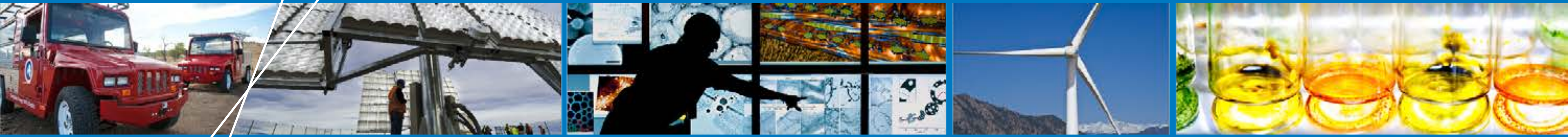
Flexible Coal: An Example Evolution from Baseload to Peaking Plant



"Innovations in Flexible Generation" Webinar

Jaquelin Cochran, Ph.D.

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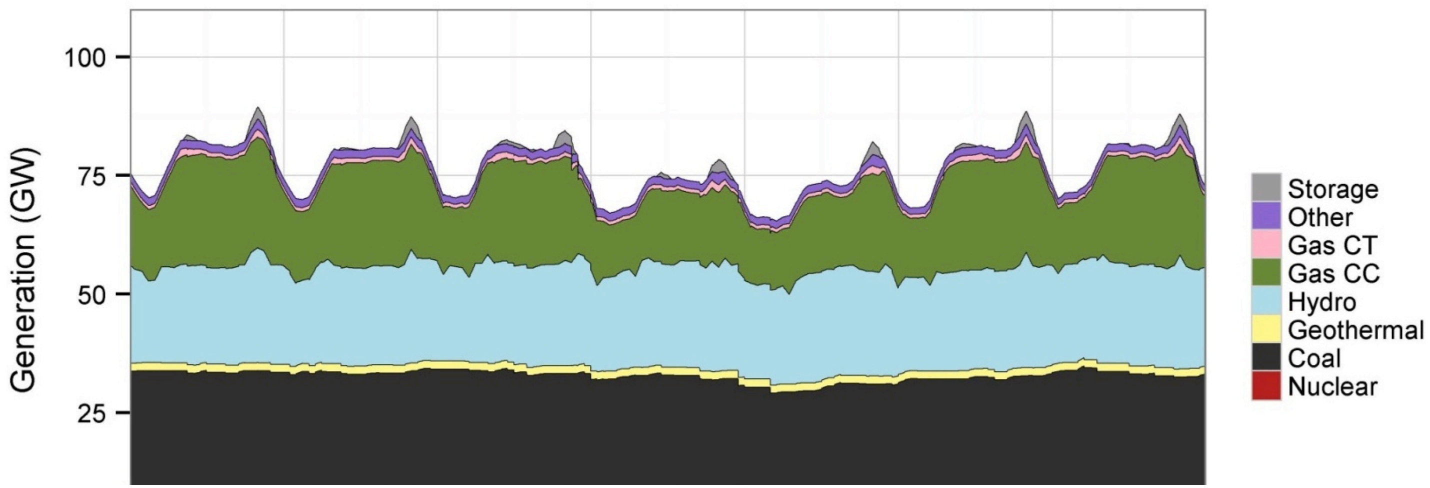
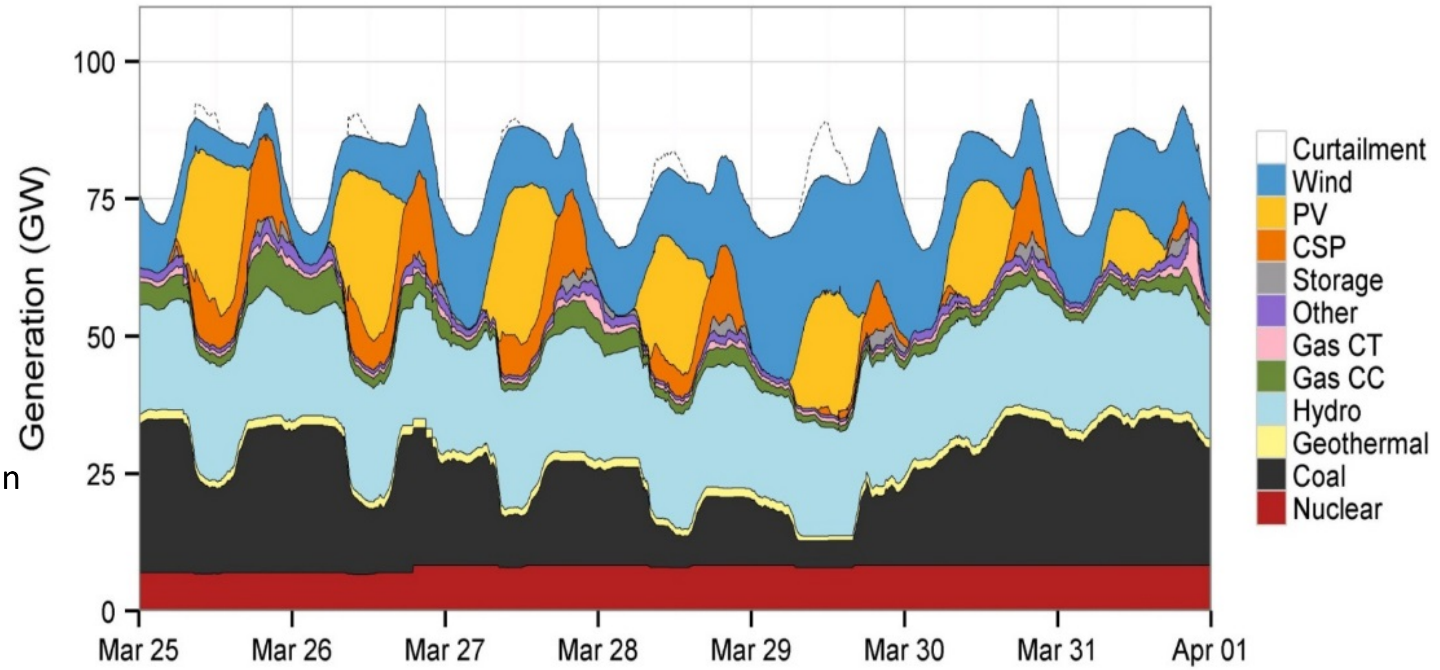
NREL/PR-6A20-62125

What are the impacts of cycling coal and gas?

0% wind and solar



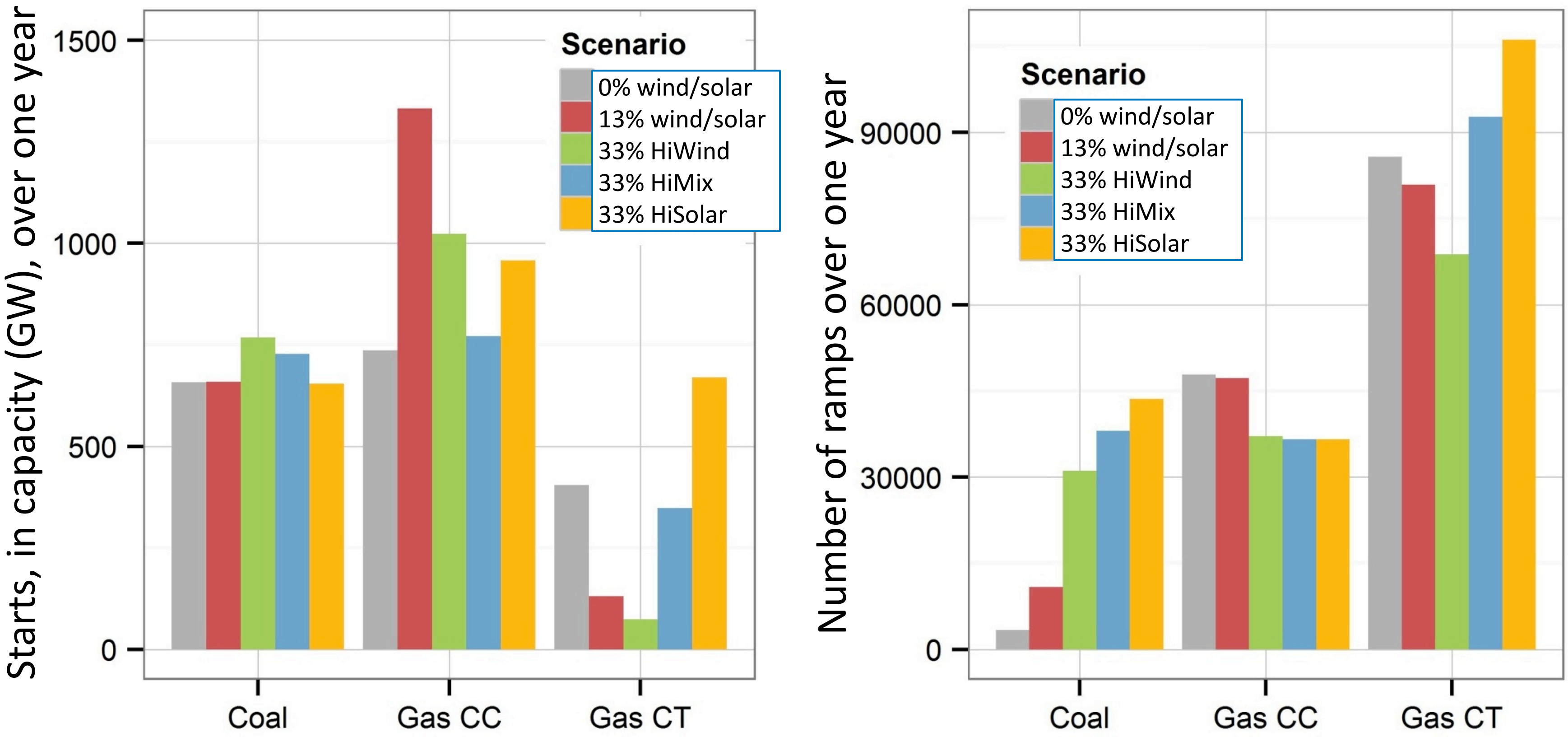
16.5% wind and 16.5% solar energy penetration



Generation dispatch for challenging spring week in the U.S. portion of WECC

Source: WWSIS Phase 1 (2010)

Coal ramping increases with wind & solar



Biggest cycling change is that coal units are ramped 10 times more in the 33% cases compared to the 0% case

Source: WWSIS Phase 2 (2013)
http://www.nrel.gov/electricity/transmission/western_wind.html

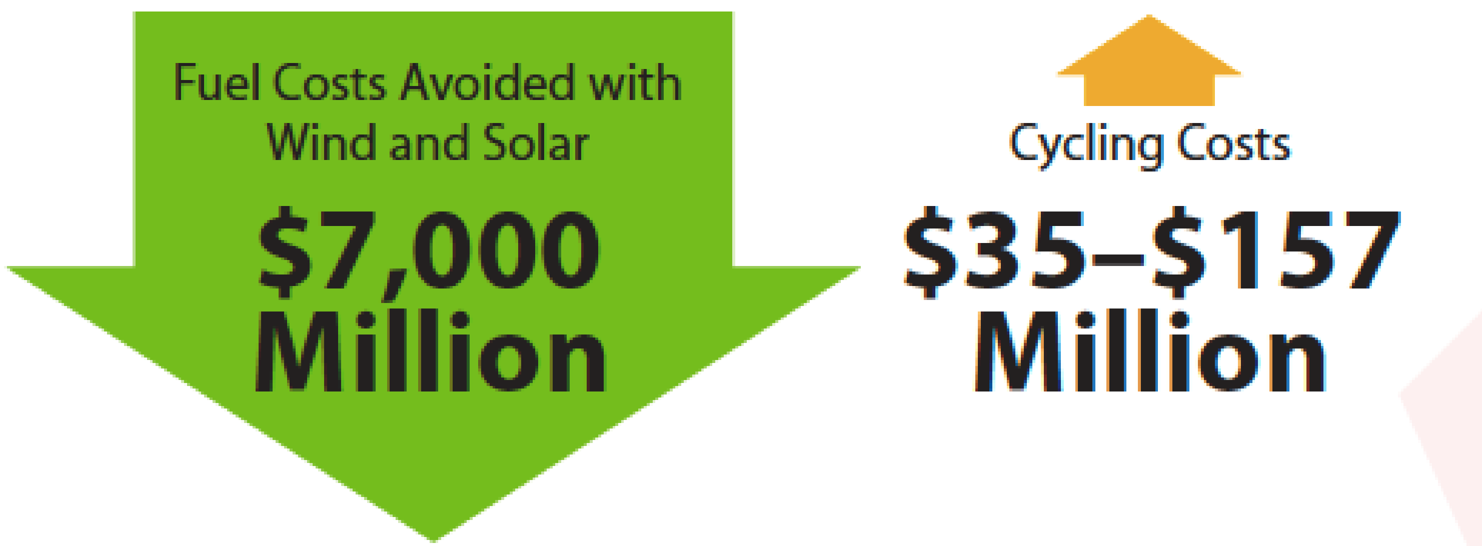
Emissions impacts of cycling are relatively small

	Emission Reduction Due to Renewables	Cycling Impact
CO_2	260–300 billion lbs 29%–34%	Negligible Impact
NO_X	170–230 million lbs 16%–22%	3–4 million lbs
SO_2	80–140 million lbs 14%–24%	3–4 million lbs

Source: WWSIS Phase 2 (2013)
http://www.nrel.gov/electricity/transmission/western_wind.html

From a system perspective…cycling costs are relatively small

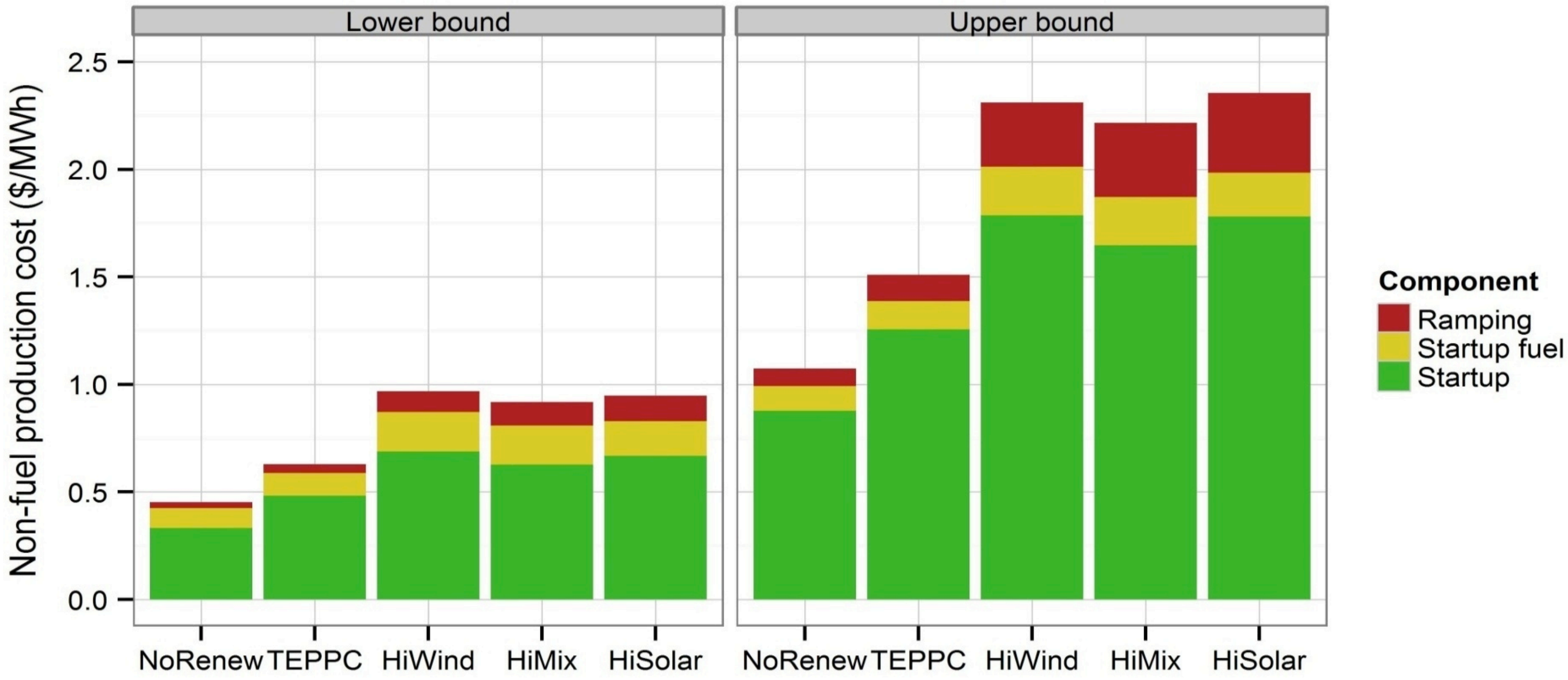
33% Wind/Solar Scenarios



Note: Capital costs for wind and solar are not reflected.

Source: WWSIS Phase 2 (2013)
http://www.nrel.gov/electricity/transmission/western_wind.html

Costs can be significant from generator perspective



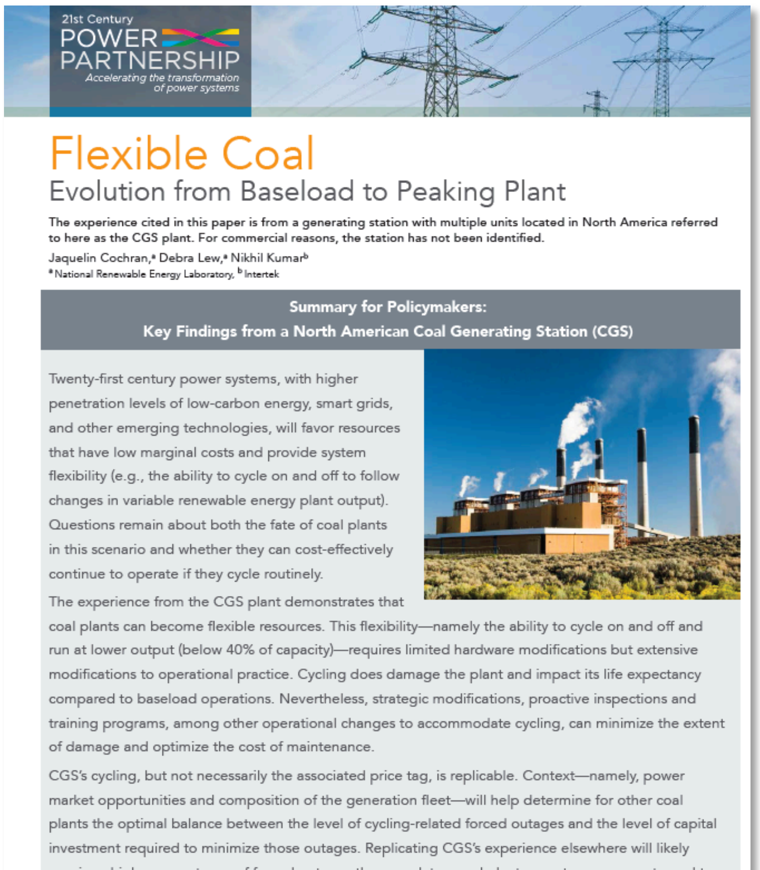
Fossil plant O&M increases by $0.5-1.3/MWh over no RE case

Source: WWSIS Phase 2 (2013)
http://www.nrel.gov/electricity/transmission/western_wind.html

Case study: Flexible Coal

How baseload plants can evolve to serve other system needs

Flexibility that helps increase RE penetration levels →



21st Century POWER PARTNERSHIP
Accelerating the transformation of power systems

Flexible Coal

Evolution from Baseload to Peaking Plant

The experience cited in this paper is from a generating station with multiple units located in North America referred to here as the CGS plant. For commercial reasons, the station has not been identified.

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Summary for Policymakers:
Key Findings from a North American Coal Generating Station (CGS)

Twenty-first century power systems, with higher penetration levels of low-carbon energy, smart grids, and other emerging technologies, will favor resources that have low marginal costs and provide system flexibility (e.g., the ability to cycle on and off to follow changes in variable renewable energy plant output). Questions remain about both the fate of coal plants in this scenario and whether they can cost-effectively continue to operate if they cycle routinely.

The experience from the CGS plant demonstrates that coal plants can become flexible resources. This flexibility—namely the ability to cycle on and off and run at lower output (below 40% of capacity)—requires limited hardware modifications but extensive modifications to operational practice. Cycling does damage the plant and impact its life expectancy compared to baseload operations. Nevertheless, strategic modifications, proactive inspections and training programs, among other operational changes to accommodate cycling, can minimize the extent of damage and optimize the cost of maintenance.

CGS's cycling, but not necessarily the associated price tag, is replicable. Context—namely, power market opportunities and composition of the generation fleet—will help determine for other coal plants the optimal balance between the level of cycling-related forced outages and the level of capital investment required to minimize those outages. Replicating CGS's experience elsewhere will likely require a higher acceptance of forced outages than regulators and plant operators are accustomed to;

- Coal plant that cycles on and off, up to twice daily
- Capital modifications critical

  But primary savings came from changes to operating procedures
- Flexibility comes at a cost—but costs can be minimized with strategic modifications and maintenance

Source: Cochran, Lew, and Kumar (2013) http://www.nrel.gov/docs/fy14osti/60575.pdf

Case study: attributes of flexibility at the plant

- Start up and shut down same day
  - Even twice daily (5-10am then 4-8pm)
- Load follow and run at minimum generation levels
  - 480 MW net capacity units running at 90 MW net
  - Down to 60 MW net (up to 6 hours) with gas support
- Provided automatic generation control
- Operated at sliding pressure (increases efficiency and flexibility at part load)

Case study: from baseload to peaking plant

- 1970's: Commissioned
- Intended to run at 80% annual CF
- Mid-80's: Nuclear came in lower on the dispatch stack resulting in cycling of coal (50% annual CF)
- 1980s: Extensive research on 2-shifting; modifications implemented
- 2000s: competitive market; initially operated at full output
- YET…significant forced outages due to latent damage from 1990s cycling
- Competitive market→incentive to operate flexibly (2 shift, min gen)

Photo from iStock 72283000

Experiences with cycling

Starts

	Average number of starts over life of unit
Cold start	523
Warm start	422
Hot start	814
Total	1,759

Recent Forced Outage Rates

Year	EFOR [%]
2002	14
2003	20
2004	33
2005	25.5
2006	22
2007-2009	16-17
2010	9
2012	20.5

Plant operators responded to changing market conditions. Decisions to modify the plant, replace parts, and lower EFOR were evaluated piecemeal, based on profit potential.

Cycling impacts

- **Thermal fatigue**, e.g., from cold feedwater entering boiler on startup, steam heating up, materials heating up at different rates
  - Boiler tube failures
  - Cracking in dissimilar metal welds
  - Tube cracks in condenser
- **Cracking** in generator rotors
- **Stresses** from changing pressure, e.g., turbine shells
- **Wear & tear** on cycling-only auxiliary equipment
- **Oxidation** from exposure to air on startup and draining
- **Corrosion** caused by O_2 entering system and changes to water quality (falling pH)
- **Condensation** from cooling → corrosion, water leakage, increased need for drainage

Foreign object damage in turbine fins (e.g., from oxides dislodging)

Photo: Cochran, Lew, and Kumar (2013)
http://www.nrel.gov/docs/fy14osti/60575.pdf

Modifications to minimize cycling impacts

Operating procedural changes

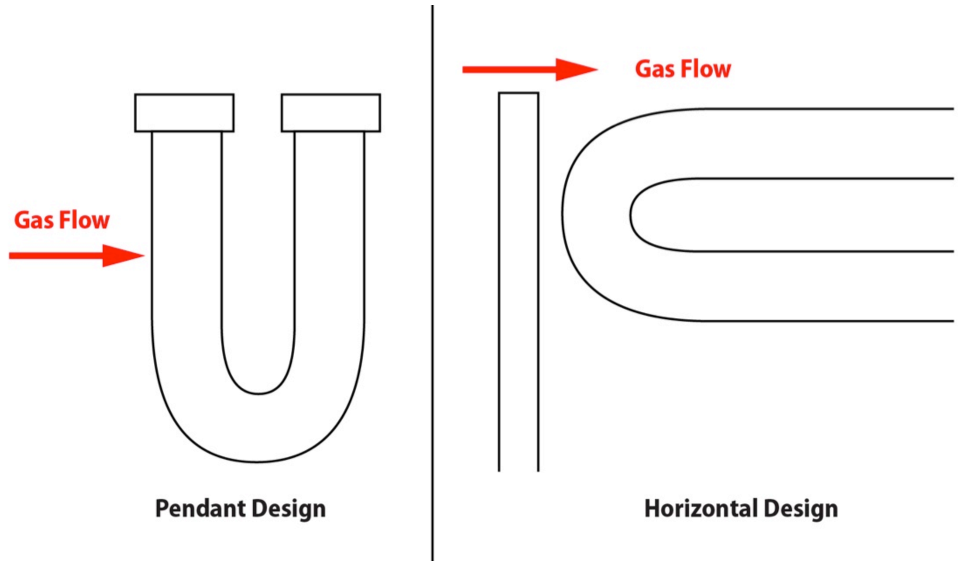
- Natural cooling
- Temperature monitoring of economizer inlet headers, turbine parts, etc.
- Changes to layup procedures
- Pressure part management
- Changes to boiler operating procedures
- Water chemistry maintenance
- Breaker maintenance
- Gap review with best practices

~90% of plant savings (post physical modifications) came from changes to operating procedures

Modifications to minimize cycling impacts

Physical changes

- **Boiler,** examples:
  - Added metal overlay to water walls to minimize oxidation
  - Replaced dissimilar metal welds
  - Strategically replaced corner tubes
- **Pulverizers** – converted water deluge system to steam inert
- **Turbines** – added drains, upgraded lubrication system
- **Rotors** – insulated key parts to reduce rotor cracking from rubbing
- **Condenser** – sacrificially plugged tubes at top of condenser due to low loads



Graphic: Lefton 2013

Note that plant had horizontal, not pendant, boiler designs and automated drains

Can my coal plant do this?

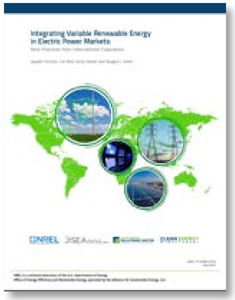
- **Physical distinctions**: boiler design is horizontal, improving drainage
- **Operating distinctions**: Much higher EFOR rates than most operators are comfortable with; tradeoff between maintenance costs and EFOR
- **Regulatory distinctions**: Can run plant without SCR up until SCR minimum generation level
- TVA is cycling coal because of cheap gas and lighter loads. e.g., 1420 MW Kingston plant:
  - More starts
  - More ramps
  - Increased $ for preventive and corrective maintenance

Conclusions

- Flexibility in plant operations is an increasingly desired service as RE penetrations increase
- Coal plant in this case study was modified to access this flexibility
- Key to success: changing operational practices; tolerance for higher EFOR rates
- Success also due to plant-specific factors, e.g., better design for drainage
- Coal can be operated flexibly—at a cost—but these costs can be minimized through rigorous inspection and training programs

Recently published analyses

21st Century POWER PARTNERSHIP



Integrating Variable Renewable Energy in Electric Power Markets: Best Practices from International Experience

Documents diverse approaches to integration of variable RE among 6 countries—Australia (South Australia), Denmark, Germany, Ireland, Spain, and the US (Colorado and Texas)—and summarizes policy best practices. ***[www.nrel.gov/docs/fy12osti/53732.pdf]***

Market Evolution: Wholesale Electricity Market Design for 21st Century Power Systems

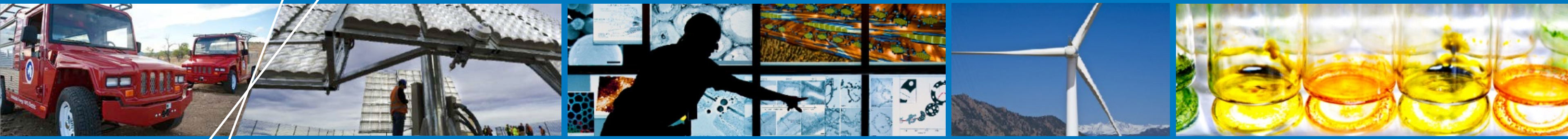
Reviews the international suite of wholesale power market designs in use and under consideration to ensure adequacy, security, and flexibility in a landscape of significant variable renewable energy. ***[http://www.nrel.gov/docs/fy14osti/57477.pdf]***

Flexibility in 21st Century Power Systems

Flexibility of operation—the ability of a power system to respond to change in demand and supply—is a characteristic of all power systems. Flexibility is especially prized in twenty-first century power systems, with higher levels of grid-connected variable renewable energy (primarily, wind and solar). ***[http://www.nrel.gov/docs/fy14osti/61721.pdf]***

Flexible Coal: Evolution from Baseload to Peaking Plant

This case study reviews how power plants intended to run at baseload can evolve to serve other system needs. The CGS case illustrates the types of changes that may occur in global power systems, especially those with legacy plants. ***[http://www.nrel.gov/docs/fy14osti/60575.pdf]***



Thank you!

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