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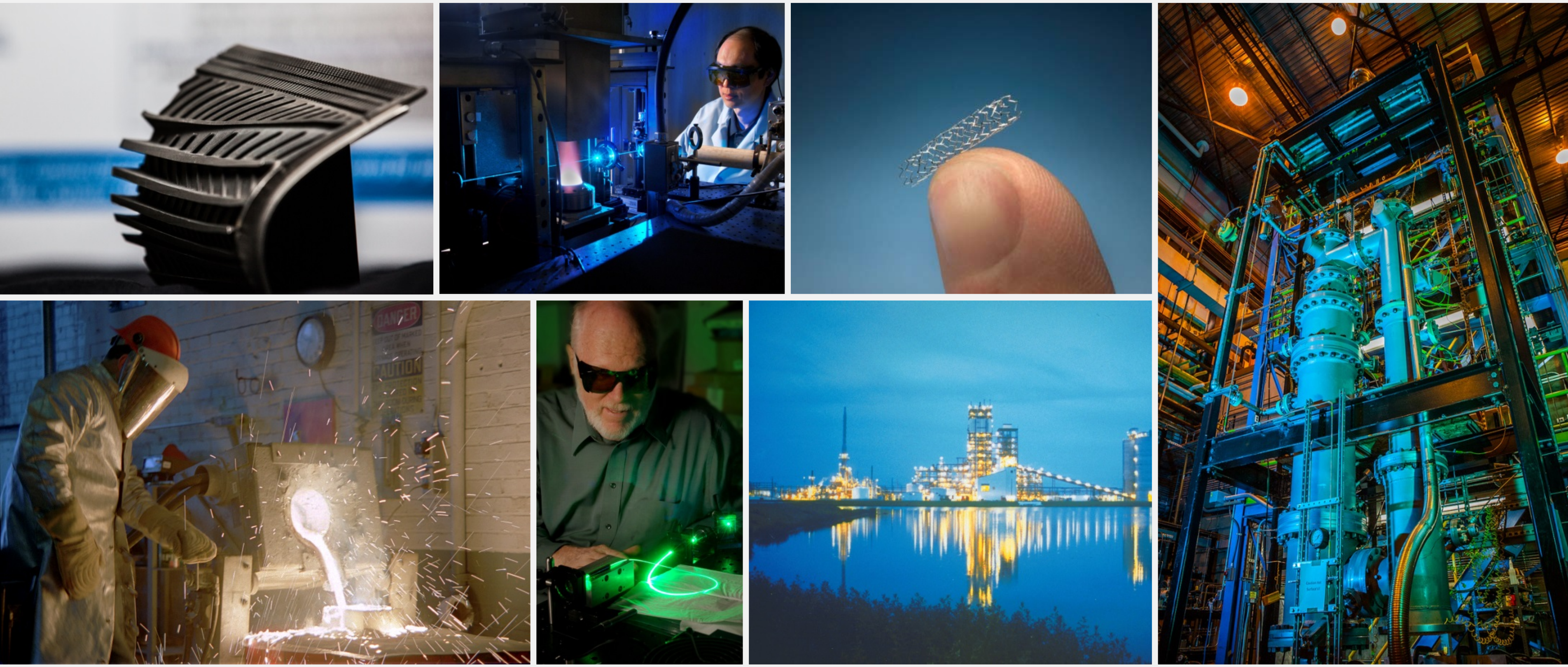

Characterizing and Modeling Cycling Operations in Coal-fired Units

EIA Modeling Meeting

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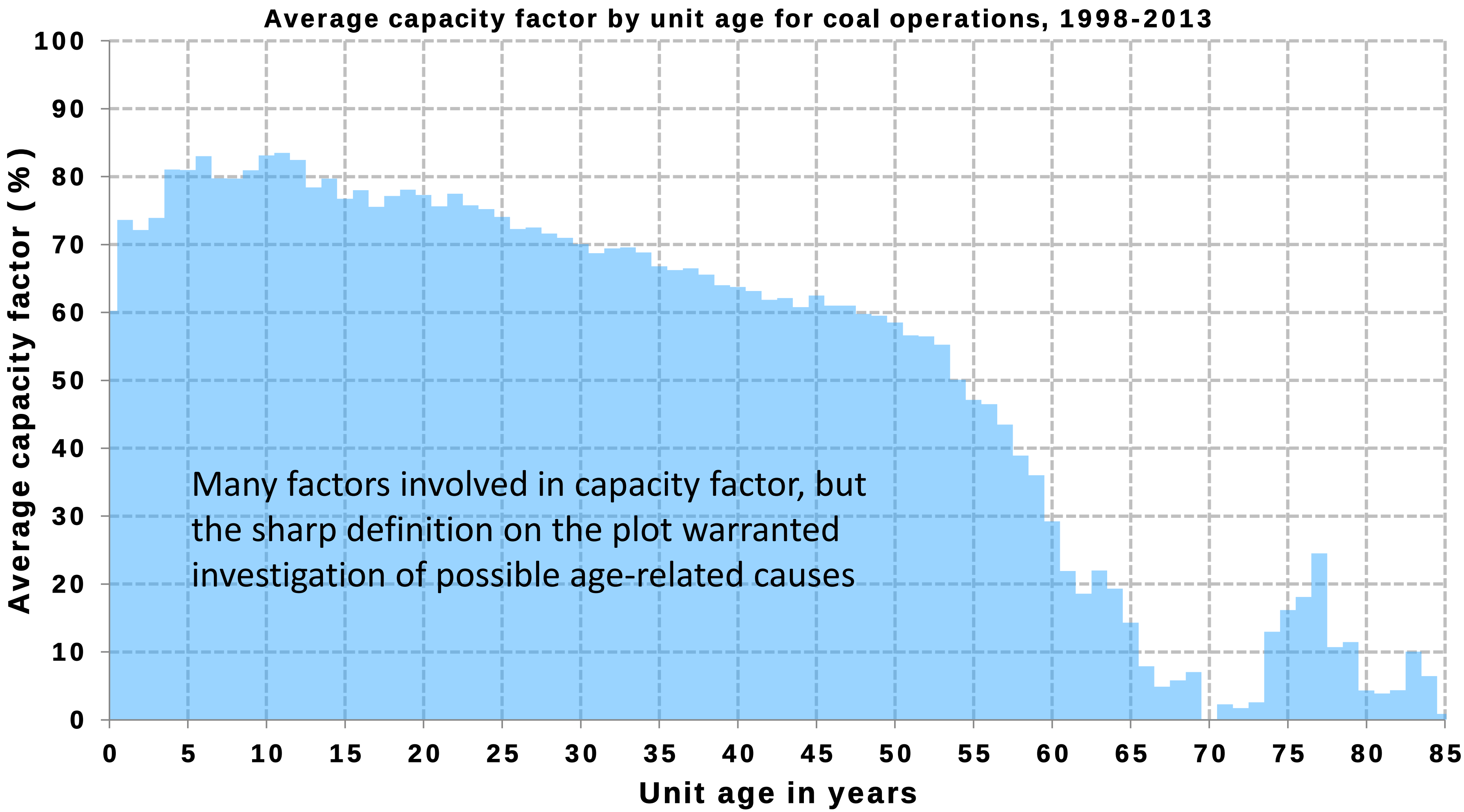
U.S. DEPARTMENT OF ENERGY | National Energy Technology Laboratory

The "Over the Hill" plot - Examining Historic Coal Unit Capacity Factors



Overview of current NETL work in this area

- **Characterization of operating modes of retiring units**
  - Defining the modes of operation and classifying units
- **Cycling impacts**
  - Literature review and technical discussion
  - Model integration and preliminary results
- **Future work**

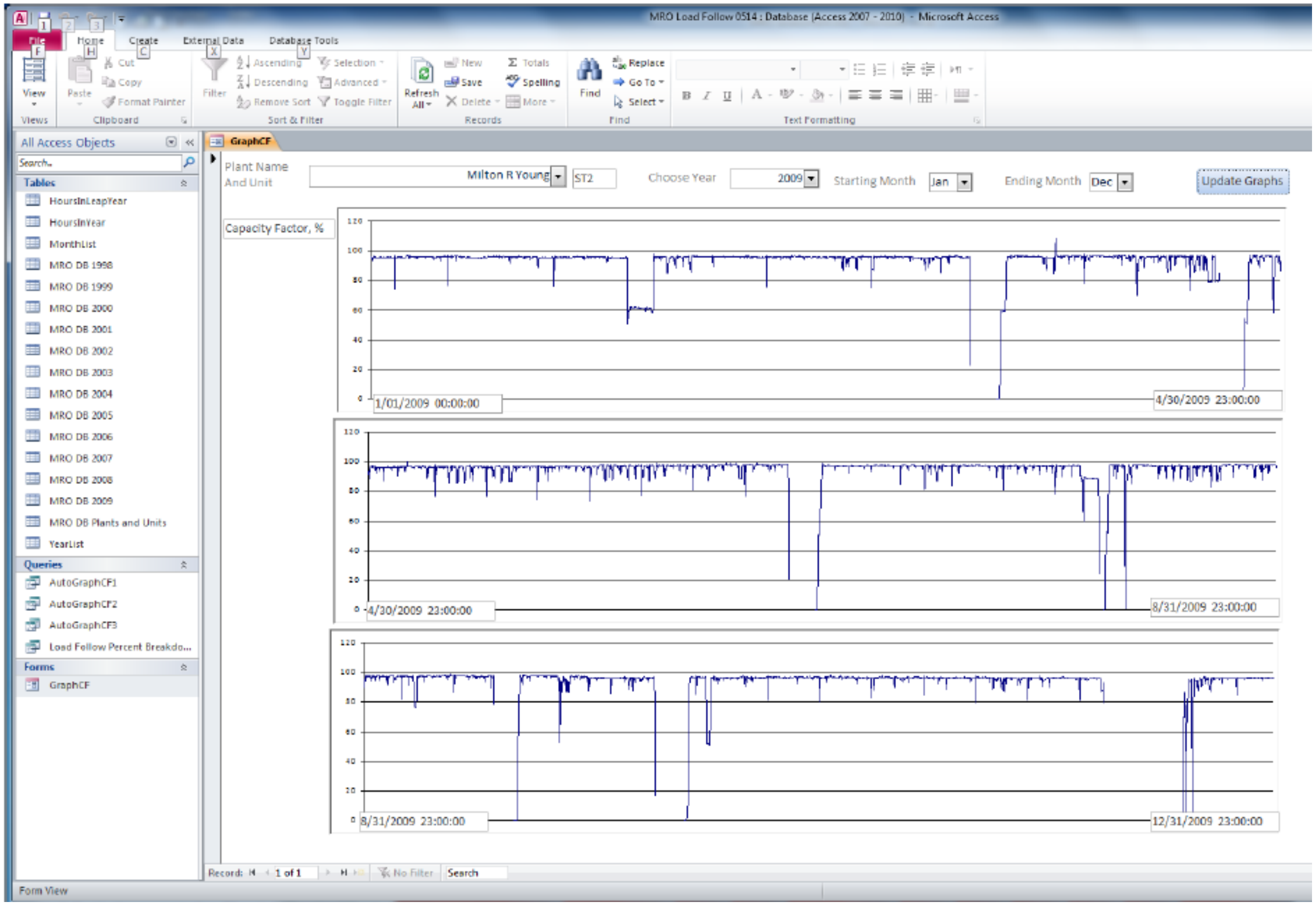
Characterizing operating modes

- **MS Access tool developed to view and sort units retiring between 2010 & 2020 by operating mode (~300 units total):**

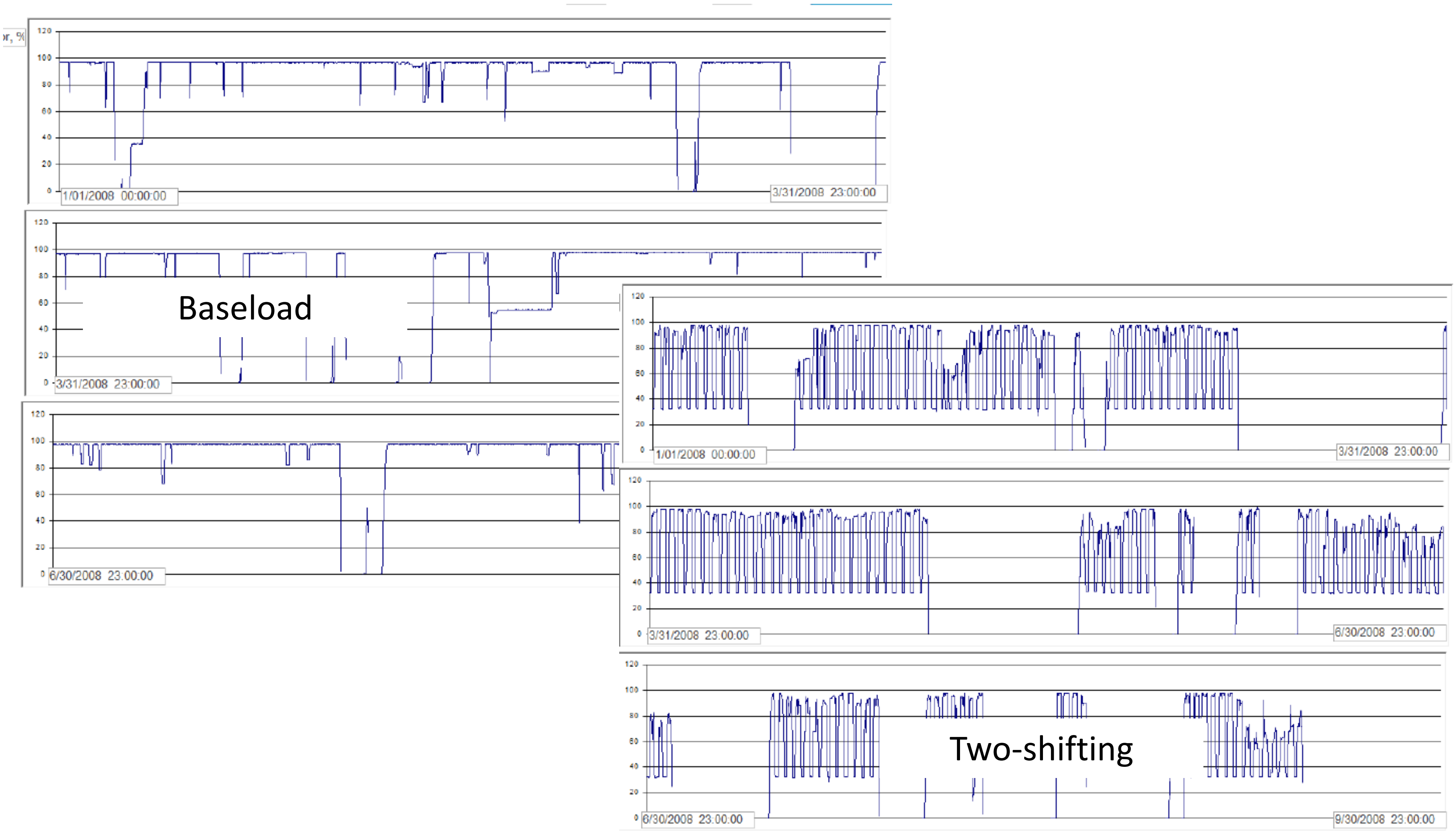
  - Baseload (BL) – Unit operates at steady output all year
  - Load Following Type 1 (LF1) – Unit typically operates at full load, but frequently drops load when demand goes down
  - Load Following Type 2 (LF2) – Unit typically operates at a set partial load, but frequently increases load when demand goes up
  - Load Following Type 3 (LF3) – Unit has variable output, but does not operate at steady output
  - Two-Shifting (TS) – Unit frequently shifts between the same two defined set points

Characterizing operating modes

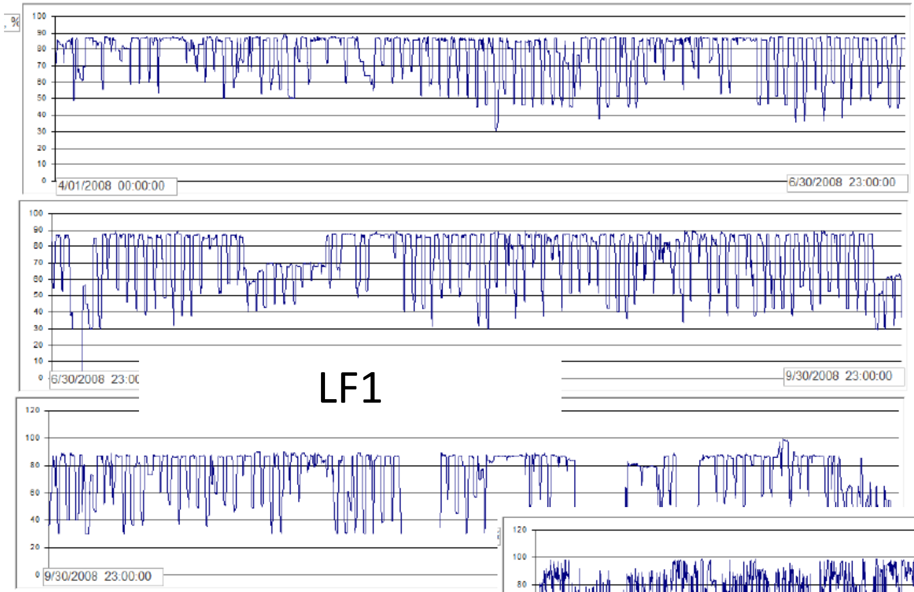
- **MS Access tool shows capacity factor by unit for specified time period:**

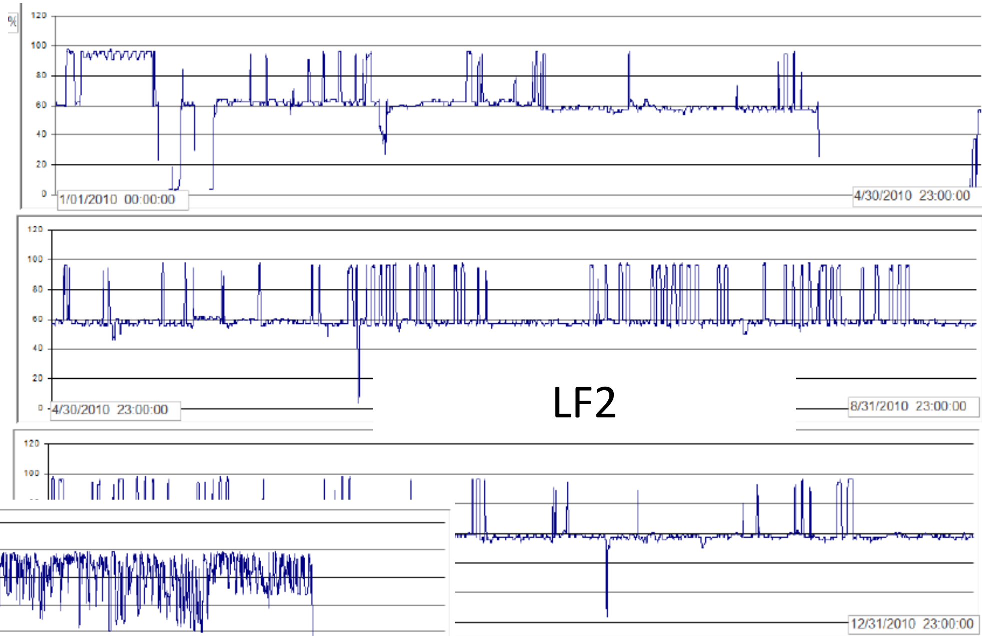


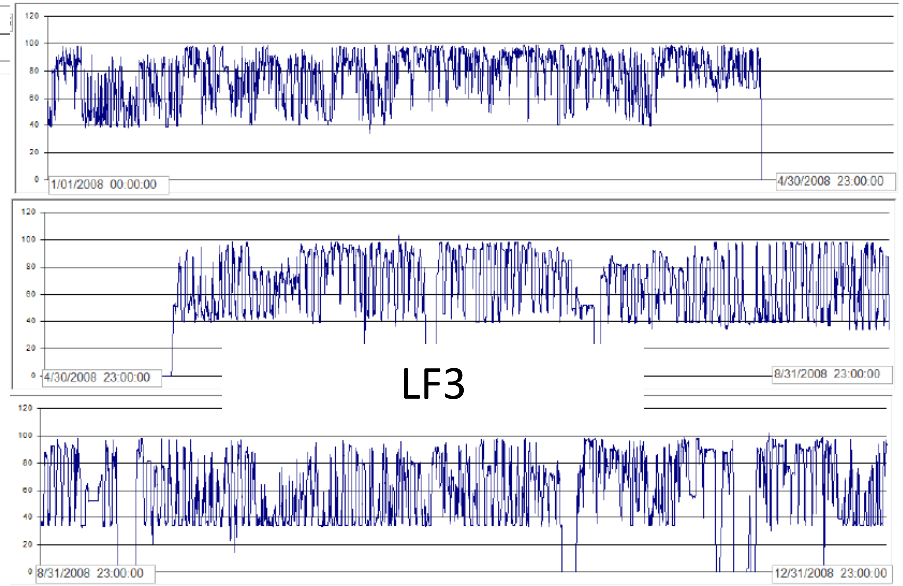
Characterizing operating modes



Characterizing operating modes

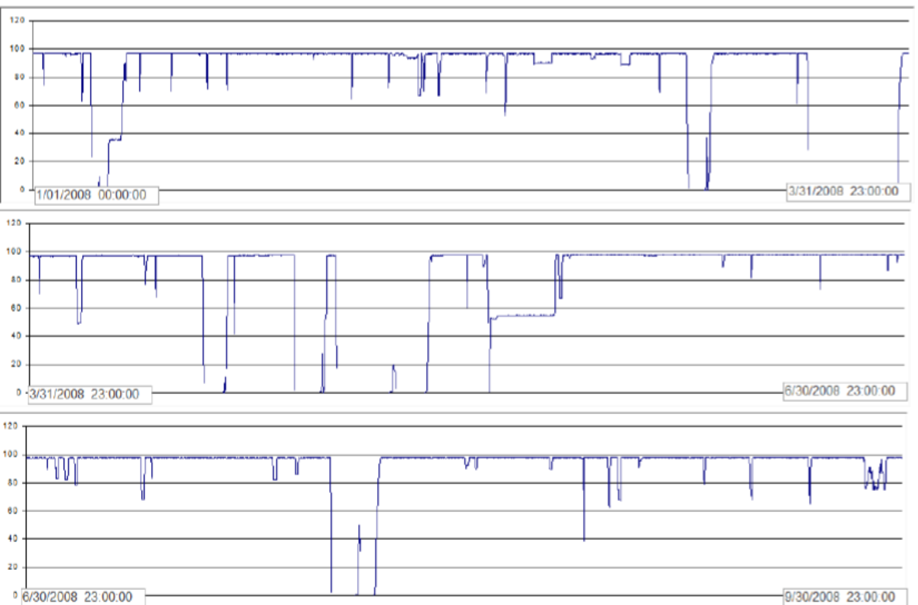




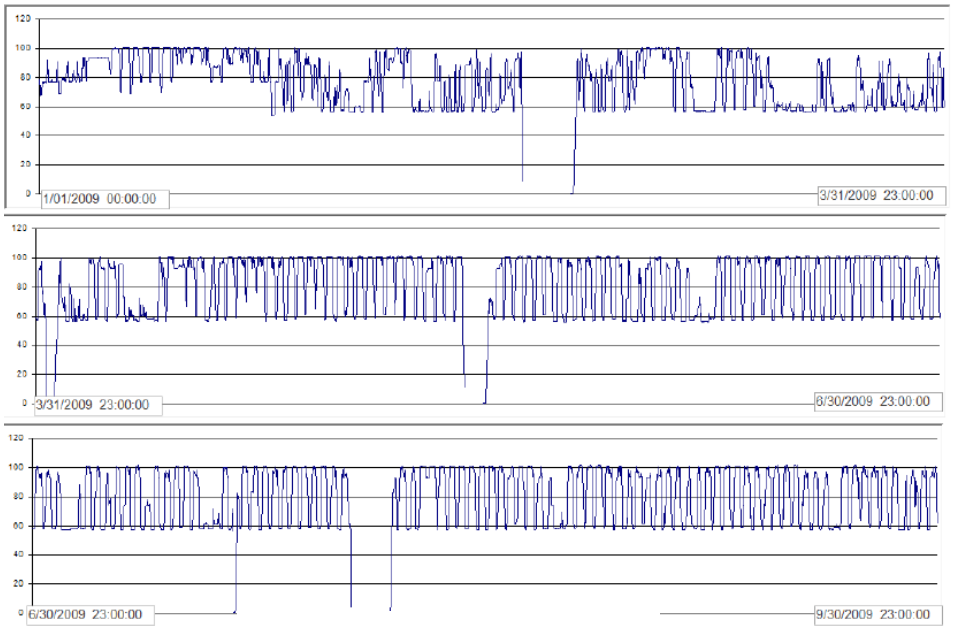


Characterizing operating modes

Eastlake, Unit 5



2008 - Baseload



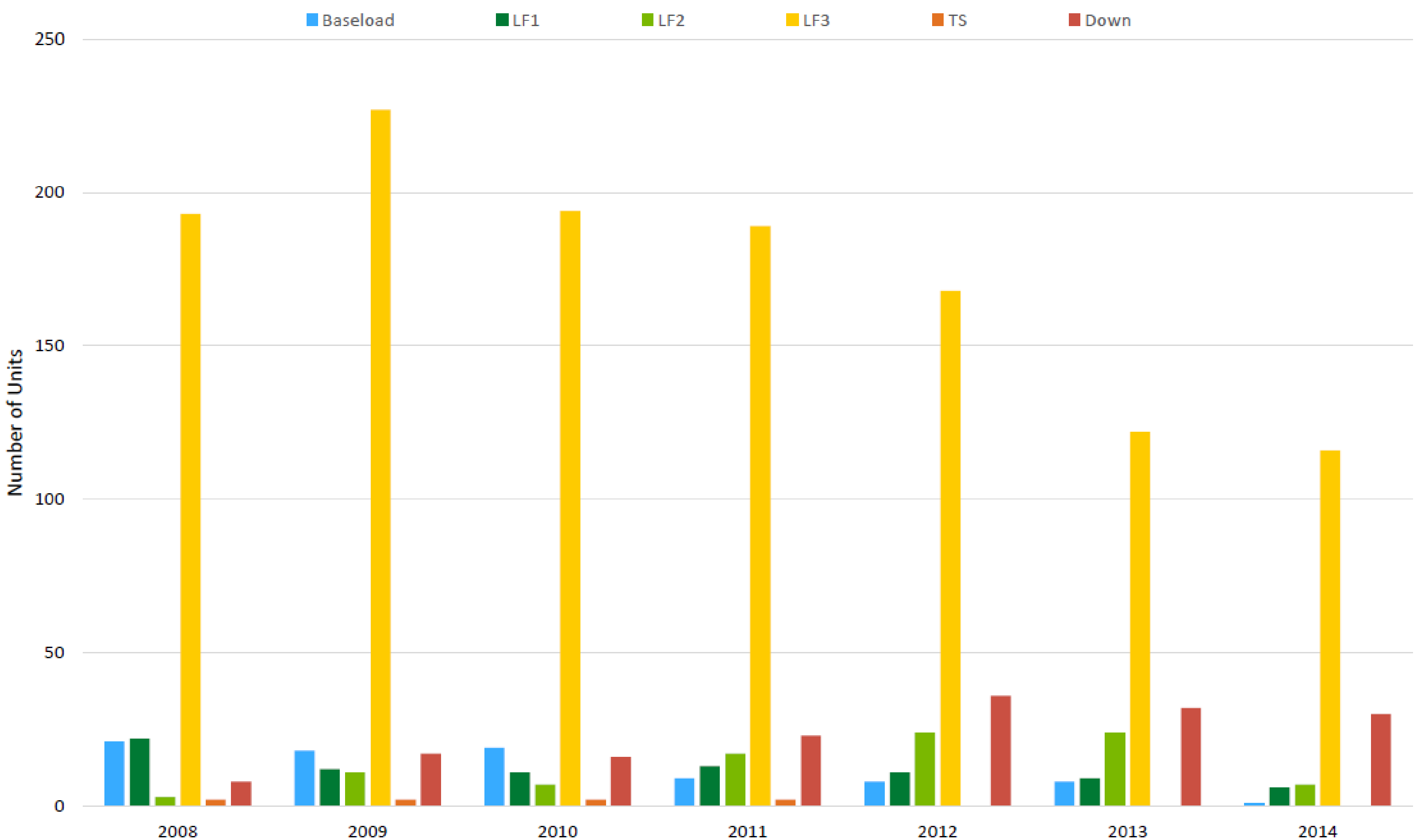
2009 – LF3/TS

Continued LF operations until retirement in 2010

2	Plant ID	Plant Name	Unit ID	Unit	Capacity MW	Commercial Online Year	Retirement Date	Retirement Year	State Abbrev	Region Abbrev	Btu/kWh - Modeled	Fuel Code		2008	2009	2010	2011	2012	2013	2014
54	1495	Eastlake (OH)	388570	4	208	1956			OH	RFC	9,792	SUB		LF3	LF3	LF1/LF3	LF3	LF3/Retired	Retired	Retired
55	1495	Eastlake (OH)	388571	5	680	1972			OH	RFC	9,137	BIT		BL	LF3/TS	LF1	LF1	LF1/Retired	Retired	Retired

Characterizing operating modes

- **Most Retiring Units Were Load Following in 2008-2014**



Cycling impacts – literature review and engineering analysis

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**

Forced outage rates higher for cycling units

- **About 3% for baseload units**
- **About 7% for cycling units**

Forced Outage Rate, %

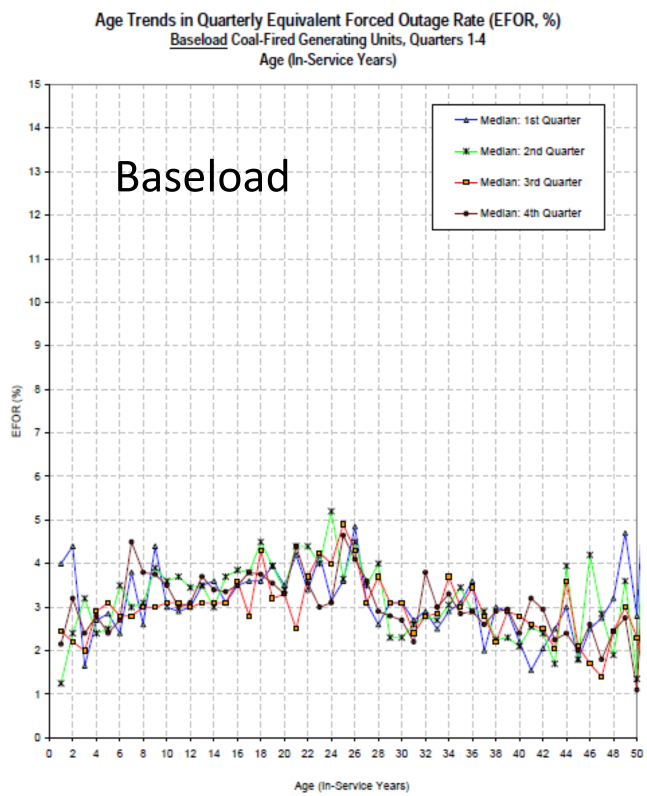


Figure 4-1
Quarterly EFOR by Age of Unit and Duty Cycle: Baseload Coal Units

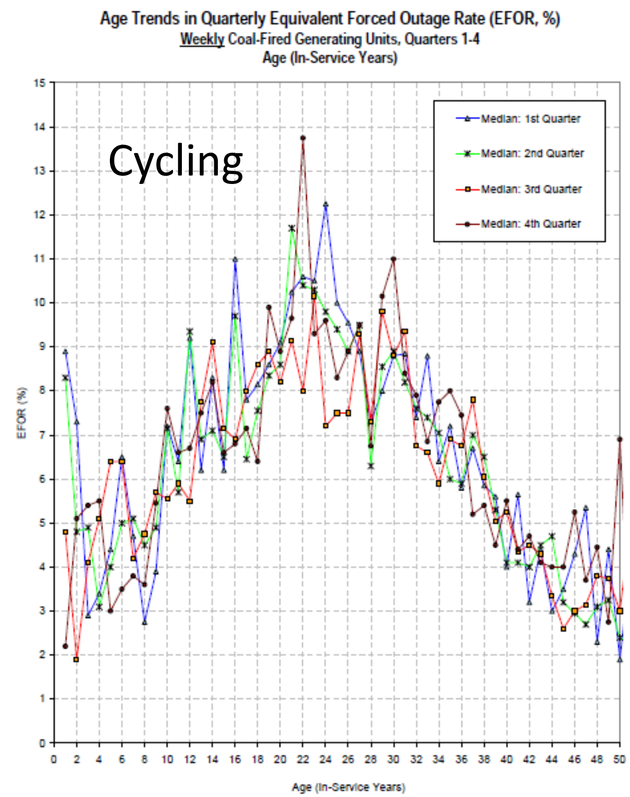
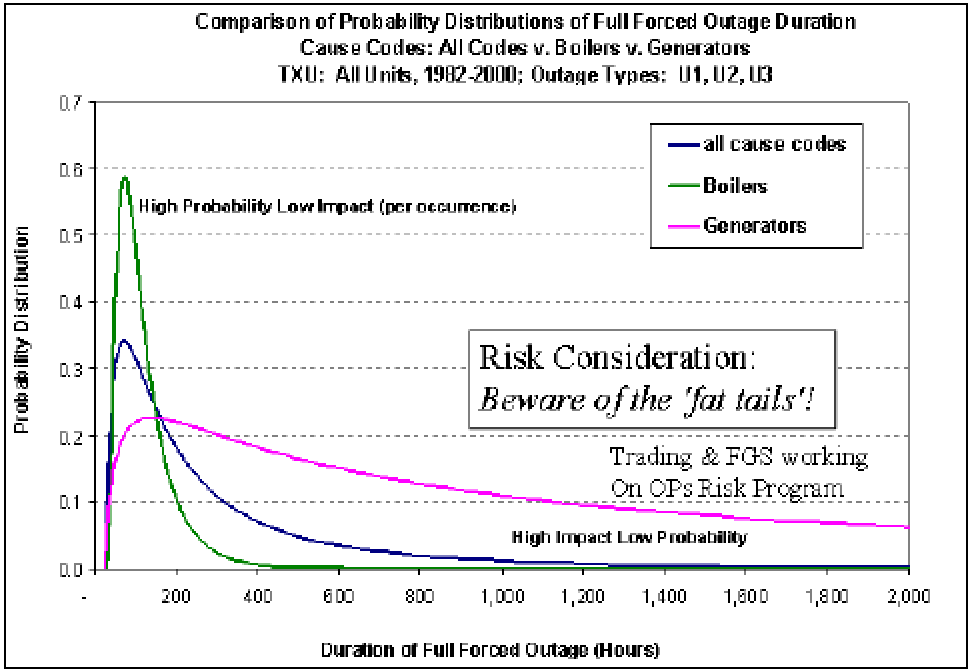


Figure 4-2
Quarterly EFOR by Age of Unit and Duty Cycle: Cycling Coal Units

Age, service years →

Component Failure Impacts

- **Failure of a boiler or condenser tube has very different impact than failure of a turbine or generator**



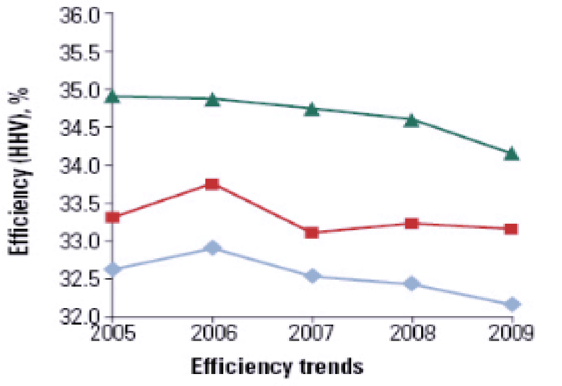
Most boiler tube failures cause about 100 hour outage, almost none more than 350 hours.

About 10% of generator failures cause > 1200 hours outage.

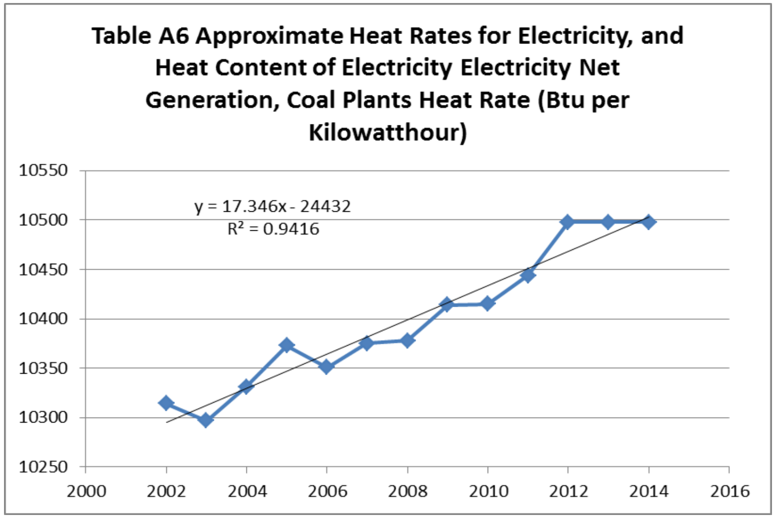
Source: Kumar, N., et al, Power Plant Cycling Costs, NREL/SR-5500-55433

Fleet Heat Rate Trends

Empirical fleet data indicates persistent heat rate increases across technologies



2. Existing coal-fired fleet performance trends, 2005–2009. *Source: Navigant*



(Data source: EIA Table A6. Approximate Heat Rates for Electricity, and Heat Content of Electricity, Published October 28, 2014)

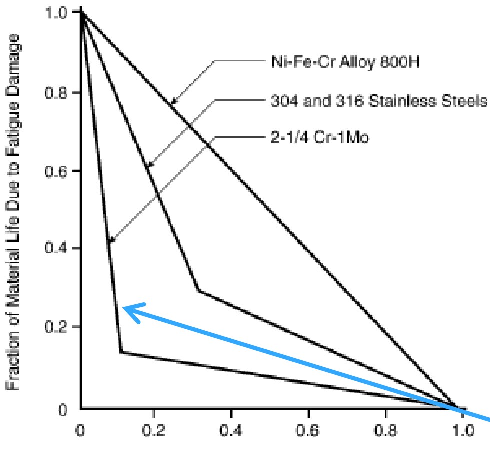
Table 1. Existing Technology Comparison, 5 Year Average

Technology	No. Units	Total Capacity, MW	NFOM, \$/MWh	EAF, %	Efficiency (HHV), %
Small Subcritical	228	49,686	14.54	82.7	31.8
Large Subcritical	65	40,111	9.09	85.1	33.0
Supercritical	85	66,469	11.69	79.6	34.4

Source: Table courtesy of Navigant Consulting, Inc., based on “Generation Knowledge Service”, 2010 - 2014

Interaction of Creep and Fatigue

EPRI 2001 Report: **"Where operational cycling is introduced on a former baseload unit, the residual life can be greatly reduced to between 40% and 60% of the original design life because of the combined effects of creep and fatigue."**



Typical plant metallurgy

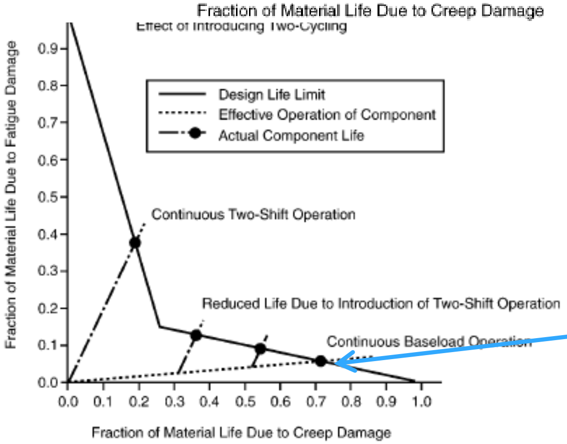
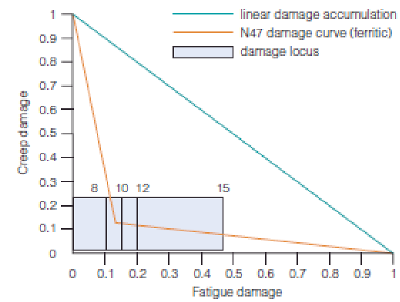


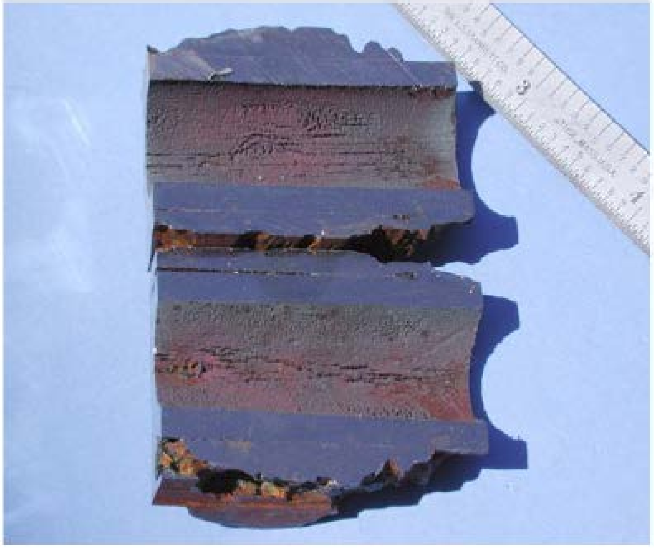
Figure 3-1
Interaction and Consequences of Creep and Fatigue
(Based on ASME N-47) for a Typical Power Plant Steel (2.25Cr1Mo)

Typical design basis of legacy CFPP



Effect of temperature ramp rate
Source: Fleming and Foster, Aging of Coal Fired Power Plants

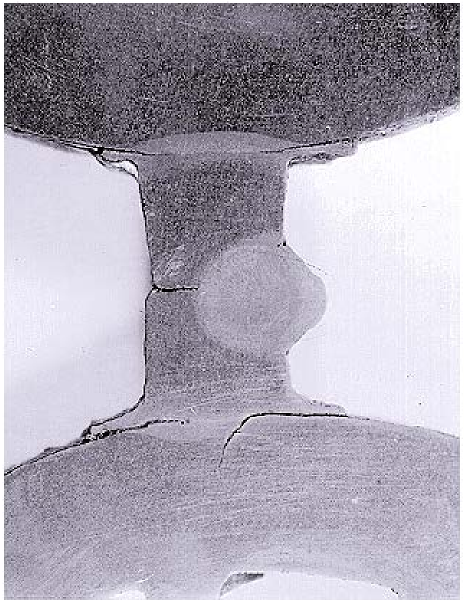
Boiler Material Failures



Boiler tube corrosion

Source: Lefton, Power Plant Asset Management

Waterwall web cracking



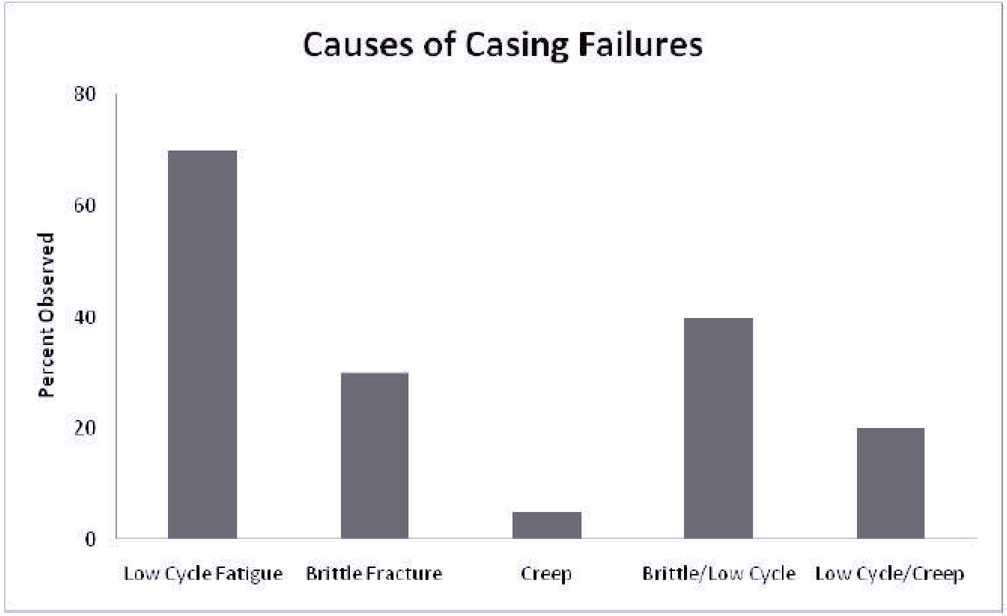
Superheater tube attachment fatigue cracking

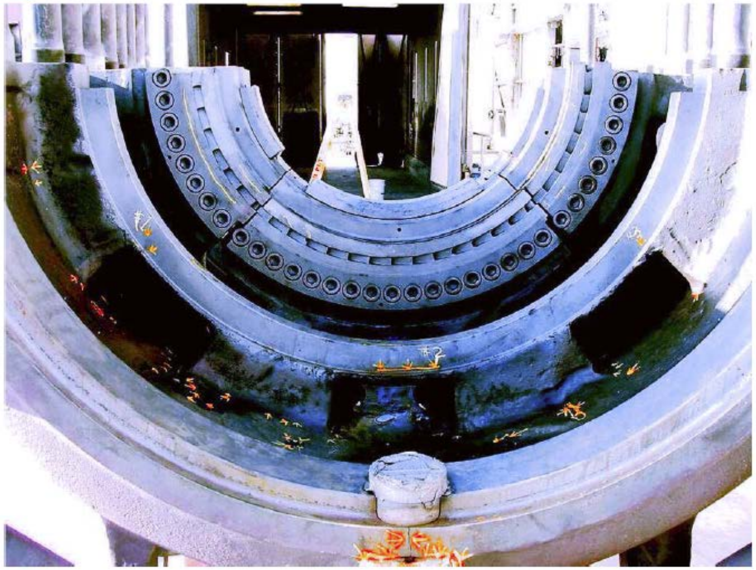
Massive caustic attack

Caustic gouging. This cutaway view shows a tube that experienced caustic attack in a cyclone inlet roof tube. The plant commenced load cycling about one year prior to this failure. *Courtesy: David N. French Metallurgists*

This is from a supercritical unit where cyclones are in the steam path rather than a steam drum

Steam Turbine Failures





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

Cycling impacts – ESIM model integration and initial results

Development of cycling Scenarios

- **Heat rate guidance from EIA-923 (2014) and EIA-860**
  - Filtered data ranked into quintiles
  - Midpoints of first, third, and fifth quintile taken to represent heat rates
- **Operating periods based on literature and judgement**
- **Residual plant life in various operating modes taken to be reasonable**
  - Little hard data on this
  - Known to be impacted by plant maintenance and investment
  - External-to-plant factors impact retirement decisions
  - Should not be taken to represent any specific plant

Operating Modes in scenario Modeling

- **Mode 1**
  - Runs 24 x 5 but does some load following, 85% effective capacity while running. One warm shutdown and startup per week. Annualized CF 51.6%, residual life 10 years
- **Mode 2**
  - Runs 16 hours per weekday, averaging 85% effective capacity. Six warm shutdowns and startups per week. Annualized CF 34.4%, residual life 5 years
- **Mode 3**
  - Runs 12 hours per weekday in two six hour periods, averaging 92 -95% effective capacity. Eleven warm shutdowns and startup per week. Annualized CF 28.8%, residual life 3 years
- ***All cases assume 85% availability and 30+ years of service at outset of cycling***

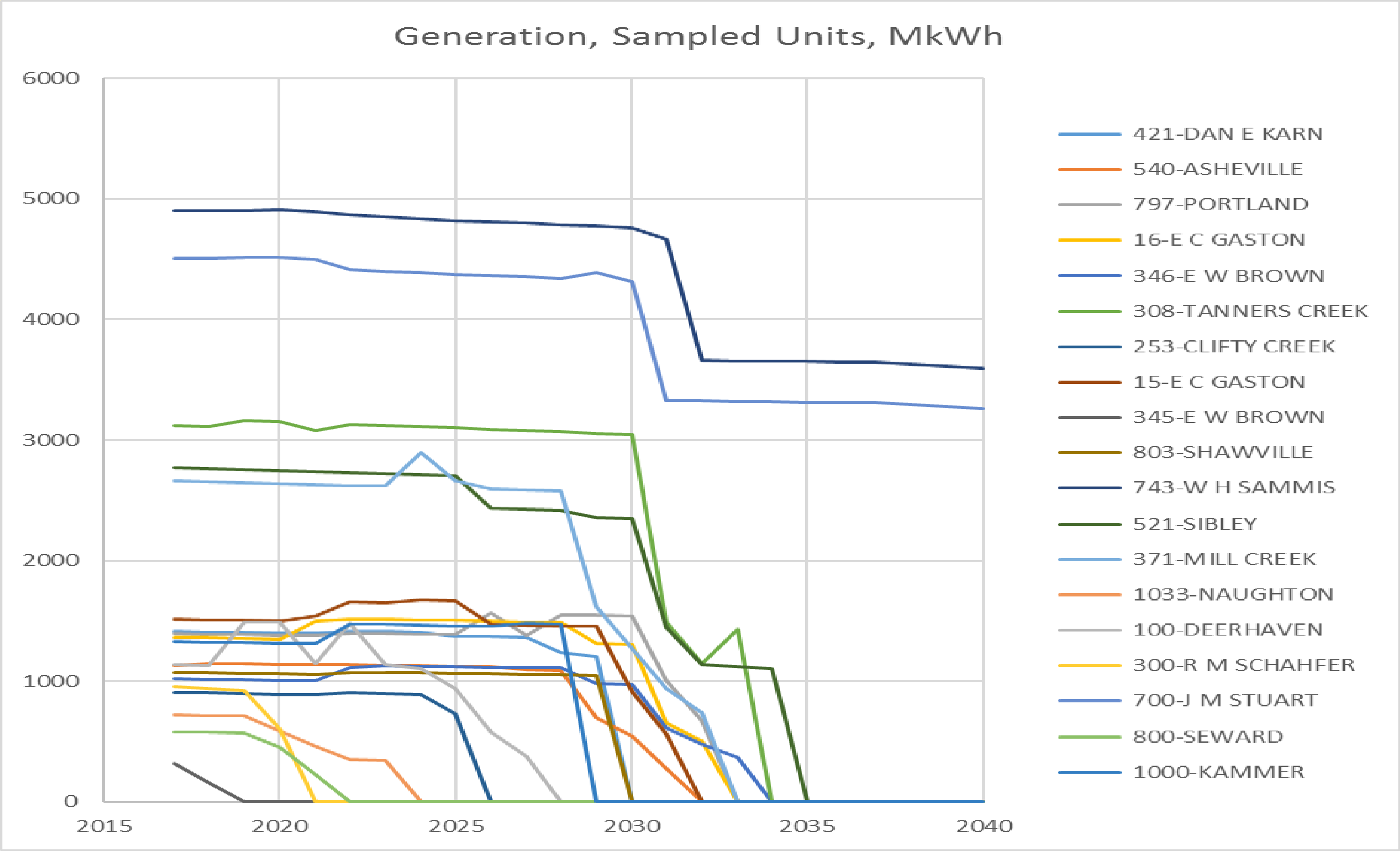
Developing the endogenous function

The model constructed a cycling damage function with interpolation between three operating modes.

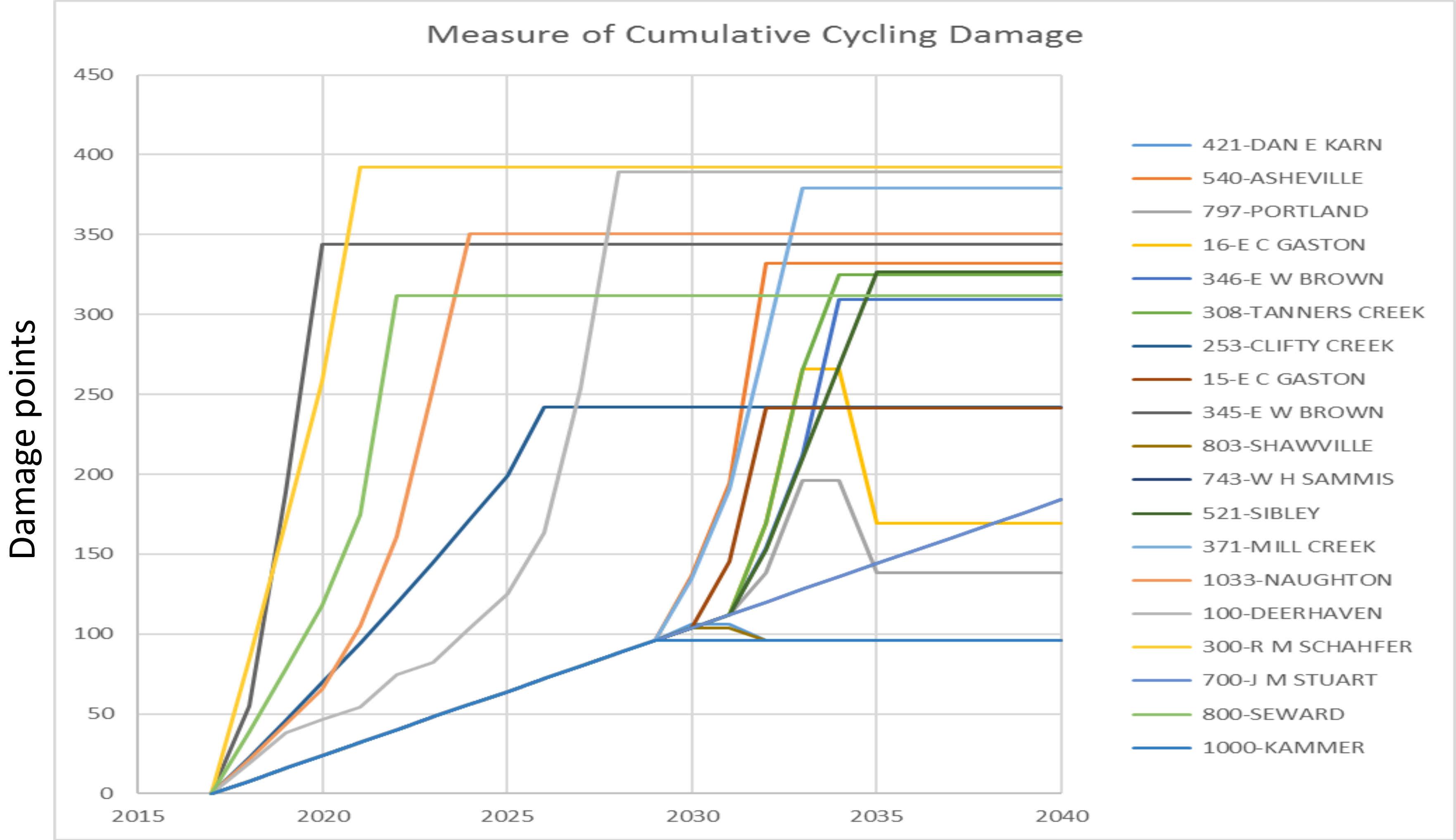
Endogenous retirement occurs when a unit accumulates 300 points.

	Penalty score assignment	Years to acquire 300 points
Modest cycling	30 points/year	10
Medium cycling	60 points/year	5
Severe cycling	100 point/year	3

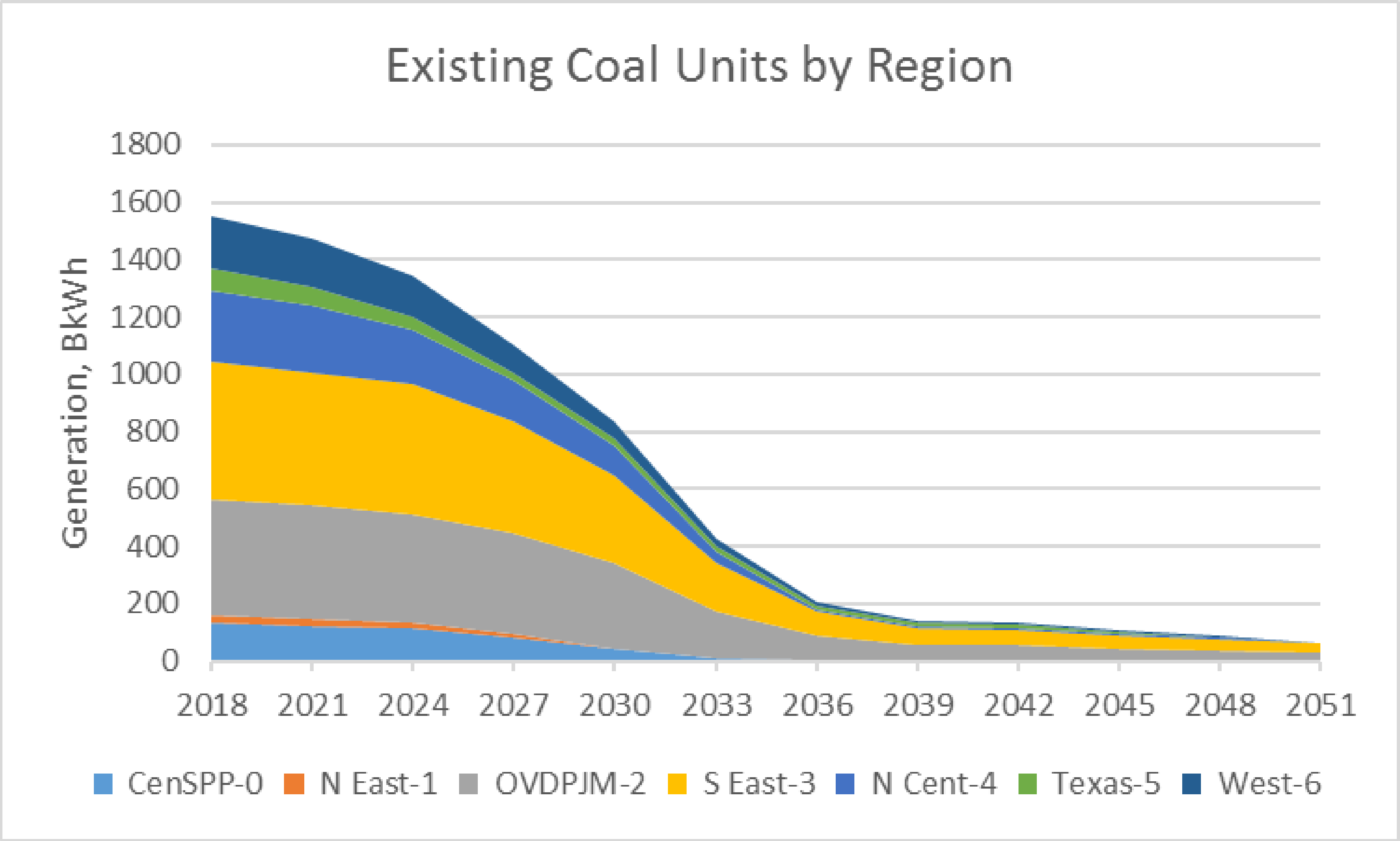
Cycling damages eventually results in endogenous unit retirements



Damages accumulate as Cycling continues and generally worsens over time

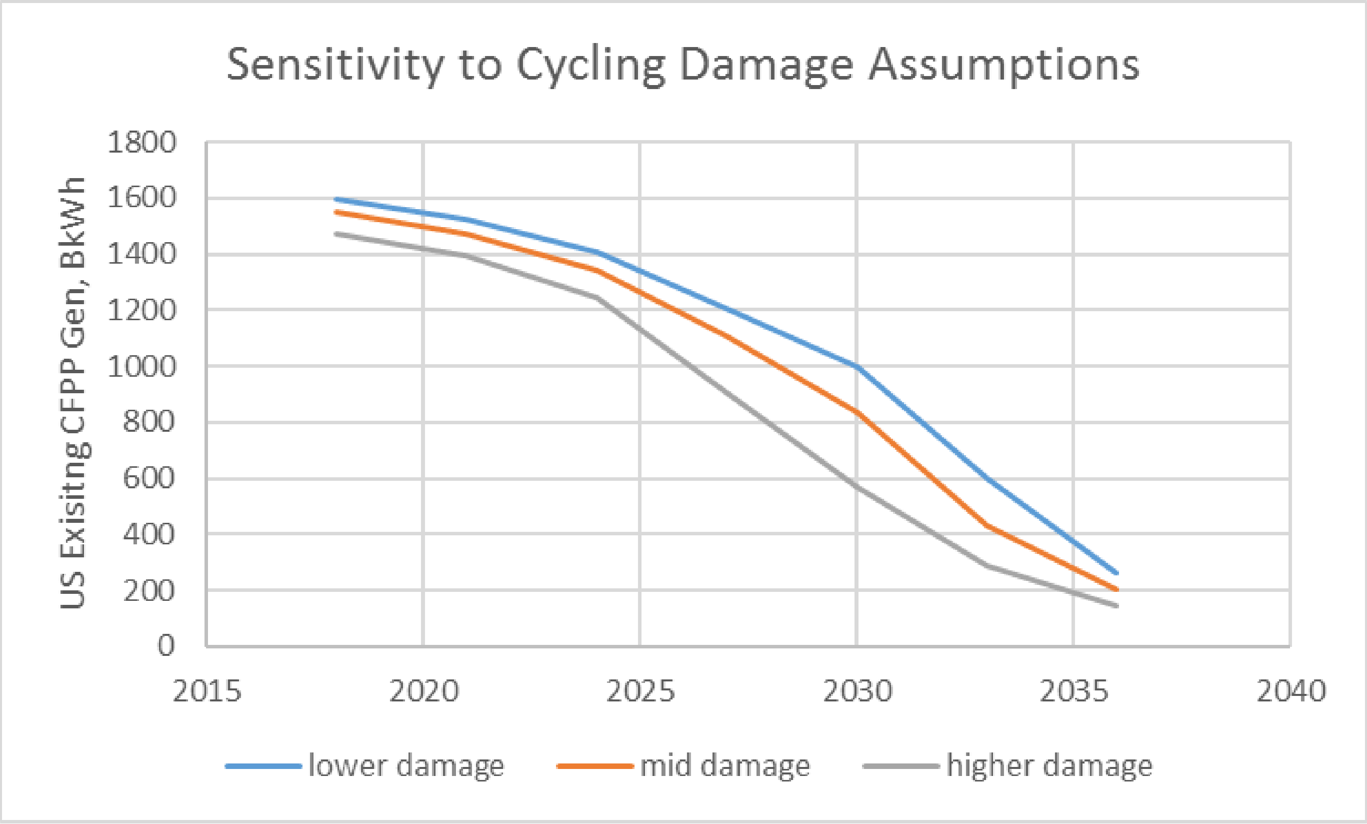


Endogenous coal retirements accelerated by damage function



Calibrating the damage function will be key to assessing the impacts

Sensitivity of Existing CFPP US Generation to a plausible range of cycling damage assumptions



Next steps and future work

- **Publication of cycling literature review and ESIM model integration late Summer**
  - Follow-on work pending to show benefits of sensors and controls (lower damage points) R&D
- **Multi-scale modeling pilot effort (engineering to grid to market) underway to model cycling impacts**
  - Engineering models will generate data to feed to grid level model, market level model will generate scenarios
- **Longer term, multi-year effort proposed to further develop data and create dynamic model linkages**

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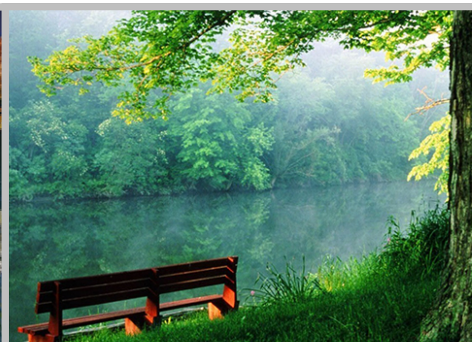
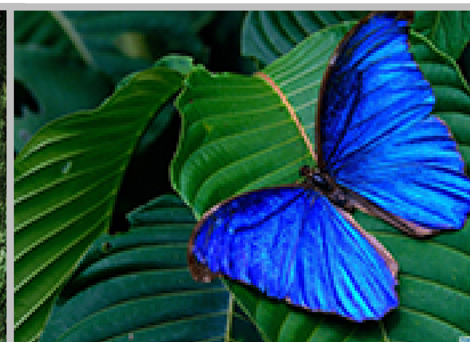
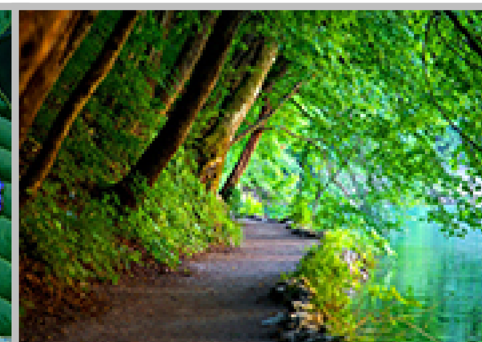

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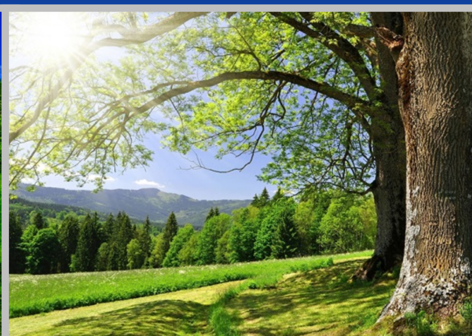

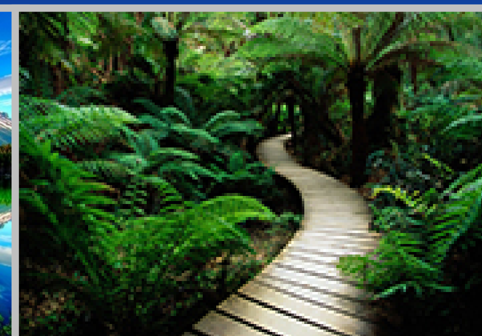

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