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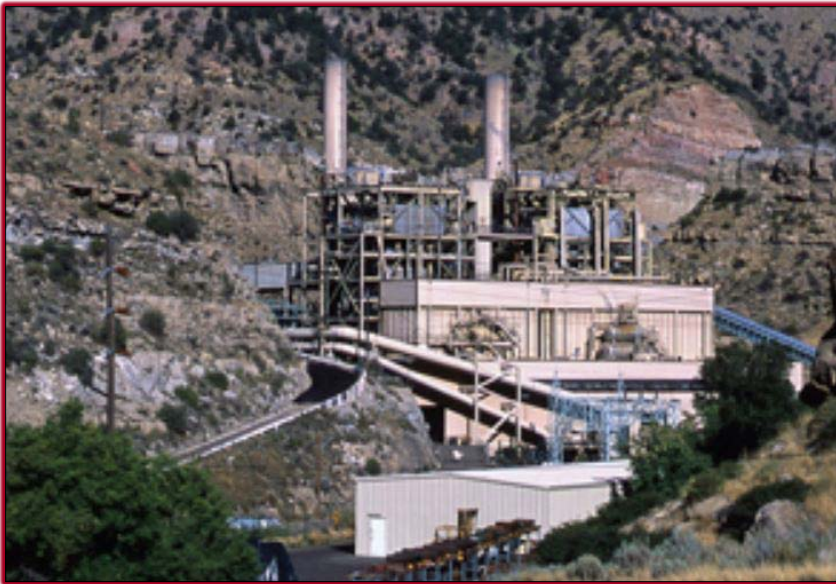


**2013 NO<sub>x</sub>-Combustion Round Table  
& Expo Presentations**

February 18 & 19, 2013, in Salt Lake City, UT / Hosted by PacifiCorp

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# Sustainability of Coal Combustion for Power Generation



Kevin Davis

Vice President, Business Development



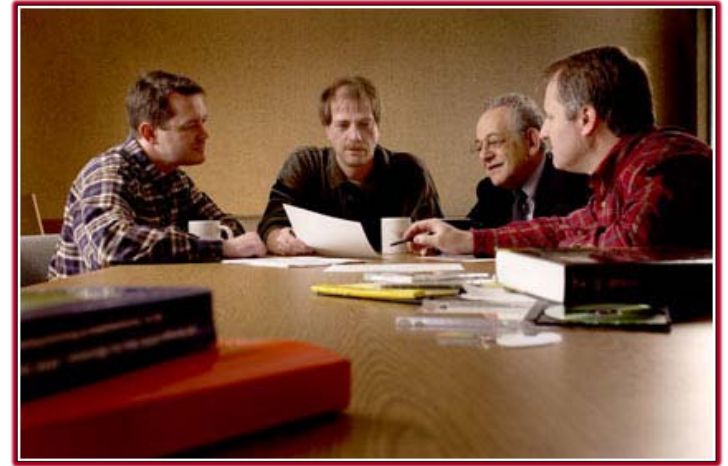
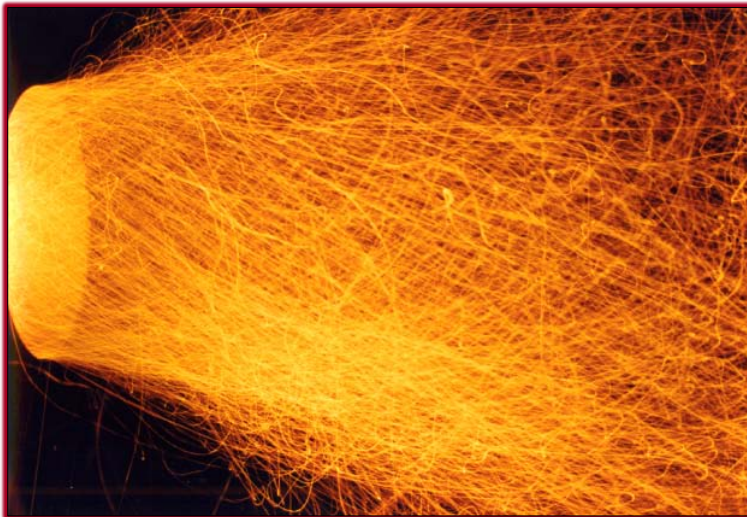
The 12<sup>th</sup> Annual NO<sub>x</sub>-Combustion/PCUG Conference

Hosted by  **PACIFICORP**  
A MIDAMERICAN ENERGY HOLDINGS COMPANY

February 18–21, 2013

# Reaction Engineering International

- ➔ Privately held consulting firm recognized for independent analysis and evaluations involving a range of industrial combustion applications

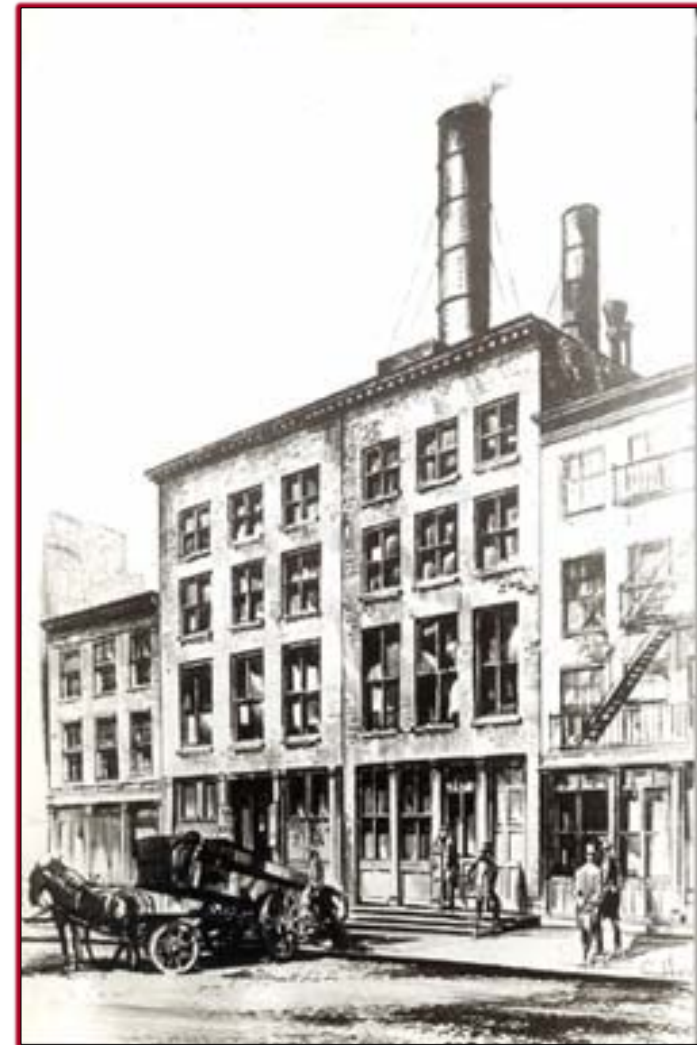


- ➔ Technical focus on multi-phase, chemically reacting flows
- ➔ Serving the utility industry since 1990
- ➔ Affiliates in Asia and Europe
- ➔ Established capabilities include advanced modeling and testing

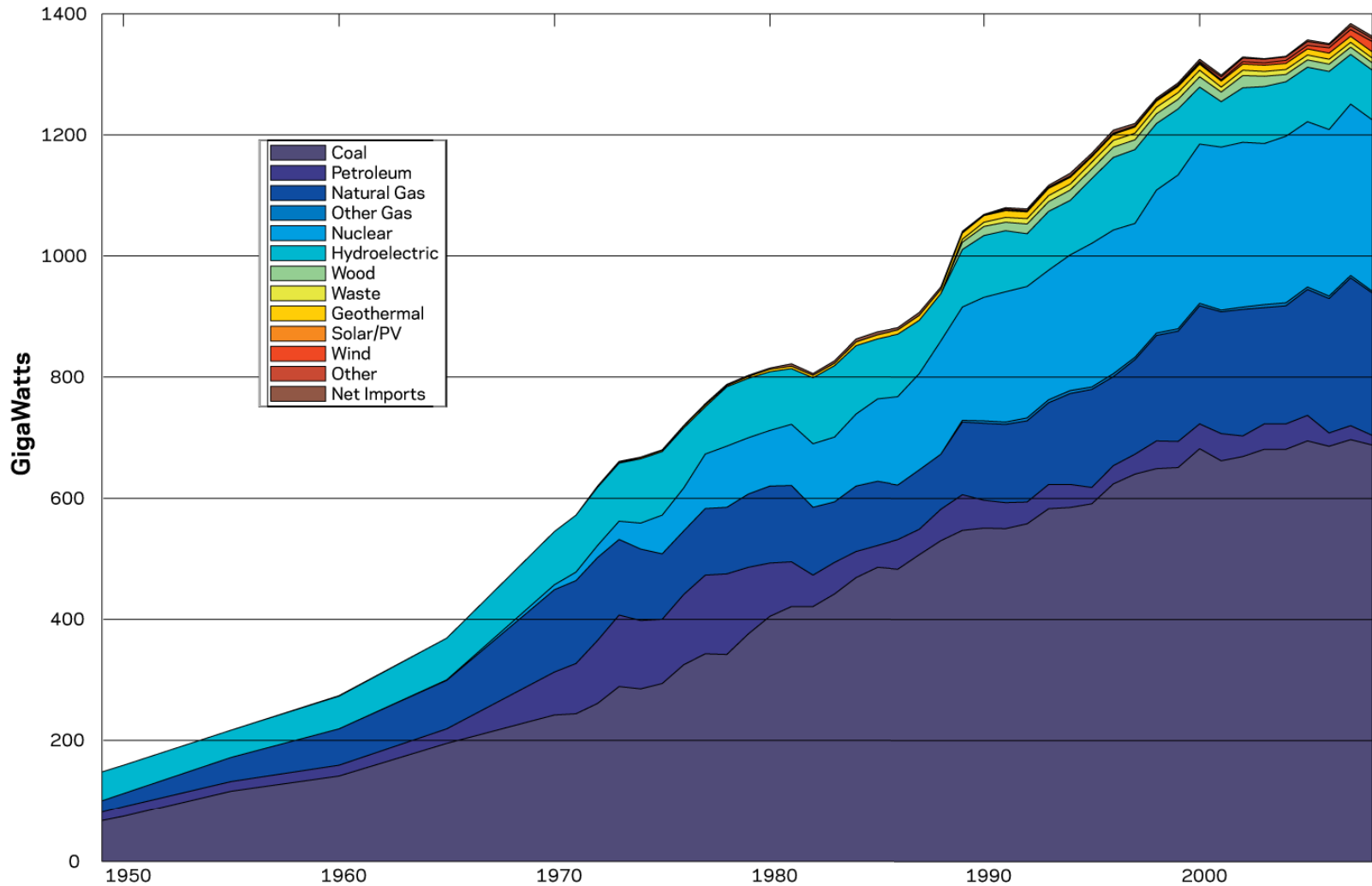
# Coal Power

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- Central generation of electricity begins in 1882
- Edison starts the first coal-fired power plant and by 1890 there were ~1000 plants, practically all coal-fired
- “The King is Dead, Long Live the King?”
  - ◆ Coal
  - ◆ Hydro
  - ◆ Petroleum
  - ◆ Nuclear
  - ◆ Solar
  - ◆ Natural Gas
  - ◆ Wind



# Historical US Electricity Production



# Recent US Generation by Source

thousand megawatthours per day

14,000

12,000

10,000

8,000

6,000

4,000

2,000

0

Forecast

2004

2005

2006

2007

2008

2009

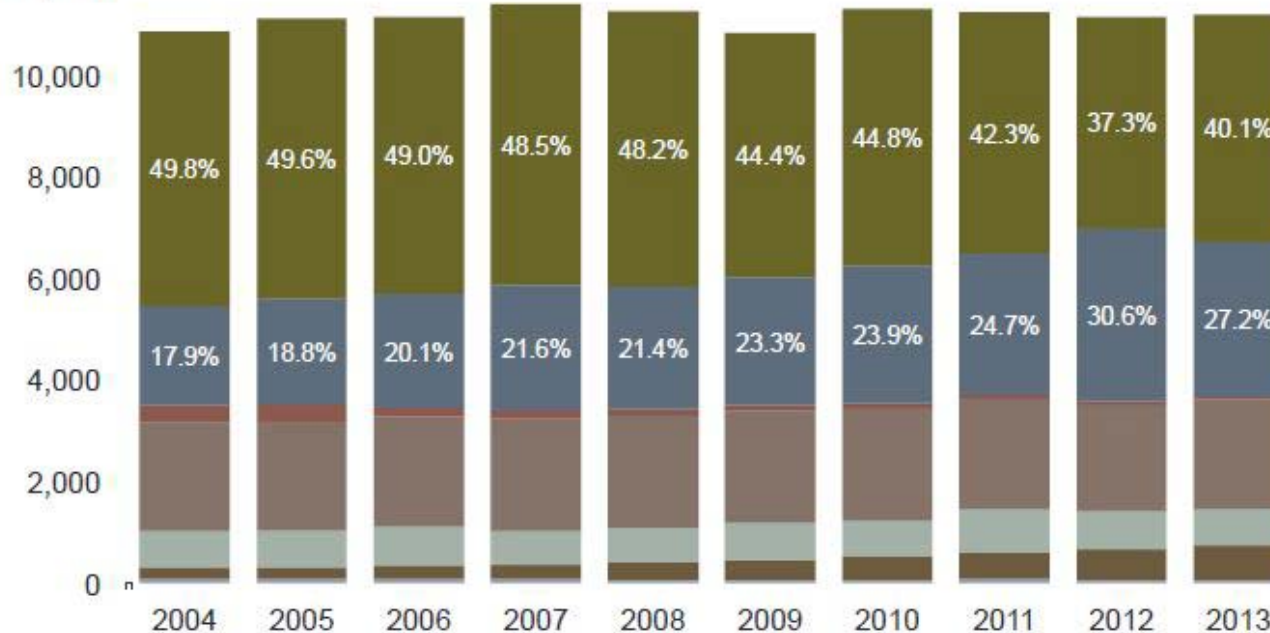
2010

2011

2012

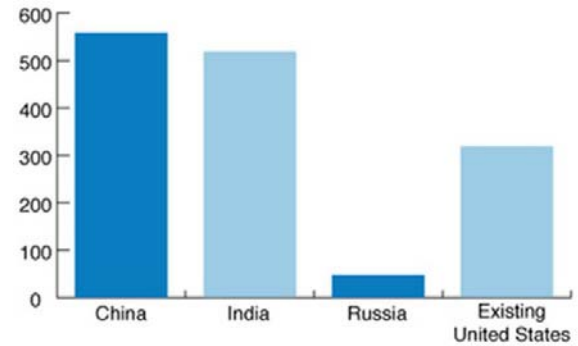
2013

- Coal
- Natural gas
- Petroleum
- Nuclear
- Hydropower
- Renewables
- Other sources



# Coal Power - Global Trends

Population of Countries that depend on coal for at least 40% of electricity

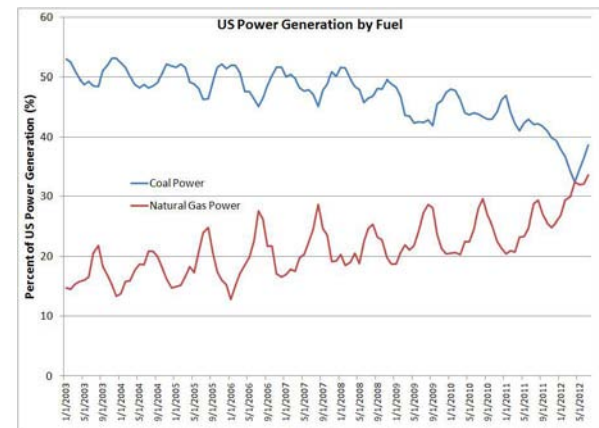
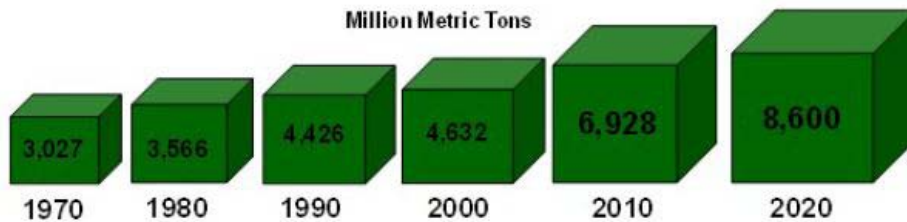


The rise of coal-based generating capacity

In Gigawatts

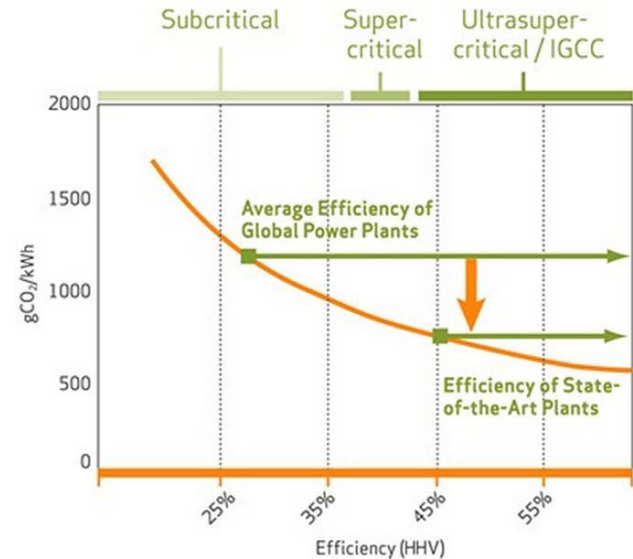
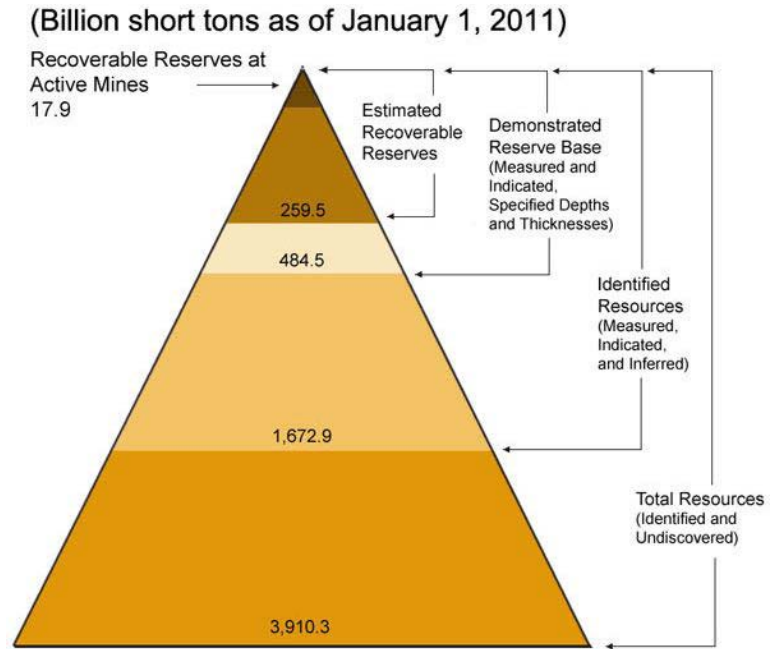
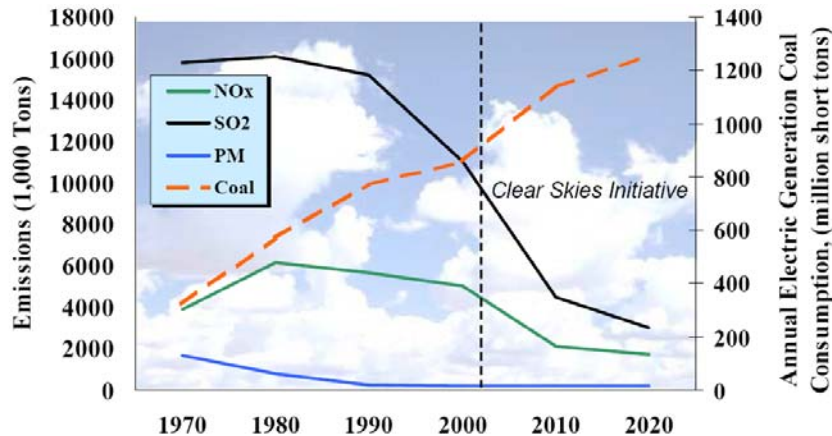


Escalating Demand for Coal



# The King's Men

- ➔ Immense Resource
- ➔ National Security Benefits
  - ◆ US reserves are the world's largest at ~23% of total
- ➔ Improved Efficiency
- ➔ Reduced Emissions



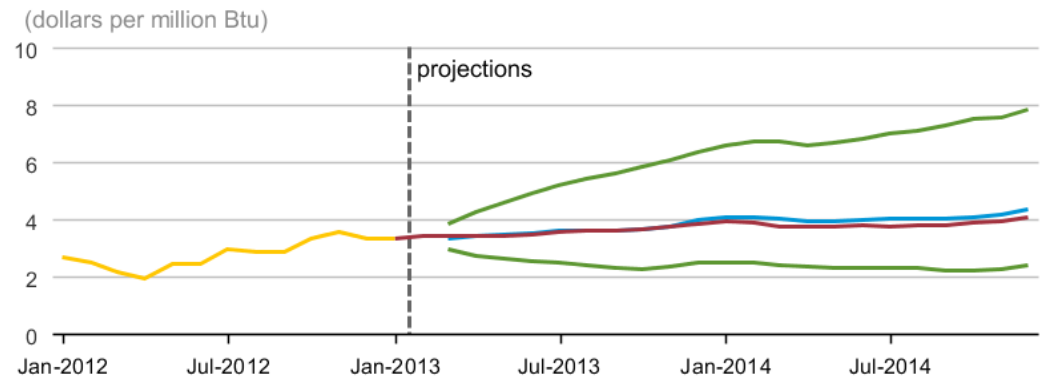
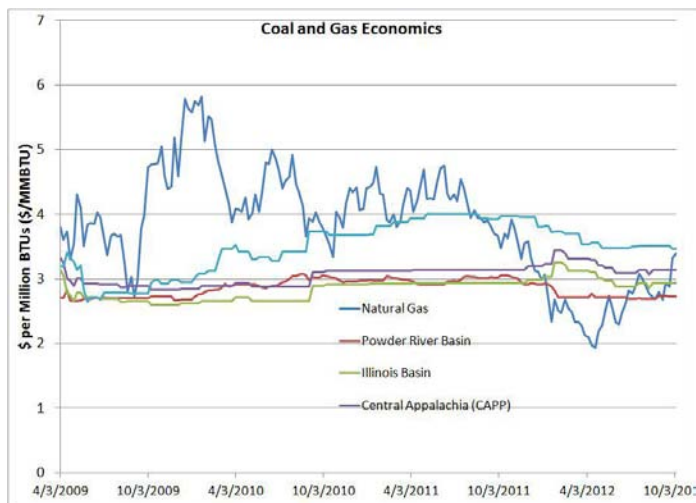
# Enemies of the King

## → Regulatory & Public Opinion

- ◆ “So if somebody wants to build a coal-fired plant they can. It’s just that it will bankrupt them...”  
– Barack Obama speaking to San Francisco Chronicle, Jan 2008

## → Fuel Costs

## → Turndown/restarts



- Historical spot price
- STEO forecast price
- NYMEX futures price
- 95% NYMEX futures upper confidence interval
- 95% NYMEX futures lower confidence interval

# MATS

## → Mercury and Air Toxics Rule

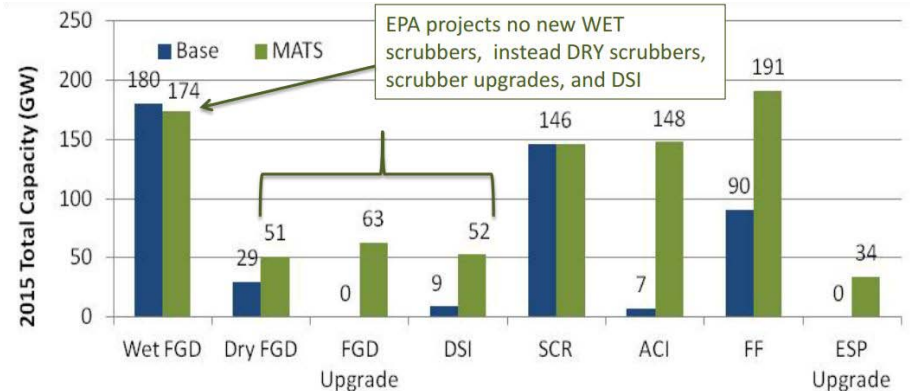
- ◆ Mercury
- ◆ Hydrogen chloride
- ◆ Particulate matter

→ MATS compliance date is April 16, 2015 and ~1,100 coal-fired units will need to be modified

→ EPA-envisioned control technologies: Scrubbers, ACI, DSI, upgraded particulate control, additives

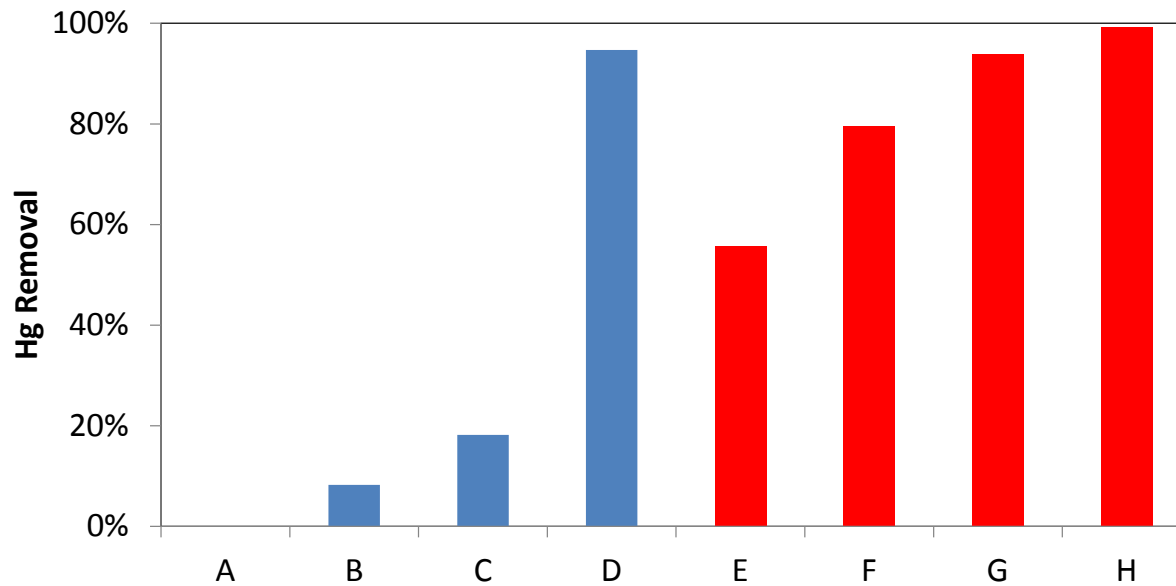
## → Areas of concern:

- ◆ Time & resource limitations
- ◆ Required monitoring approaches may be under-developed
- ◆ High sulfur bituminous coals may require additional SO<sub>3</sub> control
- ◆ FGD re-emission
- ◆ Recent experience with B-PAC and bromine-containing fuel additives has raised important questions regarding corrosion



# Evaluation of Hg Control Options

MerSim™ total plant simulation

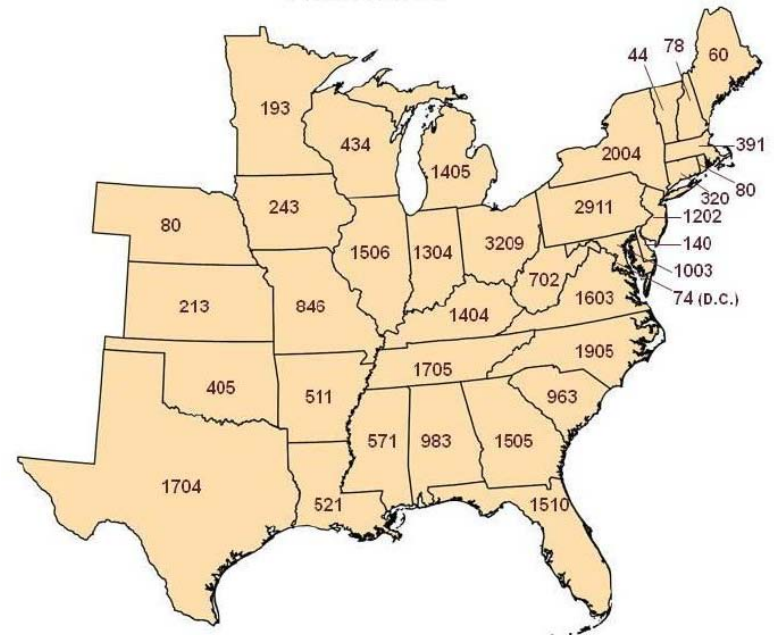


Case	Description	Plant Configuration	ACI	Boiler Additive	Hg removal
A	Baseline	Boiler + APH + ESP			0.0%
B	Co-benefit	Boiler + SCR + APH + ESP + wFGD			8.2%
C	Additive	Boiler + APH + ESP		3 gal/hr KNX	18.2%
D	Additive-Co-benefit	Boiler + SCR + APH + ESP + wFGD		3 gal/hr KNX	94.7%
E	ACI-ESP	Boiler + APH + ESP	2 lb/MMacf Darco Hg		55.6%
F	ACI-FF	Boiler + APH + FF	2 lb/MMacf Darco Hg		79.6%
G	BrACI-FF	Boiler + APH + FF	2 lb/MMacf Darco Hg-LH		93.9%
H	Additive-ACI-ESP	Boiler + APH + ESP	2 lb/MMacf Darco Hg	3 gal/hr KNX	99.3%

# CSAPR/CAIR

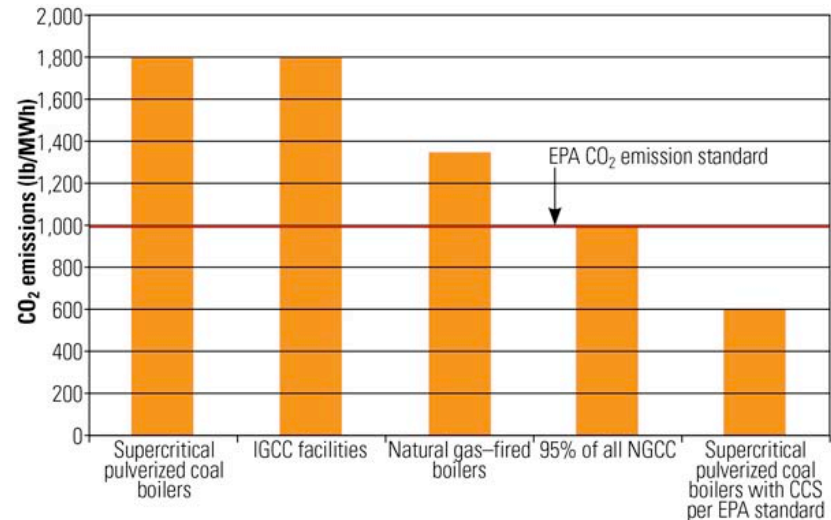
- ➔ Cross State Air Pollution Rule is intended to tighten limits on SO<sub>x</sub> and NO<sub>x</sub> in 28 eastern states and would have a significant impact on coal-fired utility boilers
- ➔ CSAPR vacated Aug 2012, full court review denied Jan 2013, Clean Air Interstate Rule in effect until satisfactory replacement rule is developed by EPA

New Power Plant Emission Standards for Eastern States  
Estimated Lives Saved Each Year Beginning in 2014  
(PM 2.5 and Ozone)



# Carbon Pollution Standard

- ➔ All new stationary sources will be required to meet an emission standard of 1,000 pounds of CO<sub>2</sub> per megawatt-hour
- ➔ “The GHG Tailoring Rule remains active and ambiguous as to what BACT will be for greenhouse gases”  
(Bell, POWER, 2012)
- ➔ Based on the current status of CCS options, this regulation may preclude construction of coal-fired power plants in the near-term



# Additional Regulatory Concerns

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## → Resource Conservation and Recovery Act

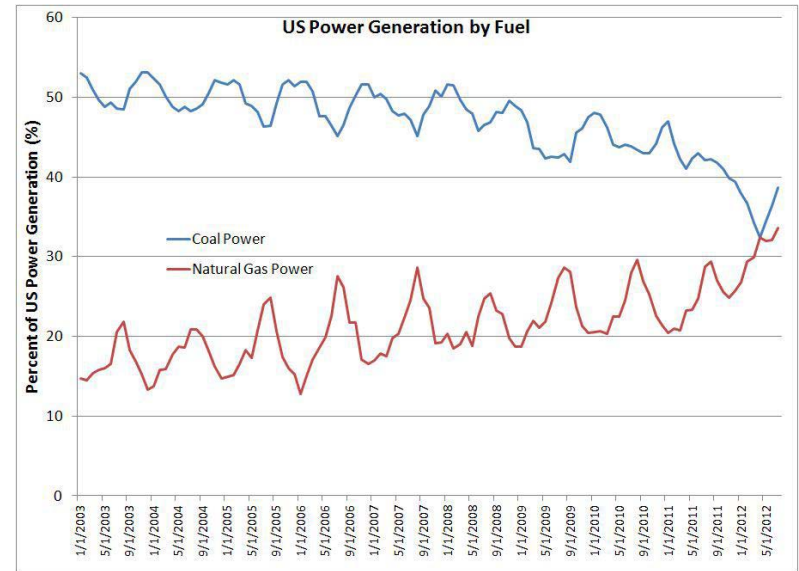
- ◆ EPA estimates that there are approximately 384 CCR landfills/surface impoundment/etc at roughly 495 coal-fired power plants.
- ◆ The EPA is considering two possible options for the management of coal ash

## → Clean Water Act

- ◆ EPA reviewed wastewater discharges from power plants and concluded that the 1982 effluent guidelines were outdated and insufficient
- ◆ Final rule currently required by May 22, 2014

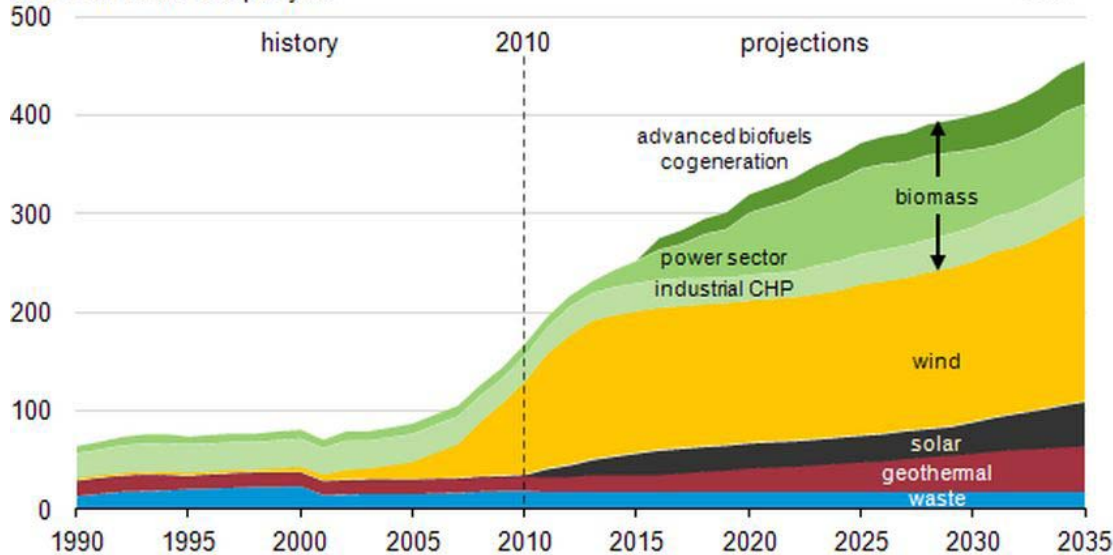
# Rivals to the King

- ➔ Natural Gas
- ➔ Renewables



Projected non-hydropower renewable electricity generation, 2010-2035

billion kilowatthours per year



# Natural Gas for Power Generation

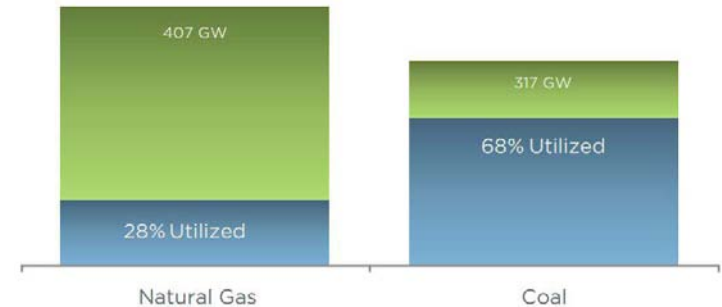
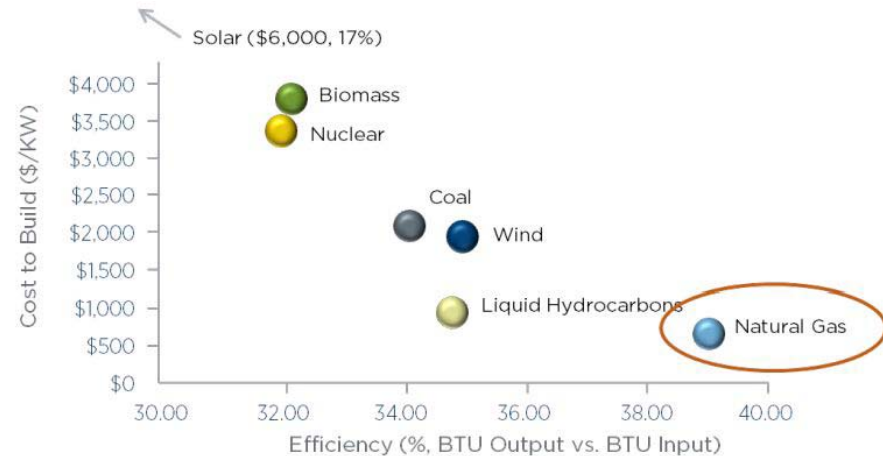
## → Advantages

- ◆ Construction costs
- ◆ Regulatory and efficiency
- ◆ Existing capacity

## → Current price is low but uncertain

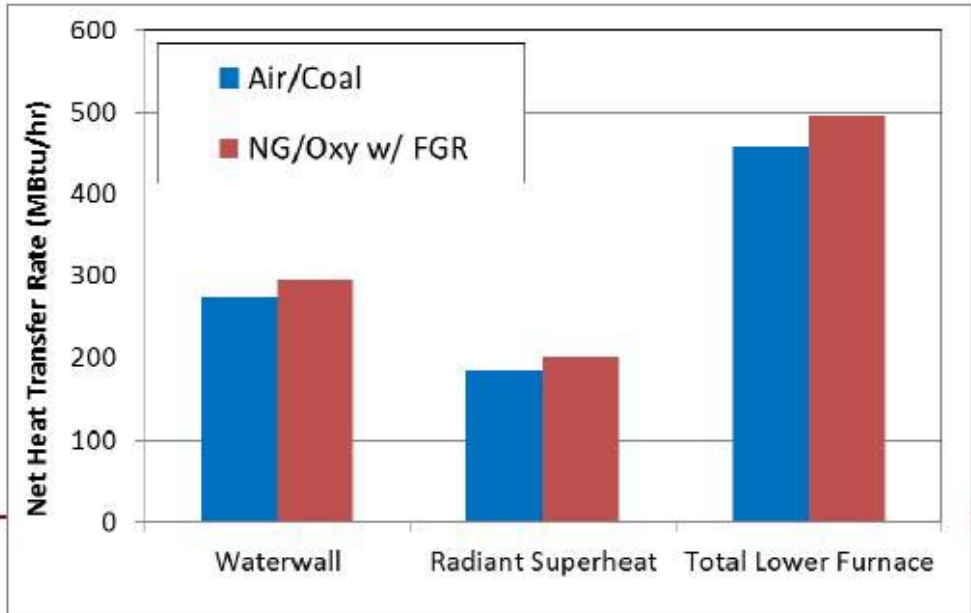
- ◆ Environmental concerns with hydraulic fracturing
- ◆ Distribution limitations/costs
- ◆ High value fuel with competitive applications:

## → Conversion of coal-fired units presents challenges



# Coal-to-gas Heat Transfer Considerations

Zone	Baseline Air-Coal		Oxy-NG (w/ FGR)	
	Heat Transfer (MBtu/hr)	% of Total	Heat Transfer (MBtu/hr)	% of Total
1	42	9.1	54	10.9
2	154	33.6	188	37.9
3	189	41.2	170	34.1
4	74	16.1	84	17.0
<b>Total</b>	<b>459</b>		<b>497</b>	



# Renewables

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➔ Wind and Biomass dominate projected increases in renewable power



➔ Biomass co-firing drivers:

- ◆ Favorable economics in regions with forest residues
- ◆ European Union Directive 2009/28/EC
- ◆ UK incentives issued through Renewables Obligation Certificates (ROCs)

➔ May 2012 projections based on the Clean Energy Standard Act of 2012 see biomass growth increasing from 4x (Nov 2011) to 7x (May 2012)

# Biomass Utilization Issues

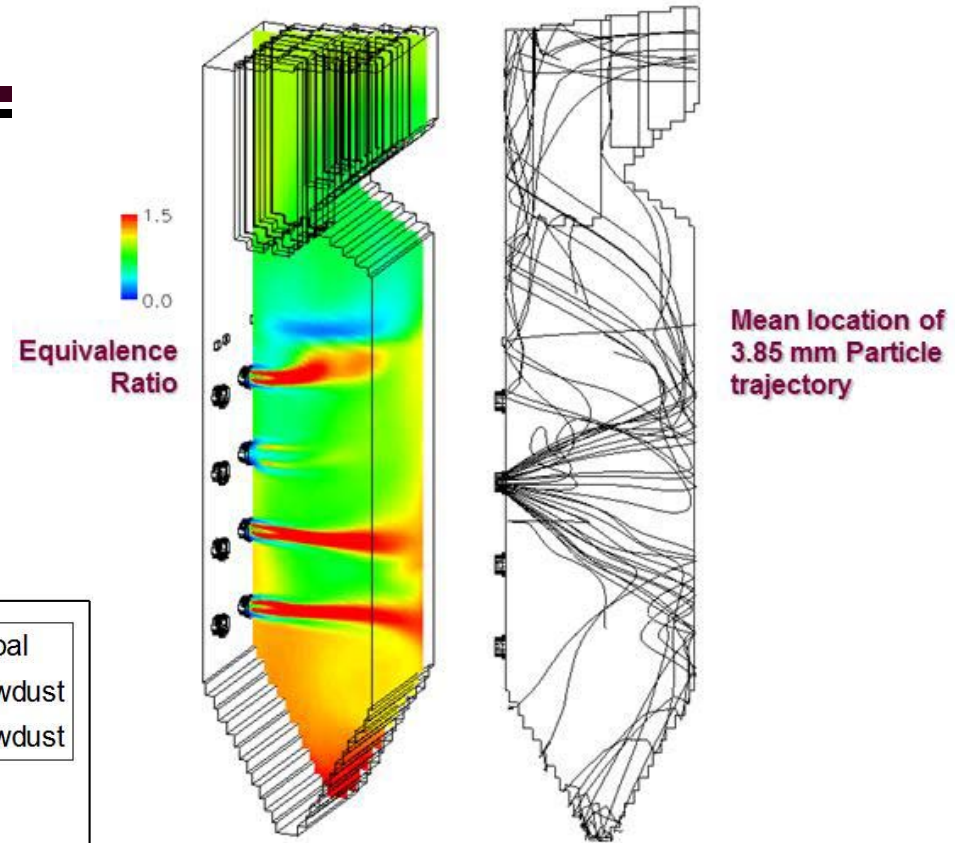
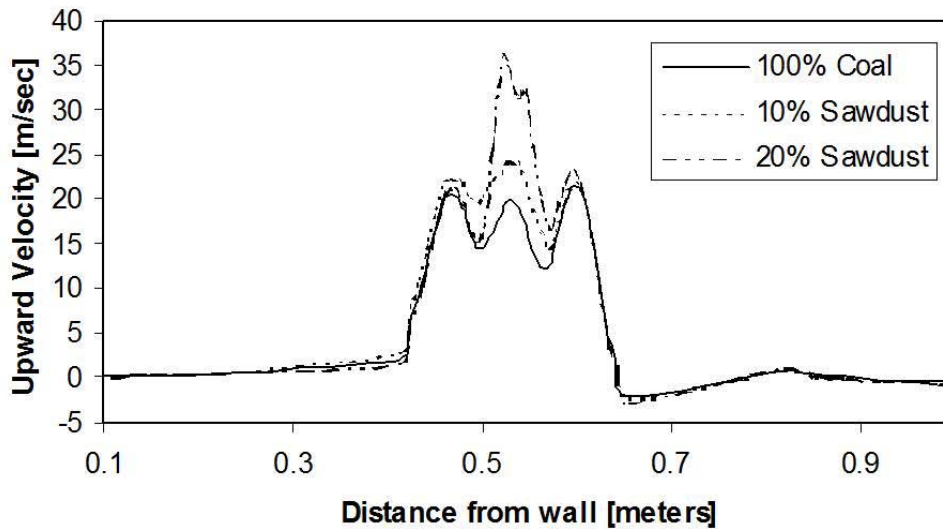
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- ➔ Fuel collection, storage, processing and handling
- ➔ Combustion
  - ◆ Combustion stability
  - ◆ Burnout
  - ◆ Temperature / Heat transfer
  - ◆ Efficiency
- ➔ Emissions
  - ◆ Carbon Dioxide
  - ◆ Sulfur Oxides
  - ◆ Mercury
  - ◆ Fine Particles
  - ◆ Nitrogen Oxides
  - ◆ Carbon Monoxide

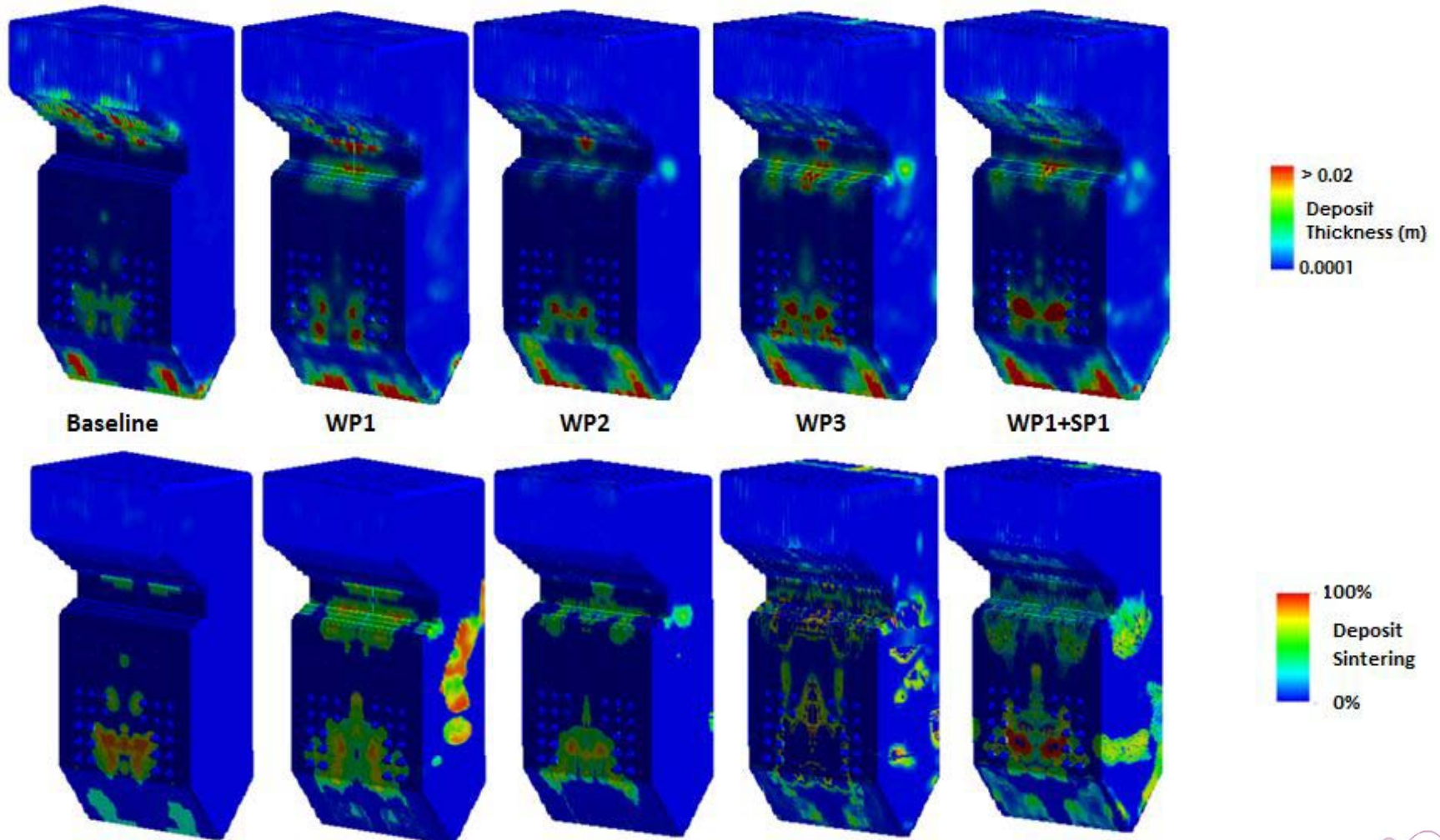


- ➔ Operational Impacts
  - ◆ Ash Deposition, Slagging, Fouling
  - ◆ Catalyst deactivation
  - ◆ Fly-ash properties
  - ◆ Corrosion
- ➔ Economics
- ➔ Regulatory

# Combustion Optimization Firing Biomass



# Ash Management



# Potential Allies of the King

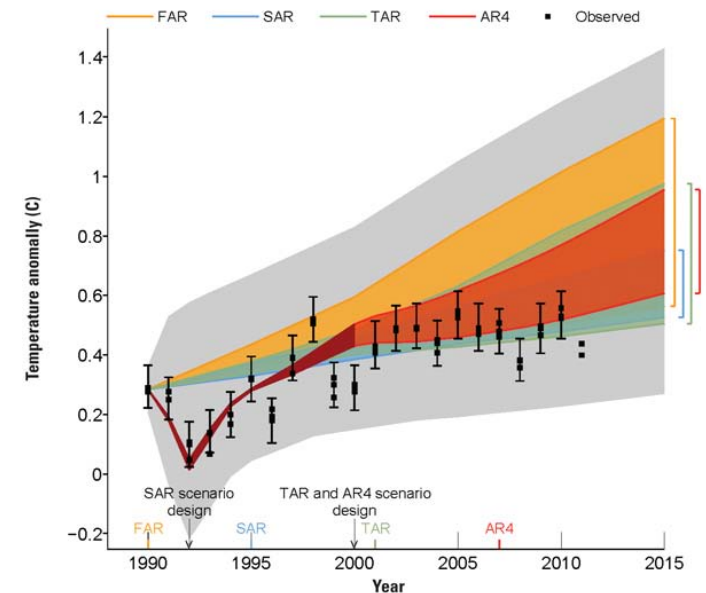
## ➔ Continued technology development for coal conversion

- ◆ Next generation IGCC
- ◆ Oxy-coal combustion
- ◆ Chemical looping
- ◆ Carbon Capture Utilization and Storage

## ➔ Higher Value Natural Gas Utilization

- ◆ Liquefied Natural Gas Export
- ◆ Chemical Process Industry
- ◆ Metallurgical coal replacement for direct-reduced-iron

## ➔ Uncertain nature of climate change predictions



# Coal Gasification Developments

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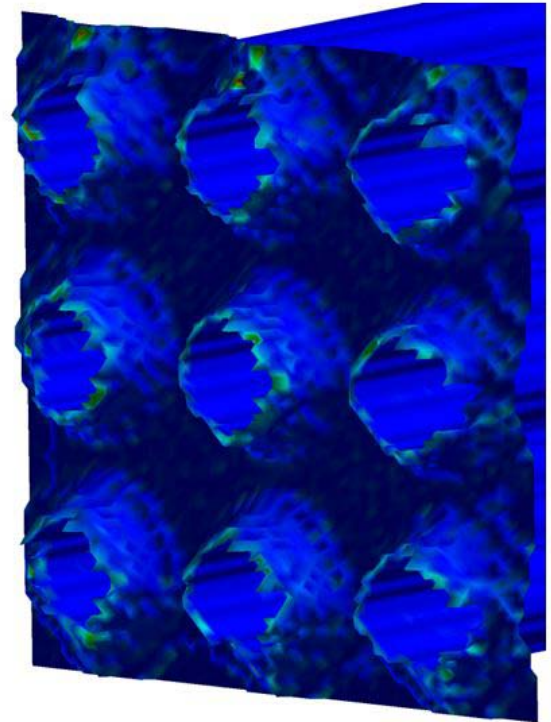
→ Many early challenges have been addressed

- ◆ Refractory life
- ◆ Fuel injector life

→ Mitigation of syngas cooler fouling progressing

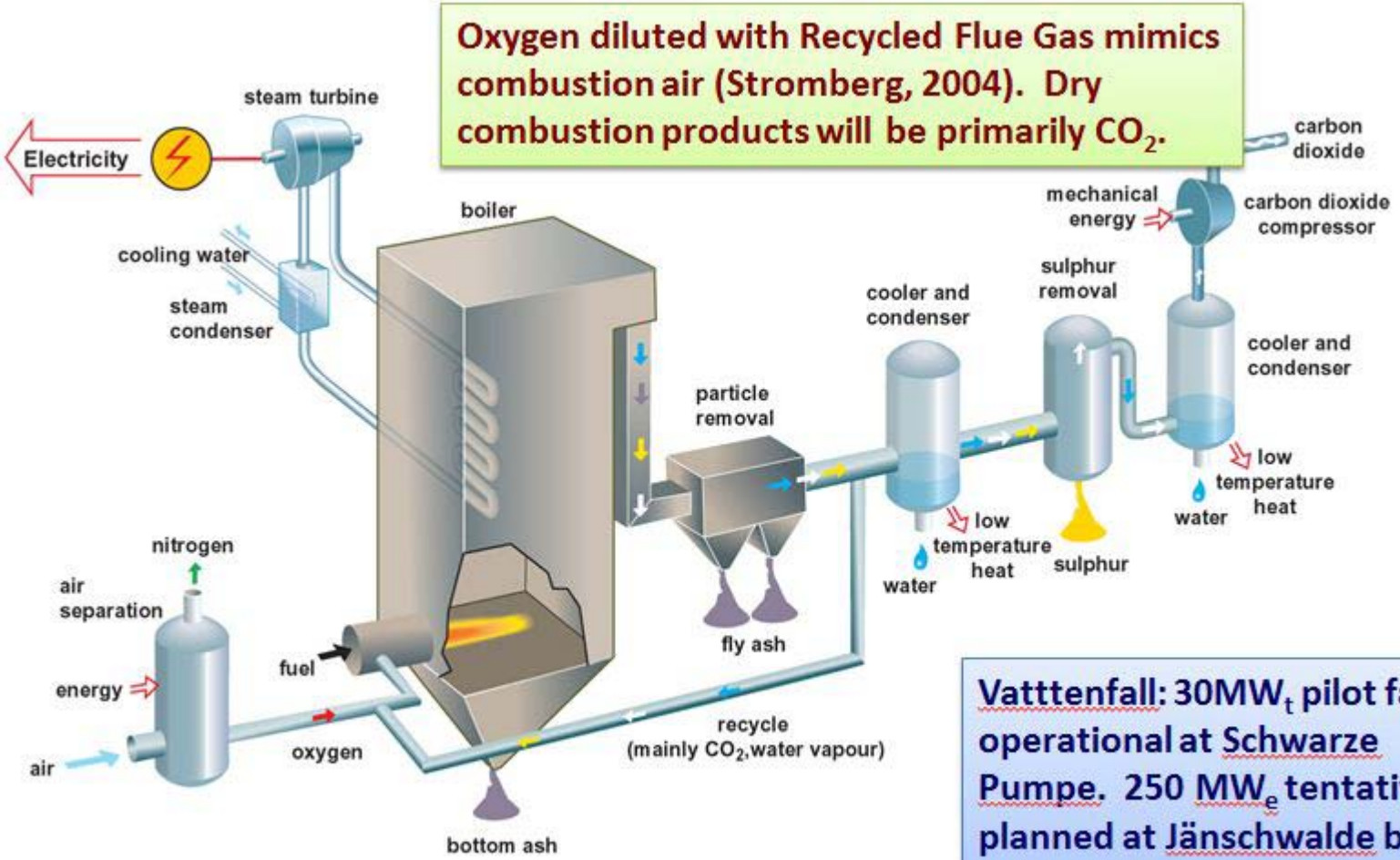
- ◆ Time between outages significantly increased at Wabash River
- ◆ DOE-funded efforts developing a fundamental understanding of fouling

→ Next generation gasifier designs under development



Deposition after 20 grid changes,  
10 hours of deposition

# Oxy-Fuel Combustion



**Vattenfall: 30MW<sub>t</sub> pilot facility operational at Schwarze Pumpe. 250 MW<sub>e</sub> tentatively planned at Jämschwalde by 2015.**

# Burner Primary Retrofit Results

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→ Matching burner primary gas/fuel ratio or momentum ratio with air-fired operation produced a stable attached flame (good retrofit strategies)



→ Matching primary velocity with air-fired operation did not provide a stable attached flame (may depend on burner flexibility)

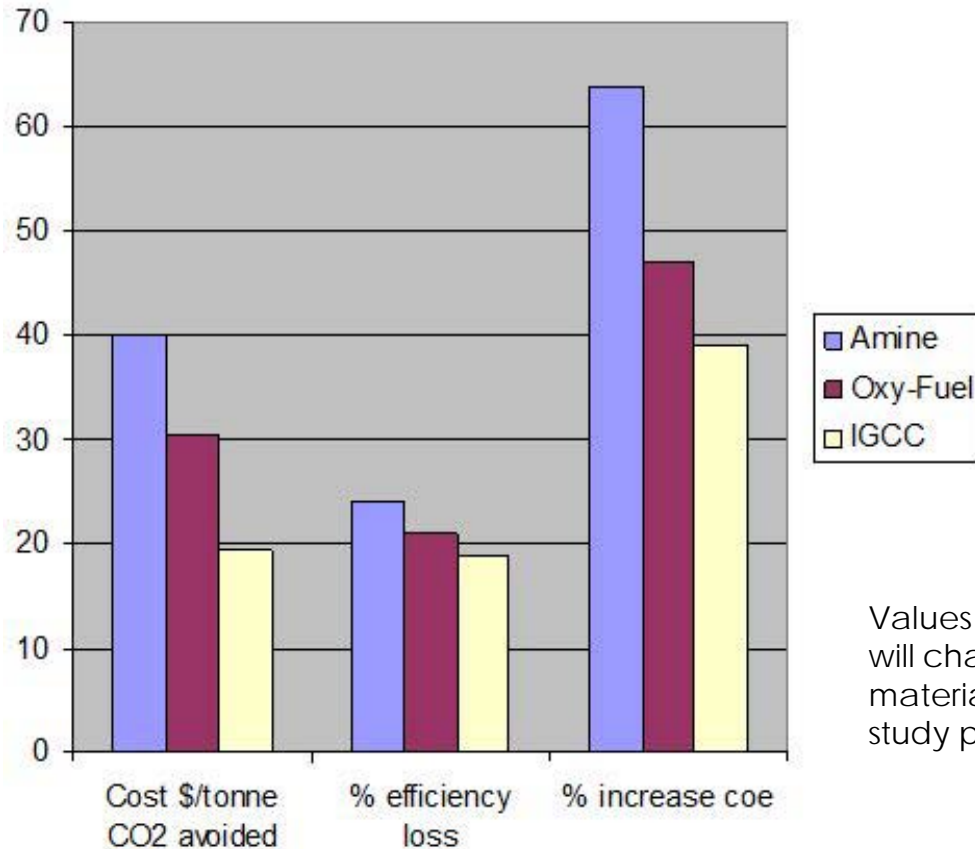


→ There is a fundamental difference in devolatilization rates and ignition between air and oxygen/FGR firing



→ A stable flame can be achieved with no oxygen enrichment in the primary

# CCS Cost Comparison



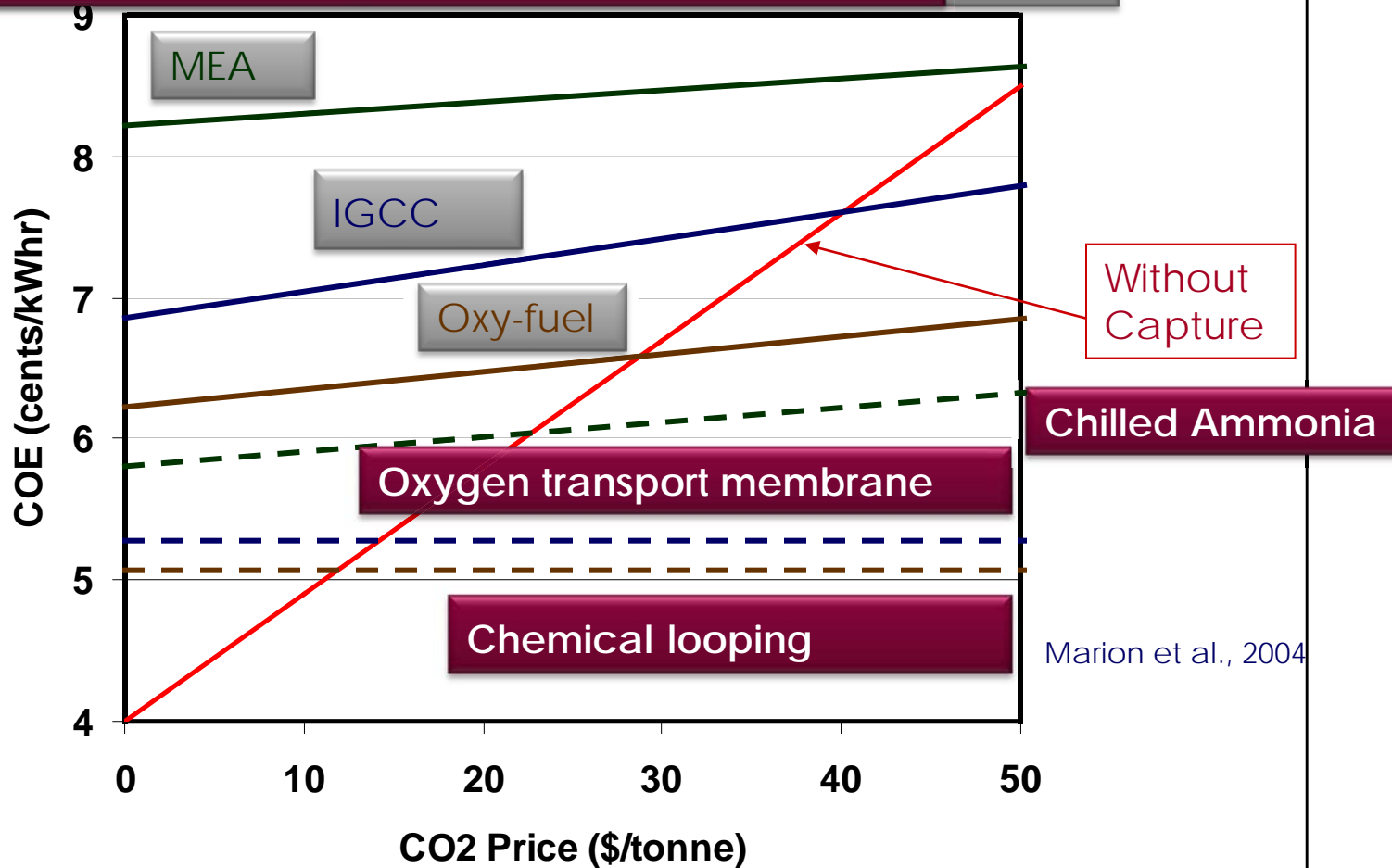
(Deutch & Moniz, 2007)

**Comparative Costs of CO<sub>2</sub> Capture, % Efficiency Loss, and Increase In Cost of Electricity (COE) for Amine Scrubbing, Oxy-Fuel Combustion, IGCC**

Values are site and fuel specific and will change with increased cost of materials and construction since study publication

# Costs of Electricity vs Carbon Price

COE for advanced technologies with CO<sub>2</sub> capture



COE (cost of electricity) for conventional boiler with payment of CO<sub>2</sub> price

Marion et al., 2004

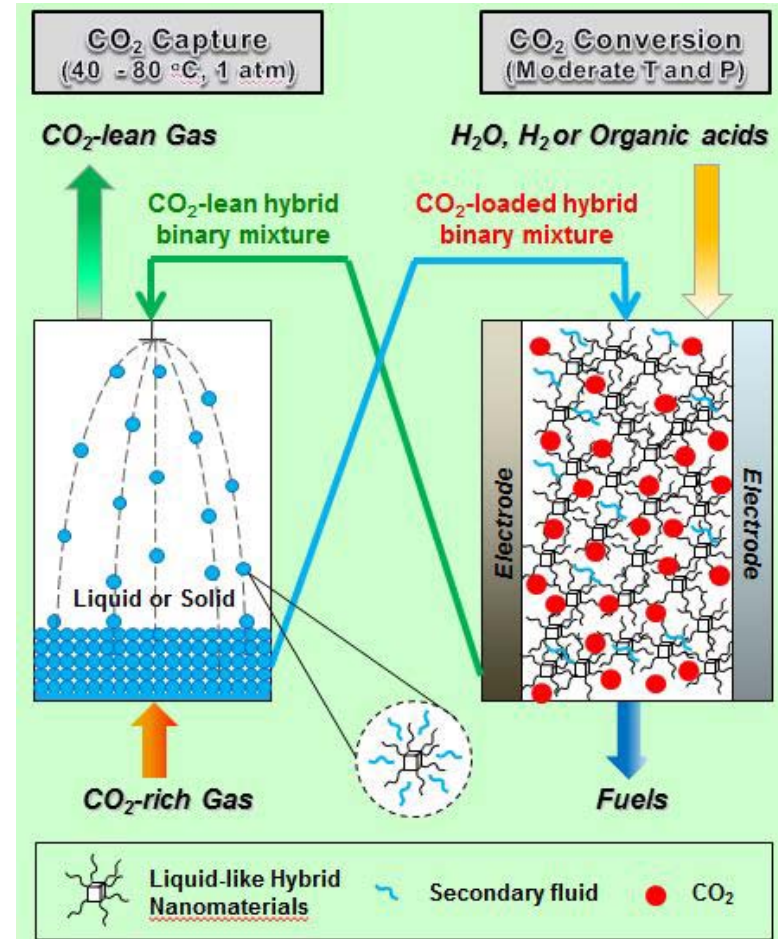
# Advanced Carbon Capture & Storage Development

## Technology Summary

- Develop novel hybrid binary fluids as dual-purpose media for CO<sub>2</sub> capture and its electrochemical conversion to fuels.
- Integrate CO<sub>2</sub> capture and conversion in a two-stage unit operation (see Figure) to improve the overall sustainability of carbon capture and conversion technology.
- Perform life cycle and economic assessments for the developed CO<sub>2</sub>-to-fuel process.

## Technology Impact

- Significantly lower energy requirements and improve economics for CO<sub>2</sub> capture and conversion through process intensification.
- Ensure US leadership in CO<sub>2</sub> capture & use technologies.



# Concluding Thoughts: The King Lives On

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- ➔ Regulation and natural gas prices are resulting in a significant near-term reduction in the fraction of US power derived from coal
- ➔ The decision to undertake coal-to-gas conversions should only occur after careful consideration of site-specific factors and portfolio diversity implications
- ➔ The increase in use of natural gas and renewables relative to coal is unlikely to continue long-term without continued political involvement
- ➔ Population growth and improved quality of life in Asia and developing nations ensures future increases in coal-generated power worldwide
- ➔ It is critical to drive technological advances that will make the continued increase in coal utilization economically and environmentally feasible