NATIONAL ENERGY TECHNOLOGY LABORATORY

Gasification Technologies Program
Overview

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U.S. DEPARTMENT OF ENERGY

Gasification Program Goal

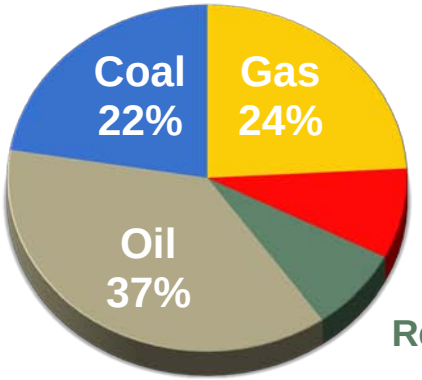
The goal of the Gasification Program is to reduce the cost of electricity, while increasing power plant availability and efficiency, and maintaining the highest environmental standards

"Federal support of scientific R&D is critical to our economic competitiveness"

Dr. Steven Chu, Secretary of Energy
November 2010

Why the Interest in Coal?

U.S.A



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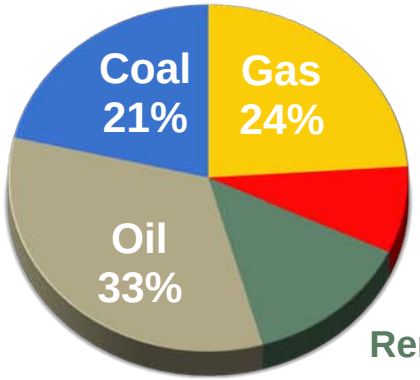
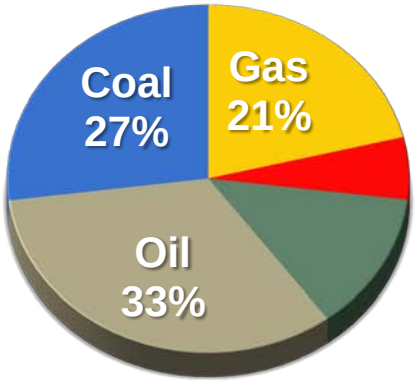


2008 *Energy Demand* *2035*

World



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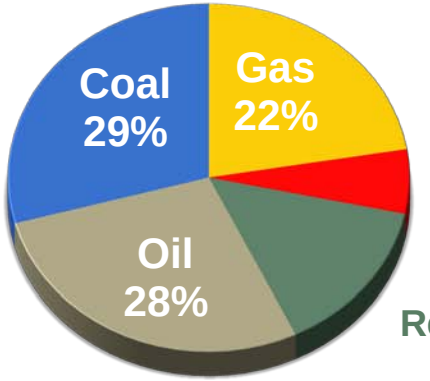
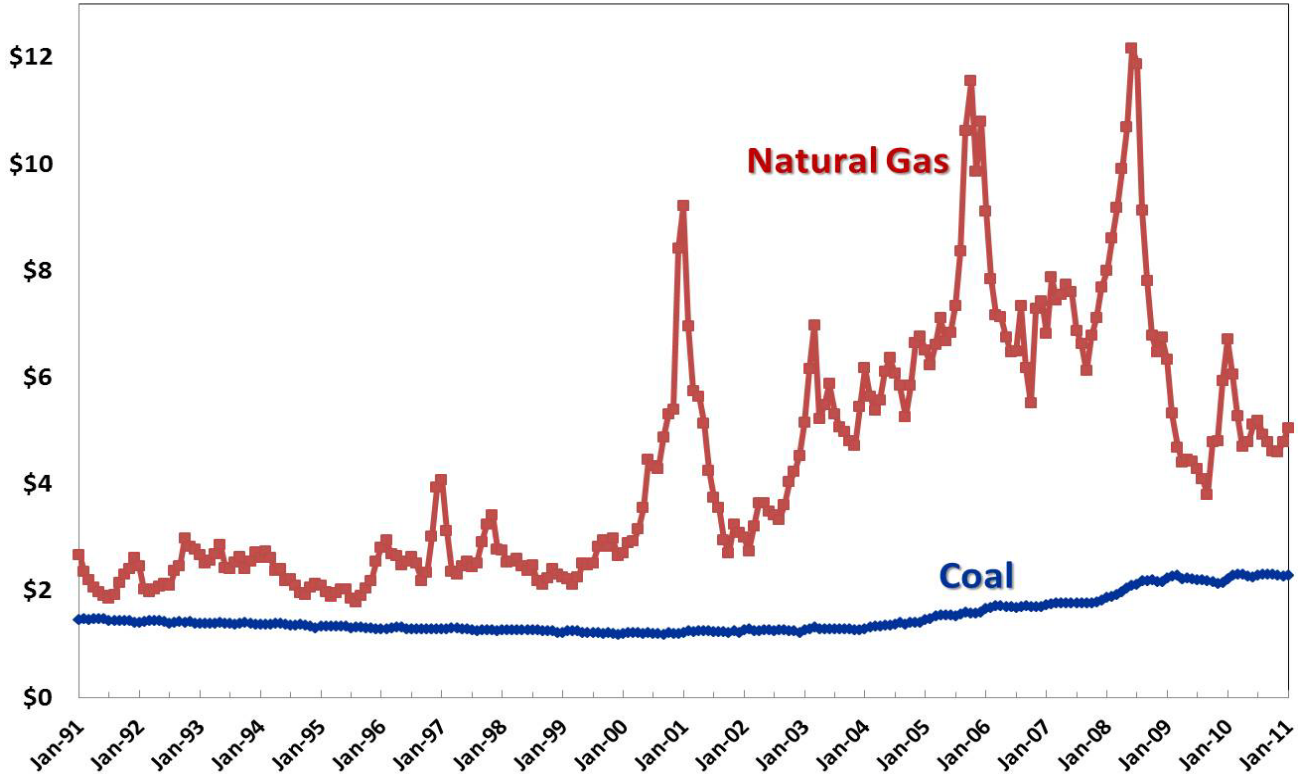


Source: *World Energy Outlook 2010, Current Policies Scenario*

*** Primarily traditional biomass, wood, and waste; includes ethanol & biodiesel**

Natural Gas Prices Fluctuate

- If CO_2 legislation passes, natural gas consumption is likely to rise
- Impact of shale gas maybe overly optimistic



U.S. Electrical Power Generation Fuel Costs, 1991-2010
($ / million Btu)

Why the Interest in Coal Gasification?

- **Continuing fuel price fluctuation**
  - Natural gas and transportation fuels
- **Energy security** – the U.S. has a lot of coal
- **Gasification can be used to make Hydrogen (H_2), Synthetic Natural Gas (SNG), fertilizer, chemicals and transportation fuels from coal**
- **Can be the lowest cost option to make power with carbon dioxide (CO_2) capture and storage**
- **Excellent environmental performance for power generation**

What is gasification?

Let's Start with Combustion Chemistry

Combustion with Oxygen

$C + O_2 \rightarrow CO_2$

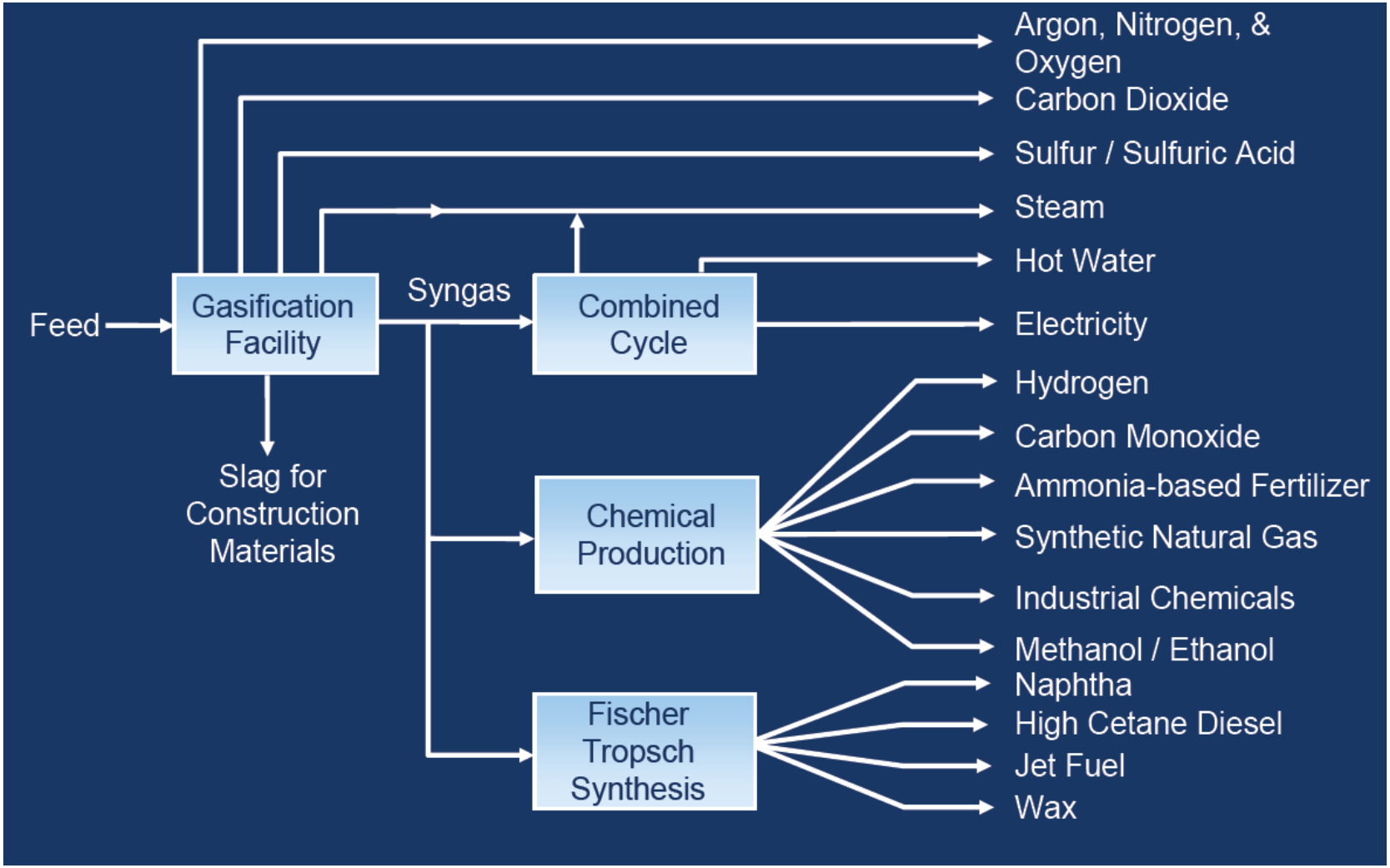
$H_2 + {}^1/_2\, O_2 \rightarrow H_2O$

Gasification – Differences from Combustion

- **Add water and high pressure**
- **Use Less air or oxygen**
- **Gasification exit gases are at high pressure, so smaller volume, smaller reactors**
- **Combustion makes heat + CO_2 + H_2O**
- **Gasification makes less heat + carbon monoxide + hydrogen (CO + H_2); called Syngas**

Why do we want to make Syngas?

Gasification Products



Source: FLUOR®

Water-Gas-Shift (WGS) Reaction

Dry syngas is ~ 40% CO + 50% H_2

For each CO molecule the WGS reaction creates one H_2 molecule and one CO_2 molecule

$$CO + H_2O + \textit{catalyst} \longrightarrow CO_2 + H_2$$

- After the WGS reaction, the CO_2 and H_2 can be separated
- High pressure CO_2 results in lower cost sequestration
- Hydrogen can be burned to make power:

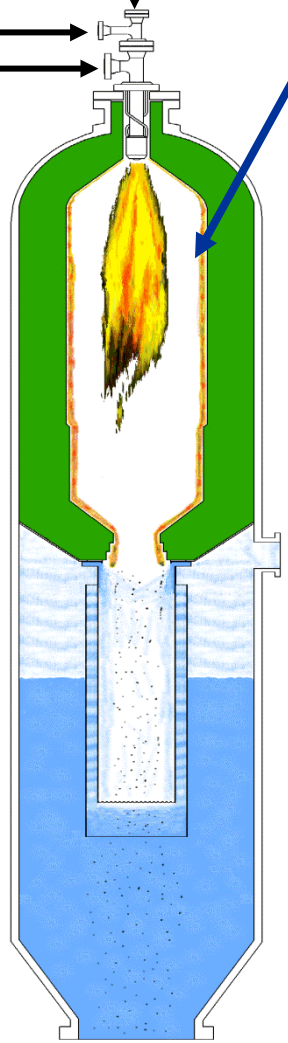
$$2H_2 + O_2 \longrightarrow 2H_2O$$

The Gasifier

Oxygen

Coal

Water



Extreme Conditions:

- 400 psig or more
- 2,600 F
- Corrosive slag and H_2S gas

Products (syngas)

CO (Carbon Monoxide)

H_2 (Hydrogen)

[CO/H_2 ratio can be adjusted]

By-products

H_2S (Hydrogen Sulfide)

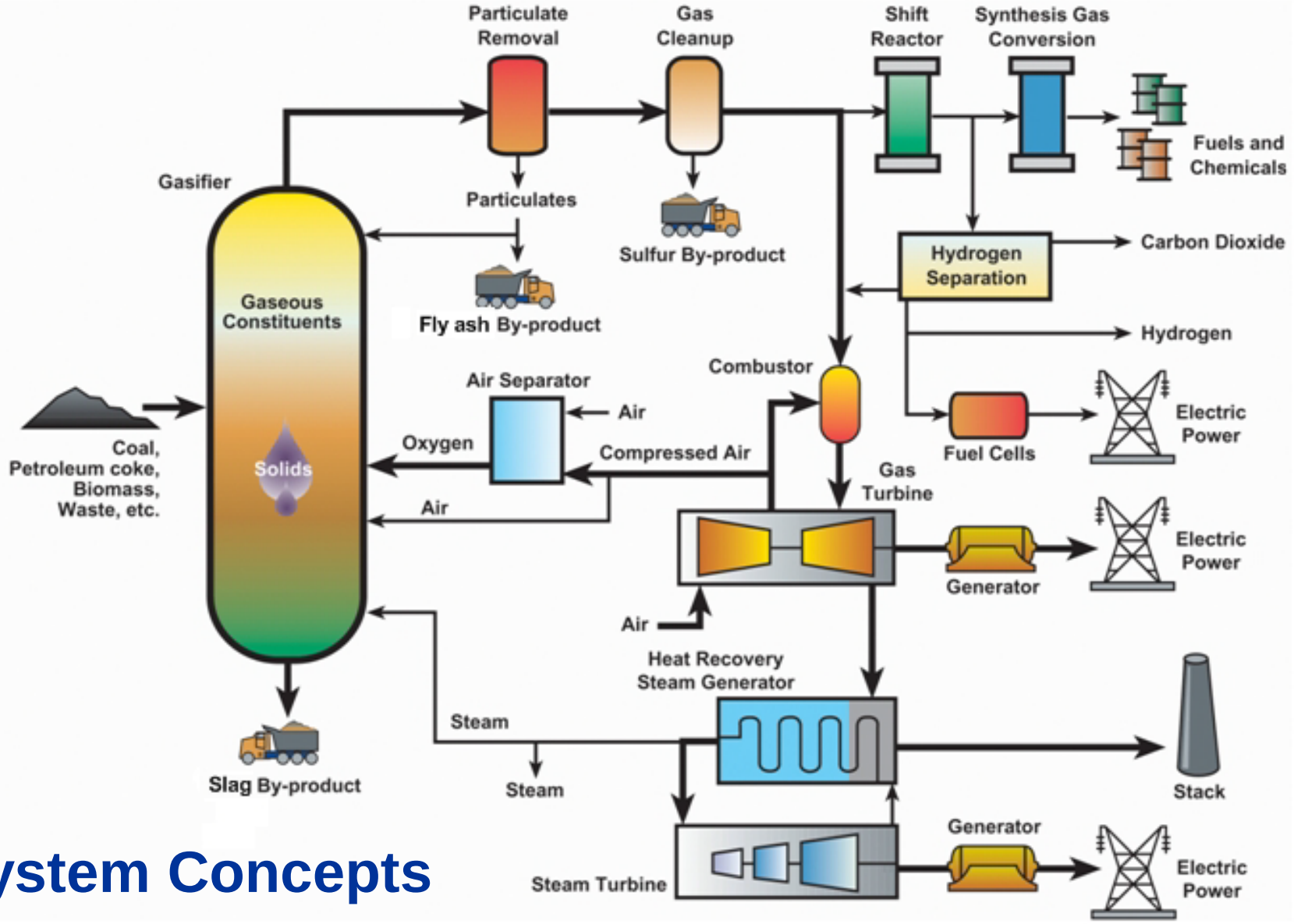
CO_2 (Carbon Dioxide)

Slag (Minerals from Coal)

Gas Clean-Up *Before* Product Use

Courtesy: Eastman Chemical

Gasification-Based Energy Production



System Concepts

Environmental Performance - IGCC Vs PC

IGCC is significantly Cleaner

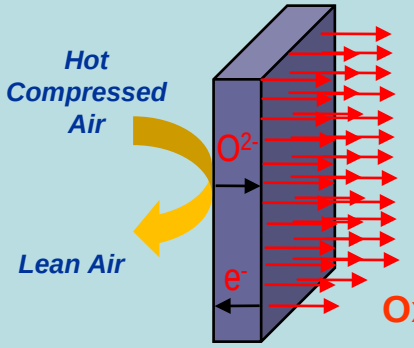
	Carbon Monoxide (CO)	Nitrogen Oxides (NOx)	Sulfur dioxide (SO2)	Mercury (Hg)	Fluorides (as HF)	Sulfuric Acid Mist	Particulates (as PM10)
Super Critical Pulverized Coal Plant	3,169	1,859	3,961	0.03	23	264	475
Integrated Gasification Combined Cycle	564	1,396	1,117	0.01	0.50	26	199
Total Reduction (Tons)	**2,605**	**463**	**2,844**	**0.02**	**22.50**	**238**	**276**
Percent Reduction	**82.2%**	**24.9%**	**71.8%**	**66.7%**	**97.8%**	**90.2%**	**58.1%**

Tons of Emissions from Comparable 600 MW Coal Based Power Plants

Reference: Wisconsin Dept. of Natural Resources, air pollution control operation permit 03-RV-166, Elm Road Generating Station, issued January 14, 2004 Table 1, page 3 (Pitt # 8 coal)

R&D to Lower Cost *with* Environmental Excellence

APCI Oxygen Membrane

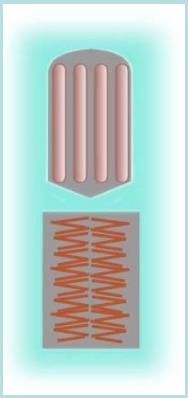


Oxygen

Reduces Capital Cost by 25% and 5.0% reduction in COE

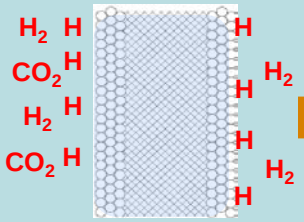
Fuel Gas

RTI Warm Gas Cleaning



- Efficiency increases by 2.9 %pt
- COE decreases by 12.0%

Eltron H_2/CO_2 Membrane



H_2 Rich Stream

CO_2

Low-rank Coal* Alternative Feedstocks*

- Energy security
- Carbon footprint reduction

Water-Gas Shift*

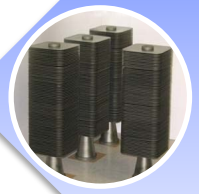
Process improvement and intensification

Improve RAM*

- Refractory durability
- Feed system reliability
- Heat removal/integration
- Temperature measurement & control
- Dynamic simulator
- CFD gasifier modeling
- Slag model development

** Advanced Gasification*

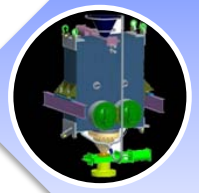
Advanced Gasification Technologies



Oxygen Production - Ion Transport Membranes (APCI)

- Testing commercial-scale modules in 5 TPD SEP
- Constructing 100-TPD intermediate-scale test (ISTU) *Startup in early 2012*
- Process modeling/conceptual design of 2,000+ TPD ITM oxygen plant
- Ceramic module manufacturing scale-up for 2,000+ TPD test facility

0.5 TPD ITM Modules



Coal Pump - Linear Extrusion Coal Feed Pump (PWR)

- Constructing 600 TPD prototype dry solids pump
- PWR Pump cost benefit analysis to be performed

Pump Concept

Warm Gas Cleanup - High Temperature Gas Cleaning (RTI)

- Design and construct a 30-50 MWe prototype system
- Operate warm syngas cleaning at commercial operating conditions
- Perform CO_2 sequestration w/ CO_2 measurement, monitoring, & verification

TECO's 250 MW IGCC

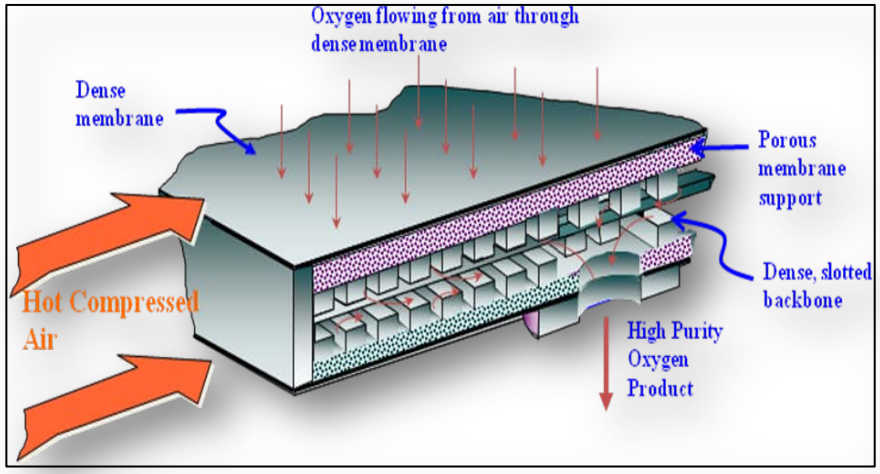
Hydrogen Separation – H_2/CO_2 Membrane (Eltron)

- Demonstrated a 1.5 lbs/day unit
- Test 12 lbs/day reactor and skid package at Eastman Chemical
- Construct and test 250 lb/day unit at Eastman
- Complete design through construction and testing of 4-10 TPD unit

1.5 lb-day H_2 Membrane

1st R&D Example

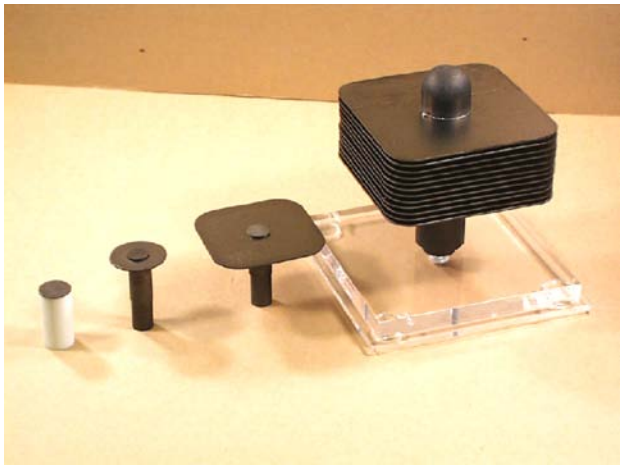
Development of ITM Oxygen Technology



0.5 TPD Stack

1.0 TPD Stack

Progression to commercial size wafers



NETL Office of Research & Development

Gasification Projects

- **Fundamentals of Gasification Kinetics: Development of Carbonaceous Chemistry for Computational Modeling (C_3M)**
  - Develop a repository of kinetic rates/yields of various coals/biomass for use in simulations
  - Establish method and protocol for porous microstructure reconstruction
  - Complete IBM method for conjugate heat transfer applications
- **Control of Carbon Feedstock Slag and Its Impact on Gasifier Operation**
  - Fabricate mixed feedstock slag compositions for high temperature evaluation
  - Determine commercial materials and potential refractory compositions to evaluate in mixed feedstock slag studies
  - Model coal and petcoke partitioning, validate using commercial experience
  - Develop user defined CFD function and verify for fly ash wall interaction
- **Advanced Virtual Energy Simulation Training and Research Facility**
  - Develop operator and immersive training systems (OTS, ITS) for IGCC plants with carbon capture
  - Integrate IGCC OTS and ITS into course content at NETL/WVU's AVESTAR Center

AVESTAR™

2nd R&D Example
Advanced Refractory For Gasifiers

Rotary Slag Test

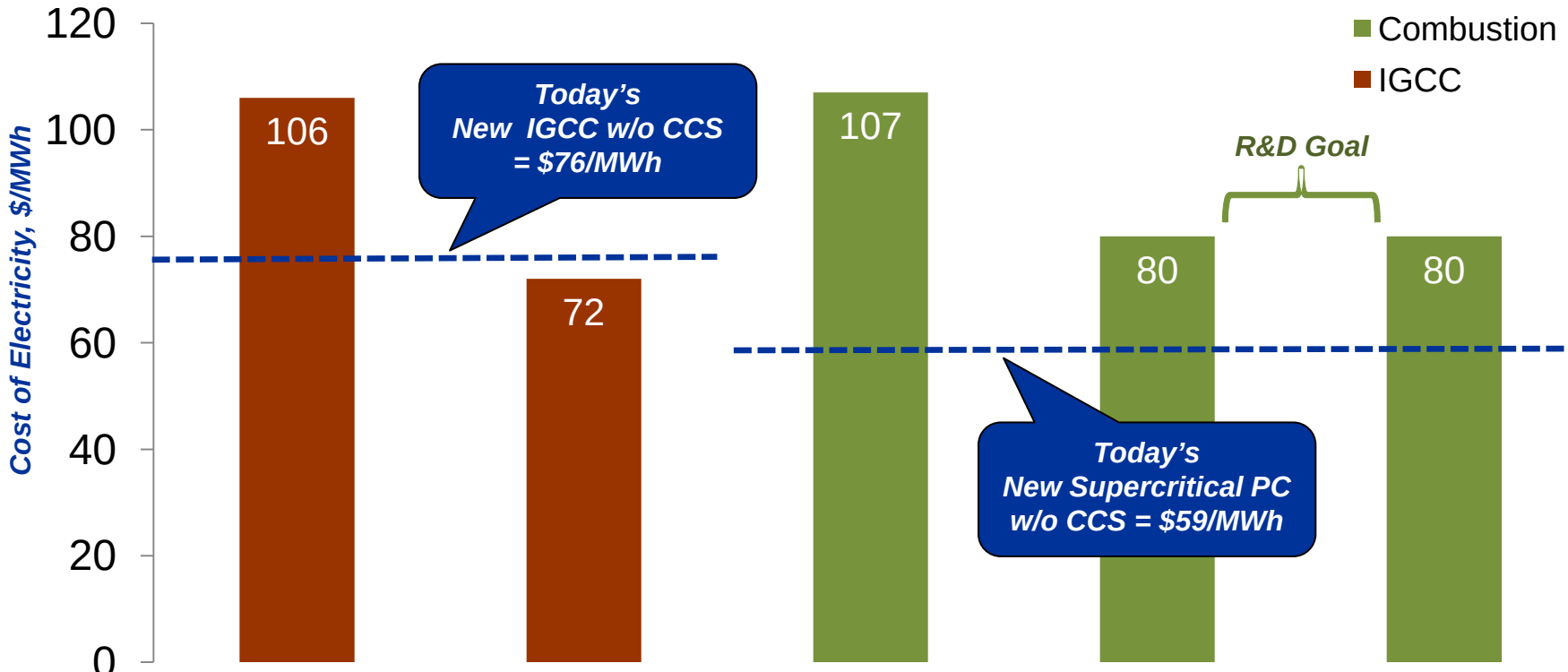
Conventional refractory after rotary slag testing

New refractory chemistry:

- Increases mechanical durability
- Reduces slag penetration

Phosphate modified high-chrome oxide refractory material

DOE Baseline & 2nd Gen CCS Systems



IGCC w/CCS R&D Progress to Date
- 7FB turbine (2400 F TIT)
- 80% Availability

2nd Gen IGCC w/CCS
Coal pump
- WGCU
- H_2 membrane
- ITM
- Adv H_2 turbine-2 (2650 F TIT)

1 on 1 configuration
- 90% Availability

Today's Supercritical PC w/CCS
- Air-fired
- 3500 psig/ 1100F/1100F
- Wet FGD
- Amine absorber for CO_2 separation
- 85% Availability

2nd Gen Advanced Oxy-Combustion PC w/CCS
Potential technology mix to meet 35% goal:
- Oxy-fired combustion
- Boiler-integrated ITM
- USC steam cycle (4000 psig / 1350F / 1400 F)
- Compact oxyfuel-specific boiler
- SO_x co-sequestration
- 85% Availability

2nd Gen Advanced Post-Combustion PC w/CCS
Potential technology mix to meet 35% goal
- Advanced solvents, sorbents or membranes
- USC steam cycle
- Advanced CO_2 compression
- 85% Availability

Key Assumptions:
- *June 2007 dollars (equivalent to January 2010 dollars per Chemical Engineering Plant Cost Index)*
- *Capital cost component includes owner's costs*
- *$1.64/MMBtu coal price*
- *"R&D Progress to Date" and "Today's SCPC" cases based on Rev 2 of Bituminous Baseline Study*
- *"2nd Gen IGCC w/CCS" case based on NETL's IGCC Pathway study, upgraded to incorporate more complex Rev 2 Bit. Baseline study costing methodology*

TIT = turbine inlet temperature WGCU = warm gas cleanup ITM = ion transport membrane USC = Ultra supercritical FGD = Flu Gas Desulfurization

Visit NETL Gasification Website

www.netl.doe.gov/technologies/coalpower/gasification/index.html