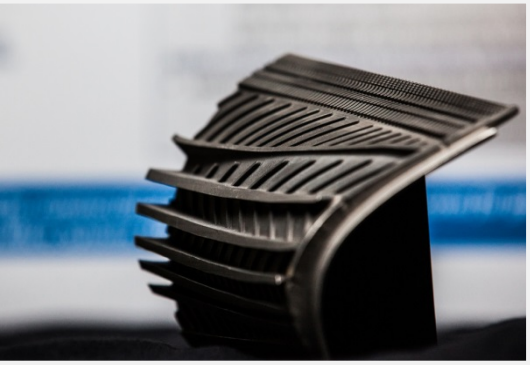
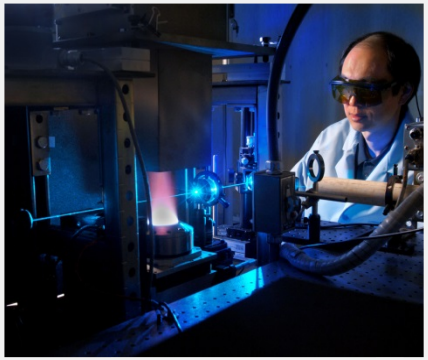
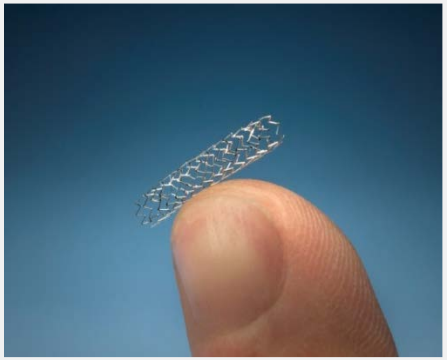
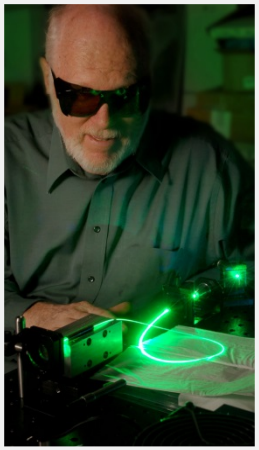
Driving Innovation ♦ Delivering Results



Coal-Hybrid Power Systems for the Future

Robert E. James III, Ph.D., Thomas J. Tarka, P.E.

US DOE NETL – Strategic Energy Analysis & Planning Division

December 9, 2015

DOE/NETL-2016/1753

U.S. DEPARTMENT OF ENERGY | National Energy Technology Laboratory

Coal – Don't Lose Hope

Value of Developing Coal Energy Technologies

- Cheap & Inexpensive: Coal prices historically low and stable over time
- Ease of Transport & Storage:
  - Spills and explosions a non-issue, multi-modal transport infrastructure in place
  - Multi-month stockpiles are the norm (not the case for natural gas and biomass storage)
- Good Backstop Fuel: Easily used in other solid fuel energy systems
- Burgeoning Use in Developing Nations:
  - Developing nations are expanding coal use as they industrialize
  - High efficiency technologies can dramatically reduce long-term emissions growth

What is the Path Forward?

- Identify pathways for coal to compete on cost and emissions basis
- Pathways must enable expanded use of renewable energy
  - Support and even leverage intermittent nature of certain renewable technologies
  - Bring down the cost of large scale integration

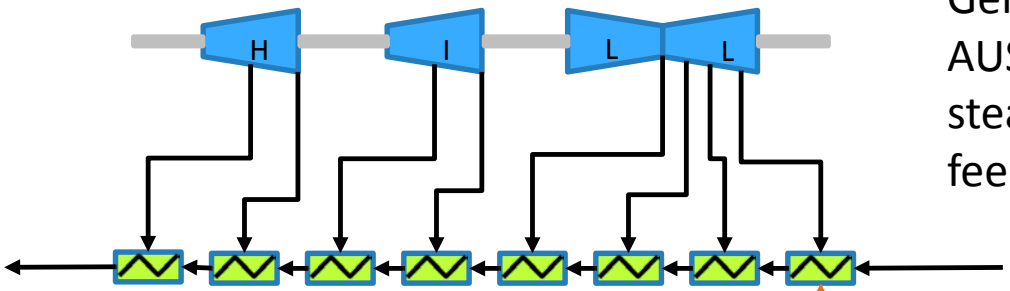
Pathways to Future Coal Usage

- **New Coal Power Technologies**
  - High efficiency, next-generation conversion pathways
  - Carbon, Capture, and Storage/Utilization Pathways
- **Hybrid: Novel Energy Systems**
  - Integration of renewables: thermal or electrical integration
  - Integrated energy storage: reduces emissions, leverages intermittents
- **Hybrid: Multi-Fuel Operation**
  - Enable feedstocks which are otherwise constrained due to cost, availability, or price volatility
  - Coal acts as the "flywheel" or enables economies of scale while lower-carbon fuel provides emissions benefits
- **Hybrid: Diverse Product Slate**
  - Combined Heat and Power (CHP)
  - Poly-generation of electricity and higher value products (chemicals, fuels)

Coal Hybrids: Selected Pathways

- **Novel Energy System: Solar Feedwater Heating**
  - Might want to add sub-bullet descriptions here
- **Novel Energy System: Integrating Intermittent Resources**
  - Should this be all renewables? I.e. geothermal and hydro too?
- **Diverse Product Slate: Combined Heat and Power (CHP)**
- **Feedstock Flexibility: Co-Firing Biomass**

Solar Thermal Feedwater Heater



General SC, USC, AUSC coal plant steam turbine feedwater schematic

Feedwater Heating
- No steam bleeds
- Increased Power Output

Solar Thermal Feedwater Heater

Technology Overview:

Integrates concentrated solar thermal energy to heat up feedwater sent to the boiler in a thermal power plant.

Status: *Demonstration Scale*

- **One domestic demonstration occurred in Colorado starting in 2010 but the entire plant was shut down in 2012**
  - Project Cost: $4.5 million
  - Designed to add 1 MWe of output to a 49 MW_e plant
  - Project designed to run for 1 year

Potential Impact: *Increased Efficiency or Peak Output*

- **Analyses in the literature point to efficiency improvements of 3.6 to 7.1%, reducing GHG emissions and coal consumption**
- **System can also be configured to boost peak power generation**

Integrating Intermittent Resources

Technology Overview:

Integrates intermittent resources such as photovoltaic solar power or wind energy into a coal power plant.

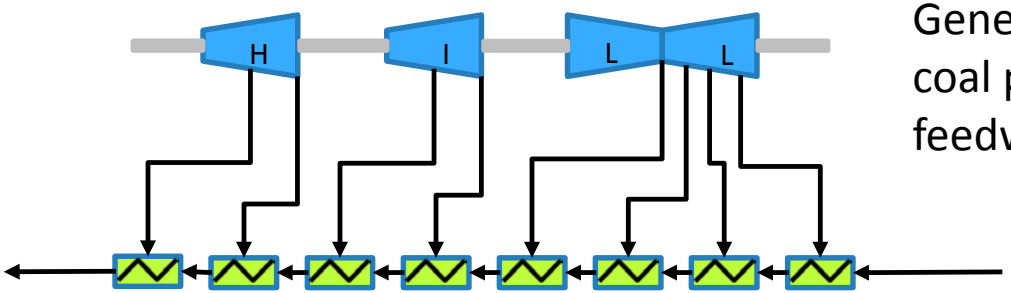
Status: *Area of Active Research, Pilot-Scale Ready*

- **Screening study underway evaluating numerous pathways**
  - Meet all or a portion of auxiliary loads with renewable resources
  - Reduce cycling needs by integrating renewable backed electrical or thermal energy storage

Potential Impact: *Increased Efficiency or Peak Output, Lower Costs*

- **Potential to increase efficiency (and emissions) by obviating auxiliary loads**
- **System can also be configured to boost peak power generation**
- **Reduce costs associated with load following and cycling via storage**

Coal Combined Heat & Power



General SC, USC, AUSC coal plant steam turbine feedwater schematic

- Heat transferred via steam or other transfer fluid
- Return fluid is recycled back to plant

City/District/Region heat load

Combined Heat & Power (CHP)

Technology Overview:

Recovers waste heat for use in heating or other processes from electricity generation process.

Status: *Commercial*

- **Common in the past for integrated campuses**
  - Colleges, small cities, government or industrial facilities
  - Some of these plants still exist
- **New CHP plants being built worldwide, with Denmark as a leader**
  - Units which began firing on coal are now being converted to biomass
  - Coal still used as baseline or backup fuel (along with gas or oil)

Potential Impact: *Increased Efficiency and Reduced Emissions*

- Greater than 90% of the energy in the fuel can be utilized
- Substantial opportunity for US cities or new developments
- Ongoing R&D in the technologies which utilize waste heat

Coal Material Feed Hybrids

- **Looking at materials to co-fire with coal**
- **Offers benefits of carbon offset or higher heat content**
- **Material Feeds could consist of**
  - **Natural Gas**
  - **Biomass**
    - » Short Rotation Woody Crops
    - » Switchgrass
    - » Corn Stover
    - » Other opportunity crops
  - **Waste**
    - » Municipal solid waste
    - » Landfill waste
    - » Other Lo/Hi heating value waste

Coal Power Hybrids

- **Renewables working in a supporting role with the Coal Plant**

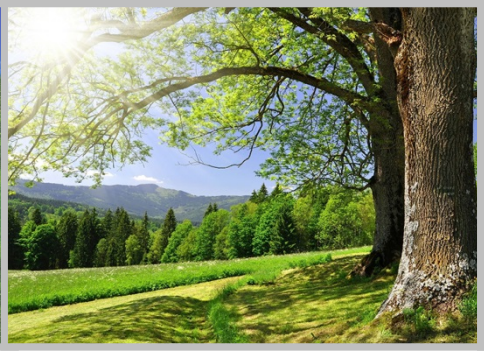
- **Operation of the renewables will enable**
  - Excess baseload power generation, boosting output MWe, or
  - Balance of plant electric loads, increasing net output of coal plant

- **Technologies of interest**
  - Solar PV
  - Wind
  - Hydro
  - Geothermal
    - Power
    - Heat for FWH if available at coal plant site

For More Information, Contact NETL

the ENERGY lab

Delivering Yesterday and Preparing for Tomorrow



Backup slides

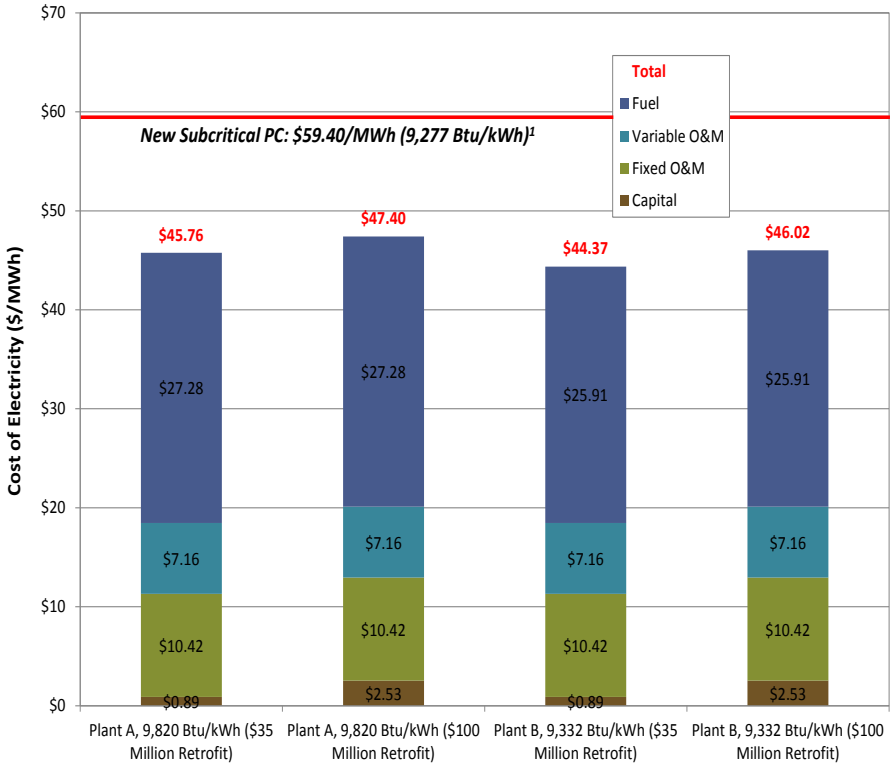
Agenda

- **Coal – Don't lose hope**
- **Pathways to Future Coal Usage**
- **Pulverized Coal Power Plant with**
  - Thermal Integration
    - Solar Thermal
    - Combined Heat and Power
  - Material Integration
    - Biomass
  - Power Integration
    - Renewables
- **Emissions Impacts**
- **Economic Impacts**
- **Conclusions**

Economic Impacts

Retrofit costs

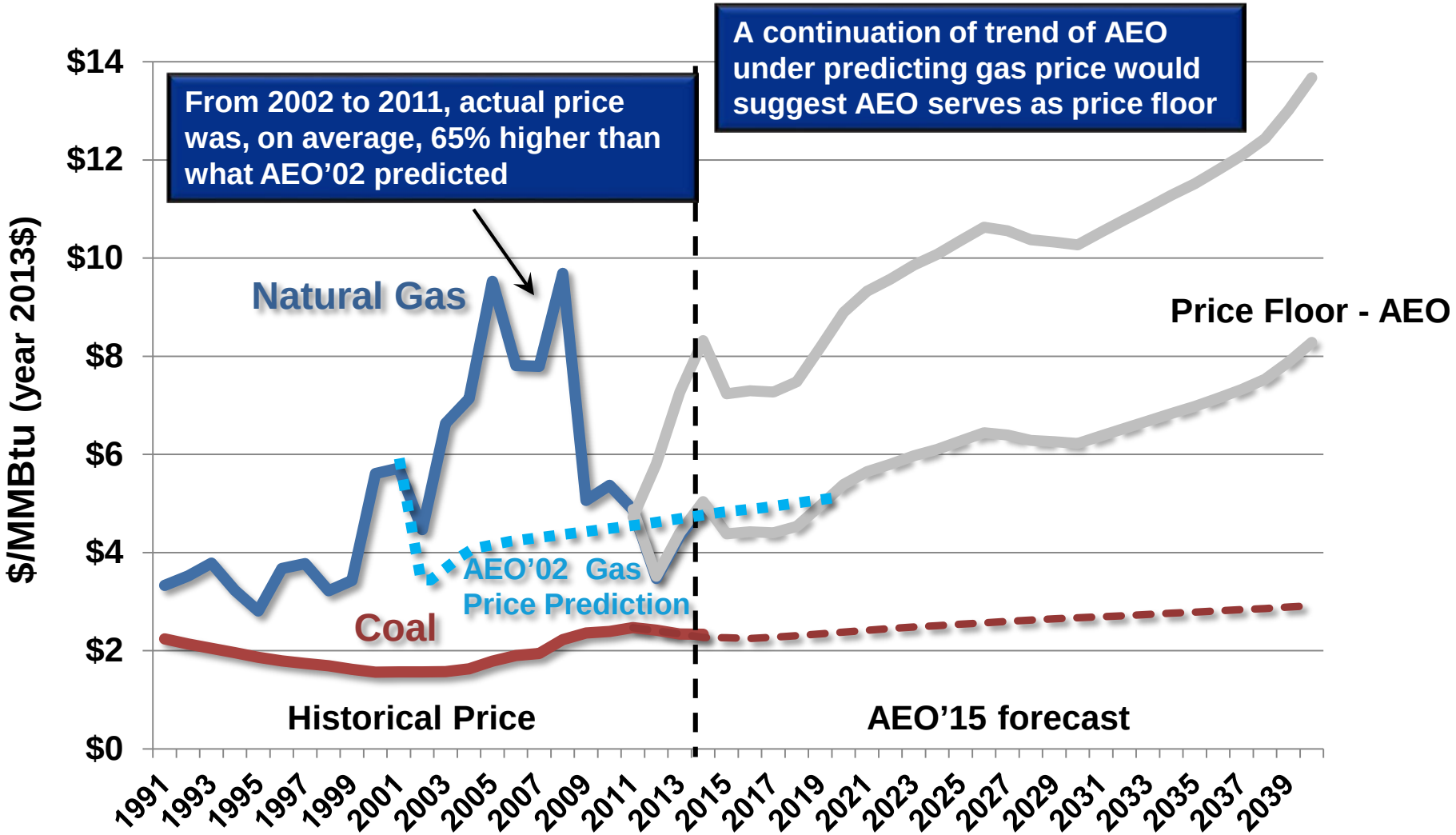
- Varied from $35-100M
- SA FWH system showed lower COE for both plant sites
- Tripling of retrofit costs did not overly affect COE
- The only results differences were for Capital and Fuel
  - Capital due to Solar Farm
  - Fuel due to transport distance



Performance & Emissions Impacts

- **Options for Improving the Efficiency of Existing Coal-Fired Power Plants**
  - 4/1/2014, DOE/NETL-2013/1611
  - Solar assisted (SA) feedwater heater (FWH) on sub-critical coal plant
  - Two plant locations:
    - Plant A - Phoenix, AZ
    - Plant B - Indianapolis, IN
  - Both locations:
    - 550 MW subcritical
    - 350,000 m^2 parabolic trough solar collection field
      - 710,000 m^2 for entire plant
    - 113,000 kg/hr extraction steam to last stage, high pressure FWH replaced by SA FWH
  - Performance
    - Plant A
      - 34.7% HHV (+2.4% points)
      - 7.1% emissions reduction
    - Plant B
      - 36.6% HHV (+1.4% points)
      - 3.6% emissions reduction

Coal and Natural Gas
Price History and Forecasts

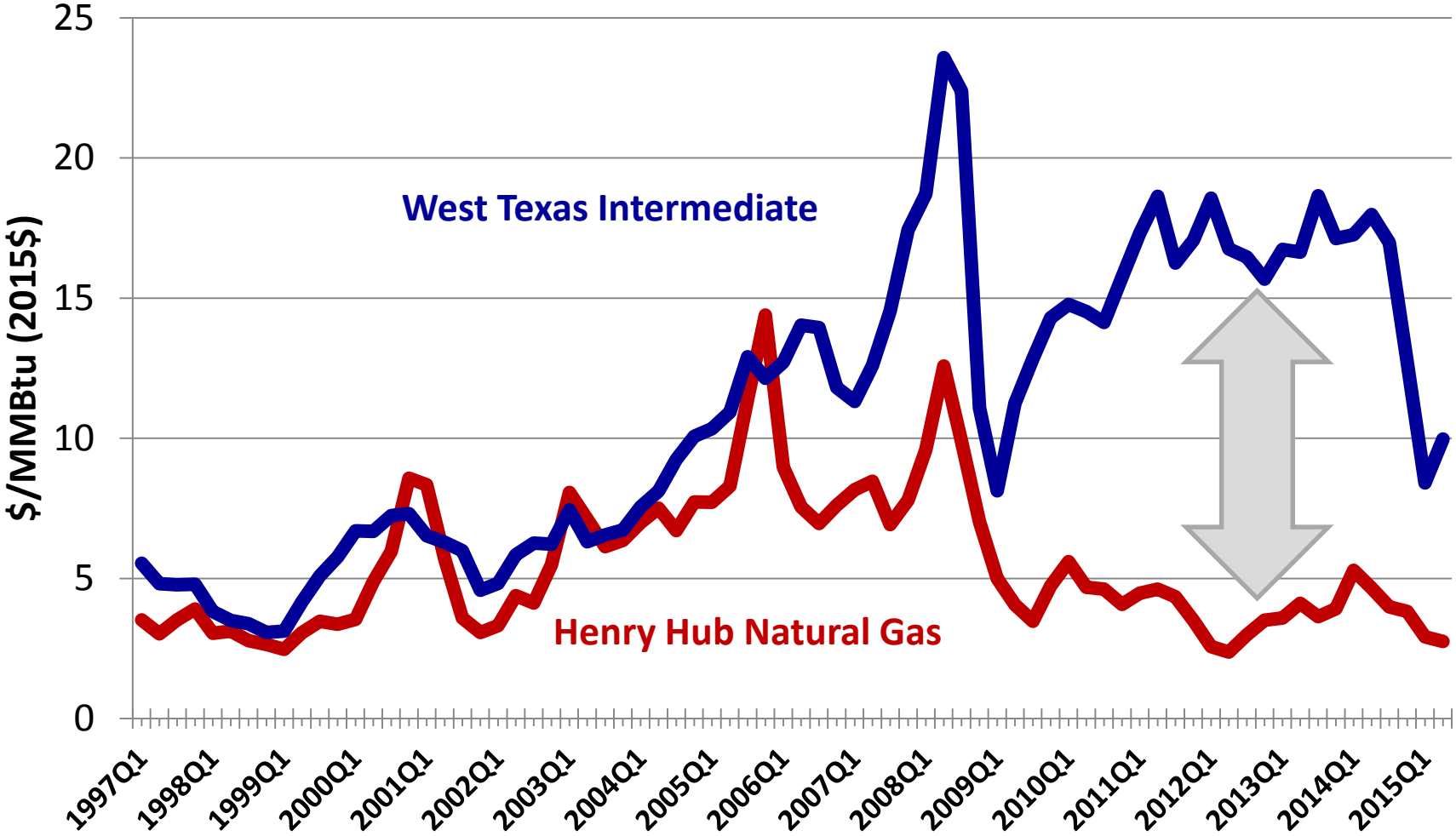


*Electric Power Sector prices

Sources: EIA, Monthly Energy Review; AEO 2015; AEO 2002

Historic Natural Gas & Oil Prices

Figure: WTI Spot Price and Henry Hub Spot Price Diverge



Source: *EIA, Short Term Energy Outlook, Data through 2015Q2*