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Future Role of Natural Gas Fired Power Generation with CCS

US Energy Association

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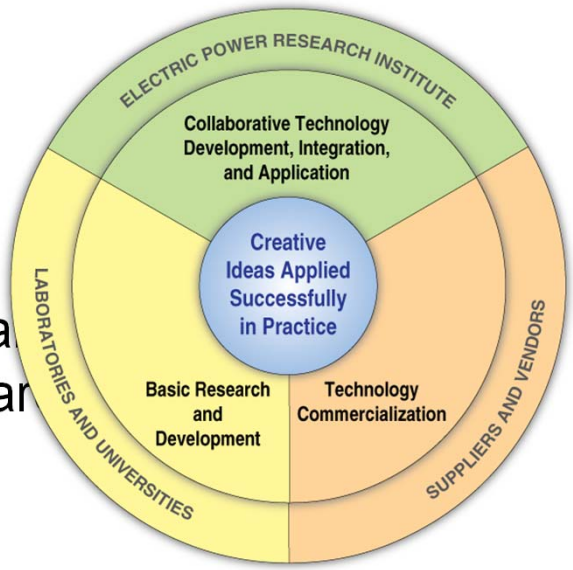
EPRI Overview



Mission

- Assure long-term availability of affordable, reliable, a environmentally responsible electricity through resear development and demonstration.

Key Facts

- 450+ participants in more than 30 countries
- EPRI members generate approximately 90% of the electricity in the United States
- ~$380M/year funding; international funding ~25%
- Non-profit 501(c)(3), independent, collaborative R&D institution

Power Sector Policy Drivers

- CO_2 emissions reduction
- Existing limits(e.g. SO_x, NO_x, Hg, thermal pollution)
- Water availability
- Environmental impact of renewables (e.g. avian, bats)
- Policy-driven technology choices (e.g. renewables)

Power Sector Technical Drivers

- **Meet demand**
- **Maintain reliability**
- **Minimize cost**
- **Recognize long lead times for technology deployment.**
- **Hedge technology risks**

Natural Gas in the Power Sector

- Electric sector gas consumption
  - 2012: electric sector gas consumption ~36% of all US consumption
  - 2014 EIA AEO projection for 2040: electric sector gas consumption ~34% of total
- Growth in NG consumption in electric sector
  - 2011-2012: increased 22%
  - 2014 EIA AEO: projects 8% growth in electric sector gas consumption (2012-2040)
- Generation share
  - 2011: 21% of total generation
  - 2011-2012: 24% increase
  - 2012: 27% of total generation (196 TWh)
  - 2040: 31% of total generation

Natural Gas - Strengths

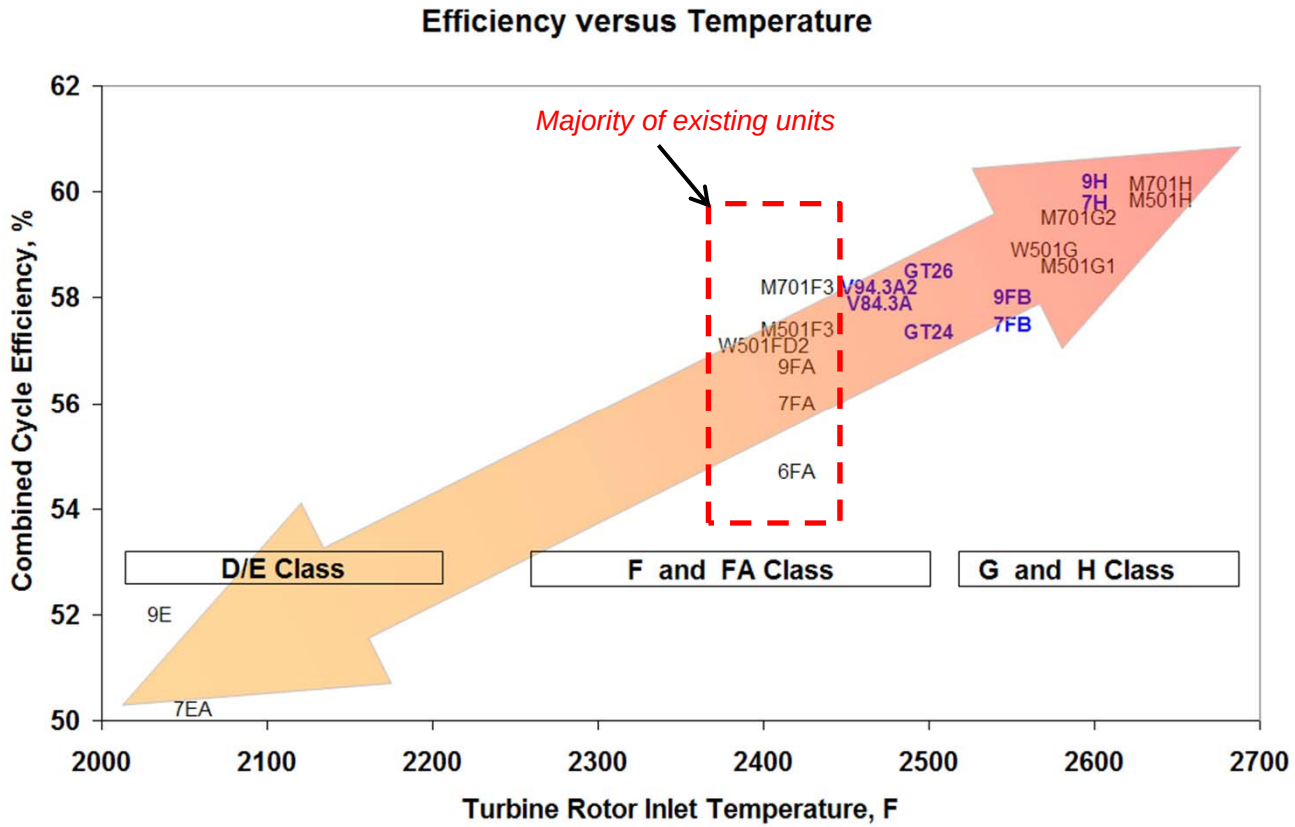
- Low NG prices make CTCCs attractive
  - breakpoint with coal regionally dependent, but generally in $4-$6/mmBtu range
- Reduced fossil plant emissions, including CO_2
- More operational flexibility compared to coal units.
- Smaller capital outlay for new capacity, can be constructed more quickly, lower water requirements compared to coal/nuclear
  - Often favored by PUCs
- Delays need to invest in more expensive options (e.g. coal, nuclear)
  - Gives lead time to develop more advanced technologies for other generation technologies.

Natural Gas – Challenges

- Dynamic combustion control
  - Balancing efficient operations w/emissions control
  - Harder if cycling
- CTCC cycling/HRSG reliability
  - Renewable portfolio standards + increasing role of demand response, end-use efficiency => increased cycling of CTCCs => performance, reliability issues
  - Heat Recovery Steam Generators (HRSGs) particularly important, problematic
- Assurance of supply, pricing
  - Potential growth of opposition to fracking.
  - Pipeline infrastructure expansion.
  - Pipeline operations and fluctuating power sector demand.
- Hedging against future high NG prices, price volatility, availability
  - Substantially increased demand for natural gas from the power sector could significantly drive prices up.
  - ~55% of electricity production costs for CTCCs = fuel cost => financial exposure in generation portfolio.

Trending Toward Higher Efficiency, Flexibility

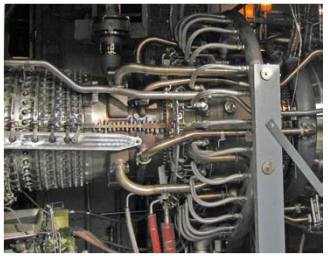
Improved Metallurgy, Coatings, Cooling, Aerodynamics, Size



R&D Focus Areas
Improved Efficiency, Flexibility, and Durability

- Fuel Flexibility
  - LNG and Natural Gas Variability
  - Lower NO_x and CO Emissions/Combustion Dynamics

- Operational Flexibility
  - Fast Startup and Shutdown
  - Frequent Cycling (Many Starts Per Year)
  - Part Load Efficiency and Low Load Emissions
  - Load Following and Frequency Control



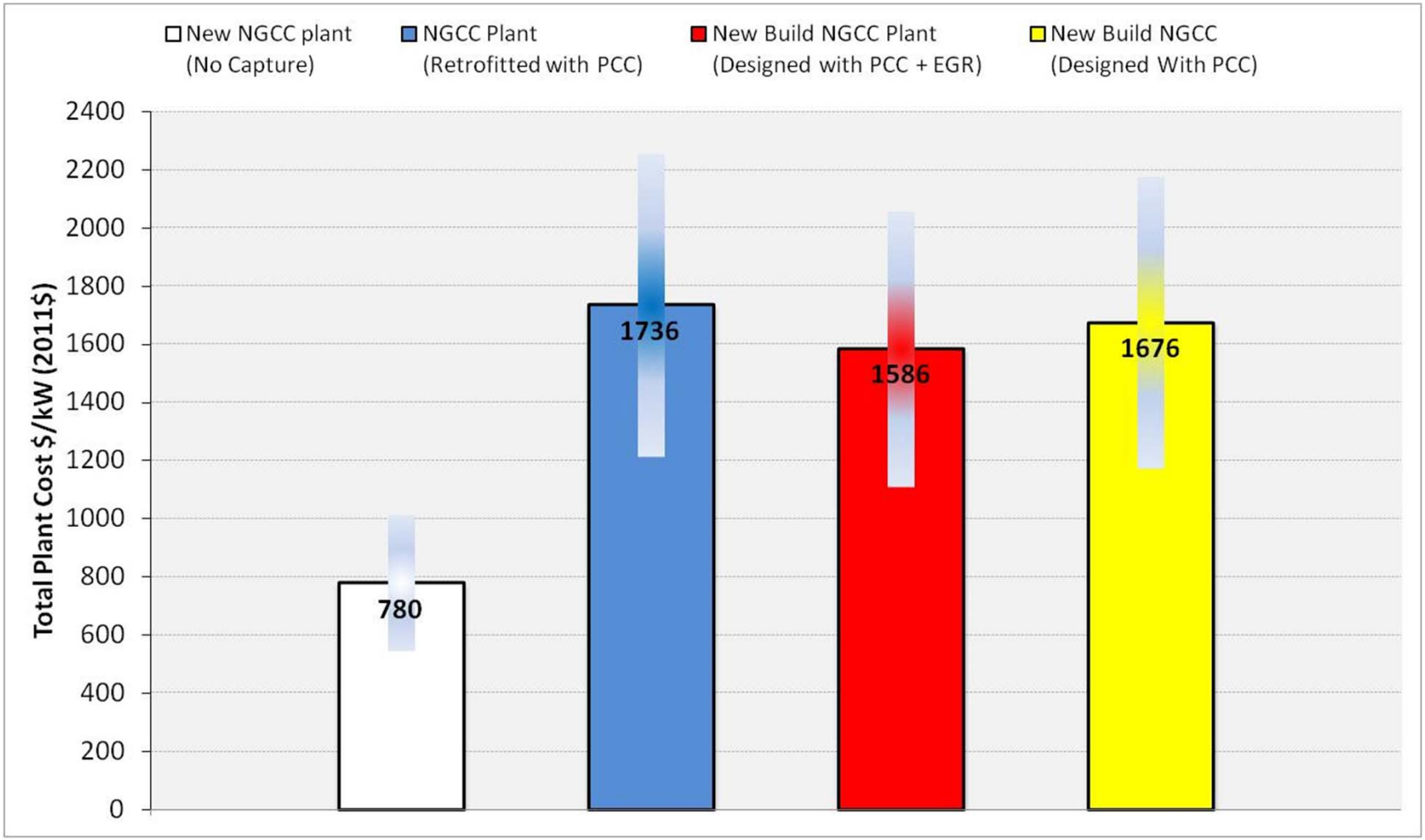
- System/Component Durability
  - Preventive Maintenance
  - Repair and Replacement Costs
  - Forced/Unscheduled Maintenance, Catastrophic Failures

R&D Focus – CTCC + CCS

- Evaluate the performance and cost impact of applying post-combustion capture (PCC) to today's NGCC
- Cases considered:
  - **Reference** 556-MWe (Net) base NGCC plant
  - **Retrofit** post combustion plant to base plant
  - **New build** NGCC plant designed with capture
  - **New build** NGCC plant designed with capture + exhaust gas recycle (EGR).
- PCC technology = advanced amine solvent (Aker Clean Carbon)
- Conclusions
  - Retrofitting is more expensive than integrated design.
  - Key sensitivities
    - Engineering, procurement & construction (EPC) contingency
    - Unit capacity factor
    - Overall levelized cost of electricity more sensitive to fuel cost than to avoided CO_2 cost

Total Plant Costs

NGCC with and without CO_2 Capture



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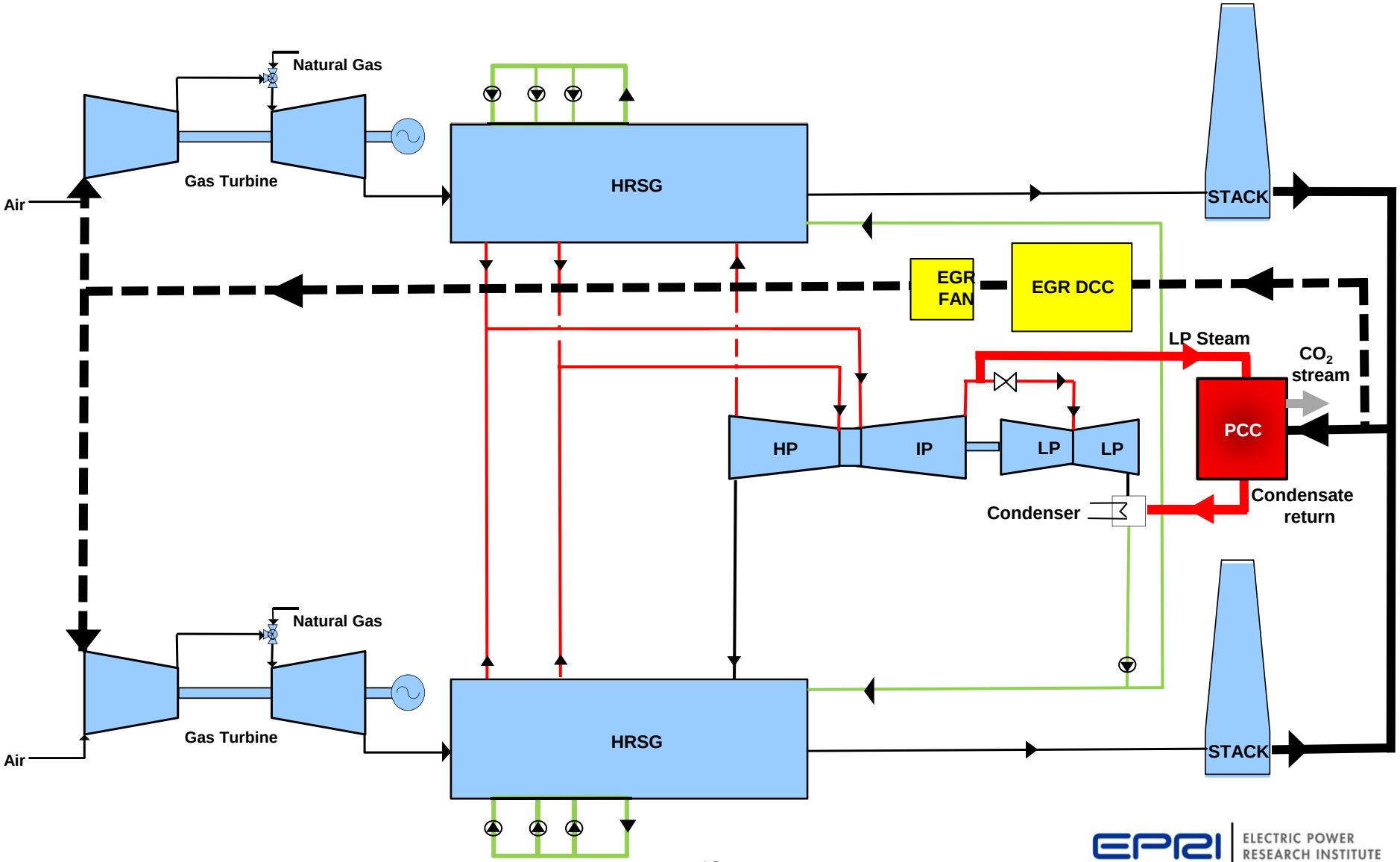
556-MWe (Net) NGCC Base Plant with PCC and Exhaust Gas Recycle



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Overview from Electricity Sector Perspective

• Environmental Policies		
– CO_2 policy	⟷	• *long-term problem*
– RPS/RES	⟷	• *good (backup); bad (competes)*
– Ash	↑	
– Env. impacts/renewables	↑	
– Water impacts	↑	
– HAPS	↑	
– Shale gas/hydro-fracking	↓	• *potential environmental issues*
• Hedge technology risk	⟷	• *good (diversity); bad (too much)*
• Capital cost/long development lead times	↑	
• Long-term demand growth	↓	• *expensive bulk energy*
• Load curve/capacity needs	↑	
• Grid reliability	↑	
• Minimizing electricity costs	↓	• *long term price volatility*

Key Takeaways

- NG is a key part of electricity sector, but drivers are diverse, creating both pros and cons for NG
- Cycling will become a larger issue with renewables, DG, end-use load mgmt. and efficiency.
- NGCC technology improving in efficiency, flexibility
- R&D issues associated with long-term reliability, maintainability.
- CCS for NGCC likely to be necessary in future.
- Diversified generation technology portfolio provides reliability, economic efficiency, operational flexibility, hedge against uncertainty in gas supply and cost.

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