Scenario Simulations of Potential Cost Savings from R&D in Sensors and Controls

Cross Cutting Program Review

NATIONAL ENERGY TECHNOLOGY LABORATORY

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U.S. DEPARTMENT OF ENERGY

Overveiw

- **Presentation of results to-date from a task performed by Argonne National Laboratory (Don Hanson and Dave Schmalzer), funded and managed by NETL**
  - Discussion of electricity generating unit damages from cycling operations
  - Overview of the EISM energy-market model used to project the impacts of continuing damage on units from cycling
  - Results from initial model runs
  - Next steps in integrating the inputs for R&D in sensors and controls

Operational Terminology

- **Heat Rate**
  - Btu/ kWh, operating, not test/design
- **Load following**
  - Operating between design (100%) and ~30%* design
- **Cycling**
  - Unit output to grid goes to zero
- **Creep (metallurgical)**
  - Time dependent deformation below tensile yield
- **Fatigue (metallurgical)**
  - Defect growth from cyclic changes in stress

* *Flexibility objective, generally requires some physical modifications*

Background on aging, cycling, and load following

Aging, cycling, and load following are not new

- Extensive literature back at least into the 1990's
- Pervasiveness of cycling and load following has grown
  - Renewable energy mandates
  - Low natural gas prices
  - Growth of NGCC capacity

- **Multiple projections anticipate increasing non-dispatchable generation impacting operation of CFPP**
  - EPRI, CAPUC, ERCOT, Argonne, others
  - ISO/RTO electricity market rules
  - Recent EPRI study examining ramp rates and operating modes to accommodate greater wind and solar generation capacity

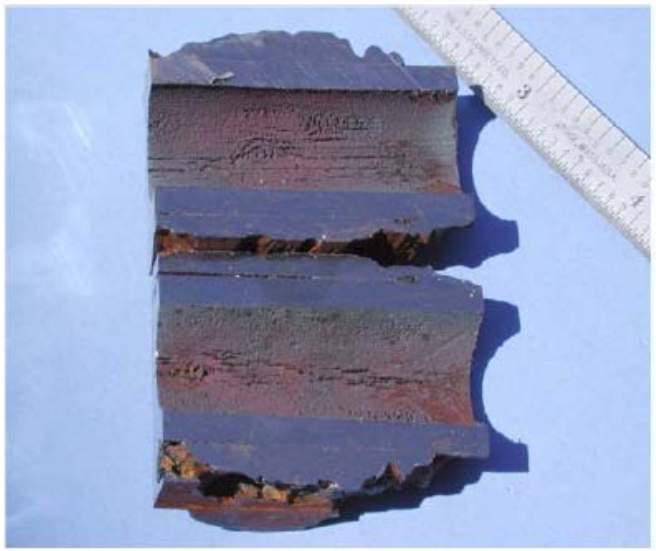
Operating issues, low load and cycling

- Configuration of coal mills, combustion air, and burners
- Balancing steam production, superheat, attemperation, reheat, boiler feedwater heating
- Maintaining NOx conversion, controlling NH3 slip, avoiding ammonium bisulfate deposits
- EPA reduction of startup, shutdown, malfunction waivers
  - EPA issued SIP revision call
  - Litigation briefs due Oct. 19, SIP revisions due Nov. 22

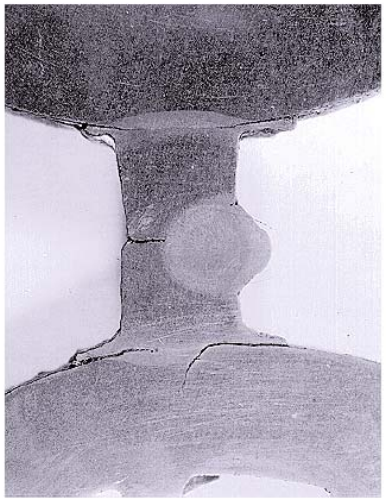
Known Physical Processes that Increase Heat Rate and Cause Forced Outages

- Wear of seals and turbine blades
- Fouling and deposition on heat transfer surfaces and steam turbine blades
- Aging of refractories and structural shells, particularly boilers
- Component failure from corrosion, fatigue, and creep
- Interaction of fatigue and creep under cycling and temperature swings

Boiler Material Failures



Waterwall web cracking

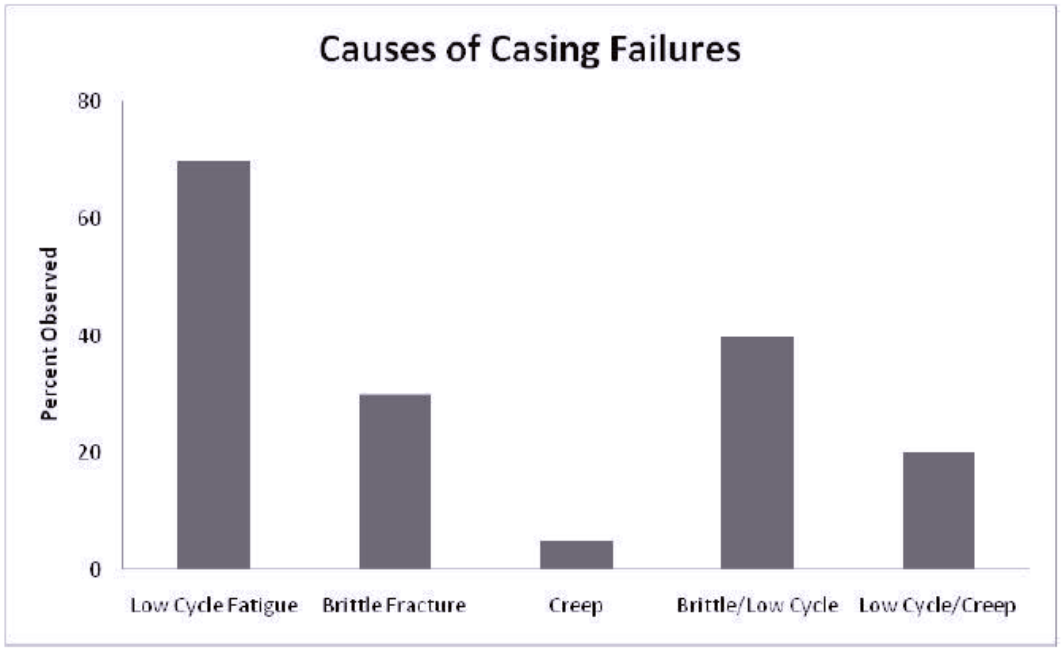


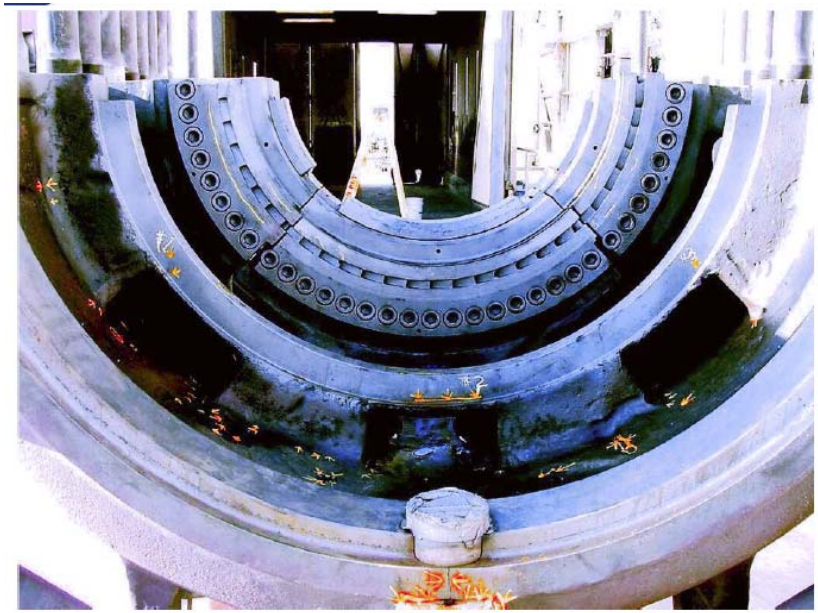
Boiler tube corrosion

Superheater tube attachment fatigue cracking

Source: Lefton, Power Plant Asset Management

Steam Turbine Failures





Source: Lefton, S., Power Plant Asset Management, Intertek AIM

Impacts of cycling on units

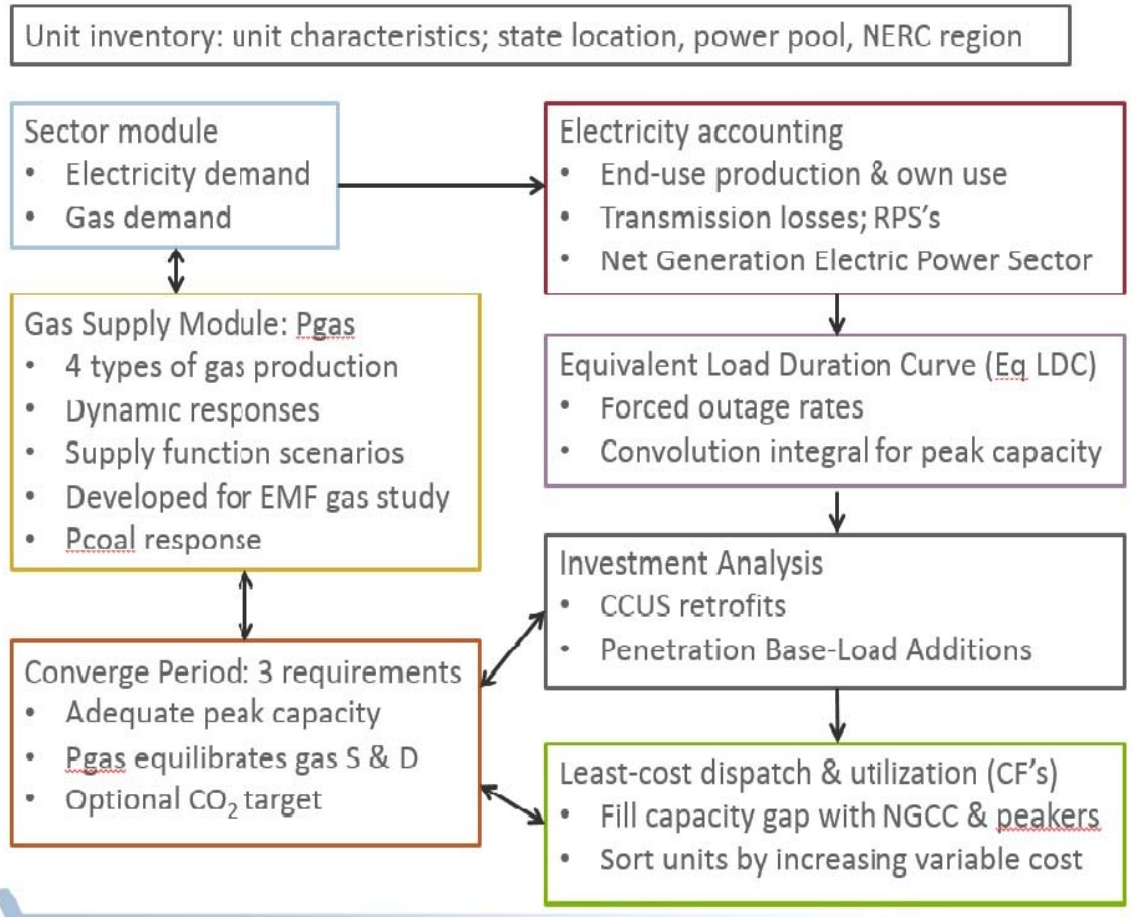
- Increased Operating and Maintenance costs,
- Lower efficiency, i.e., increased fuel consumption and emissions
- Loss of generating revenue
- Shortened remaining useful life due to accumulated damages (to be discussed further)
- Existing coal-fired power plants (CFPP) built in the 1960's were designed for baseload (24/7) operation
- These CFPP have limited tolerance for swings in operations

ESIM model overview

Modeling the techno-economic impacts of cycling

- The electric power sector component of the AMIGA Integrated Assessment Model
- Includes a unit inventory of existing power plants
- Dispatches existing and new coal/biomass fired units, NGCC units, and advanced units with direct gas combustion and CO_2 separation against load duration curves for six U.S. regions
- Dispatch order and capacity factors based on variable cost ranking, i.e., merit order (or some alternative, potentially more efficient criterion)
- Includes cumulative cycling damages resulting from low dispatch operation
- Compares scenario costs and investment requirements
- Includes a dynamic gas supply scenario model originally calibrated to EIA NEMS runs.
  - With higher and lower gas supply curve scenario shifts
- Upgraded object-oriented computer code implementation
- We modeled a Base Case and CO2 tax case to examine the impacts of cycling on existing units

Electricity Supply and Investment Model -- ESIM

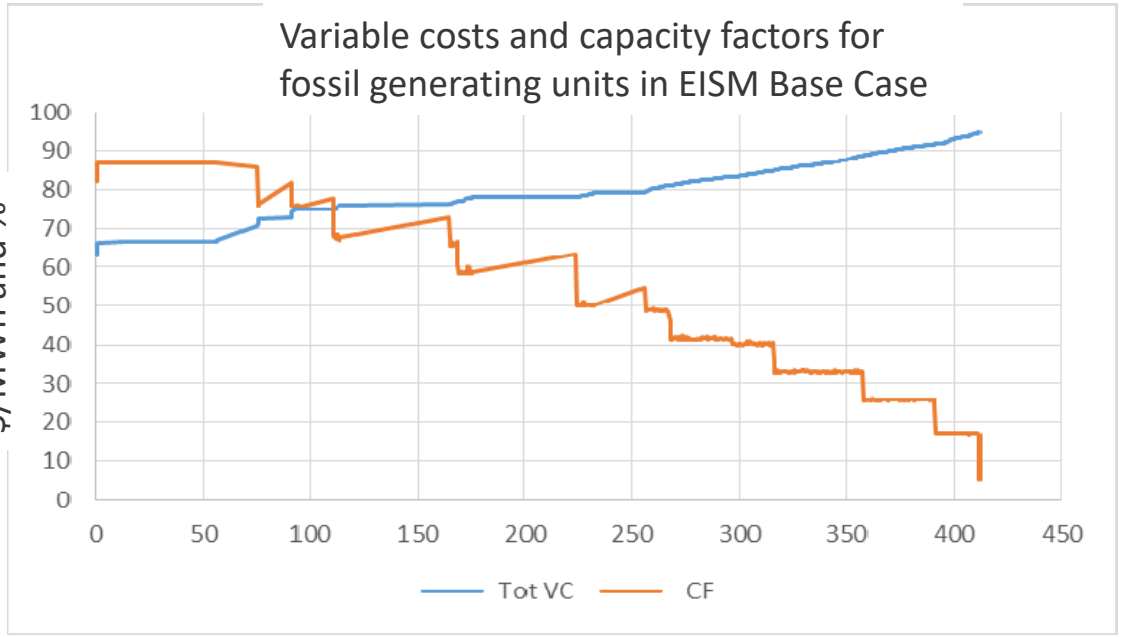


Advantages of EISM for this effort:

- Complete unit inventory with unique attributes (costs, heat rate, etc)
- Robust electricity market with Load Duration Curves allow for modeling of cycling units
- Technology-rich: able to change model inputs (operational and cost-based) in order to determine impacts of R&D

Total variable costs of units dispatched and their resulting capacity factors

The variable cost curve is relatively flat, implying that small changes in gas prices or CO_2 prices would have large effects on shifting generation from coal units to NGCC units, resulting in increased cycling of the coal units.

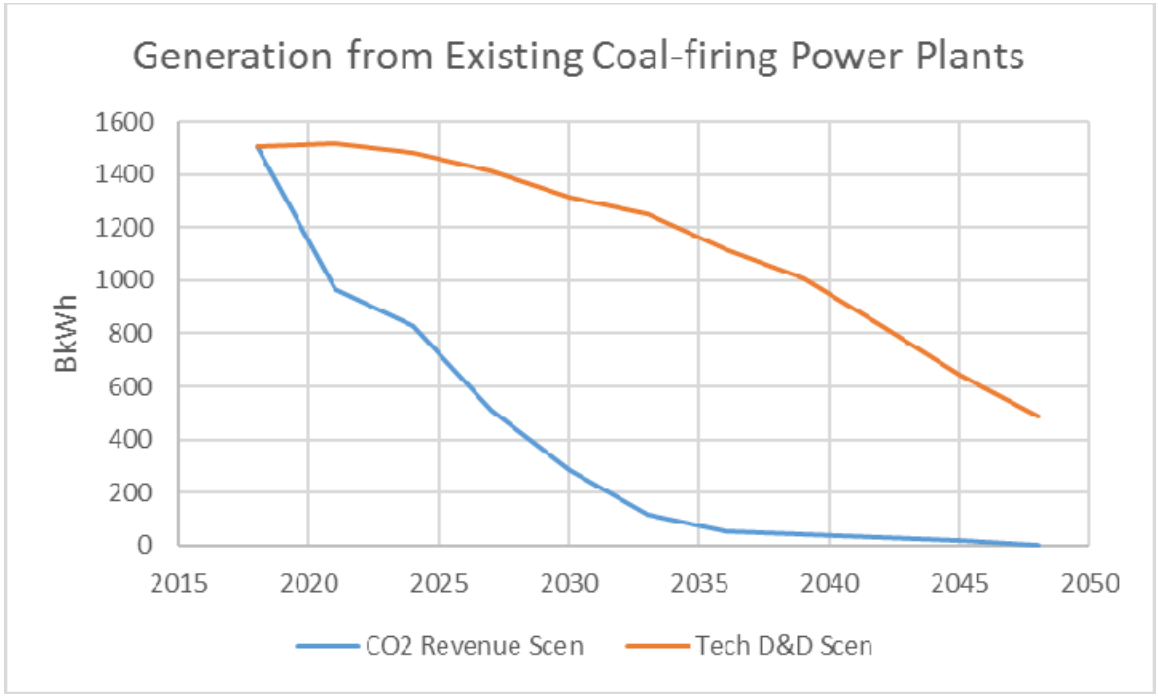


This knife-edge response, combined with historic power plant operating design, creates a special situation for reducing emissions compared with other sectors of the economy

A vicious circle

- The impacts due to lower capacity factors that are forced on existing coal plants are not immediate, but rather show up later as increased maintenance costs, higher forced outage rates, lower availability, and worsening efficiency.
- These impacts serve to further reduce the dispatching of coal plants, which further deteriorates the units and causes the worst ones to retire.
- New NGCC capacity will likely be the replacement capacity for the retiring coal plants.
- The NGCC capacity additions will push down capacity factors of many remaining coal units, causing most damage to those coal units that are most severely cycled and causing rapid retirement of those units.
- In summary, we see a process in which impacts on most existing coal plants don't show up for some years, until their turn comes to be pushed into a low capacity factor range, at which point their retirement happens quickly (see example units on next slide.)

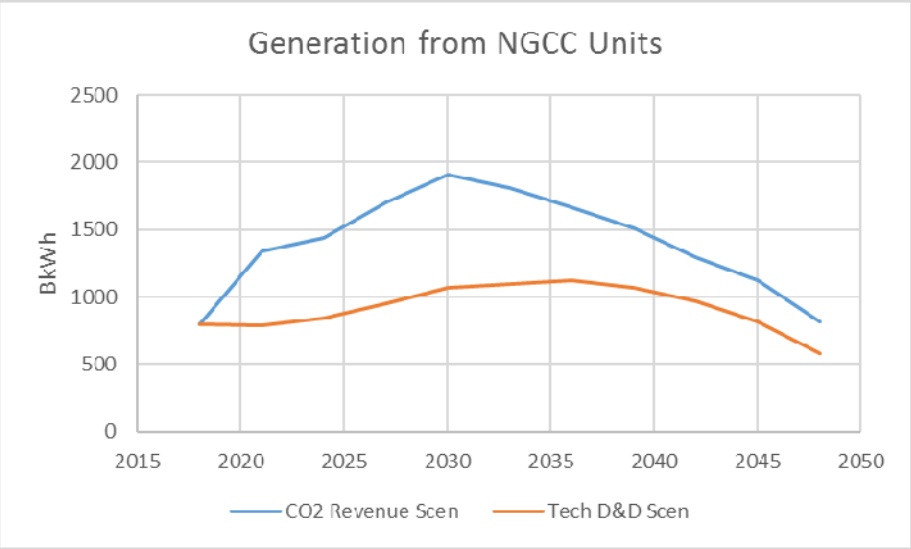
Electricity generation from coal in two scenarios



Even the Reference case shows more cycling damage and retirements than the AEO 2016 Reference Case.

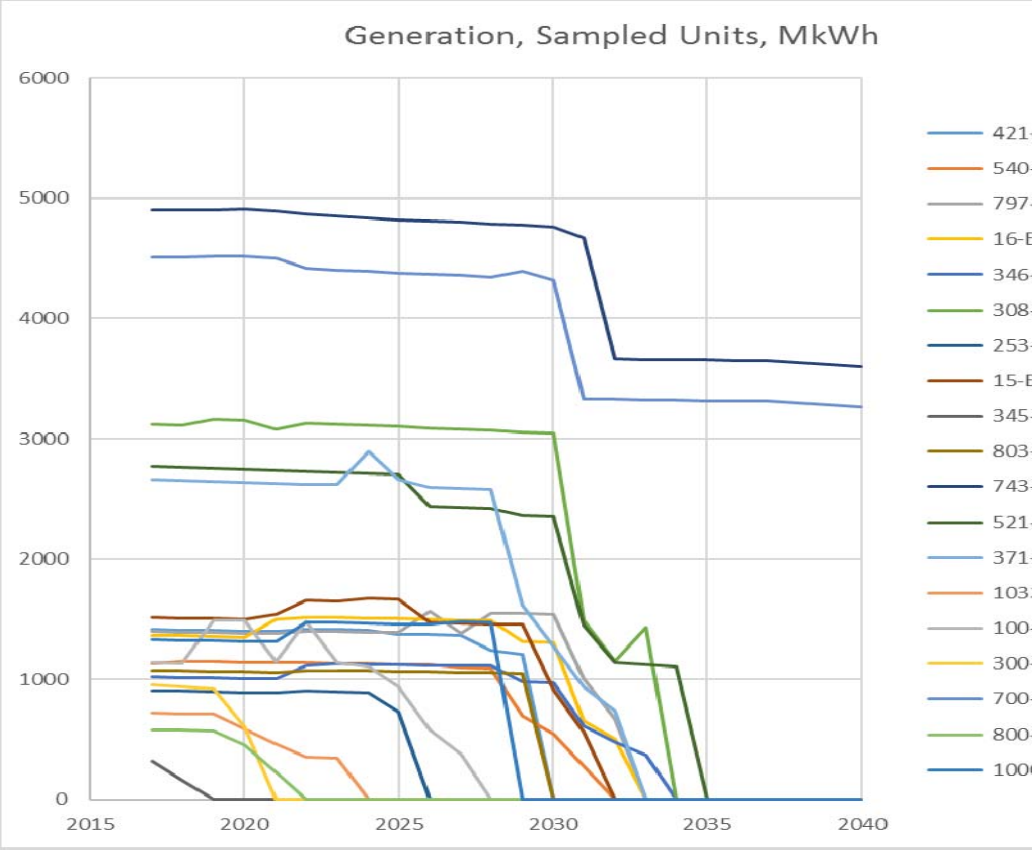
Natural gas generation in two scenarios

Much of the difference in CFPP generation is made up by increased utilization of existing NGCC units and adding more NGCC capacity as needed



But so much investment in new NGCC capacity gets in the way of achieving long-run year-2050 emission reduction targets

Generation and retirement of selected coal units



Sample coal units with low generation retiring soon, those with medium generation retiring in the middle time frame, and those with initially high generation retiring in about a decade as even they get pushed to the end of the dispatch order. The two top units are retrofitted with CCS and remain in operation.

Conclusions and next steps

- Endogenous modeling of cycling impacts indicate significant potential deterioration in the operational capabilities of coal-fired units that are not shown in any other models
  - Most other models show flat coal generation after a decline to 2020
- CO2 Control regimes would exacerbate these issues and would likely force even earlier retirement and stronger switch to natural gas
- R&D in sensors and controls have the potential to reduce heat rate losses and increases in operating costs
  - Continuing work will focus on incorporating these improvements into model inputs and performing model runs to isolate the potential impacts of this R&D

Review papers on power plant cycling damages

- Donald Hanson, David Schmalzer, Christopher Nichols, Peter Balash, "The Impacts of Meeting a Tight CO_2 Performance Standard on the Electric Power Sector," *Energy Economics*, 2016; see on-line Appendix on cycling damage literature review at http://dx.doi.org/10.1016/j.eneco.2016.08.018

- EPRI, 2001. Damage to Power Plants due to Cycling, Report No. 1001507

- Kumar, N., P. Besuner, S. Lefton, D. Agan, and D. Hilleman, (2012), *Power Plant Cycling Costs*, Intertek AIM (formerly APTECH), Subcontract Report No. NREL/SR-5500-55433, NREL, Golden CO, July 2012.