NREL
NATIONAL RENEWABLE ENERGY LABORATORY

How Does Wind Affect Coal? Cycling, Emissions, and Costs

Composite photo created by NREL

Debra Lew,

Greg Brinkman, Michael Milligan NREL

Steve Lefton, Intertek APTECH

Dick Piwko, GE

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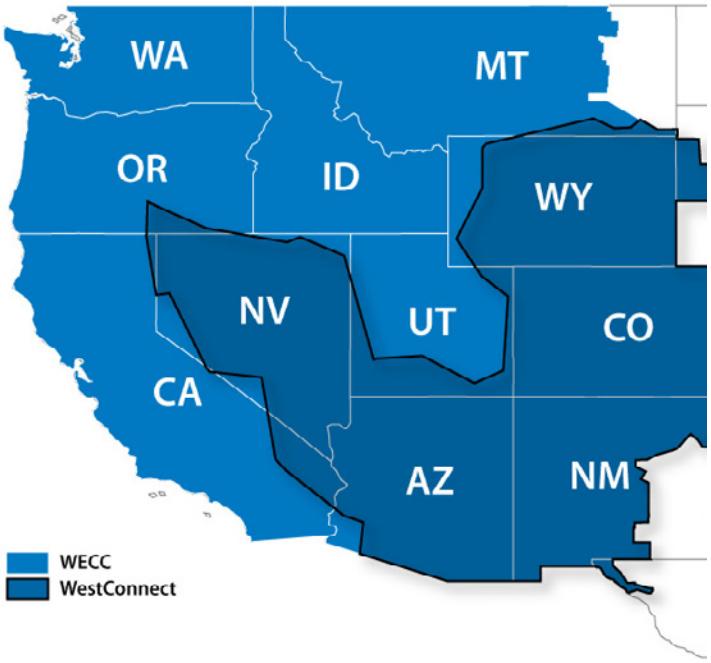
What is the Impact of Wind on Fossil Plants?

- Does wind increase emissions?
  - Bentek study (April 2010) claims coal cycling results in increases in total SO_2, NO_x and CO_2 emissions in Xcel/PSCO and ERCOT.
  - Xcel refutes (May 2010) this, saying they have added significant wind since 2007, resulting in declining total emissions.
- What is the impact of wind on 'wear and tear' on the fossil units?
  - Numerous wind integration studies have been undertaken, with criticism that they do not account for the full impact of 'wear and tear' on fossil units.
  - Studies of specific plants to determine 'wear and tear' costs are confidential.
- Can't we upgrade fossil plants to better cycle/ramp?
  - Ontario (IESO) claims their coal units are more flexible than their gas units

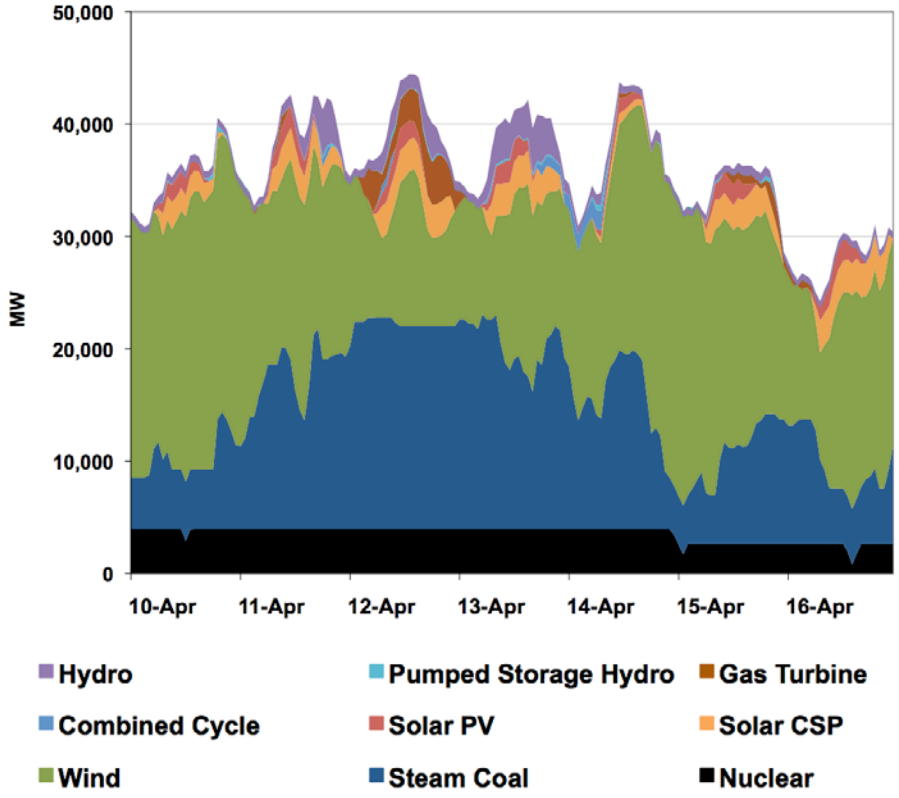
Integration of 35% Wind and Solar in the West

Western Wind and Solar Integration Study

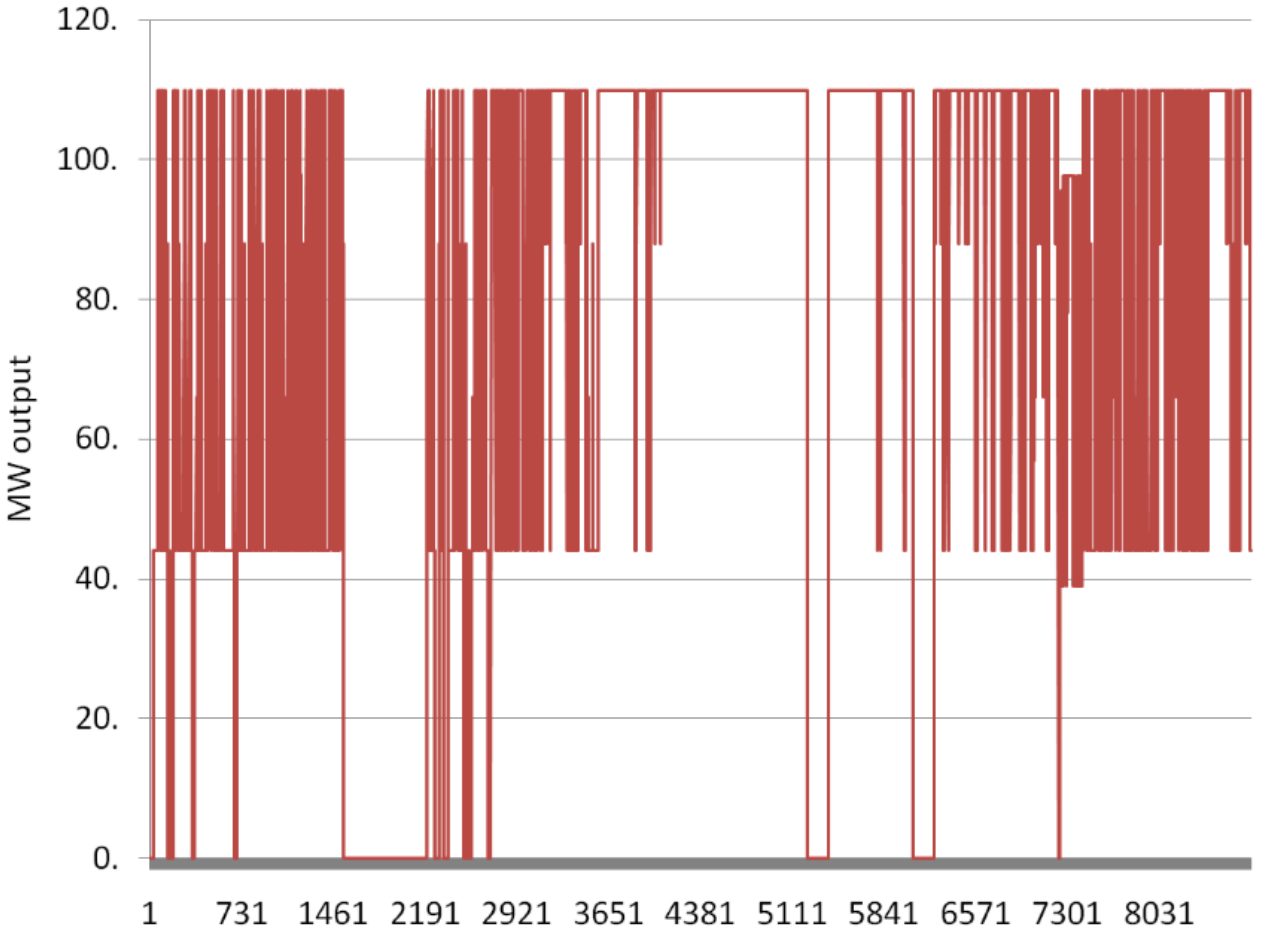
To assess the operating impacts and economics of wind and solar on the WestConnect grid.



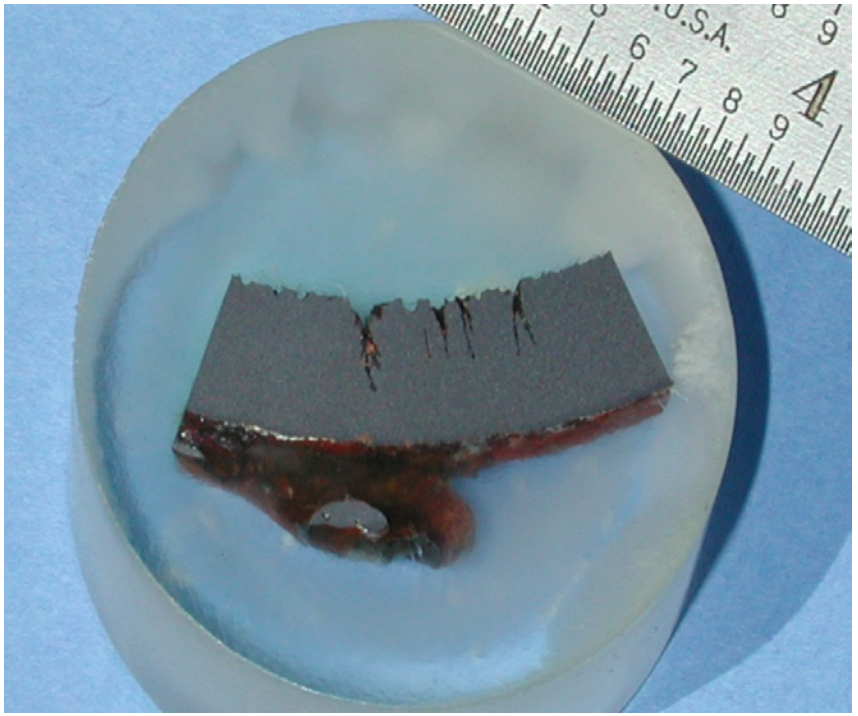
The worst week of three years:



Can the Fossil Fleet do This?

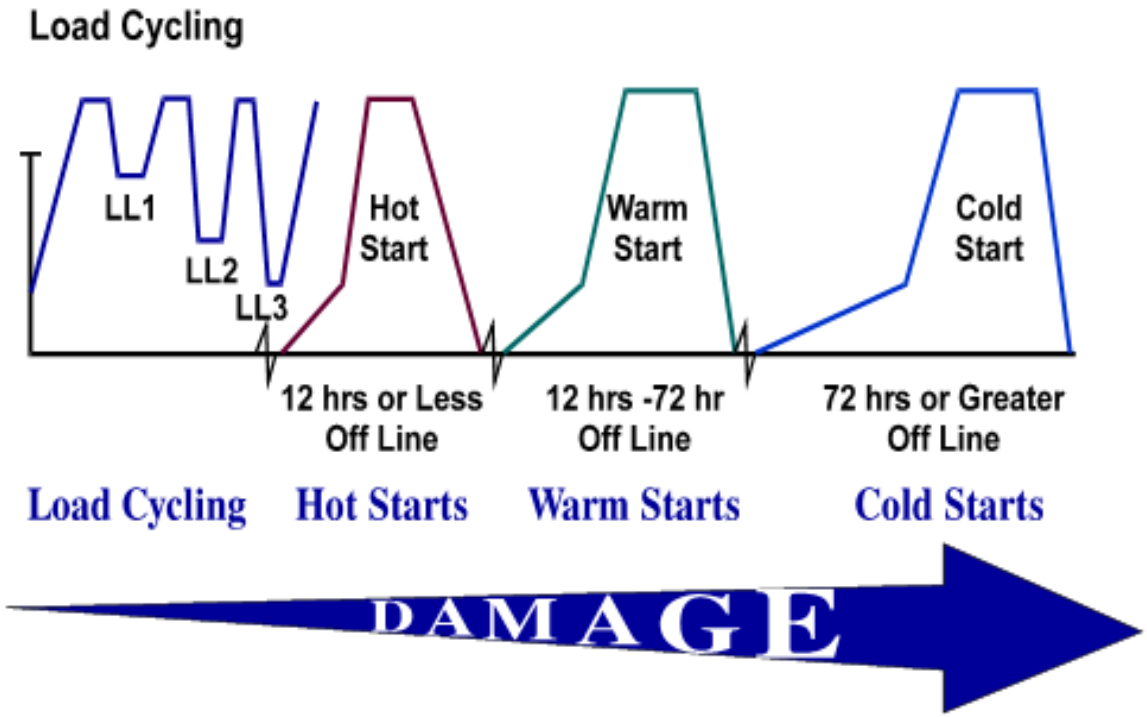


Boiler Corrosion Fatigue



Source: Steve Lefton, Intertek APTECH, with permission.

Generation Unit Cycling Definitions



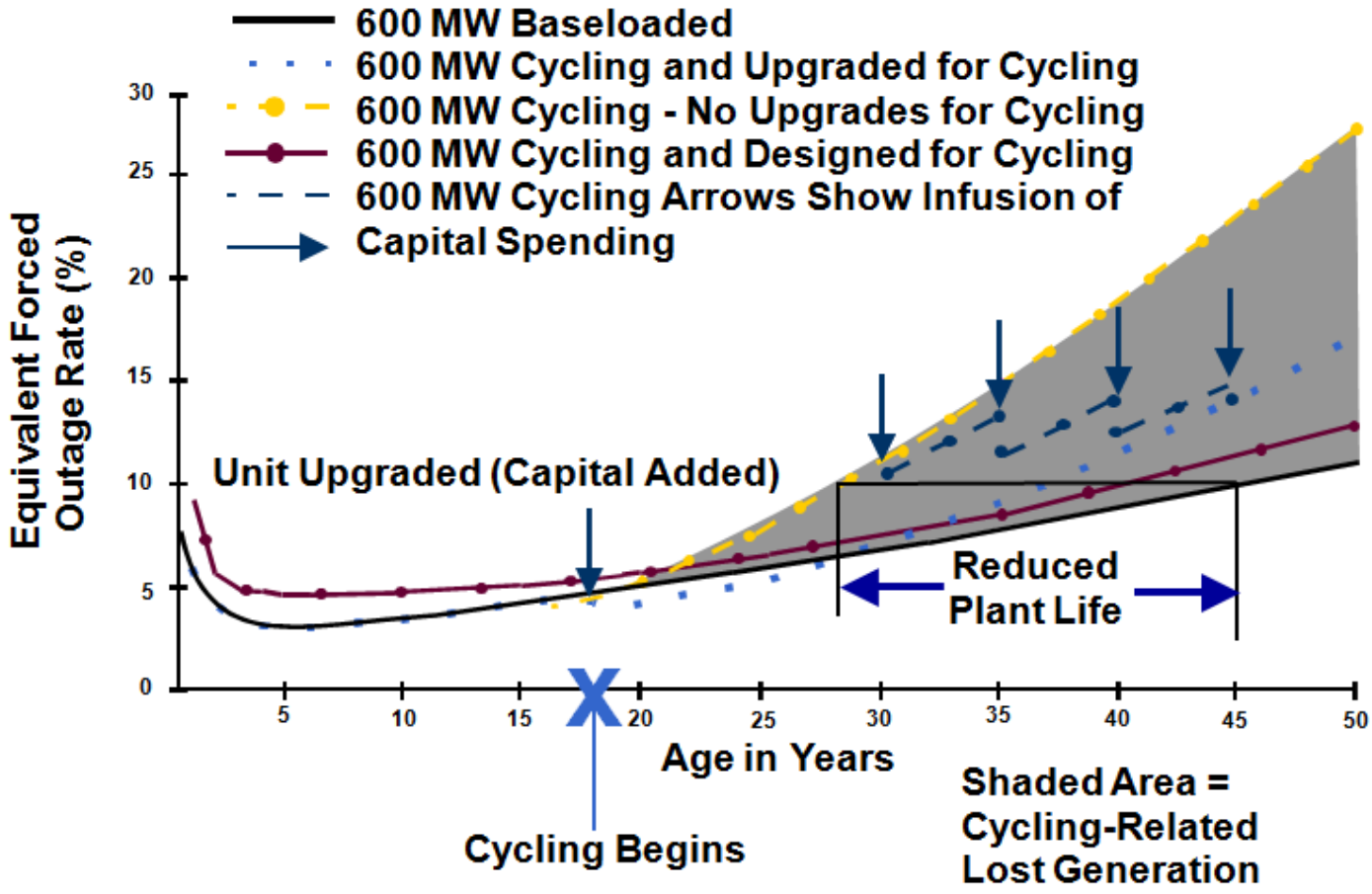
EHS

Load Cycling

- LL1: Lowest Load at Which Design SH/RH Temperatures can be maintained
- LL2: Current “Advertised” Low Load
- LL3: Lowest Load at Which the Unit can Remain On-Line

Source: Steve Lefton, Intertek APTECH, with permission.

Cycling Effects



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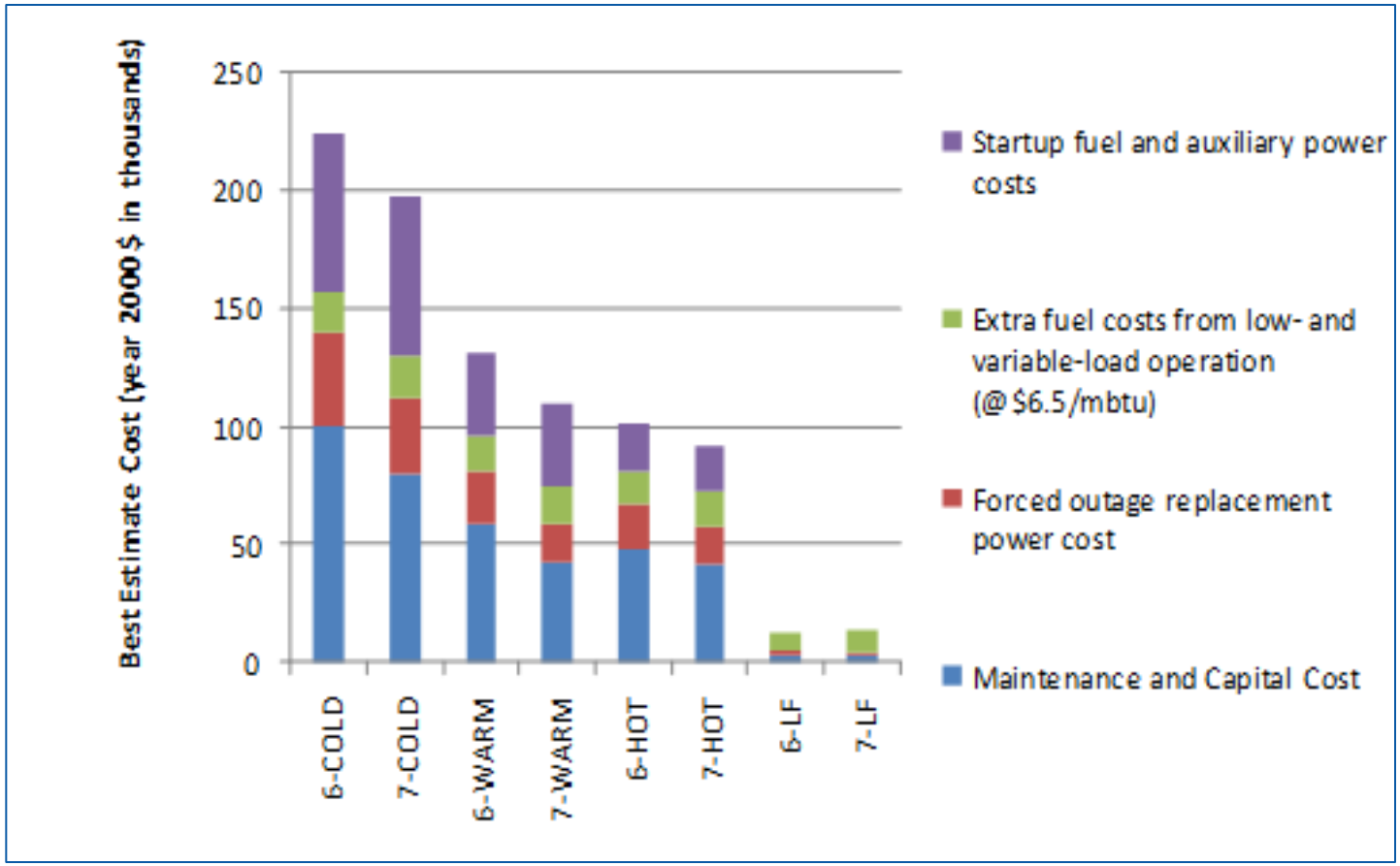
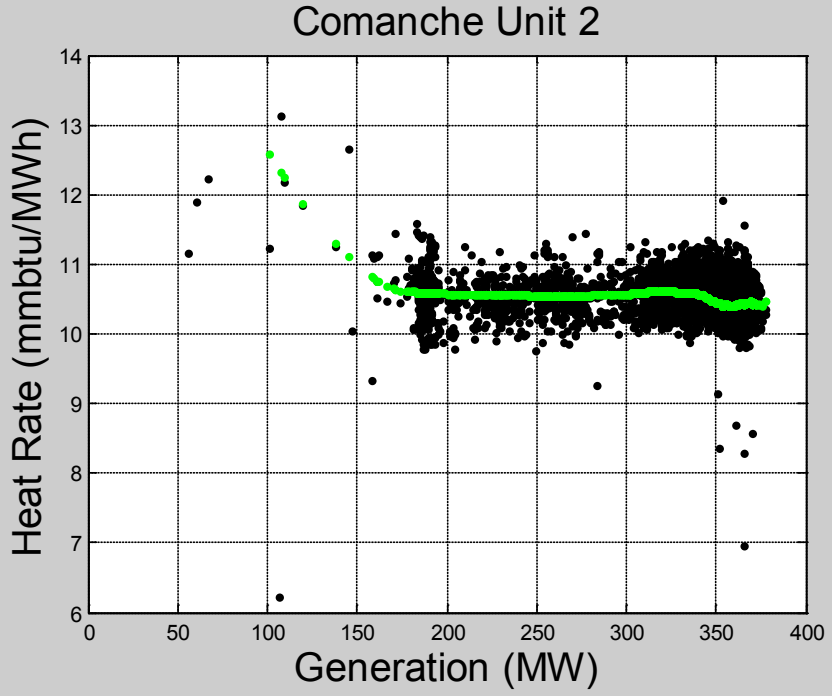
Typical Cycling Cost Breakdown for Two Large Units

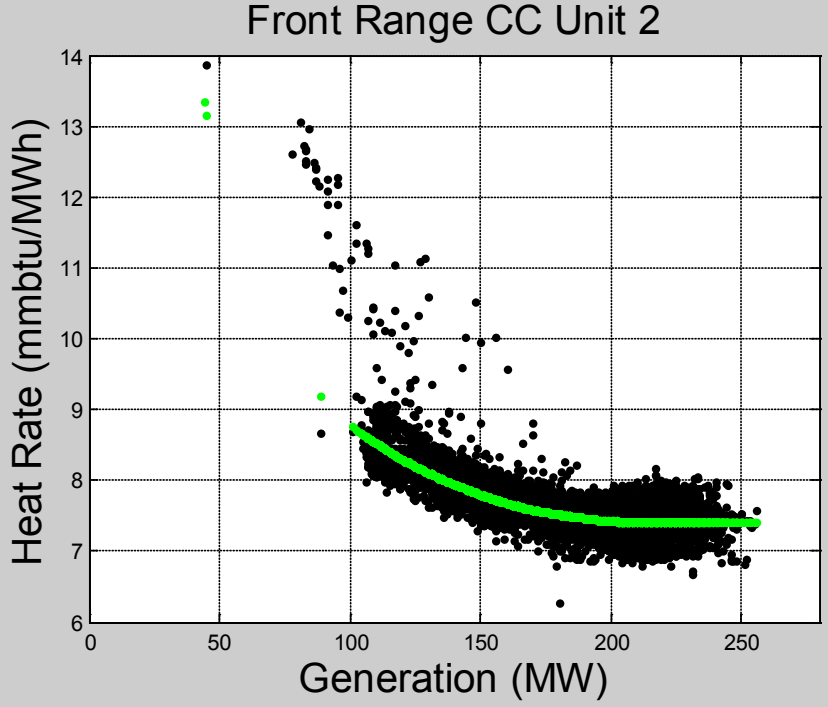


Source: Steve Lefton, Intertek APTECH, with permission.

Heat Rate and Emission Curves

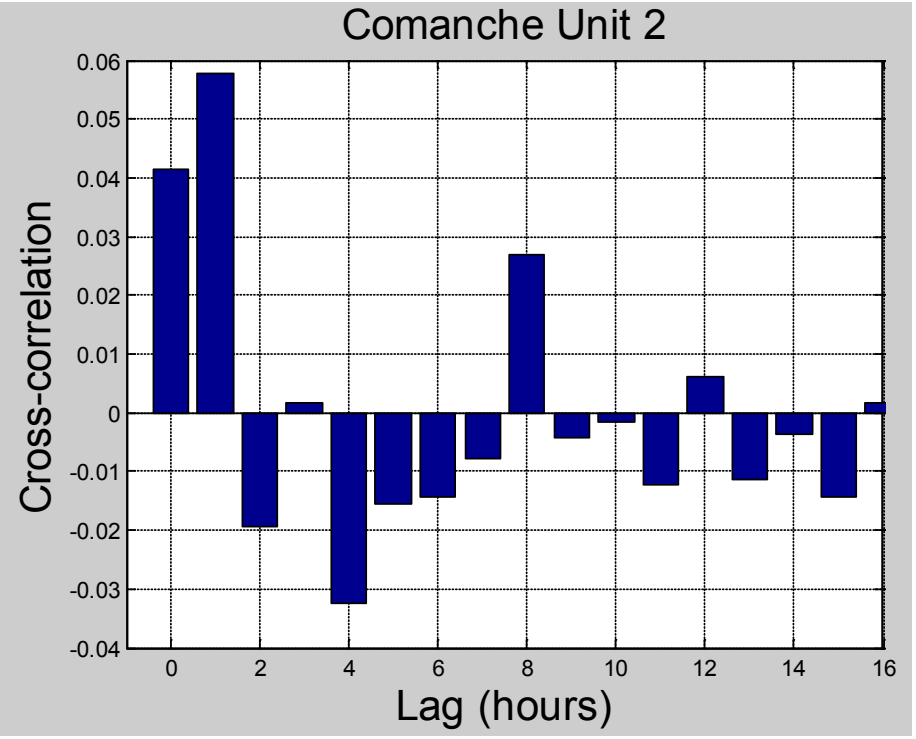
- Local linear fit for every unit.
- Compile emissions at full load and 50% of full load.
- Residuals used for subsequent analysis.
- Eliminate units with obviously clustered data, caused by:
  - Installation of pollution control equipment during year;
  - Part-time operation of pollution control equipment;
  - Combined cycle units in various modes of operation.

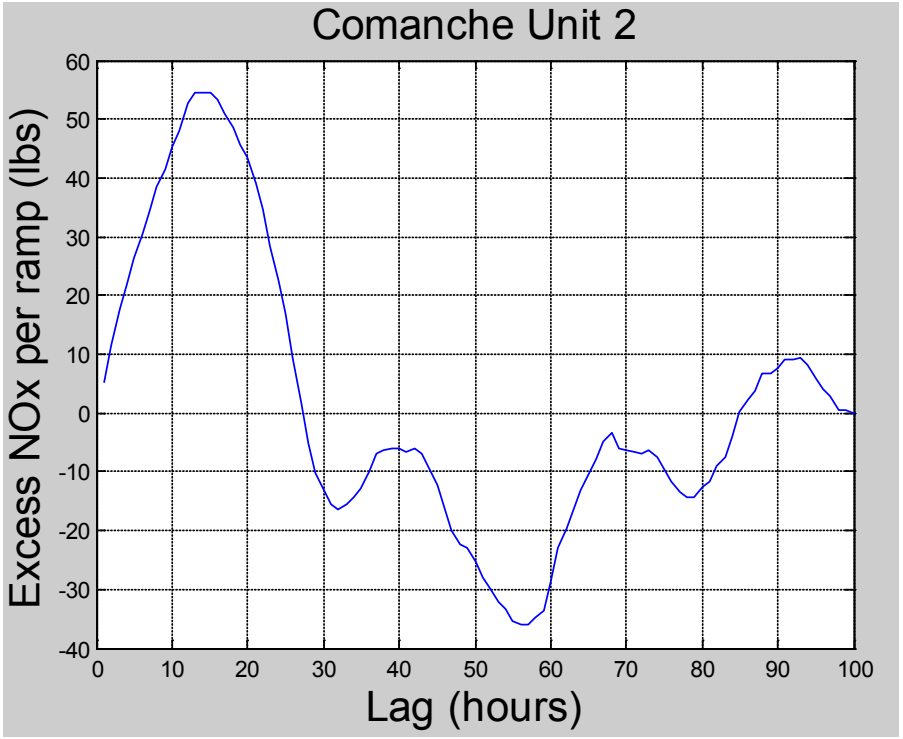




Time-Lagged Pollution Control Failures?

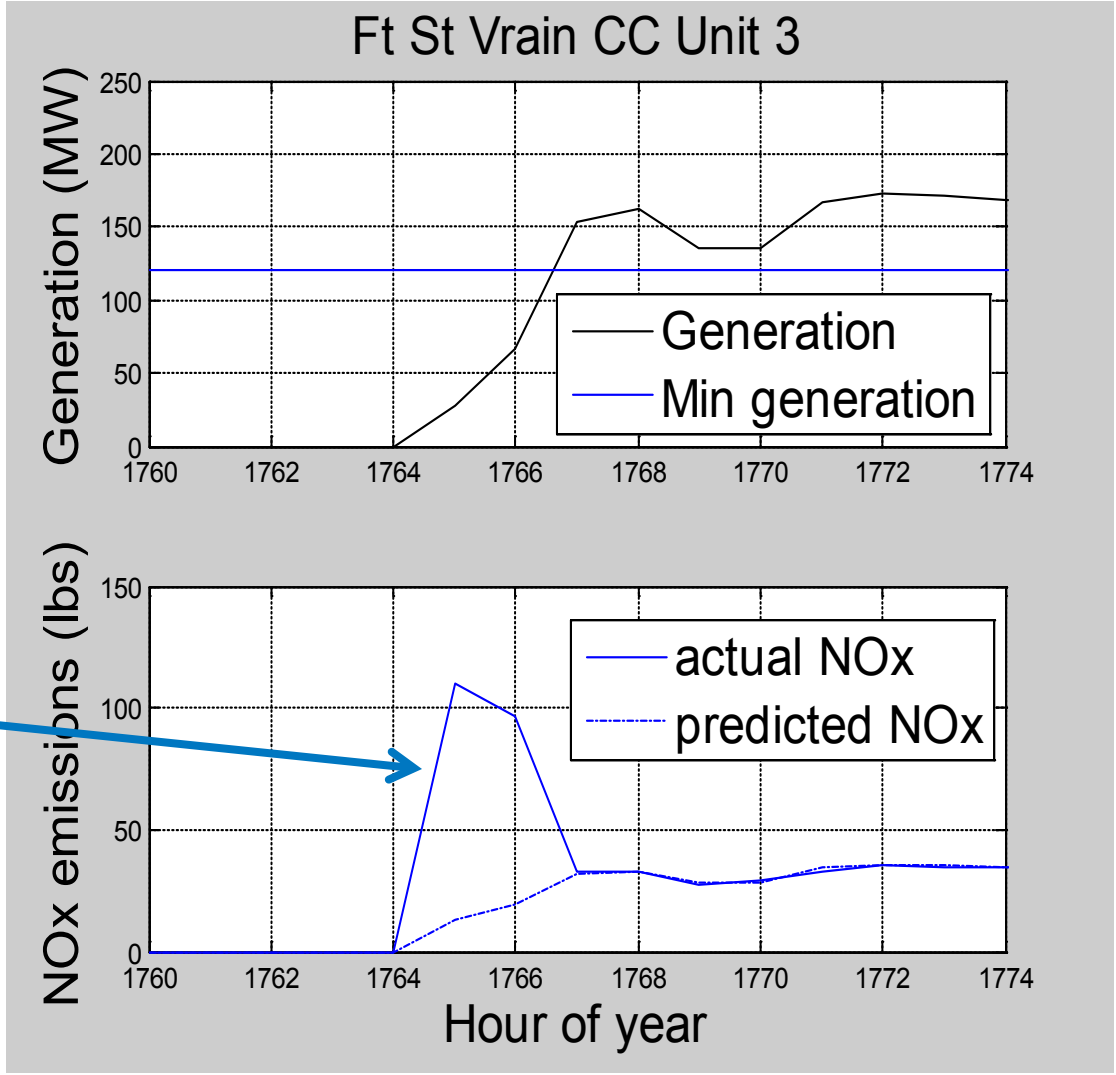
- Lagged cross-correlation between unit ramp rate and the change in emission residuals (see figure on left) —
  - Should identify if pollution control problems are impacted by ramping.
- If evidence of a correlation exists, sum the residuals for all hours impacted by ramping (within 10 hours of a 5% hourly ramp) and average to determine excess emissions caused by ramping (see figure on right).





Startup Emissions

- Add up residuals from all hours prior to and following a startup until unit reaches its minimum generation level.
- Integral between the predicted and actual NO_x curves.



Results (explanation)

All results are generation-weighted averages by type.

Part-load penalty:

- Percentage increase in emissions (lbs) per unit of generation (MWh) when the unit is operating at 50% of maximum generation (compared to maximum generation).

Ramping penalty:

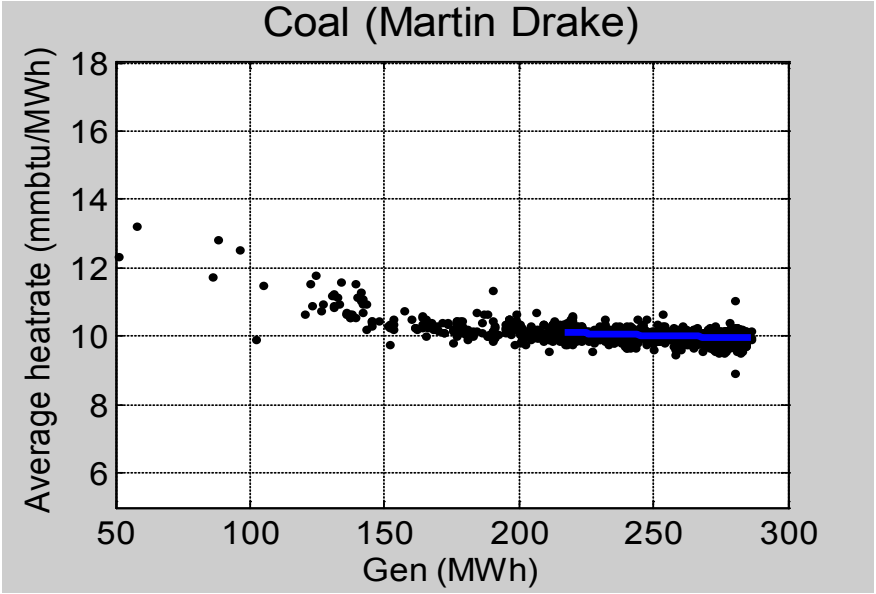
- Ratio of the increased emissions due to a 5% hourly ramp to the emissions from the unit during one hour of full-load operation.

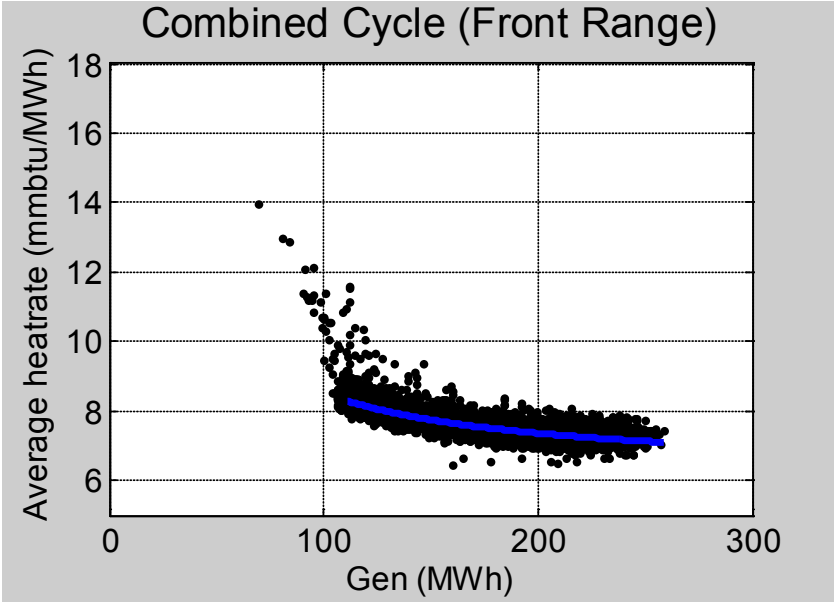
Startup penalty:

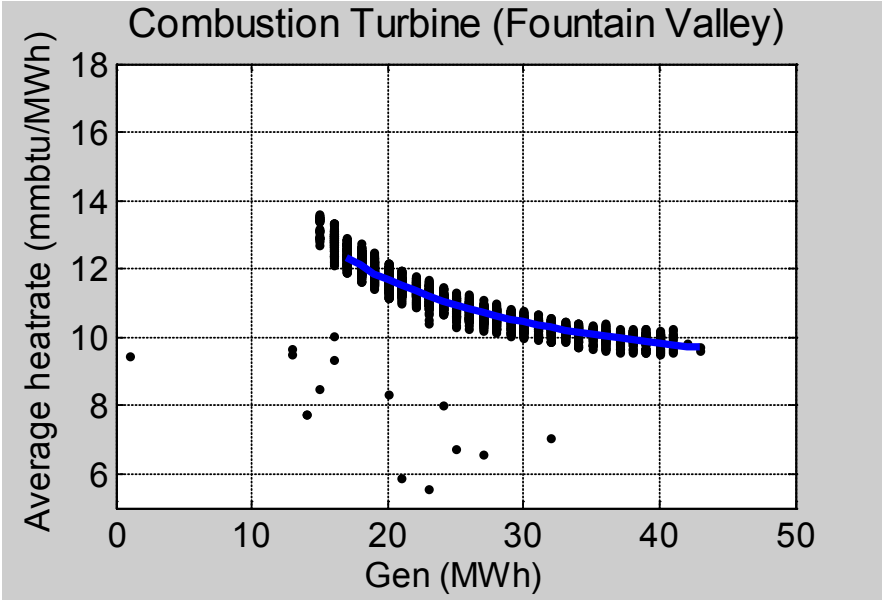
- Ratio of the increased emissions due to a startup to the emissions from the unit during one hour of full-load operation.

Emissions Analysis

- Part-load and full-load properties;
- Data from continuous emission monitors;
- Run PLEXOS with unit-specific heat-rate curves, emission cost sensitivities.







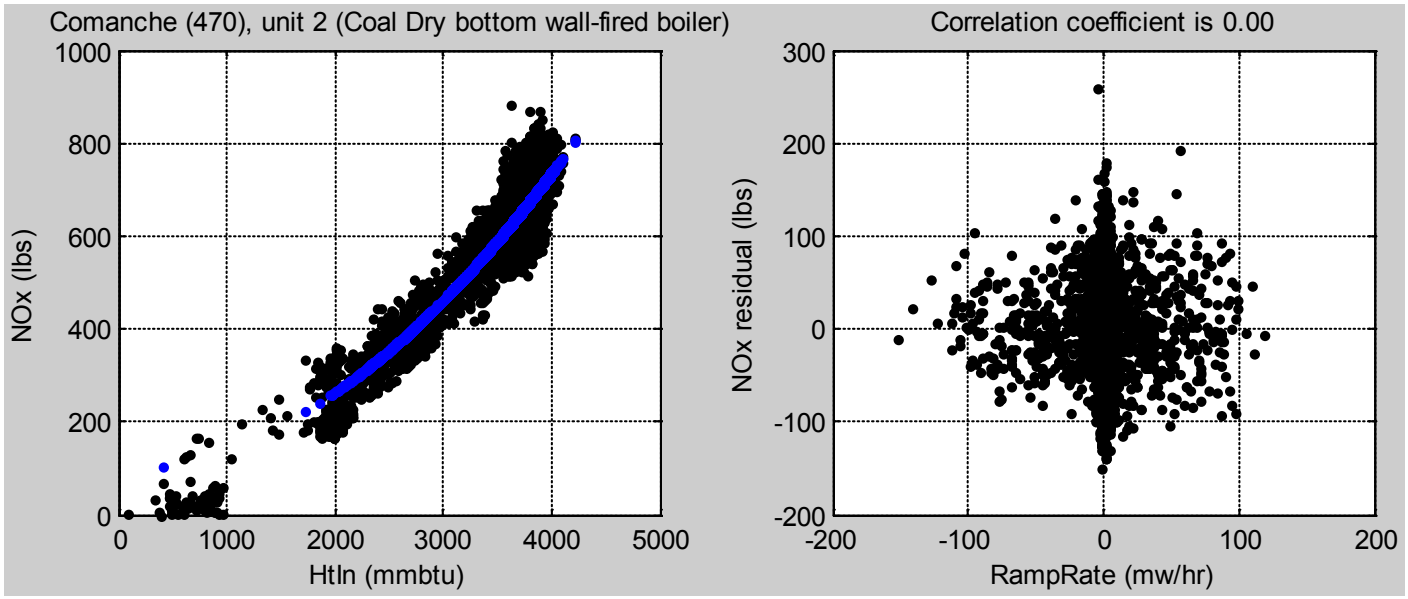
Results (heat input or CO_2)

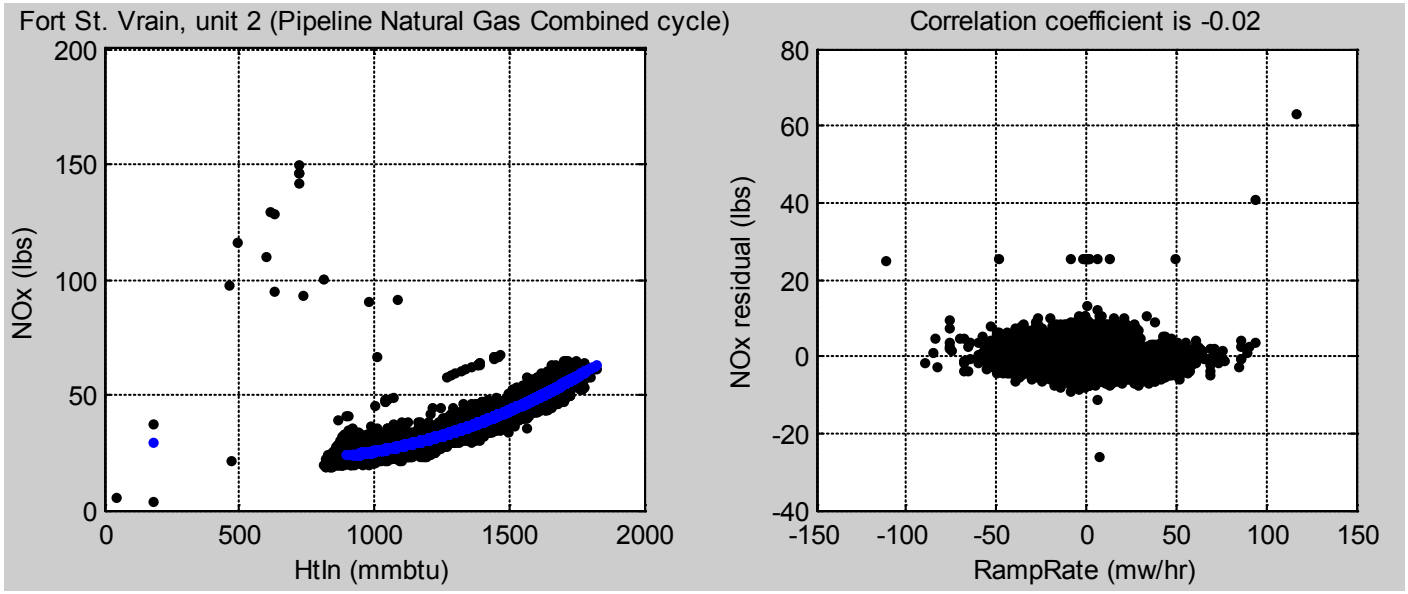
Unit type	Part-load penalty	Ramping penalty	Startup penalty
Coal	5.1%	0.4%	110%
Gas CC	15.6%	0.3%	32%
Gas CT	12.4%	0.3%	32%

No_x Emissions vs. Heat Input, Ramp Rate

NO_x curves vary widely between generators.

Little evidence that dynamic ramping impacts emissions.





Results (NO_x,SO_2)

Unit type	Part-load penalty	Ramping penalty	Startup penalty
Coal (NO_x)	1.2%	2.8%	290%
Gas CC	30%**	0.7%	950%**
Gas CT	19%	0.8%	670%**
Coal (SO_2)	5.4%	13.4%	270%

**These numbers are highly sensitive to input assumptions (percent loading) and/or a small number of extreme outliers (some are bad fits).

WWSIS Phase 2

1. Obtain better data for wear and tear costs of thermal units during cycling and ramping;
2. Examine emission impacts of thermal generation cycling and ramping in greater detail;
3. Optimize unit commitment and economic dispatch with these inputs and examine impact of increasing penetrations of wind and solar on thermal units;
4. Examine mitigation options to reduce costs of thermal unit cycling and ramping.

Wear and Tear Cost Data

- Intertek APTECH has analyzed some 400 thermal units to determine wear and tear costs due to ramping and cycling. They have also developed a Cycling Advisor model to optimize commitment and dispatch of thermal generation with these costs taken into account.
- Split thermal units into 7 categories by size and type.
- Costs to include:
  - Hot, warm, and cold start;
  - Cost for normal ramp rate from min. to max. and for fast ramp rate;
  - Cost for different min output levels.
- Apply cost data to WWSIS-1 results to determine ‘ceiling’ on costs.

PLEXOS Modeling of WECC

- As with WWSIS-1, model all of WECC because renewables in WECC impact WestConnect.
- Benchmark PLEXOS model with WECC-TEPPC model.
- Build base scenario:
  - Opportunity to build more realistic base scenario;
  - May include refining solar datasets to model centralized PV;
  - Incorporate new wear and tear cost data.
- Cases:
  - Run with and without wear and tear cost data;
  - Run at different renewable energy penetration levels;
  - Run with different mitigation options.

Mitigation Options

- Work with GE power plant experts on emissions, combined cycle, steam turbines.
- Examine initial modeling results:
  - What are the parameters that have the biggest impact on production cost? Mingen, downtime, ramp rates;
  - What are the impacts that are most important to mitigate? Efficiency, emissions, equipment lifetime.
- Propose and rank mitigation options:
  - E.g., Cycling specific coal units off in spring, upgrade units to better cycle/ramp.
- When does it make sense to upgrade a unit and what kind of upgrades are needed?

Contact Information

Debbie Lew

NREL

303-384-7037

debra.lew@nrel.gov

http://www.nrel.gov/wwsis