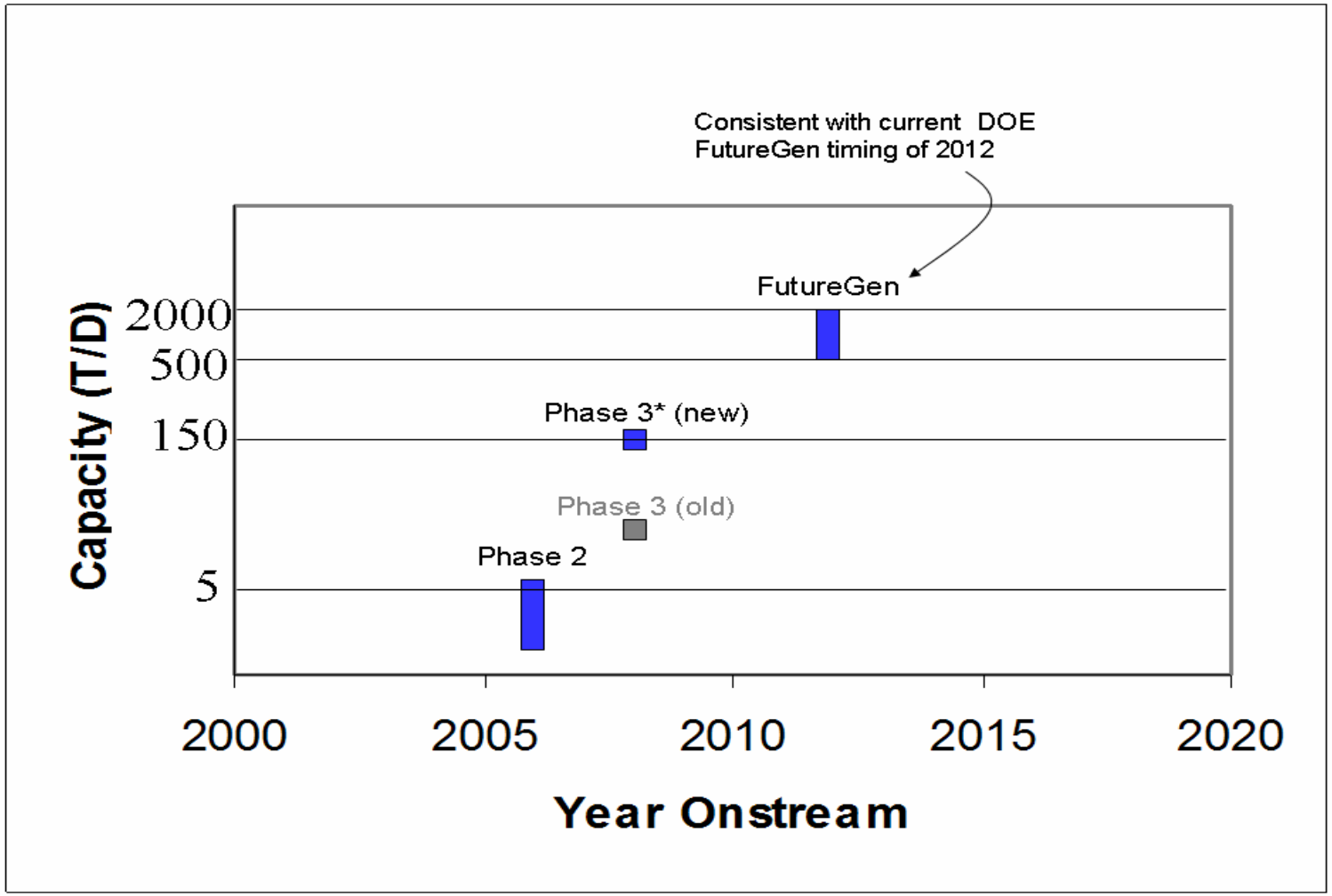
Courtesy of Air Products

Pilot scale vessel is a prototype for commercial scale concept



Conceptual 2000 TPD ITM Oxygen Vessel

ITM Oxygen Development Plan Being Developed With The DOE



Economic Advantage of Warm Gas Cleaning

	Base Case MDEA	RTI HTDS w/DSRP	Rectisol
Type / Capital Cost (in $millions)	Cool Gas	Warm Gas	Cold Gas
Low Temp Gas Cooling	12.3	0	12.3
NH_3 + AG Removal	19.3	38.7	49.7
S Recovery + Tail Gas Treat	32.3	7.4	27.6
Power Generation / HRSG	150.8	138.6	164.8
Delta Cost ($ millions)	0	- 30.0	+ 39.6
Delta Cost (as % of Base)	0 %	- 7.9%	+ 10.5%

Ultra-Clean Warm Gas Cleanup Progress

RTI Process Development Testing at Eastman Chemical

Field Test Objective:

First integrated evaluation of warm-gas contaminant cleanup technologies with coal-derived gas at a commercial gasification plant

Preliminary Test Results, Eastman (Kingsport):

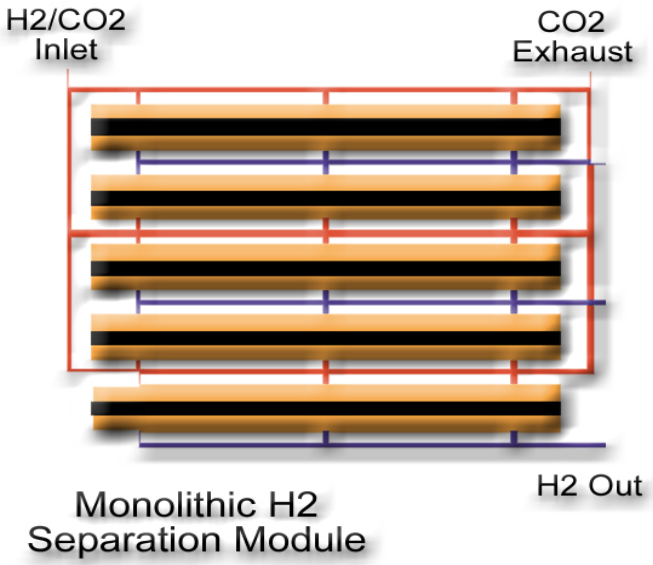
- **Preliminary results: H_2S and COS reduced to <0.5 ppm at 700°F (Dec. 2005) Operation**
- **Operation up to 800 psig and 900 °F**
- **Arsenic accumulates on sorbent, impacting regeneration; guard bed to be installed**
- **2000 hr test run scheduled for June/July 2006**

Potential Offered:

- **Achieve ultra-clean syngas**
- **Reduce total plant capital cost by $80-$100KW**
- **Improve thermal efficiency by 1-2 points**

Hydrogen Separation Technologies

- Permeation testing of Eltron layered composite membrane achieved hydrogen separation flux target at 420 ºC and 150 psi; performance confirmed at NETL
- One-stage separation of ORNL advanced porous inorganic membrane yields 99.3% H2; development underway for testing at a gasification site in FY07
- Two-stage CO_2 hydrate process cost marginally better than Selexol; program directed to focus exclusively on single-stage promoter-enhanced process; go/no-go decision in 2QFY07



Summary of Hydrogen from Coal Cases

	Case 1	Case 2	Case 3
Gasifier*	Conventional	Advanced	Advanced
Separation System	PSA	Membrane	Membrane
Carbon Sequestration	Yes (87%)	Yes (100%)	Yes (100%)
Hydrogen Production (MMSCFD)	119	158	153
Coal (TPD) as received	3000	3000	6000
Efficiency (%) (HHV basis)	59	75.5	59
Excess Power (MW)	26.9	25	417
Capital ($MM)	417	425	950
RSP of Hydrogen ($/MMBtu) / ($/kg)	8.18 / 1.10	5.89 / 0.79	3.98 / 0.54

* Conventional gasification technology assumes quench gasification (GE technology; formerly Texaco); advanced gasification technology assumes advanced E-Gas gasification.

- Membrane RD&D is estimated to reduce the cost of hydrogen from coal by 25%.
- Co-production of hydrogen and electricity can further reduce the cost of hydrogen production by 32%.

Source: Hydrogen from Coal, Mitretek Technical Paper MTR 2002-31. July 2002.

Eltron Research - Hydrogen Transport Membranes

- Achieved target H_2 permeation rates and have confirmed with testing at NETL unit
- Progressed from single phase ceramic to cermets and layered composite membranes
- Transition to testing at higher pressures, elimination of sweep gas, scale-up, and cermet development
- Testing and design have shown improved H_2 productivity with multi-stage membranes processes and with integrated HTM/WGS

ORNL – Microporous Membrane

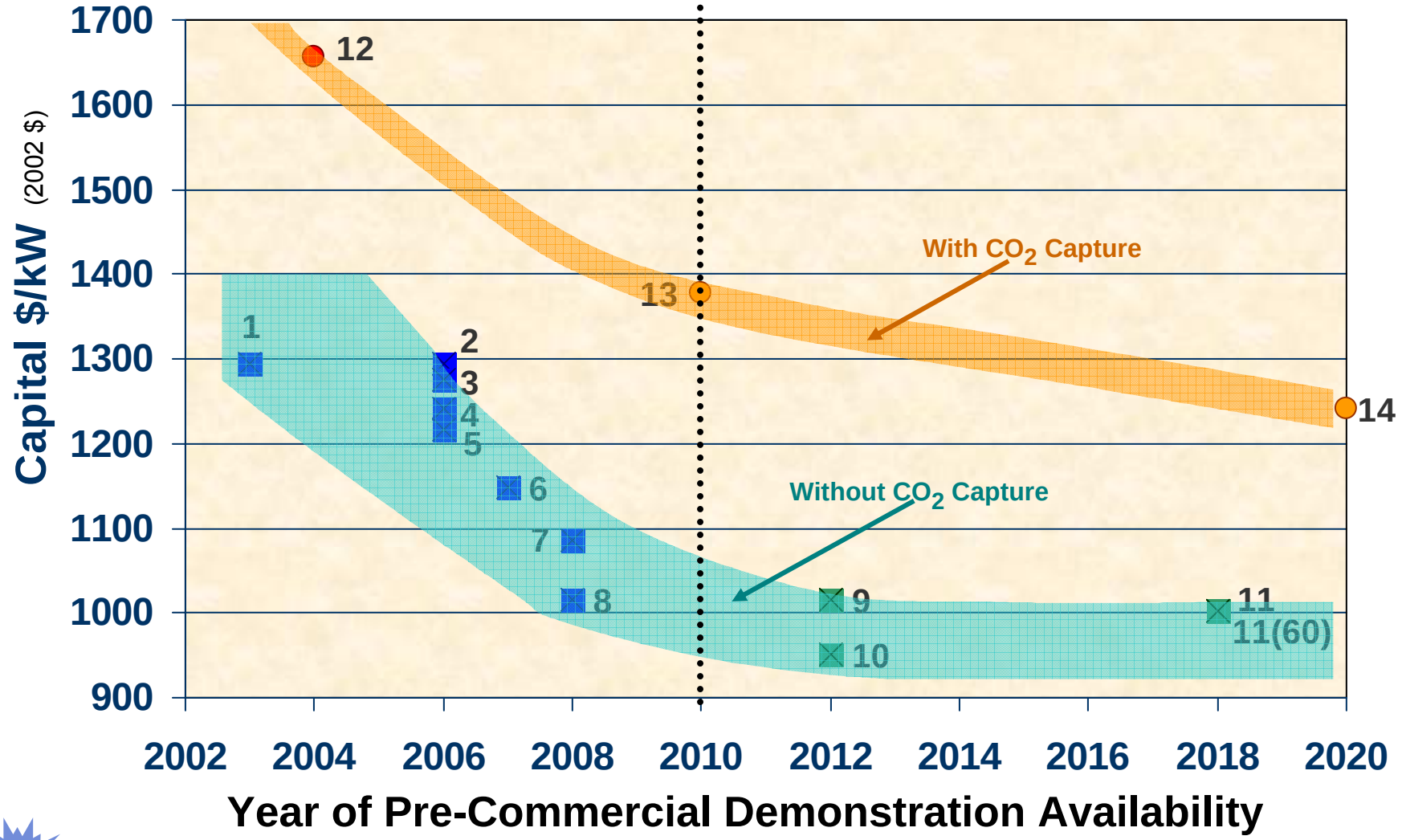
Notable Achievements

- A versatile and flexible fabrication technology was developed
- An excellent process for fabrication of hydrogen separation membranes was demonstrated
- Inorganic membranes that will, for example, separate from a synthesis gas stream 95% of the hydrogen at 99+% purity in a single stage were developed
- Economic goal of <<$100/ft^2 fabrication cost of microporous inorganic membranes was achieved (~$10-20/ft^2)
- A successful Classification and Nonproliferation Review was accomplished
- Established an excellent position for fabrication scale-up and system integration R&D

H_2/CO_2 Separation Membranes Schedule

- **Eltron**
  - Expects major decisions in 2007 for
    - Impurity management technology
    - Cermet seal and cermet material
    - Membrane configuration (Tubular vs. Planar)
    - Eltron reach decision point with commercialization partners
  - Will determine size scale-up and testing plans to demonstrate commercial viability
- **ORNL**
  - Sub-module tests at Eastman and/or PSDF (2007),
  - DOE optimization design studies (2006) and industrial partner collaboration (2006) lead to conceptual design of commercial module by 2008
  - Complete commercial module tests in 2010 (FutureGen)
  - Initiate design of full-scale test demonstration unit in 2010
  - Anticipate full-scale demonstration by 2012 or 2013

Capital Cost ($/kW) Timeline



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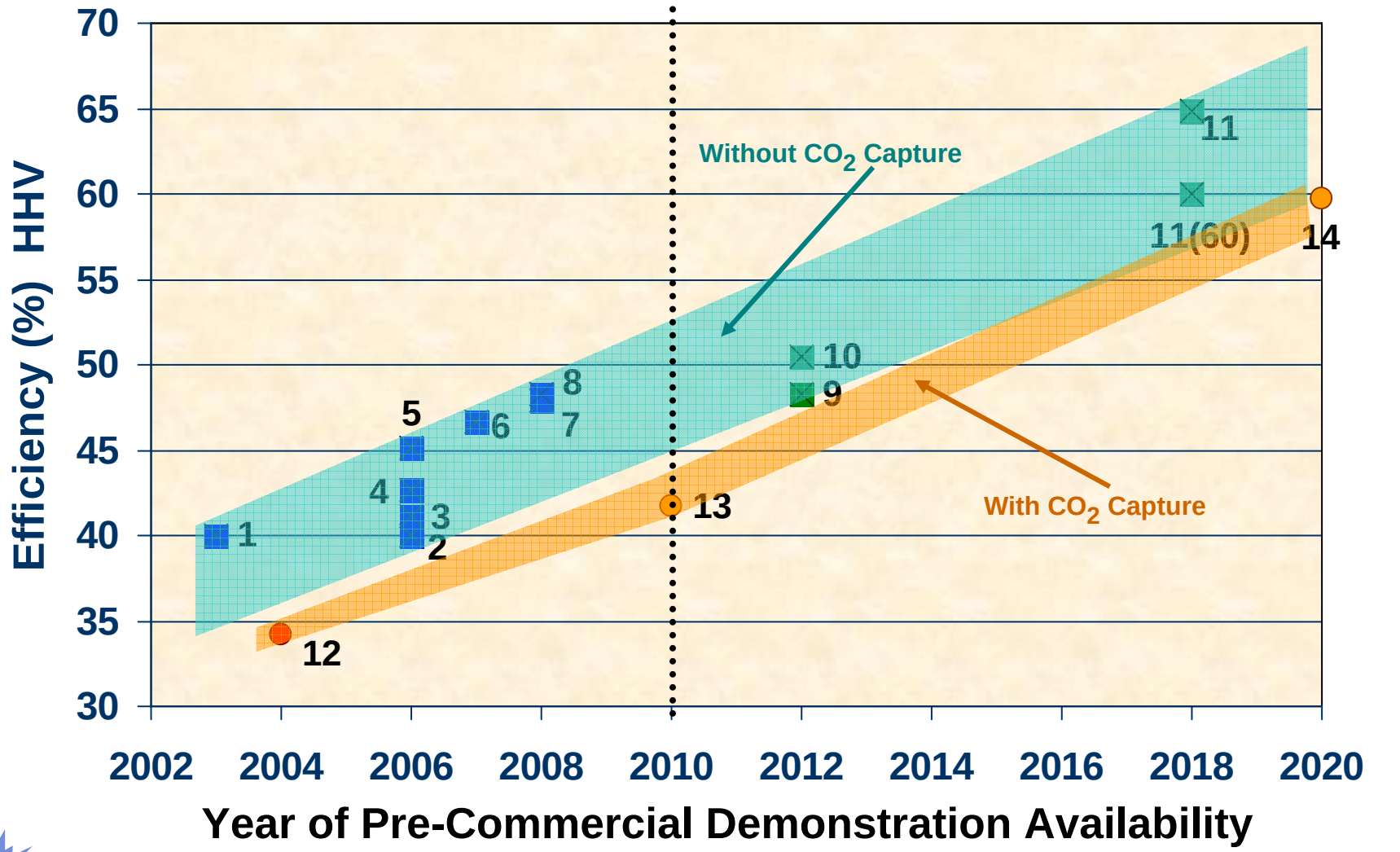
Efficiency Timeline



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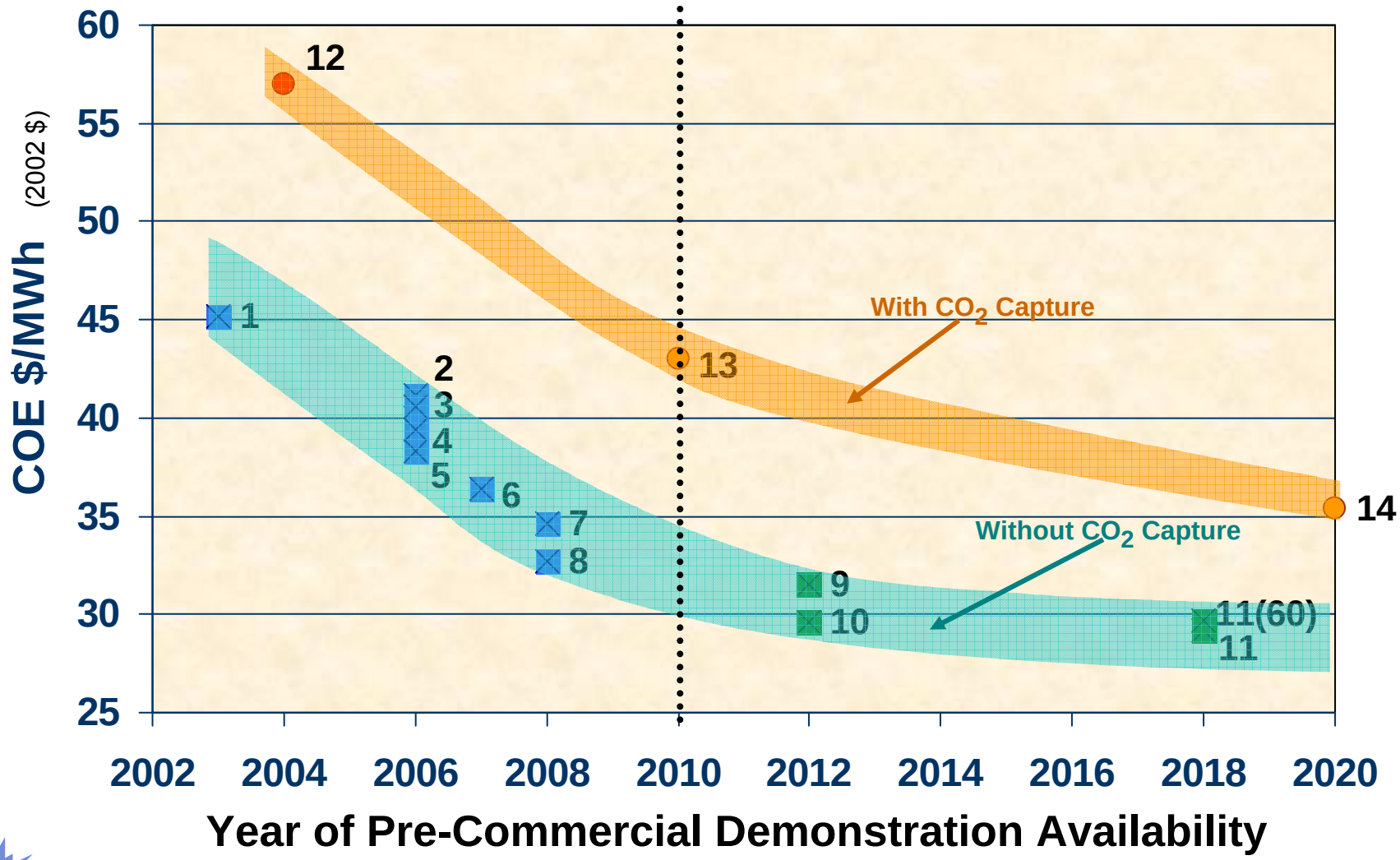
COE Timeline



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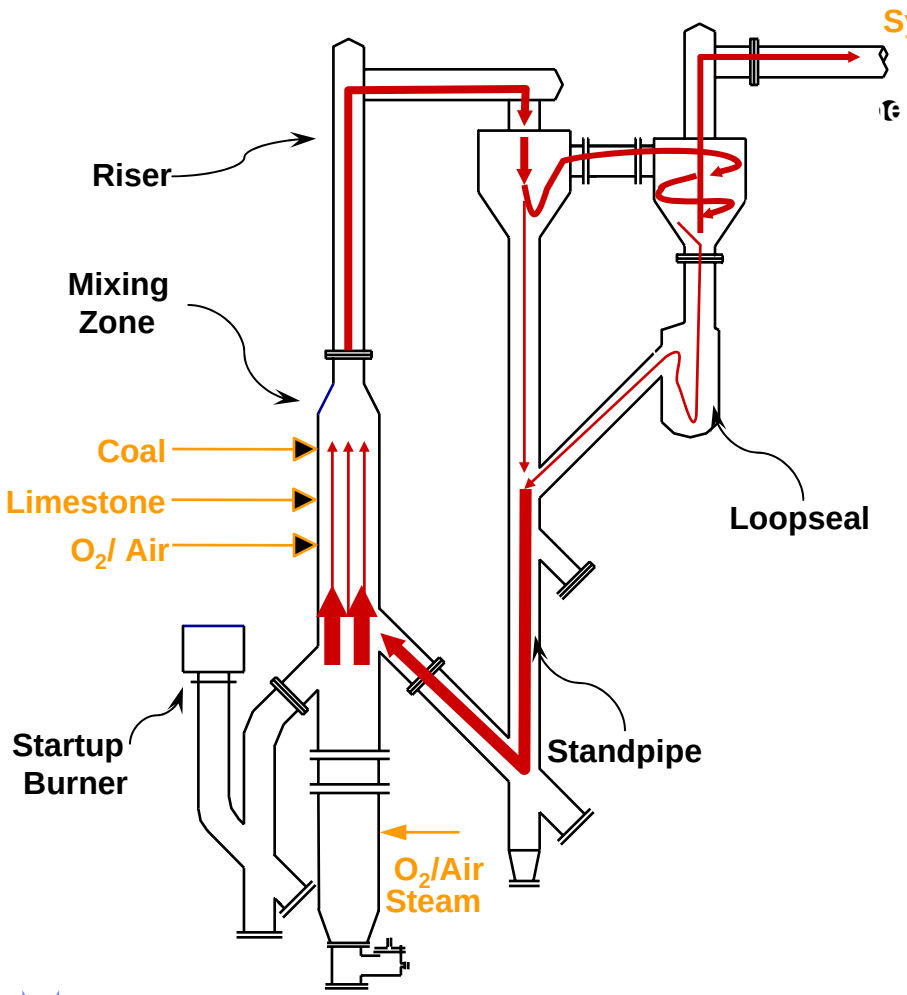
BACK-UP

Current Test Program for Transport Gasifier



Tests Underway in 5-year Test Plan:

- Continue air blown gasification optimization on different coals
- Continue O_2 blown gasification optimization on different coals
- Improve coal/limestone feed and preparation
- Improve ash cooling/pressure letdown systems
- Improve system integration and controls
- Integrate gasifier with existing PSDF combustion turbine
- Evaluate improved syngas cleanup options
- Continue fuel cells tests on coal-derived syngas
- Advanced Instrumentation and automated controls