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World Energy Situation and 21st Century Power Technology

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Three Key Aspects of EPRI

Independent

Objective, scientifically based results address reliability, efficiency, affordability, health, safety and the environment

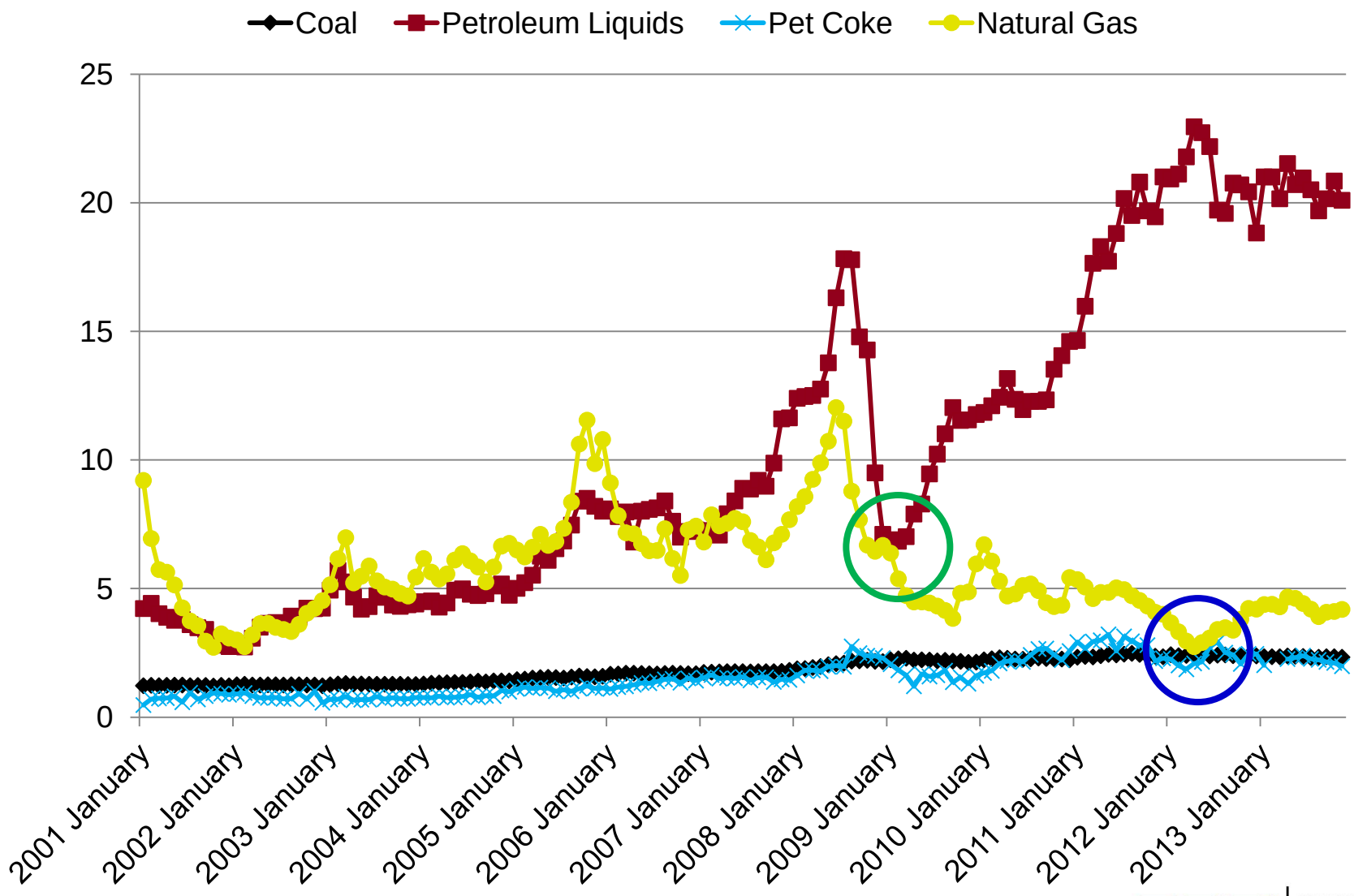
Nonprofit

Chartered to serve the public benefit

Collaborative

Bring together scientists, engineers, academic researchers, industry experts

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



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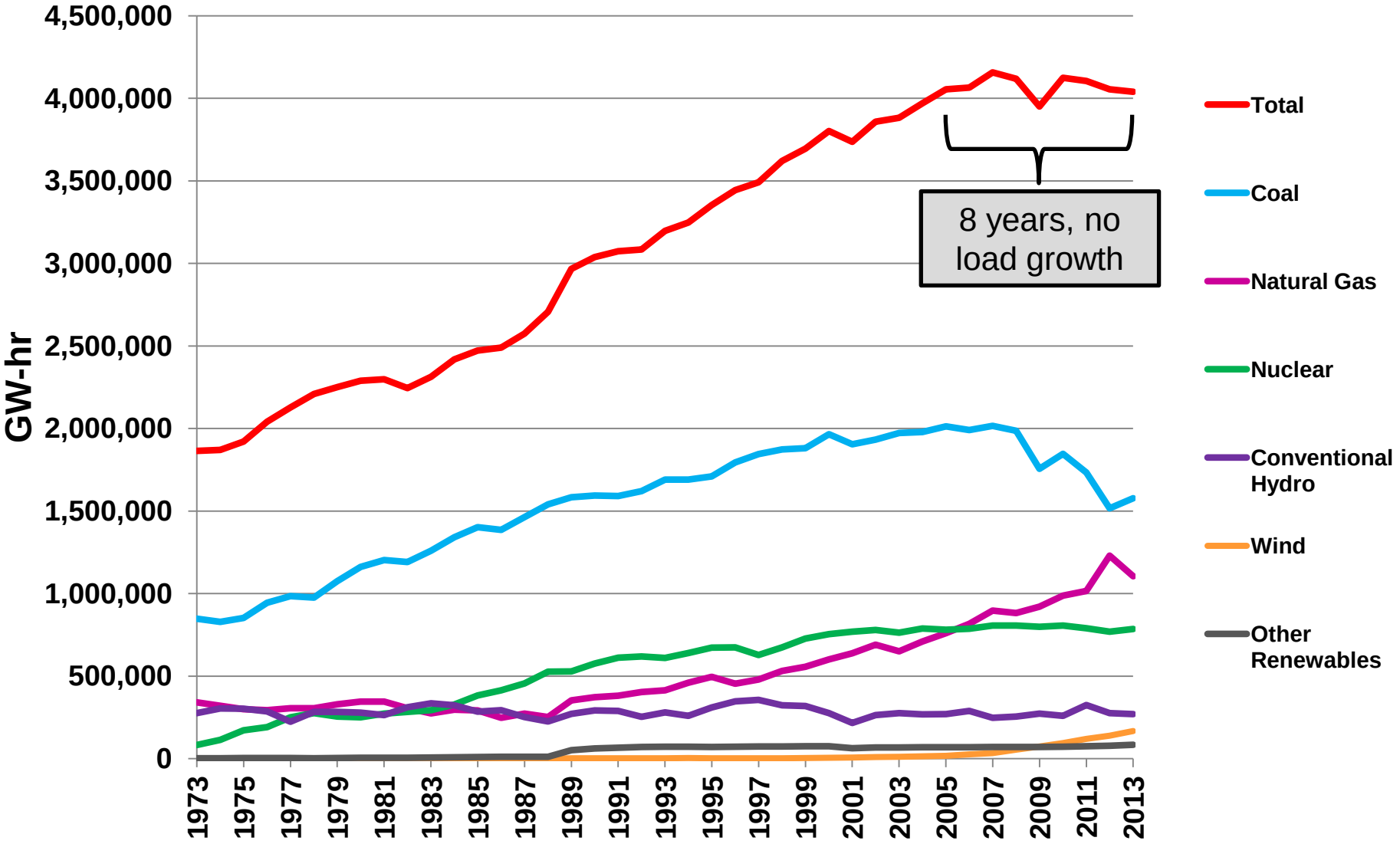
US Power Demand is Flat – No Need for New Coal



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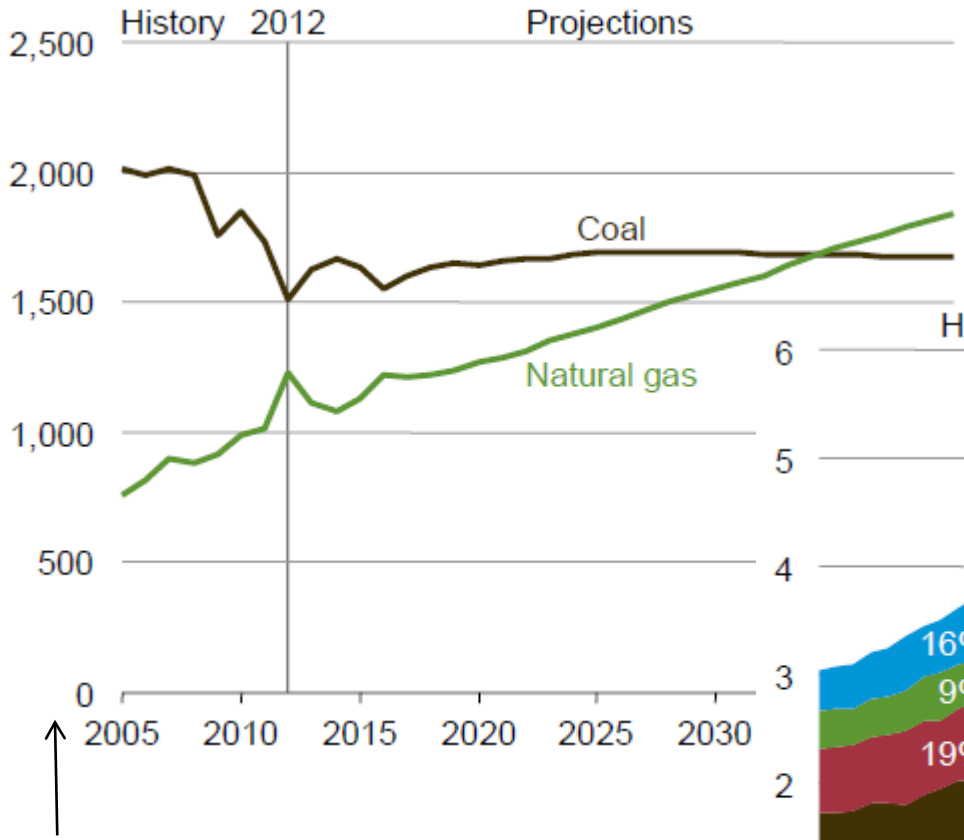
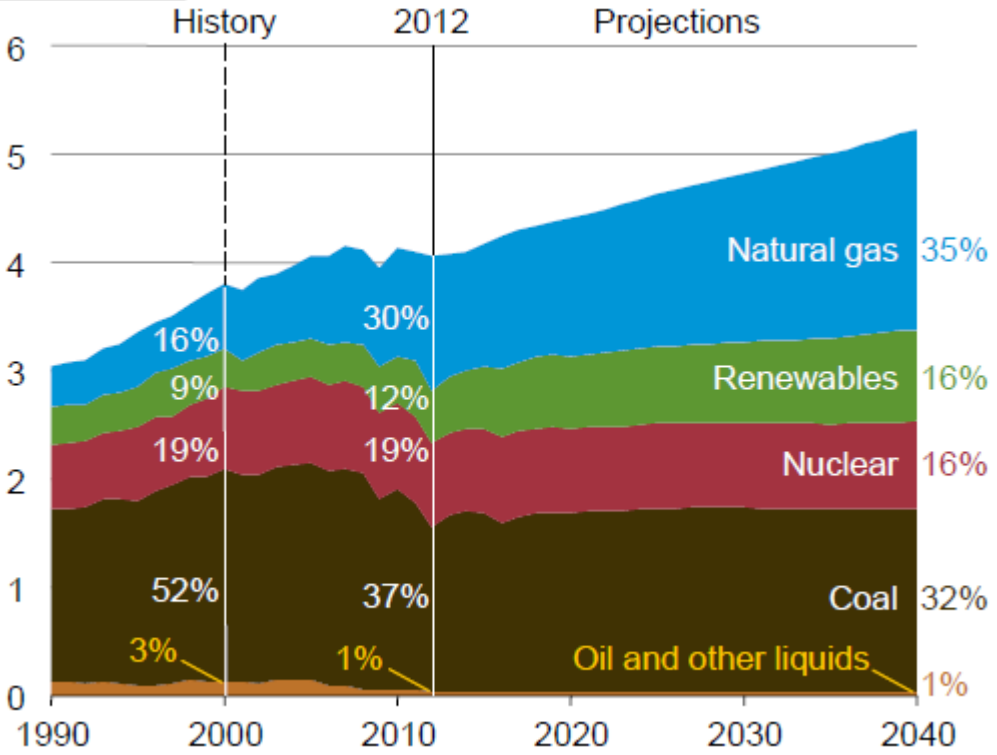
US Power Generation Predictions – EIA Annual Energy Outlook 2014



Millions of MWhr per year



Billions of MWhr per year

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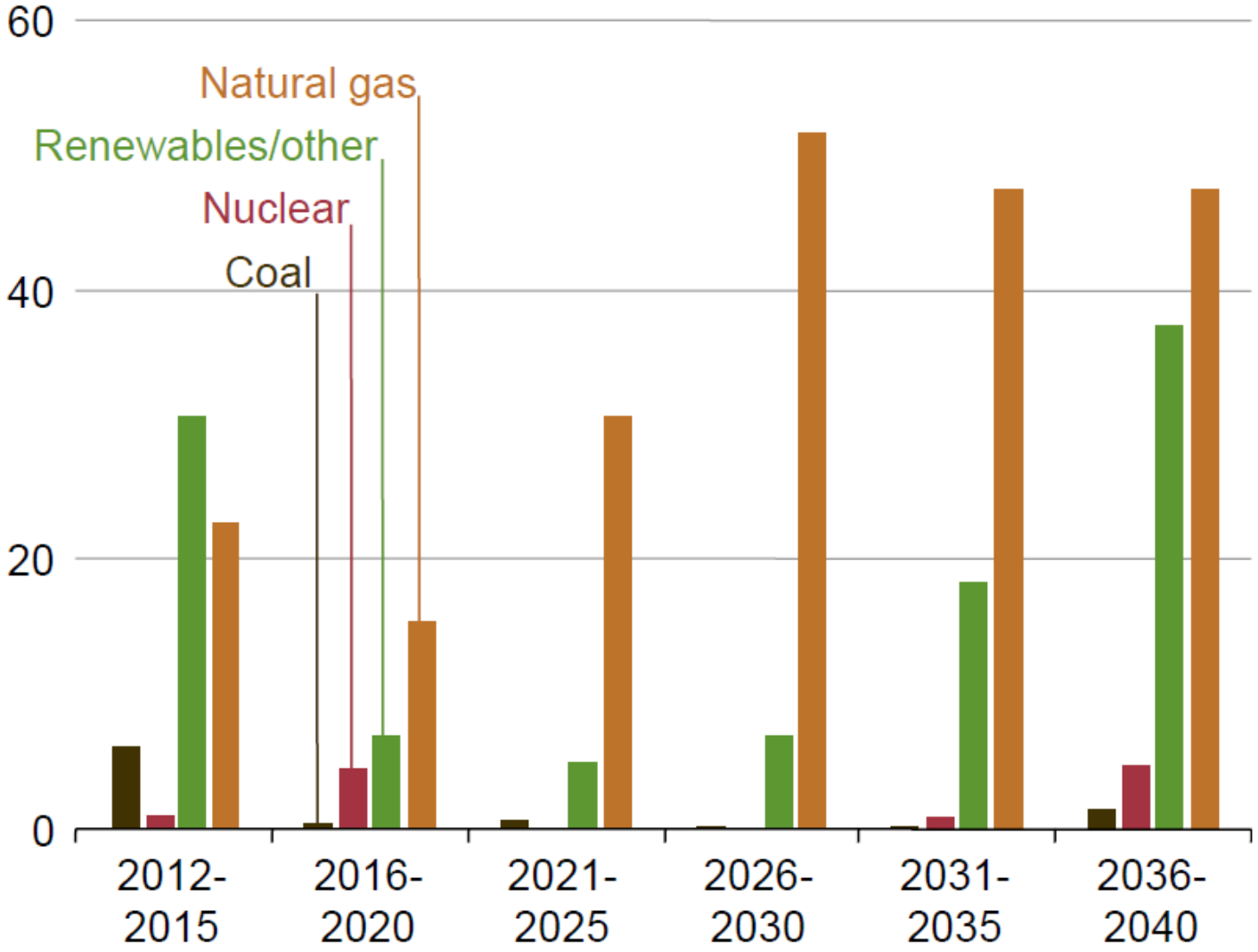
Most new US capacity additions predicted to be natural gas and renewables *(gigawatts)*

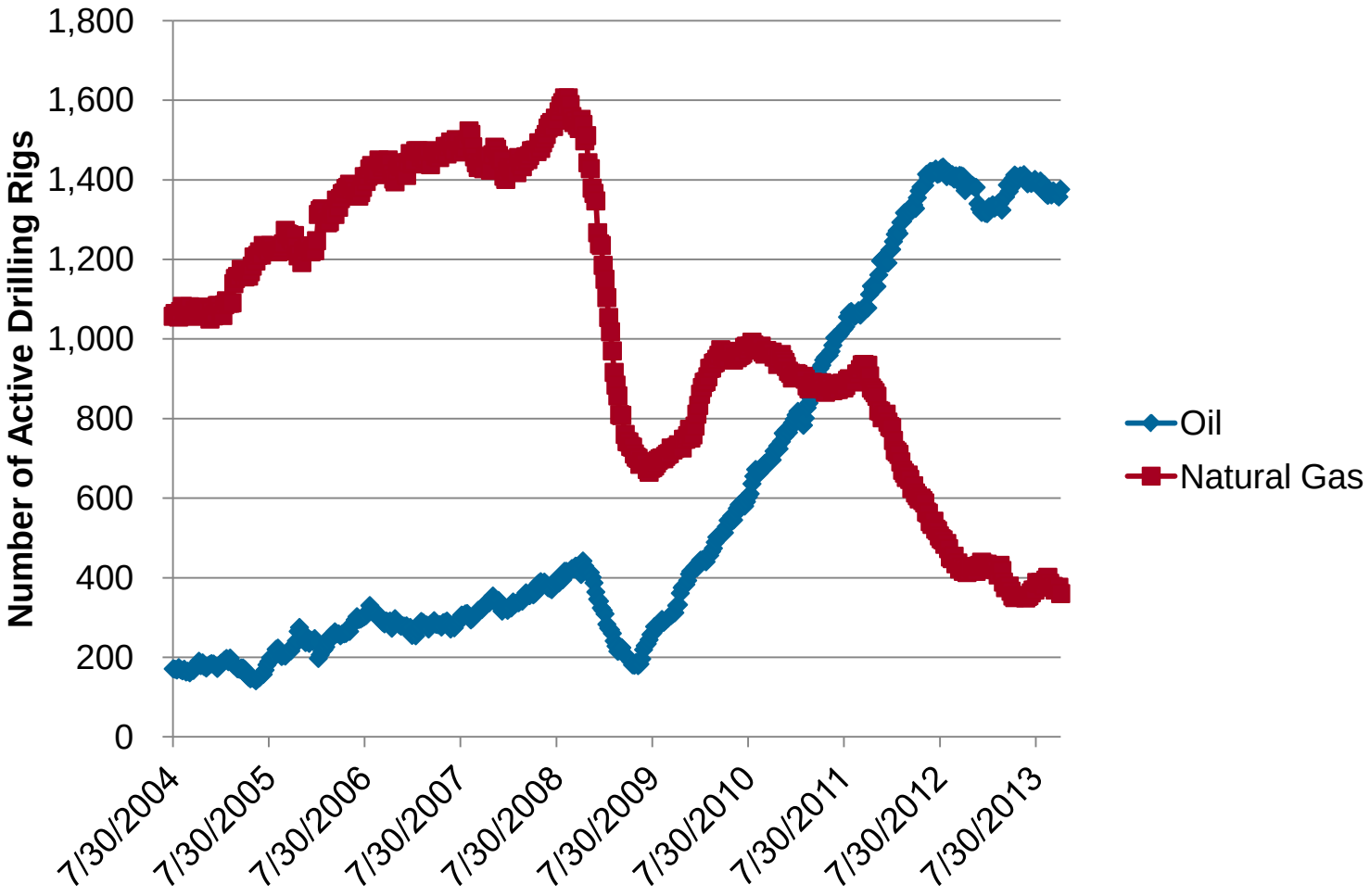


Source: EIA, Annual Energy Outlook 2013

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

Source: *Waterborne Energy, Inc.* Data in $US/MMBtu

Updated October 7, 2013

2169

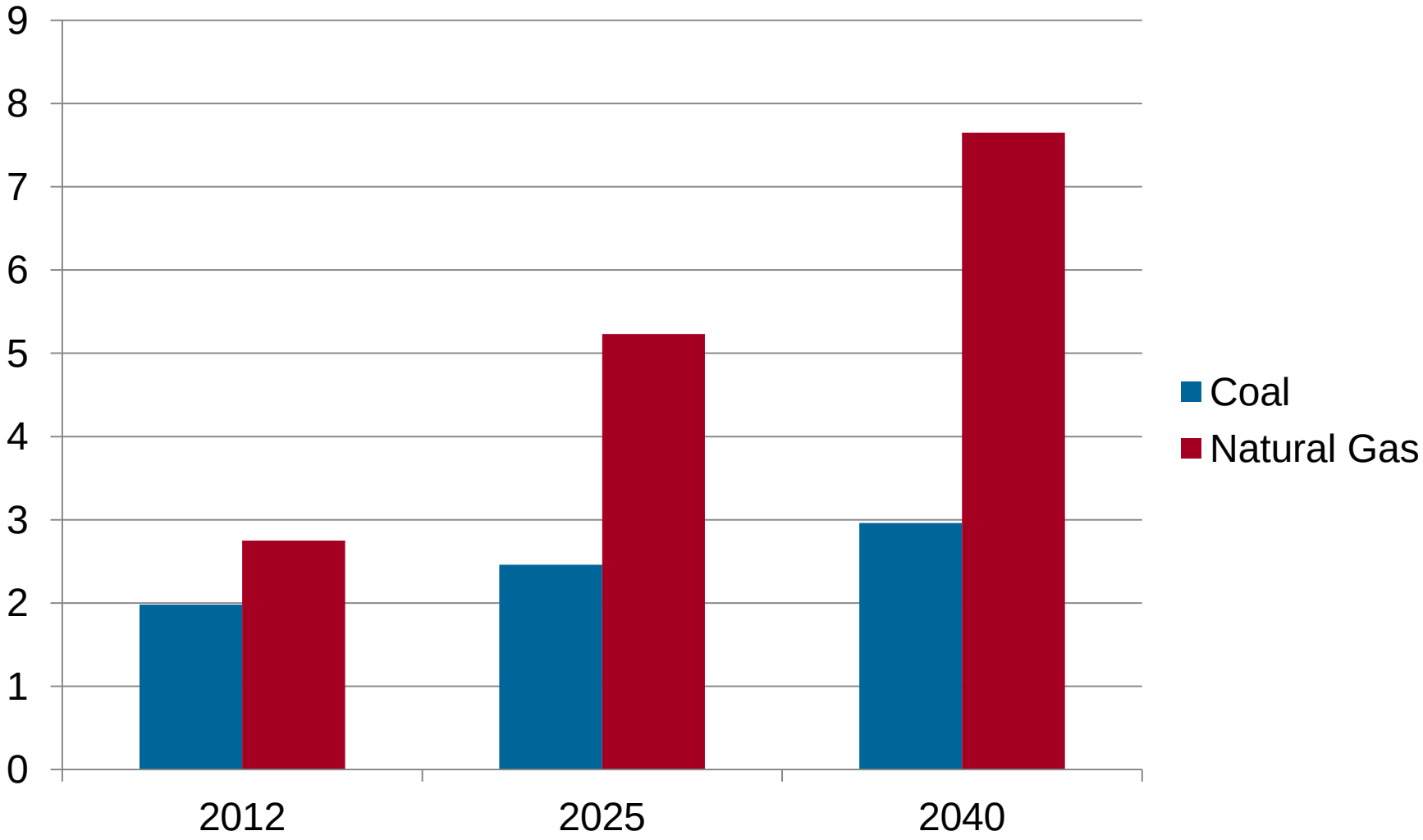
US LNG Export Facilities

- Approved for Construction
  - Seven LNG export facilities
  - Total capacity 9.9 billion cubic feet per day
  - Total capacity 73.7 million tons per year
  - Approximately 14.7% 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 CO_2 emission standard for new power plants impact coal power?

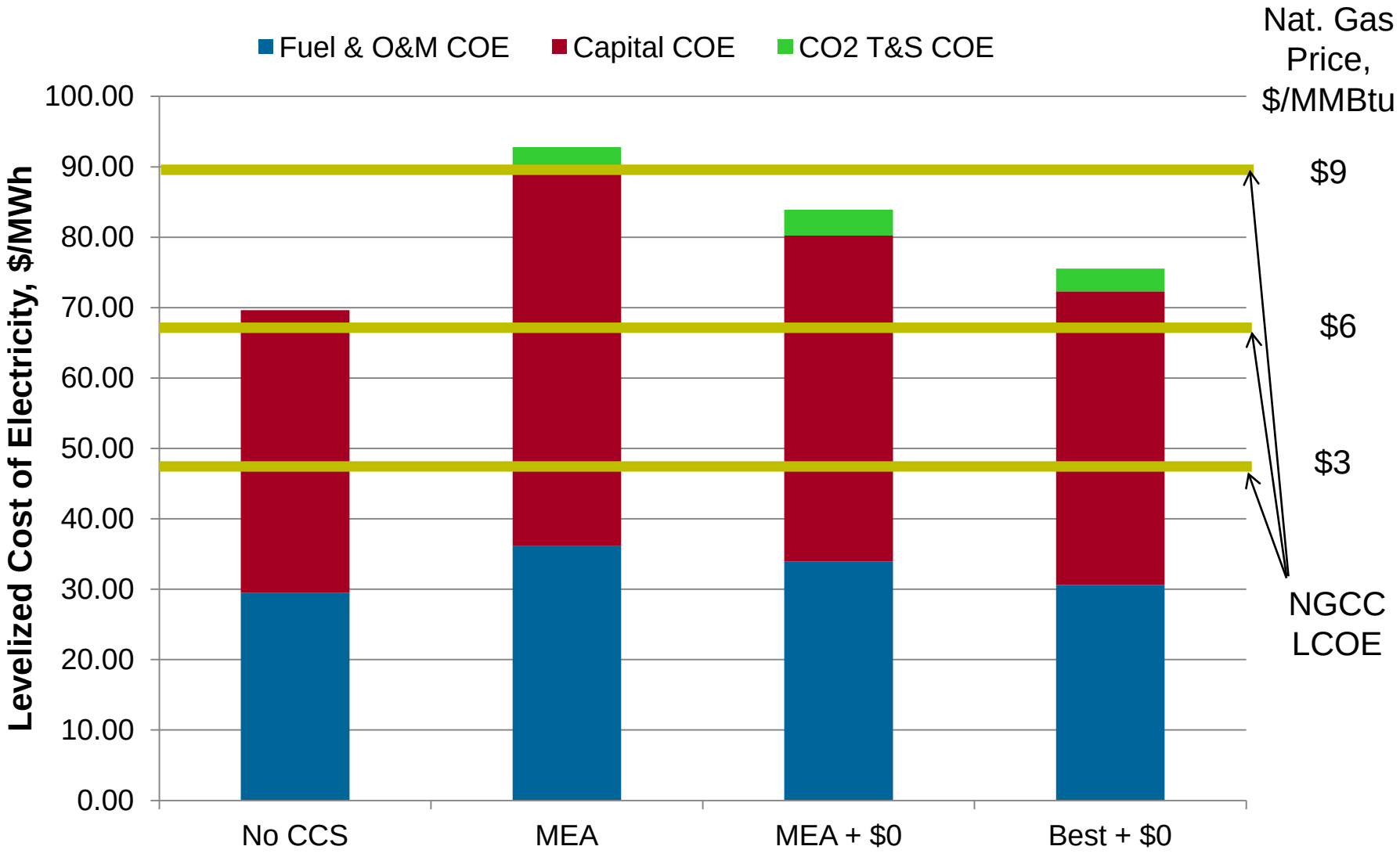
Proposed US rules for CO_2 emissions from new power plants

Separate limits are set for coal and gas:

- Coal: 500 kg CO_2/MWh, gross, rolling 12 month average
- Gas turbines ≥ 250MW: 455 kg CO_2/MWh, gross, 12 month average
- Gas turbines 73-250MW: 500 kg CO_2/MWh, gross, 12 month average

- Will require new coal plants to include ~50% CO_2 capture
  - More efficient plants will need less CO_2 capture
- Natural gas combined cycle plants should be able to meet the standard without any additional equipment

Impact of CO_2 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 can be built at zero capital cost
Best + $0	Assumes CCS system consumes 3.6% of the net power of “No CCS” case, which is the thermodynamic minimum needed to separate CO2 and compress it to 150 bar. Also assumes the CCS system 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 CO_2 for transport & storage

Impact of Proposed CO_2 Standard on Coal Power in the US

- To be competitive, new coal power plants will need:
  - A significant improvement in CO_2 capture technology, **and**
  - A significant improvement on coal power plant technology, or
  - An increase in natural gas prices to approximately $9/MMBtu
- Note that in many parts of the world natural gas prices are already at or above $9/MMBtu, which means even with today's CCS technology a coal-fired power plant meeting the 500 kg CO_2/MWhr would be a competitive option

Key Question:

Is CCS Ready for Use on Commercial Coal Power Plants?

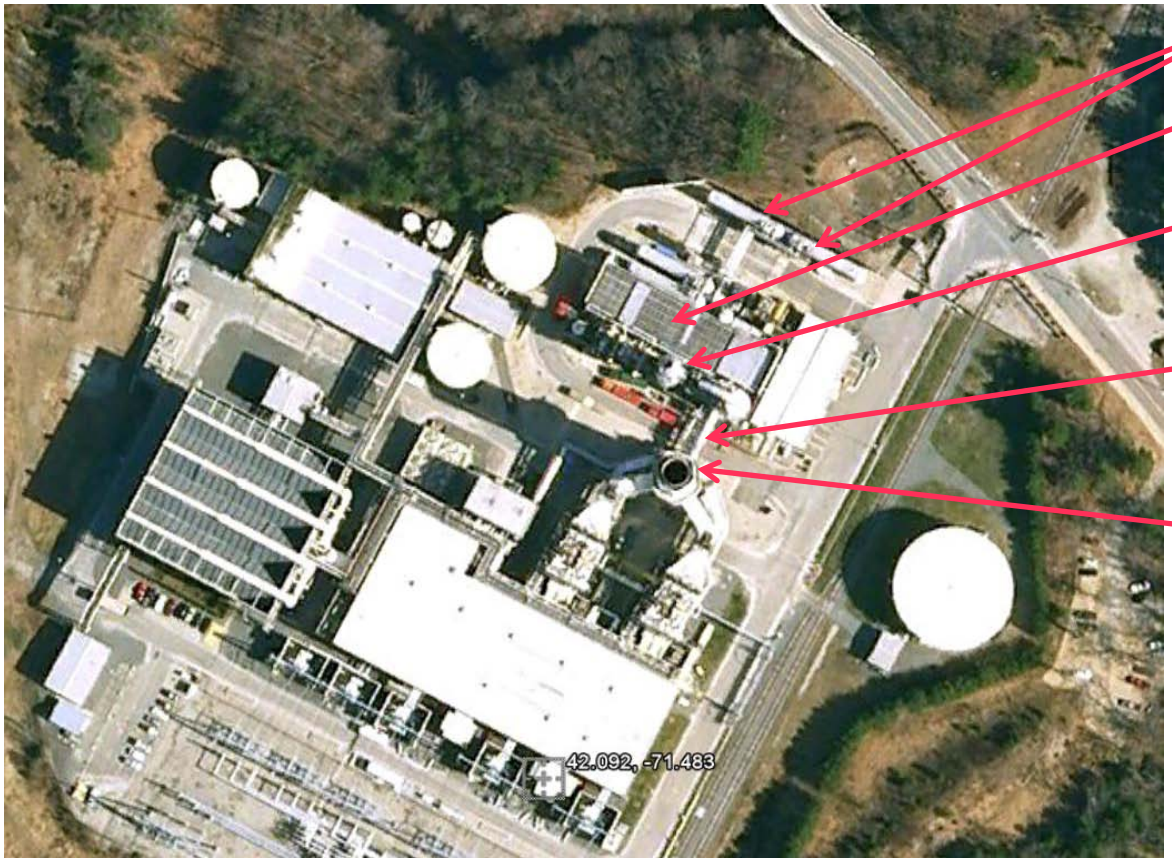
Largest CO_2 Capture System Ever Operated on a Coal Power Plant

- 400,000 ton/yr CO_2 from 100 MW Lubbock Power & Light power plant
- Operational 1983-1984 for EOR Floods
- Dow Amine Technology

Photo courtesy Gas Processing Solutions LLC

CO_2 Capture System on a Natural Gas Combined Cycle Plant – Bellingham, Mass.

Photo from Google Maps



Tanks for storing liquid CO_2

Fin-fan coolers for capture system

CO_2 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

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Southern-MHI CCS Demo

Project Overview

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

- **MHI KM-CDR advanced amine CO_2 combustion capture**
  - ~25-MW_e demonstration at Alabama Plant Barry in AL
  - ~500 tonnes-CO_2/day
  - Capture started in June 2011; over 200,000 tonnes captured so far
  - Injection is occurring in the Citronelle dome ~19 km away and started in August 2012; goal of 100,000 tonnes reached in 2013
  - Operation will continue through September 2014 followed by three years of monitoring the stored CO_2
- **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 US Dept of Energy

Large CO_2 "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

All the current large-scale CCS projects use CO_2 for Enhanced Oil Recovery (EOR)

1. **Weyburn EOR** – CO_2 from coal gasifier in ND, 2.8 million ton/yr
2. **Shute Creek EOR** – CO_2 from natural gas processing, 7 million ton/yr
3. **Enid EOR** – CO_2 from fertilizer production, 0.7 million ton/yr
4. **Val Verde EOR** – CO_2 from nat. gas processing, 1 million ton/yr
5. **Century Plant EOR** – CO_2 from nat. gas processing, 8 million ton/yr
6. **Port Arthur EOR** – CO_2 from steam methane reformer (US DOE project), 1 million ton/yr

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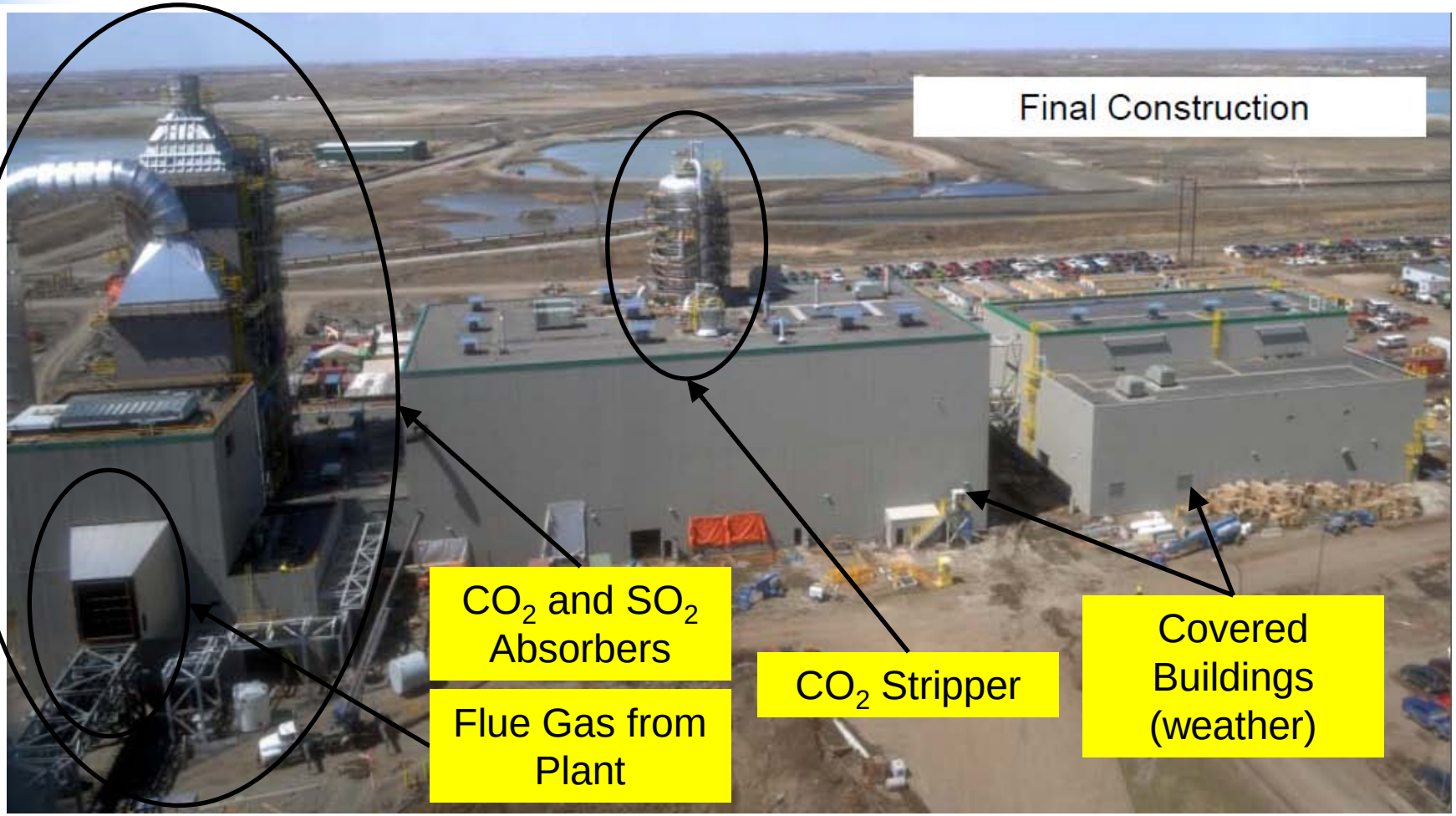
Starting up in 2014-2015

Map from Global CCS Institute

- **Boundary Dam:** 90% CO_2 capture retrofitted to 150 MW coal power plant, ~1 million tons CO_2 per year for EOR
- **Kemper County:** new 582 MW IGCC with ~65% CO_2 capture, ~3 million tons CO_2 per year for EOR

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

Boundary Dam

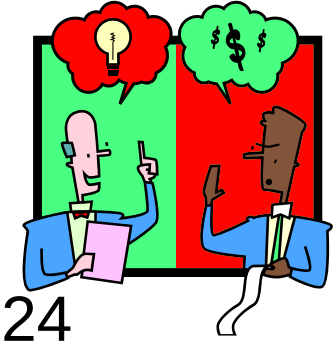


Used with permission from SaskPower

Mississippi Power's Kemper County IGCC Mid-2013

Photo courtesy of Southern Company

CCS Demonstrations Are Expensive



- SaskPower's Boundary Dam project's budget is $1.24 billion for 110 MW net or ~$11,000/kW
  - Cost includes upgrade of boiler and steam turbine as well as the CO_2 capture system
  - Canadian federal government provided $240 million subsidy
  - SaskPower has indicated that a second project would be 30% less expensive
- Mississippi Power's Kemper County IGCC has reached $4.2 billion or ~$8000/kW "total project cost"
  - Estimated cost at beginning of project (April 2010) was $2.4 billion – current cost is 167% of that estimate

The View from Australia

- "Love-Hate" Relationship with coal
- Lack of growth in power demand means no one is building new power plants, so little opportunity for demonstrating advanced coal technology 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)
  - Three proposed IGCC projects have died – high costs, lack of proven CO_2 storage were partly the cause
- Desire by coal-rich states to find new markets for their coal
  - Victoria is investigating opportunities to produce exportable chemical and dried brown coal products from its huge brown coal resources.

The View from Germany

- ~10 GW of new coal-fired power plants have been built this decade
  - Role of natural gas in power has declined
- "It is illegal to have a CCS project in Germany" – Lars Stromberg, former VP of R&D for Vattenfall
  - You cannot legally inject CO_2 under German soil
- No Nukes!
- Strong subsidies for wind & solar have driven up the retail price of electricity to three times USA price

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 CO_2 storage will occur offshore
  - At least one project looking at feasibility of EOR offshore
- Proposed limit of 450 kg CO_2/MWhr for new power plants

The View from Canada

- CO_2 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% CO_2 capture
- Alberta's ambitious CCS demo program has encountered difficulties
  - TransAlta's Pioneer Project was canceled, $800 million subsidy & $15/ton CO_2 emission "tax" not sufficient, Shell Quest oil sands upgrader a "go"
- Ontario moving forward with phasing out coal power

The View from Japan

- Short-term – use LNG and quickly add gas turbines to overcome loss of nuclear power
- Longer-term – nuclear power may be allowed to play a more limited role in supplying electricity
- Coal power may also increase
  - One IGCC is under construction and two more have been announced
  - Osaki “CoolGen” IGCC+CCS project is only planned large-scale CO_2 capture project
  - CO_2 storage may require ocean transport to reach suitable storage sites

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 CO_2 "solution" for today
  - Goal of building 700ºC USC demo plant has been announced
  - May include CO_2 capture for enhanced oil recovery in next 5-year plan

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 700ºC steam conditions
  - Will start testing components in existing power plant
- No plans for CCS demonstration but ~$1/ton tax on coal is funding “low carbon technologies” including renewables

Summary of Issues Impacting Coal Power Around the World

- Several countries now proposing CO_2 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 CO_2
- 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 low emission coal power technologies, more collaboration is needed among the OECD nations and between OECD nations and the rapidly growing economies of the developing world
  - The developing economies want new coal power plants but are unwilling to pay extra for advanced technologies
  - Developed countries may be willing to pay extra, but do not need new coal power plants
  - We all need to find secure places to store captured CO_2

Together…Shaping the Future of Electricity