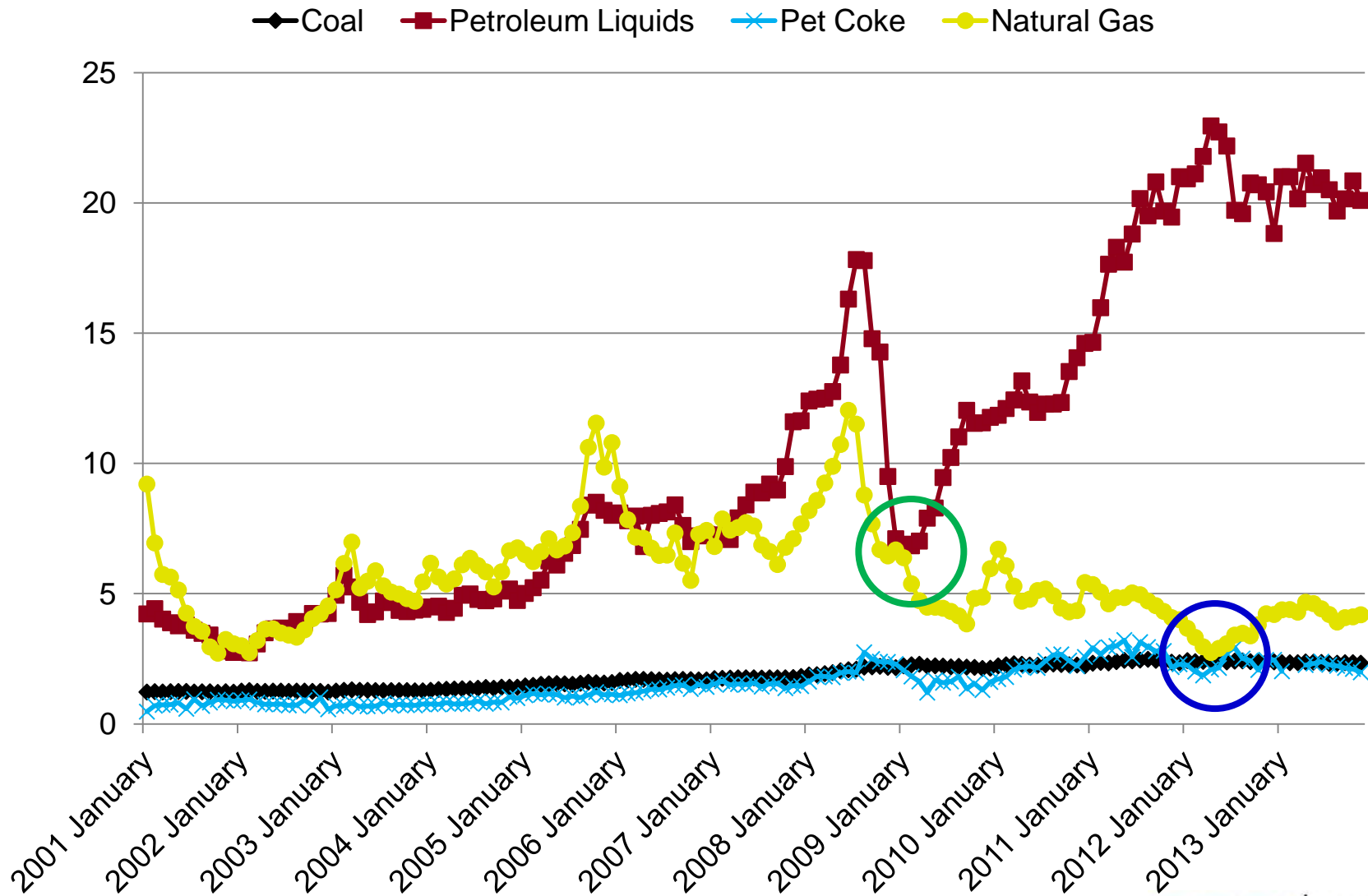




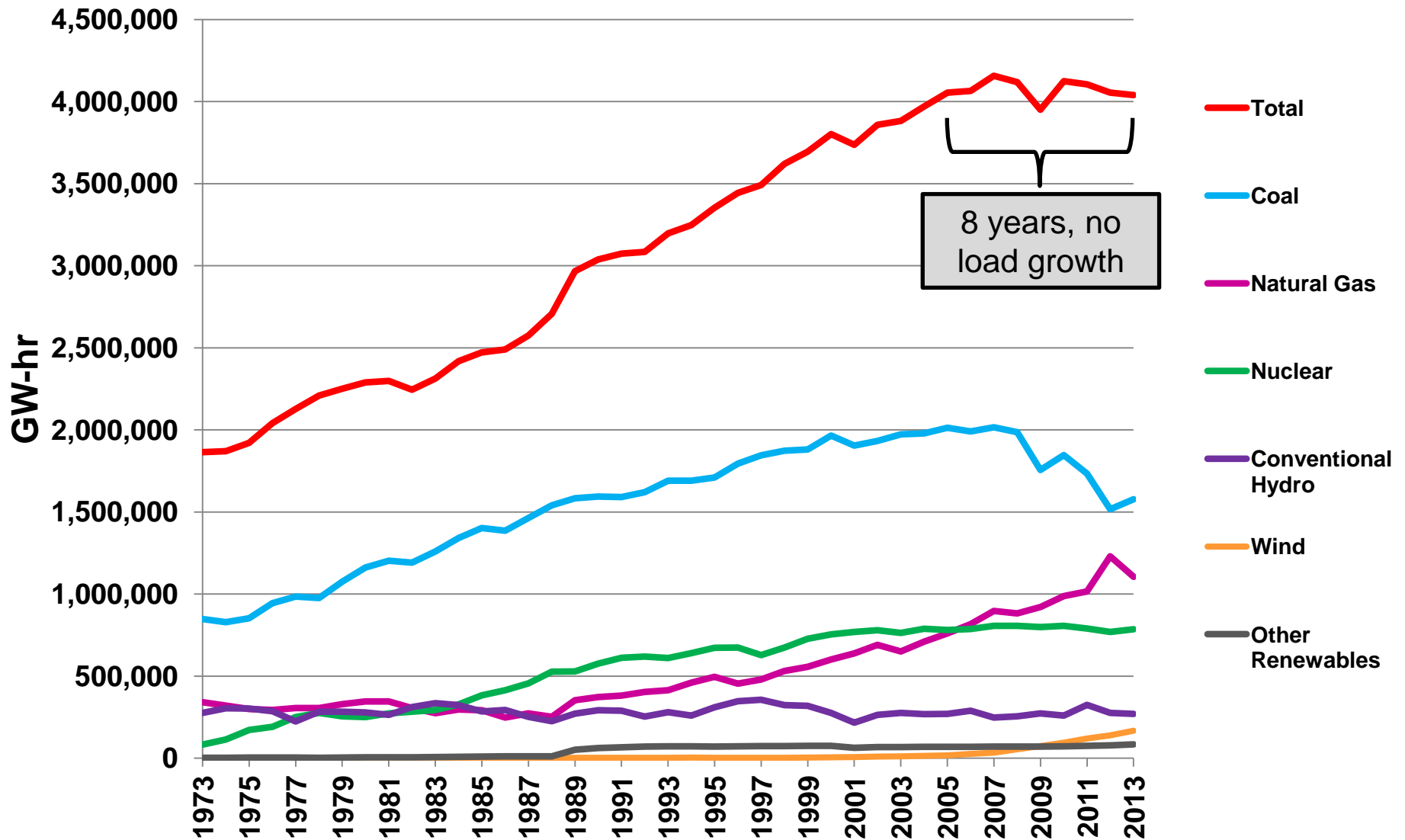
World Energy Situation and 21st Century Coal Technology

Dr. Jeffrey N. Phillips
Senior Program Manager
11th AECE Technical Forum
February 25, 2014

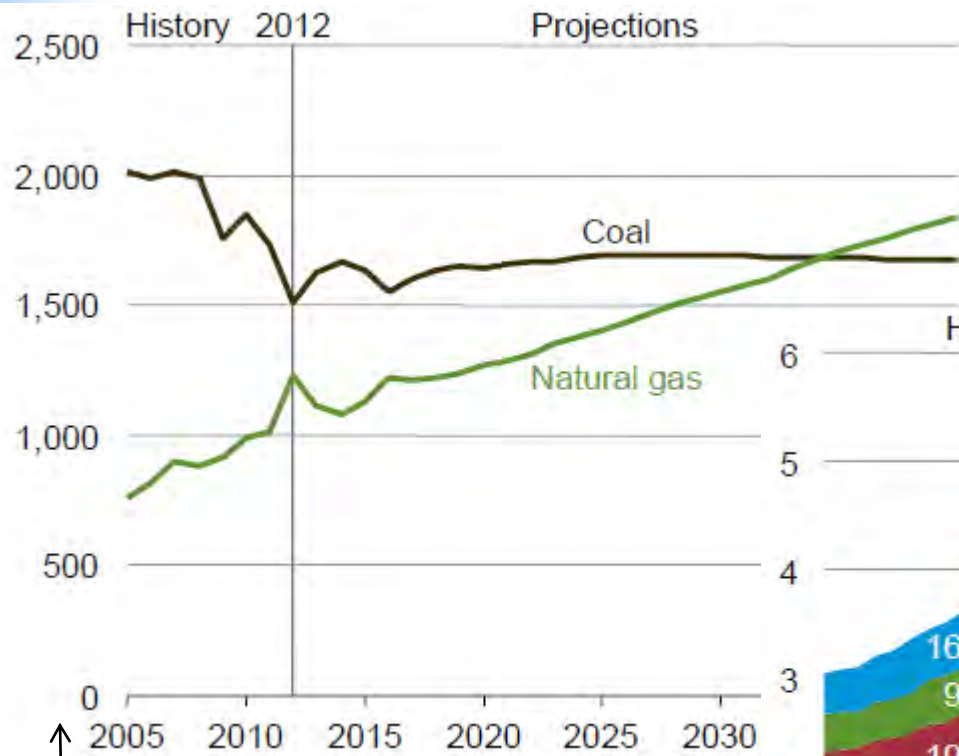
Average Cost of Fossil Fuels Delivered to US Power Plants (\$/MMBtu, no inflation adjustments)



US Power Demand is Flat – No Need for New Coal

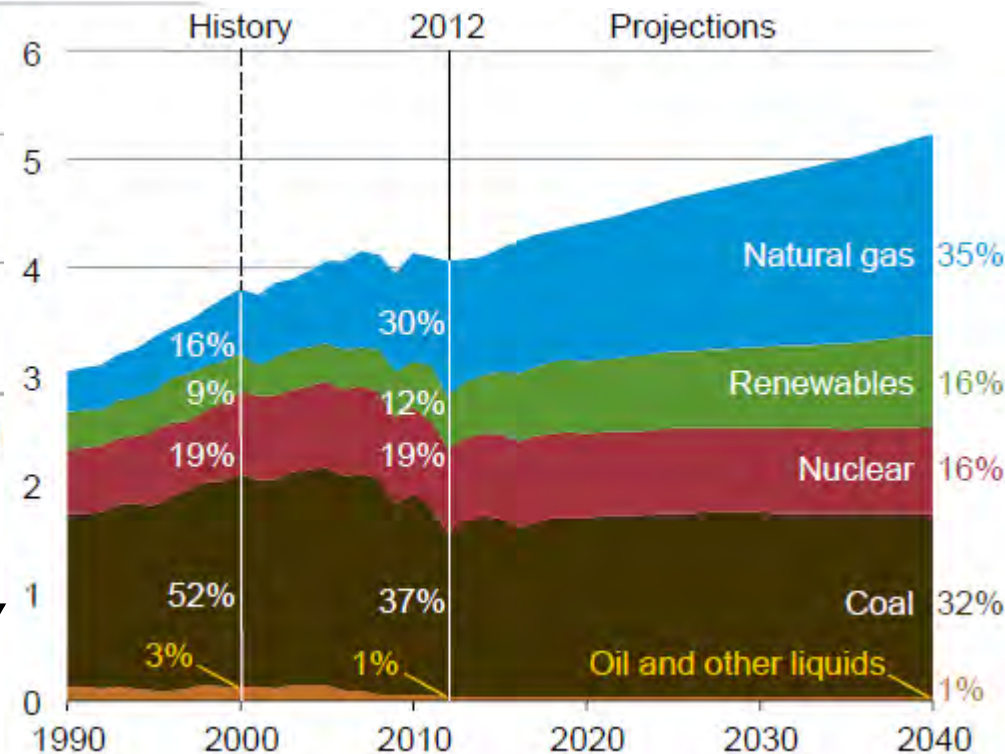


US Power Generation Predictions – EIA Annual Energy Outlook 2014

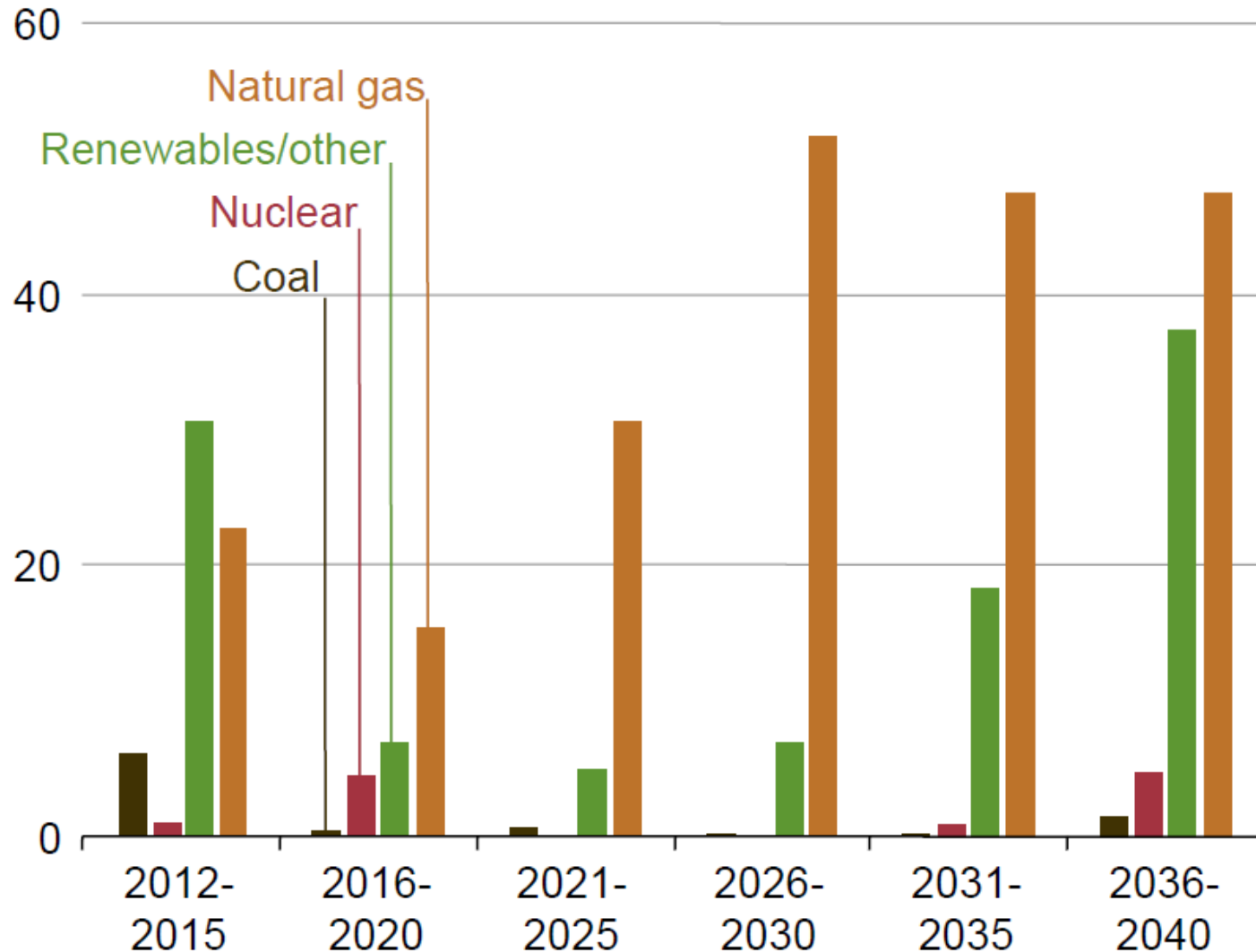


Millions of MWhr per year

Billions of MWhr per year



Most new US capacity additions predicted to be natural gas and renewables (*gigawatts*)



Source: EIA, Annual Energy Outlook 2013

Key Question:

What is the future of IGCC for coal power?

“It was the best of times, it was the worst of times” – Charles Dickens



Buggenum, The Netherlands

Shell coal gasifier for IGCC –
permanently stopped in 2013



Tianjin, China

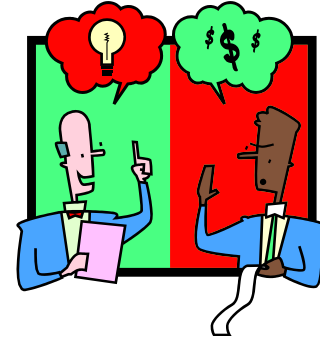
Two Shell coal gasifiers for chemicals
production – still operating

IGCCs face strong headwinds in Europe

- Vattenfall permanently closes its 250 MW IGCC located in Buggenum, The Netherlands
 - Cites decrease in power demand in EU and high fixed costs of the comparatively small coal power plant
- The Elcogas IGCC in Spain has seen a similar lack of demand for power
 - Did not operate for 5 months in 2013



Capital Cost Increases Hit US IGCCs



- Duke Energy's Edwardsport IGCC: \$3.5 billion or \$5663/kW "total project cost"
 - Estimated cost at beginning of project (Oct. 2006) was \$1.9 billion – actual was 184% of this estimate



- Mississippi Power's Kemper County IGCC has reached \$4.0 billion or \$7670/kW "total project cost"
 - Estimated cost at beginning of project (April 2010) was \$2.4 billion – current cost is 167% of that estimate

Mississippi Power's Kemper County IGCC Summer 2013



Photo courtesy of Southern Company

The Cost of First-of-a-Kind?



- Both the US Dept of Energy and EPRI have predicted costs for “nth-of-a-kind” IGCCs which are much lower than Edwardsport or Kemper
- DOE/NETL-2011/1498 report cites an IGCC with 60% CO₂ capture having a “total overnight cost” of \$3024/kW
 - This report is cited in EPA’s Greenhouse Gas New Source Performance Standard proposal – Sept 2013
- Adjusting Kemper’s costs to “total overnight” results in a current estimate of \$7190/kW – 238% higher than DOE’s

How do you get to the “nth” project when the 1st is so costly?

Asia IGCC Projects (1400 + MW)

• China

China - GreenGen - 250 MW – TPRI
 5 other IGCCs in planning
 300 more gasifiers by 2020



Source: World Resources Institute.

Korea

KOWEPCO IGCC - 300 MW – Shell/ GE Start up – 2015

POSCO Coal to SNG – E-Gas™

Japan

Osaki CoolGen - 170 MW IGCC with EAGLE Gasifier, TEPCO&MHI - 2 x 500 MW

Reliance Jamnagar Polygen, India

Project Highlights **E-Gas technology**

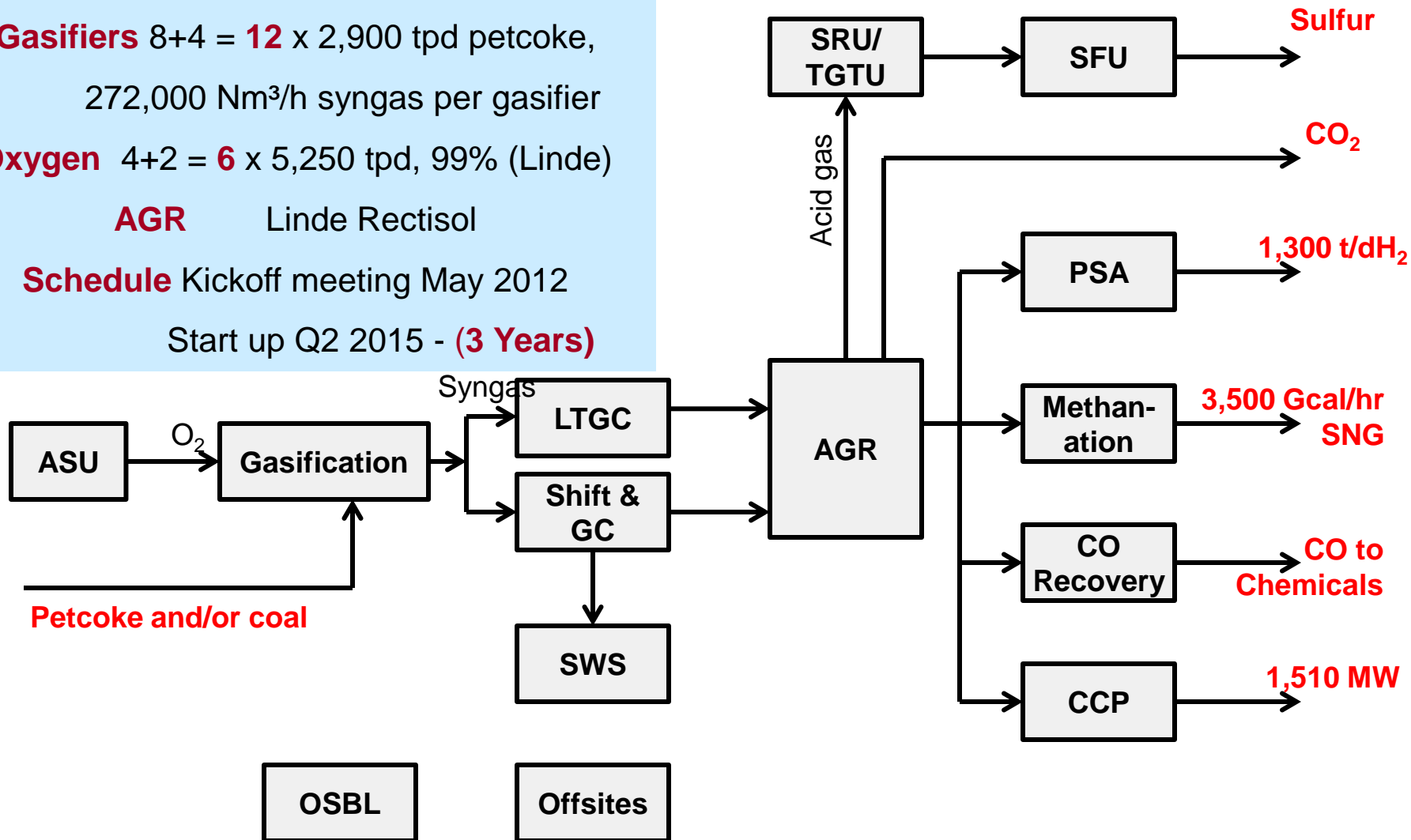
Gasifiers 8+4 = **12** x 2,900 tpd petcoke,
272,000 Nm³/h syngas per gasifier

Oxygen 4+2 = **6** x 5,250 tpd, 99% (Linde)

AGR Linde Rectisol

Schedule Kickoff meeting May 2012

Start up Q2 2015 - **(3 Years)**



Source: Thomas Matthew, CoalAsia New Delhi, 2013

Key Question:

Can the Asian IGCC and Polygen projects avoid the large cost overruns of the US IGCC projects?

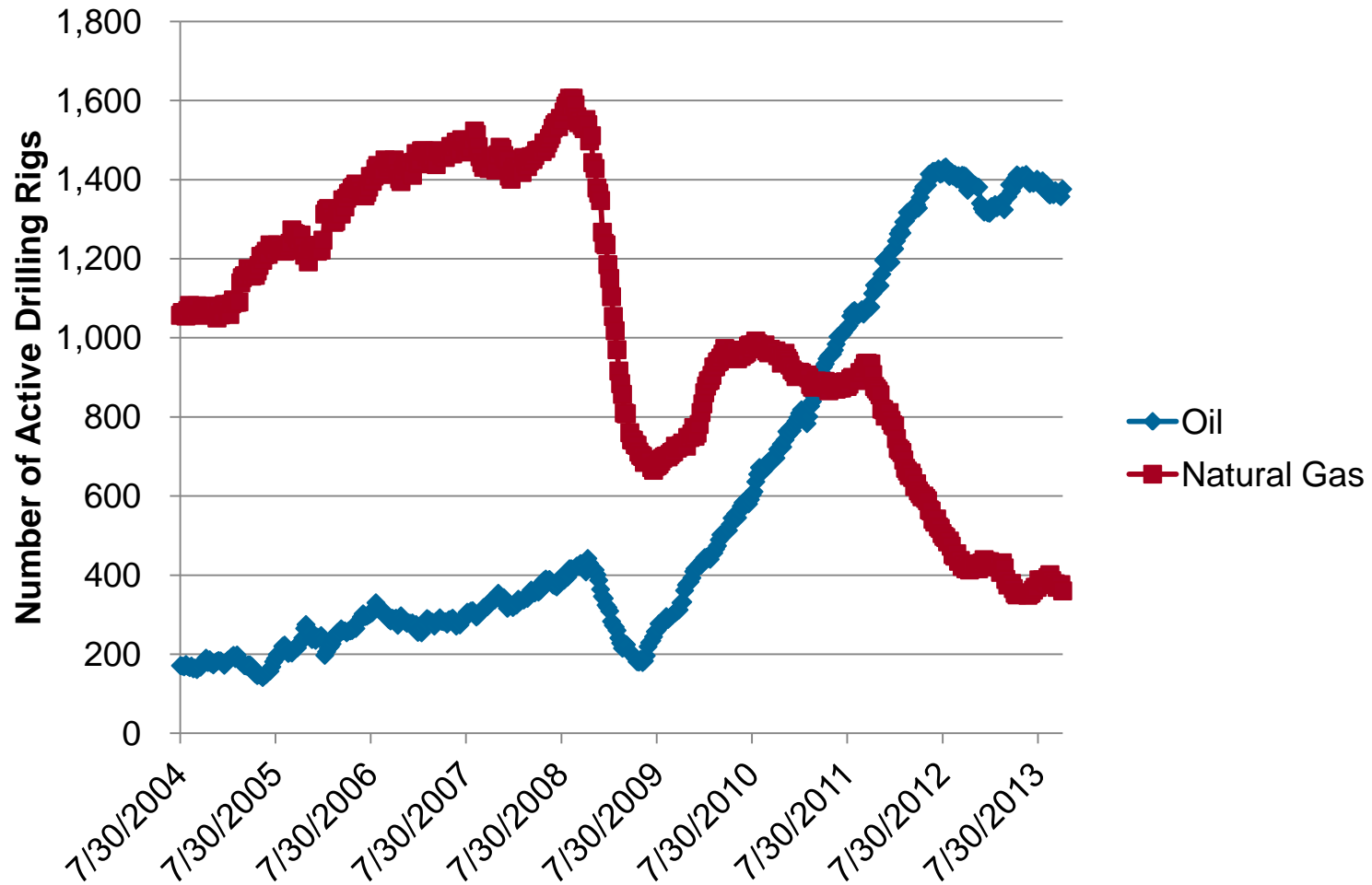
Conclusions on Gasification

- The commercial application of gasification technology is very robust in Asia
- At the same time it has lost its appeal in North America and Europe
- If demand for energy picks up in Europe, interest in gasification may return
- In North America, unless natural gas prices return to $> \$8-10/\text{MMBtu}$, demand will be limited to niche applications
- The future of IGCC technology will be determined by the current projects under construction in Asia

Key Question:

Can US Shale Gas Continue to Keep US Natural Gas Prices Low?

Impact of Natural Gas Prices on Drilling in North America (July 2004 to November 2013)



70% Decrease in Natural Gas Drilling Since 2008

World LNG Estimated November 2013 Landed Prices



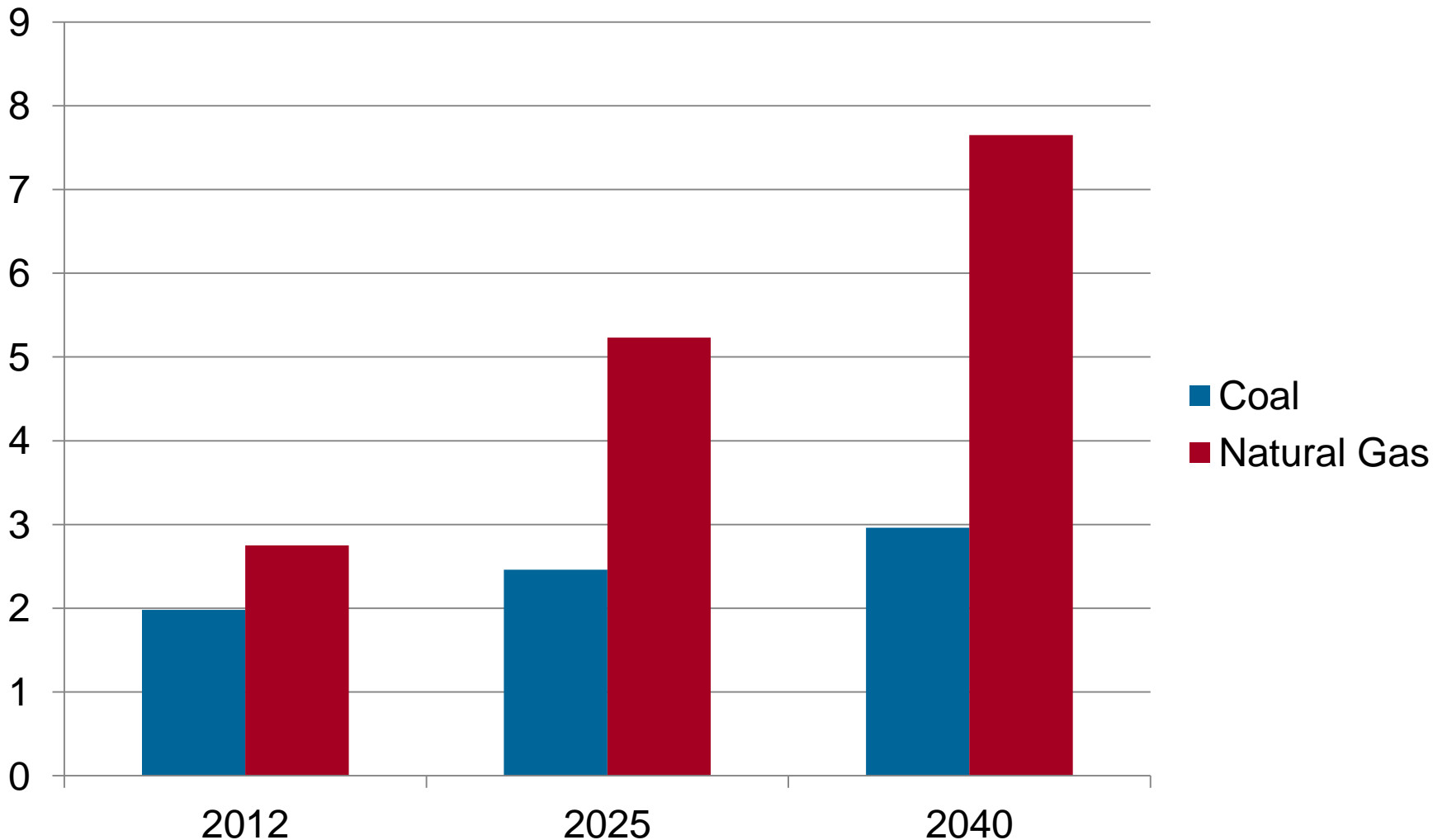
US LNG Export Facilities

- Approved for Construction
 - Six LNG export facilities
 - Total capacity 8.4 billion cubic feet per day
 - Total capacity 62.5 million tons per year
 - Approximately 12.5% of total US natural gas production
- Construction Permits Under Review
 - Approximately 20 additional LNG export projects have filed with the US government for approval
 - Total LNG capacity could be as high as 20 billion cubic feet per day or 150 million tons per year



US Government Predictions for US Fuel Prices, \$/MMBtu

Source: www.eia.doe.gov 2014 Annual Energy Outlook



Key Question:

How will the new US CO₂ emission standard for new power plants impact coal power?

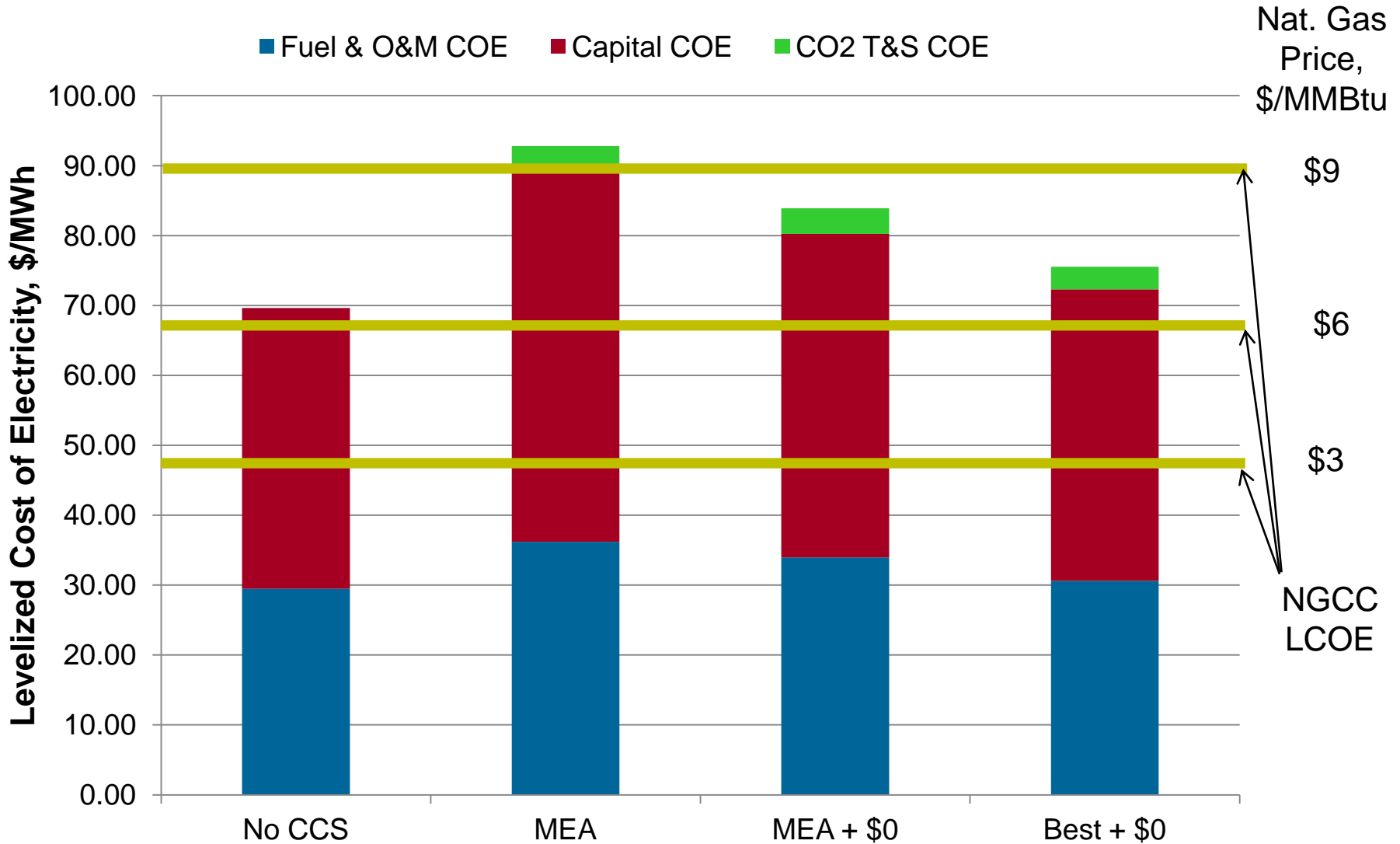
Proposed US rules for CO₂ emissions from new power plants



Separate limits are set for coal and gas:

- Coal: 500 kg CO₂/MWh, gross, rolling 12 month average
- Gas turbines \geq 250MW: 455 kg CO₂/MWh, gross, 12 month average
- Gas turbines 73-250MW: 500 kg CO₂/MWh, gross, 12 month average
- Will require new coal plants to include ~50% CO₂ capture
 - More efficient plants will need less CO₂ capture

Impact of CO₂ Emission Standards for New US USC Coal Power Plant



Legend for chart in previous slide

Case	Description
No CCS	No CO ₂ capture
MEA	37% CO ₂ capture using MEA solvent
MEA + \$0	Same as “MEA” case but assumes MEA system adds zero capital cost
Best + \$0	CCS system consumes 3.6% of the net power of “No CCS” case and is available at no capital cost – the best one could hope for!

- All plants are based on 600°C supercritical steam cycle, burn Powder River Basin coal sub-bituminous coal, and pay \$10/ton CO₂ for transport & storage

Impact of Proposed CO₂ Standard on Coal Power in the US

- To be competitive, new coal power plants will need:
 - A significant improvement in CO₂ capture technology, **and**
 - A significant improvement on coal power plant technology, or
 - An increase in natural gas prices to approximately \$9/MMBtu

Key Question:

Is CCS Ready for Use on Commercial Coal Power Plants?

Largest CO₂ Capture System Ever Operated on a Coal Power Plant

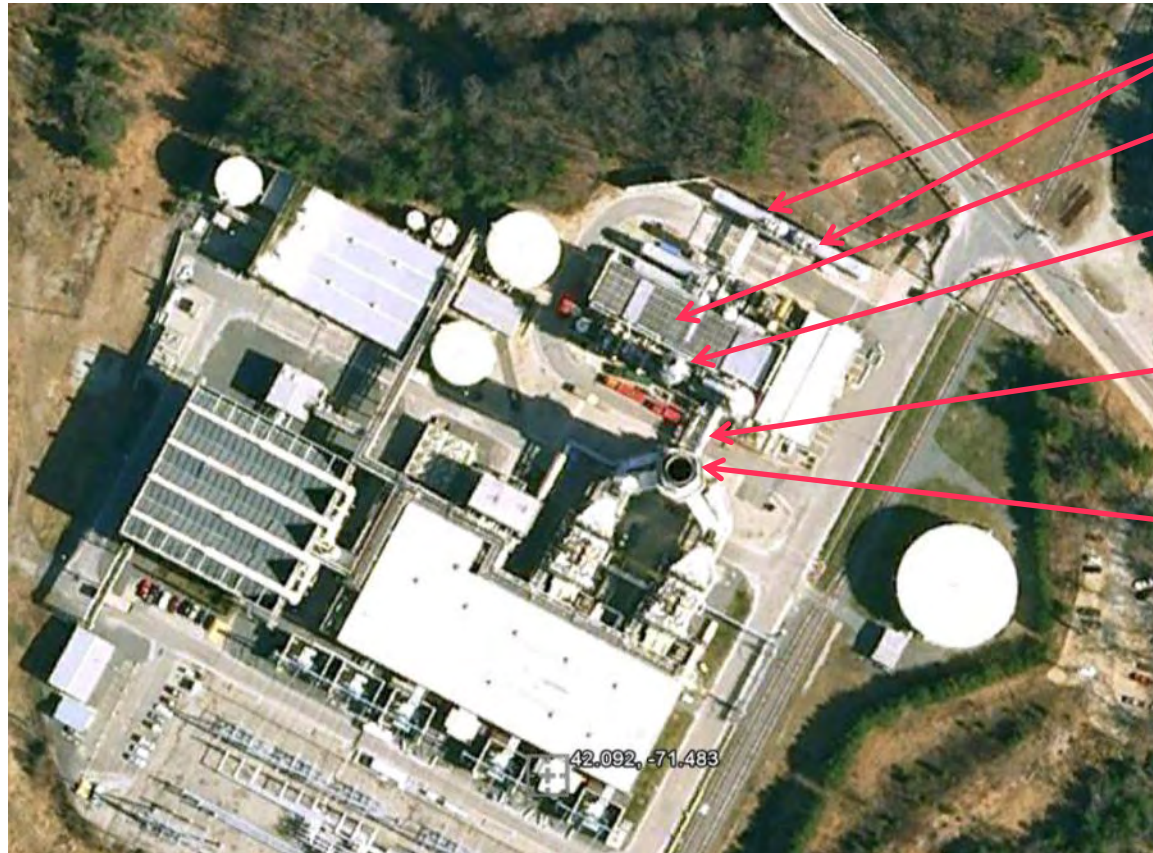
- 400,000 ton/yr CO₂ from 100 MW Lubbock Power & Light power plant
- Operational **1983-1984** for EOR Floods
- Dow Amine Technology



Photo courtesy Gas Processing Solutions LLC

CO₂ Capture System on a Natural Gas Combined Cycle Plant – Bellingham, Mass.

Photo from Google Maps



Tanks for storing liquid CO₂

Fin-fan coolers for capture system

CO₂ absorber vent

Exhaust duct going to capture system

Combined exhaust stack for two W501D gas turbines

**Captured ~100,000 tons/year for carbonated beverages
– no longer in operation**

AEP-Alstom CCS Demo

Project Overview

- **Alstom's chilled ammonia CO₂ post-combustion capture**
 - ~20-MW_e demonstration at AEP's Mountaineer Plant in WV
 - Designed for ~100,000 tons-CO₂/year
 - Injection occurred in saline reservoir using two on-site wells
 - Capture started in September 2009 and storage in October 2009; ~57,000 tons were captured and ~42,000 tons stored
 - Capture project was completed in May 2011
 - Location of the injected CO₂ continues to be monitored per AEP's injection permit



Alstom's Chilled Ammonia Process at AEP's Mountaineer
Property of Alstom Power and/or AEP

Power consumption was 22% less than generic amine technology

Southern-MHI CCS Demo

Project Overview

- **MHI KM-CDR advanced amine CO₂ combustion capture**

- ~25-MW_e demonstration at Alabama Plant Barry in AL
- ~550 tons-CO₂/day
- Capture started on June 3, 2011; over 100,000 tons captured so far
- Injection is occurring in the Citronelle dome ~10 miles away and started on August 20, 2012; goal of 100,000 tons reached in 2013

- **EPRI's role:**

- Manage collaborative, select and manage test contractors, develop test plan to perform capture testing, and document results
- Leading the storage effort for DOE with ARI and Denbury



MHI's KM-CDR Process at Plant Barry
Property of MHI and/or Southern

Large CO₂ “Capture-to-Storage” Projects in Operation



Map courtesy Global CCS Institute (with additions by EPRI)

~10 projects worldwide – None at a power plant

Large-scale CCS projects operating in North America

Map & data from Global CCS Institute



1. **Weyburn EOR** – CO₂ from coal gasifier in ND, 2.8 million ton/yr
2. **Shute Creek EOR** – CO₂ from natural gas processing, 7 million ton/yr
3. **Enid EOR** – CO₂ from fertilizer production, 0.7 million ton/yr
4. **Val Verde EOR** – CO₂ from nat. gas processing, 1 million ton/yr
5. **Century Plant EOR** – CO₂ from nat. gas processing, 8 million ton/yr
6. **Port Arthur EOR** – CO₂ from steam methane reformer (US DOE project), 1 million ton/yr

All the current large-scale CCS projects use CO₂ for Enhanced Oil Recovery (EOR)

Starting up in 2014

Map from Global CCS Institute



- **Boundary Dam:**
90% CO₂ capture retrofitted to 150 MW coal power plant, ~1 million tons CO₂ per year for EOR
- **Kemper County:**
new 582 MW IGCC with ~65% CO₂ capture, ~3 million tons CO₂ per year for EOR

Both receiving large government subsidies. Will give power industry “real life” experience in operating large-scale CCS

Summary of Issues Impacting Coal Power Around the World

- Several countries now proposing CO₂ emission limits for power plants that (nearly) match those of a natural gas fired combined cycle
- Many Asian countries are strongly committed to continued use of coal for power and more inclined to try coal gasification
- Several important coal-using nations have not found suitable storage sites for large amounts of CO₂
- Public distrust of nuclear power may create demand for more coal power in some countries
- Global economic slump has decreased electric power growth in developed countries
 - *This limits opportunities to demonstrate new coal power technology including CCS*

Final Conclusion

- In order to develop coal power technologies for the 21st Century, more collaboration is needed among the OECD nations and between OECD nations and the rapidly growing economies of the developing world
 - The developing economies need new coal power plants but are unwilling to pay extra for advanced technologies
 - Developed countries are willing to pay extra, but do not need new coal power plants
 - We all need to find secure places to store captured CO₂

Together...Shaping the Future of Electricity



Background Information

The View from China



- 733 GW of installed coal power generation at end of 2011
- 890 GW planned by 2015
- 1500 GW anticipated by 2030
 - This would be ~5 times current US coal power capacity
- 222 coal gasifiers now installed in China
 - Almost all for non-power applications
 - 250 MW GreenGen IGCC is first gasification facility for power only
 - See polygen as way to meet variable demand for power
- Higher efficiency is their CO₂ “solution” for today
 - Goal of building 700°C USC demo plant has been announced
 - Looking for “developed” countries to provide funding for CCS demos in China

The View from Korea

- World's 2nd largest importer of coal for power (2010 data)
- Increasing interest in coal gasification due to very high cost of LNG
 - Korea Western building a 300 MW IGCC (no CO₂ capture)
 - IGCCs get 25% credit in renewable portfolio standard
 - POSCO building an SNG plant that will use sub-bituminous coal
- Concerned about rising cost of internationally traded bituminous coal
 - Have significantly increased imports of sub-bituminous coal to try to offset cost increases
 - Interested in upgrading technologies for low rank coal (drying, briquetting, cleaning)
- Official plan calls for coal power generation capacity to level out at 28 GW (~25 GW now)
 - However, “huge” public resistance to building more nuclear power plants, so more coal may to be added
- Only suitable CO₂ storage capacity appears to be offshore



The View from Taiwan

- With few domestic fuel options, Taiwan is dependent on energy imports including coal
- Awarded contract for three new 800 MW SCPC units to replace two older (built in 1968) 300 MW coal units
- Have roadmap to implement a CCS demo project
 - Currently characterizing site for storage
 - 10,000 ton pilot injection in 2014-15
 - 100,000 ton demonstration in 2018-2020
 - Goal to be ready for commercial scale CCS by 2025



The View from Australia



- “Love-Hate” Relationship with coal
 - CO₂ emissions price of A\$23 per tonne began in 2012 for large emitters, but new prime minister wants to scrap the CO₂ tax
- Lack of growth in power demand means no one is building new power plants, so little opportunity for demonstrating CCS in near term
- “Flagship” CCS projects have mostly stalled. No large scale coal CCS project under construction (though Gorgon LNG is a large CCS project)
- Desire by coal-rich states to find new markets for their coal
 - Victoria intends to issue new allocations for brown coal mines, with no new power plants being built this means CTX or upgrading to briquettes

The View from India



- Ambitious plans for more generation capacity
 - Just under 200 GW now, want 600 GW additional by 2032
 - Much of that will be coal
- An extreme shortage of coal supply
 - Demand for coal growing at 10%/yr, domestic production growing at 5%/yr
 - Many power plants have only 1 day coal supply on site
- Government has announced goal to build an 800 MW USC with 700°C steam conditions
 - Will start testing components in existing PC soon
- No plans for CCS demonstration

The View from South Africa

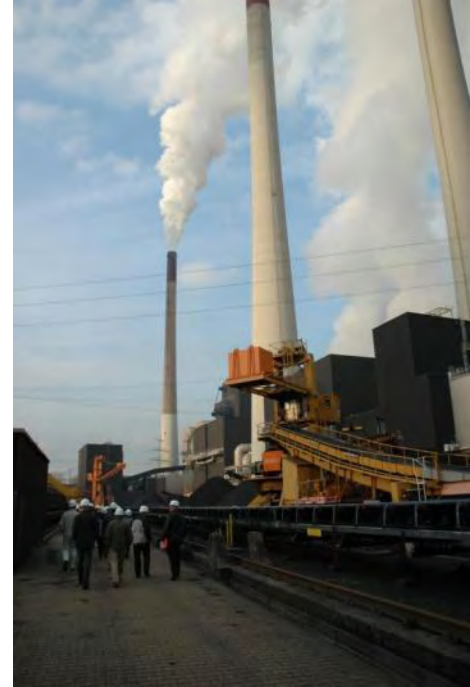


- Power generation shortfall remains very tight
 - Three mothballed power stations have been brought back into service
 - First unit of Medupi 6 x 700 MW SCPCs is expected to be commissioned in 2013
 - Work on second 6 x 700 MW SCPCs has started
- Government has announced aggressive goal for reducing CO₂ emissions
 - 34% emission reduction below business as usual by 2020 and 42% by 2025.*
 - Published CO₂ storage “atlas” in 2010. Small potential for storage inland. Majority offshore. All unproven.
 - No announced plans for a CCS demonstration. The South African Centre for Carbon Capture and Storage is considering a storage demonstration but nothing officially announced.
- Work on underground coal gasification continues.
 - First gasifier has been successfully shutdown. Second gasifier started in 2012 and co-fires the gas into Majuba power station.

*Note that these commitments were conditional on a fair, ambitious and effective outcome in the international climate negotiations in Copenhagen and on financial and technical support from the international community.

The View from Germany

- In July 2011 ~10 GW of new coal-fired power plants were under construction
- “It is illegal to have a CCS project in Germany” – Lars Stromberg, former VP of R&D for Vattenfall
 - You cannot legally inject CO₂ under German soil
- No Nukes!
- Strong subsidies for wind & solar – only provide 10% of generated power but represent ~50% of price of the “full basket” of electricity



The View from UK



- On-again, off-again large CCS demonstration program is “on again”
 - Last of the original candidates, Longannet, dropped out citing high cost of offshore transport & storage
 - Drax’s White Rose oxy-combustion project and a Shell/SSE natural gas combined cycle are the currently “preferred” projects
 - One billion pounds may be available for one of the projects
- Any CO₂ storage will occur offshore
 - At least one project looking at feasibility of EOR offshore
- Proposed limit of 450 kg CO₂/MWhr for new power plants

The View from Canada



- CO₂ emission limit for new coal plants:
 - 420 kg/MWhr net
- SaskPower's Boundary Dam CCS project will be world's only commercial coal power plant with 90% CO₂ capture
- Alberta's ambitious CCS demo program has encountered difficulties
 - TransAlta's Pioneer Project was canceled, \$800 million subsidy & \$15/ton CO₂ emission "tax" not sufficient, Shell Quest oil sands upgrader a "go"
- Ontario moving forward with phasing out coal power