Impacts of Renewable Generation on Fossil Fuel Unit Cycling: Costs and Emissions
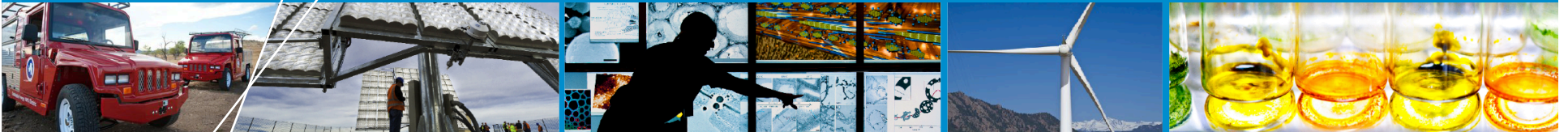
Clean Energy Regulatory Forum
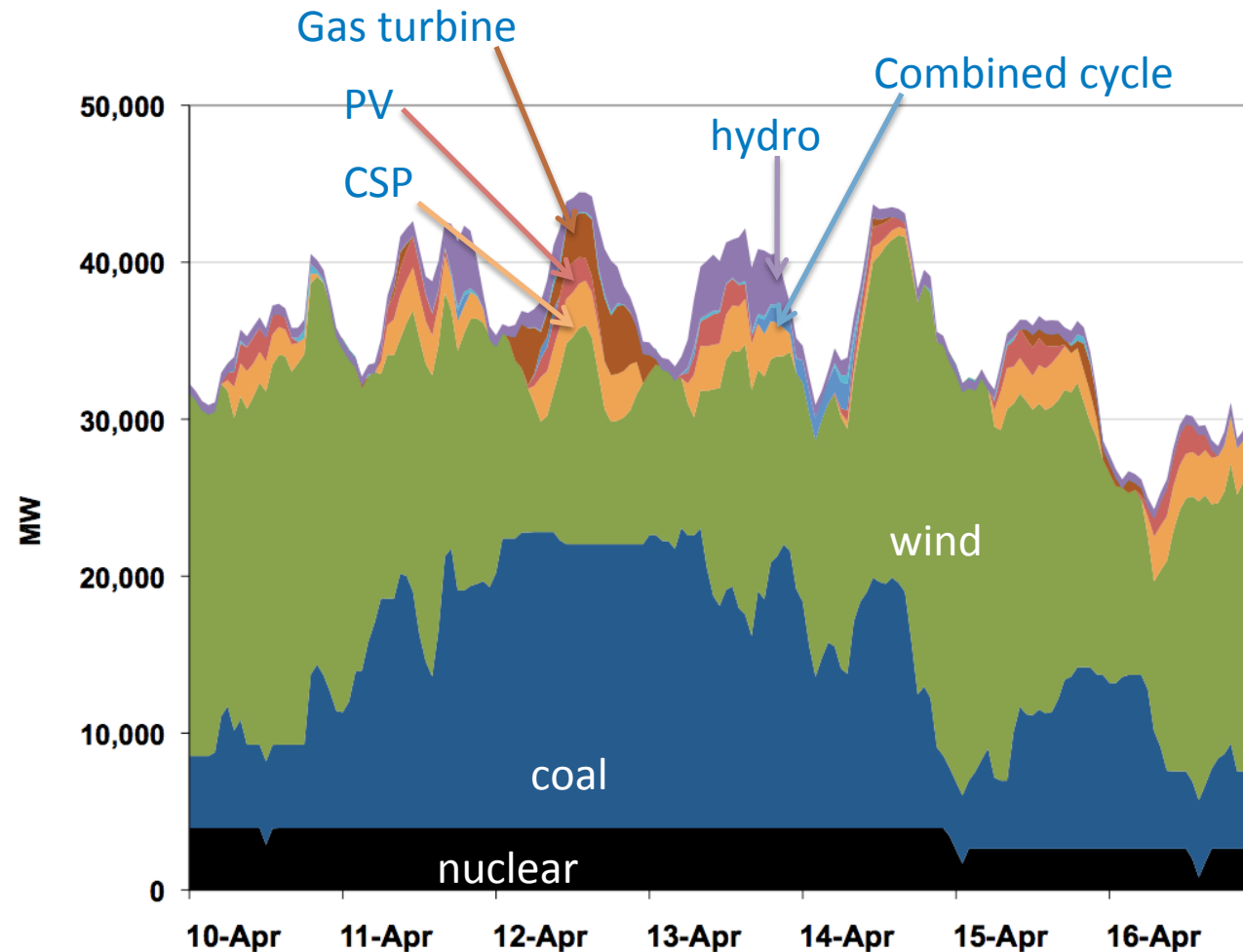
Greg Brinkman

April 19, 2012

Overview

- **Why are we concerned about cycling of conventional generators?**

- **How much does cycling cost?**

- **Cycling impacts on the value of renewables to the grid**

- **How does cycling impact emissions?**

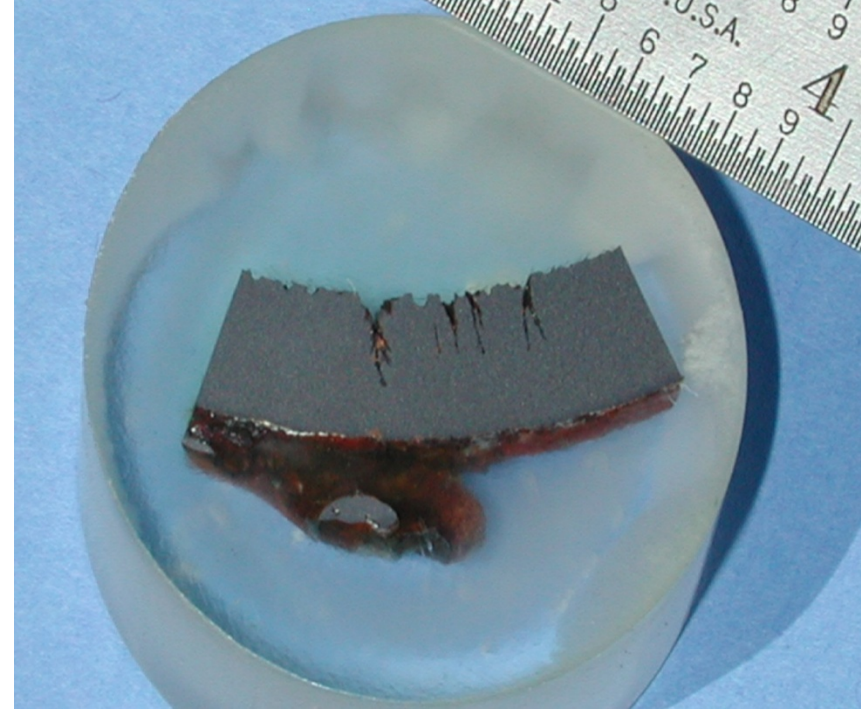- **Cycling impacts on the emission benefits of renewables**

What happens to emissions and wear and tear costs?

Source: Western Wind and Solar Integration Study, 2010

Adding wind and solar generation leads to more startups and ramping at existing thermal units, especially coal

Boiler Corrosion Fatigue

Source: Steve Lefton, Intertek APTECH, with permission.

Startups and ramping can lead to fatigue on various parts of a generator due to thermal stresses (temperature change)

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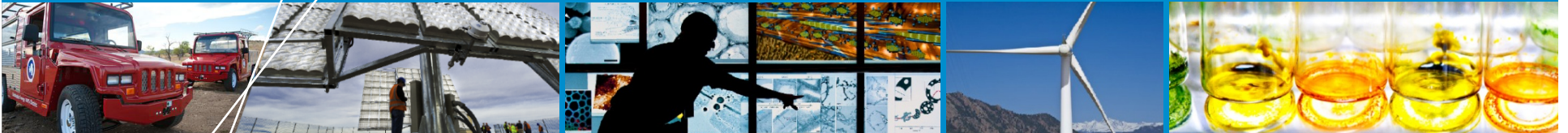
How much does cycling cost?

APTECH methods to estimate cycling costs

- APTECH has analyzed over 400 units worldwide to estimate impacts of cycling
- 170 units met criteria for including in database to estimate typical costs
 - U.S. units, recently analyzed with newest methods

Top-down

- Regression analysis
- Filter all maintenance costs for potential cycling-related repairs
- Include all historical cycling information and maintenance cost timing

Bottom up

- Detailed analysis of 7-10 years of work orders
- Specific analysis of all major plant components
- Operator interviews
- Used to confirm top-down analysis

Cold start costs (per MW capacity)

Cold Start Cost Lower Bounds-Includes Outliers
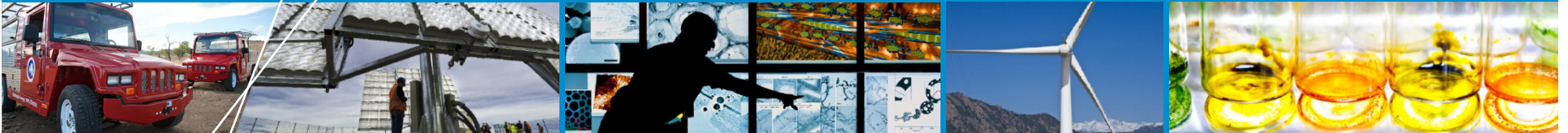(Maintenance and capital cost per MW capacity)
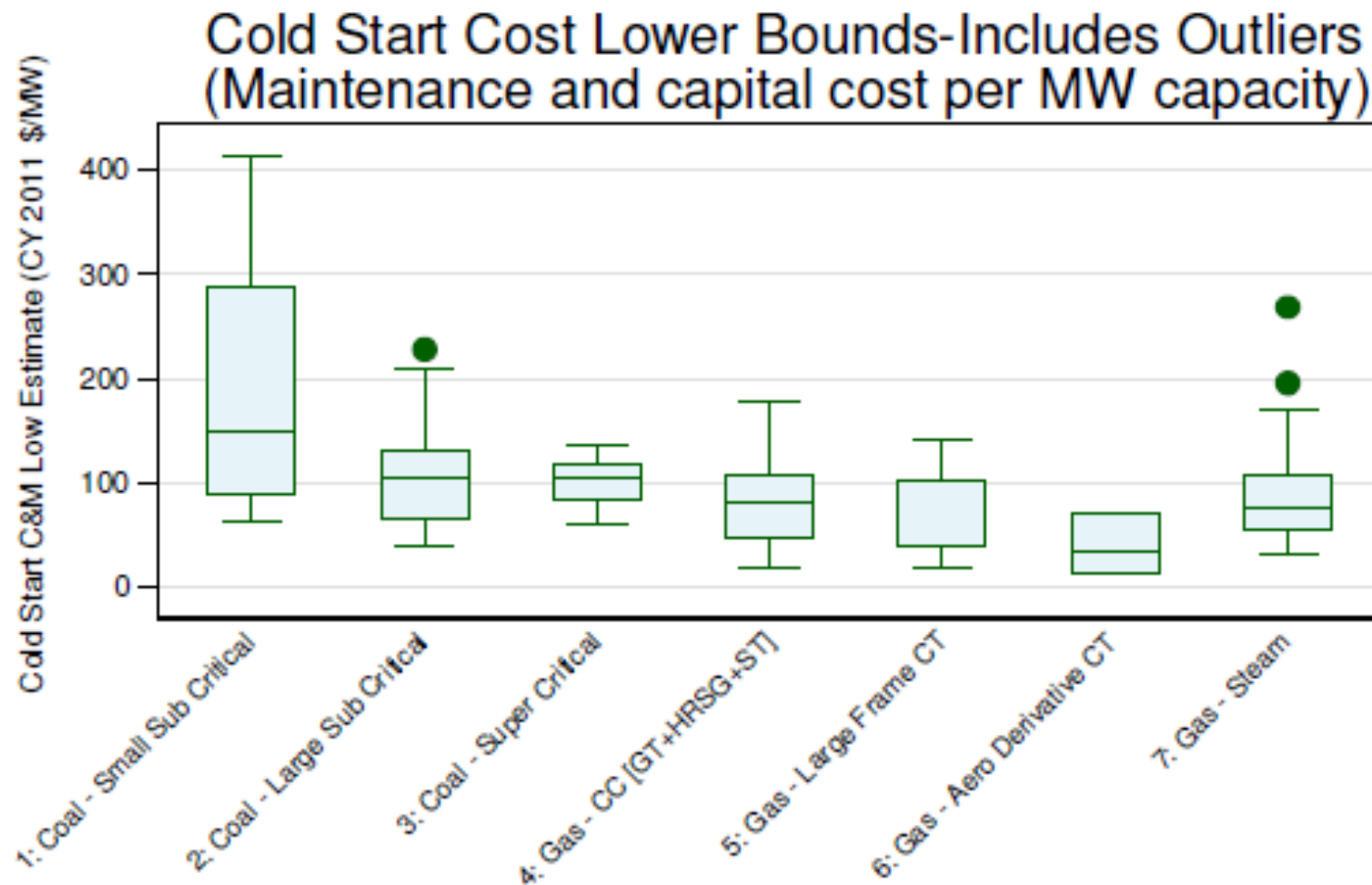
Coal start costs are highest, but gas startup costs still significant
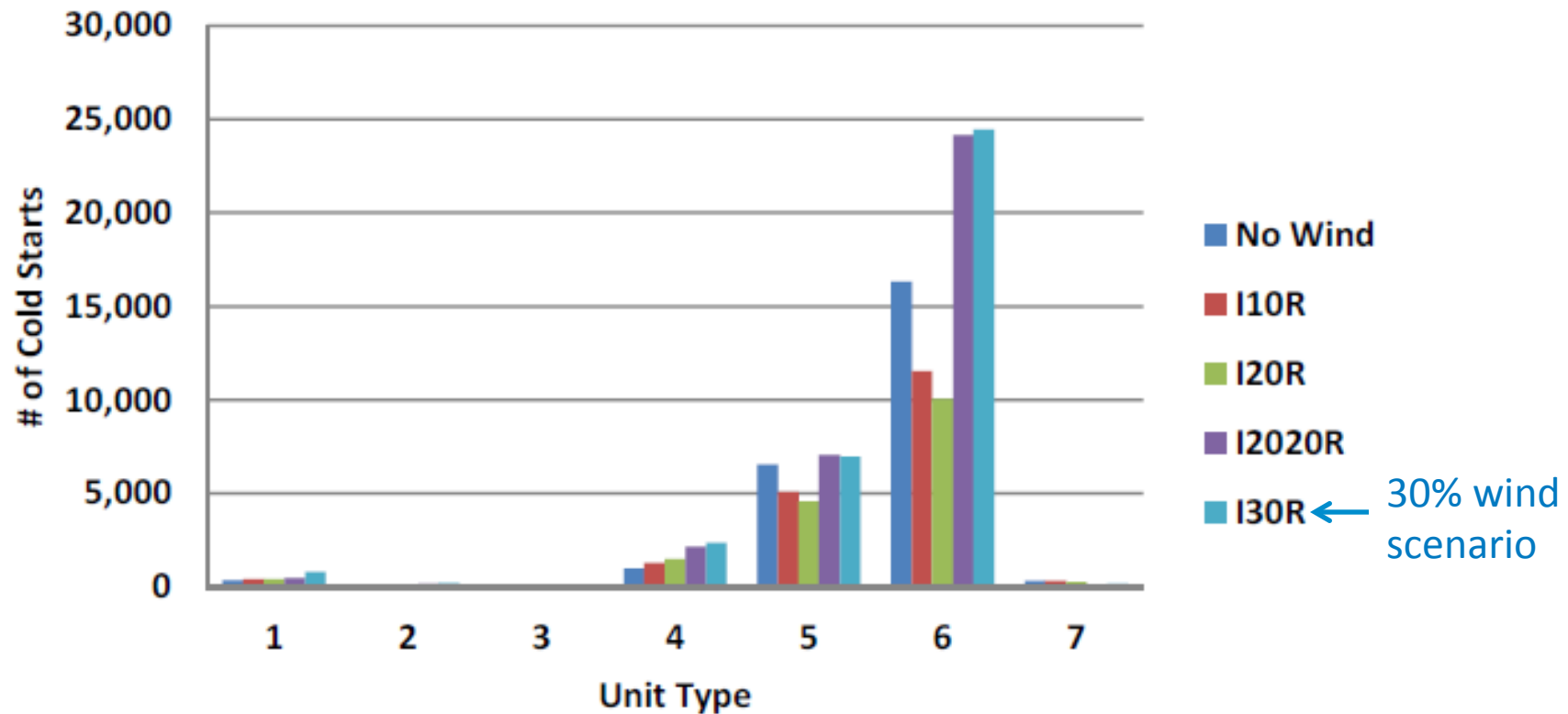
Load following (ramping) costs
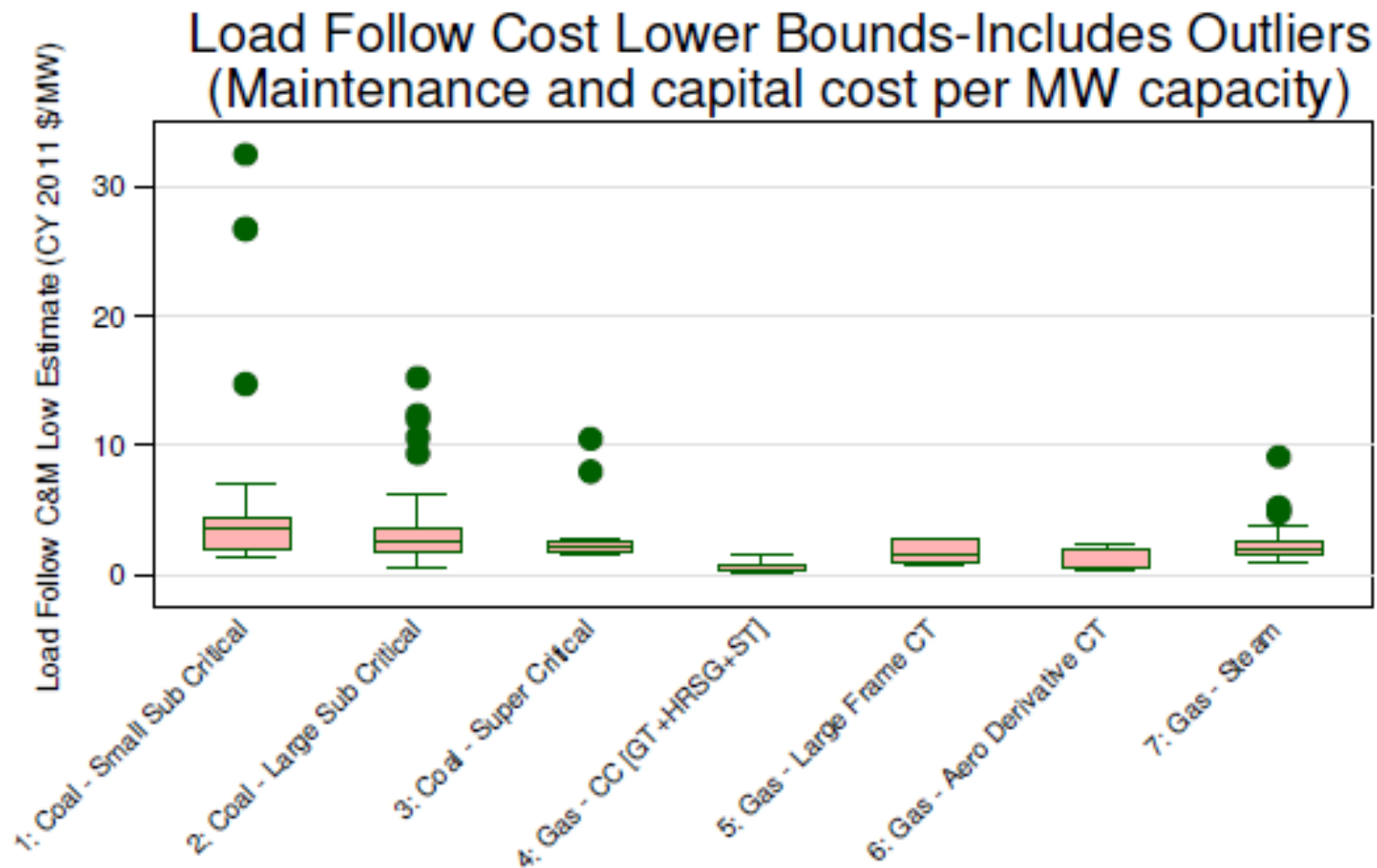
Load following costs are much lower than startup costs, but they happen more frequently

Re-analysis of Western Wind and Solar Integration Study phase 1 results – Cycling impacts on the value of renewables to the grid
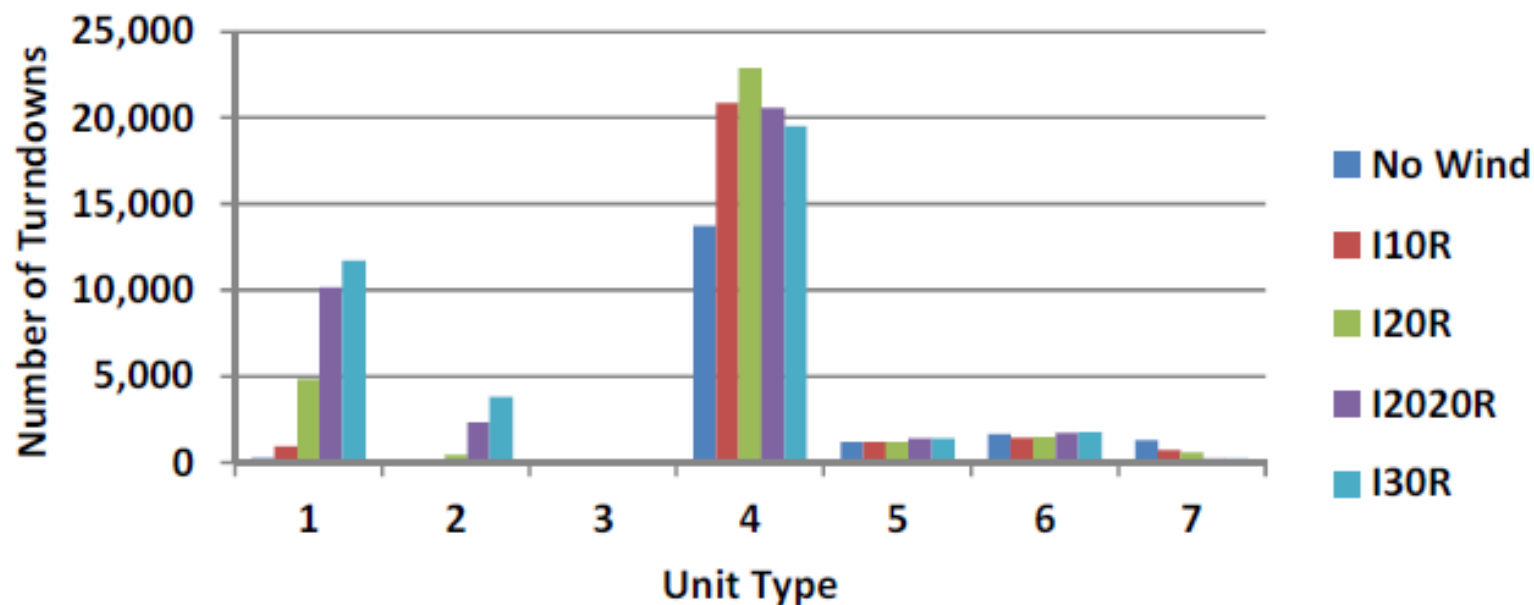
Number of cold starts

Cold starts of coal units go up significantly, but the total number of cold starts of coal units is still small

|	
1	Coal - Small Sub Critical
2	Coal - Large Sub Critical
3	Coal - Super Critical
4	Gas - CC
5	Gas - Large Frame CT
6	Gas - Aero Derivative CT
7	Gas - Steam

Number of ramping events

Ramping of coal units goes up significantly, little change for gas units

|	
1	Coal - Small Sub Critical
2	Coal - Large Sub Critical
3	Coal - Super Critical
4	Gas - CC
5	Gas - Large Frame CT
6	Gas - Aero Derivative CT
7	Gas - Steam

Operating costs – including cycling cost
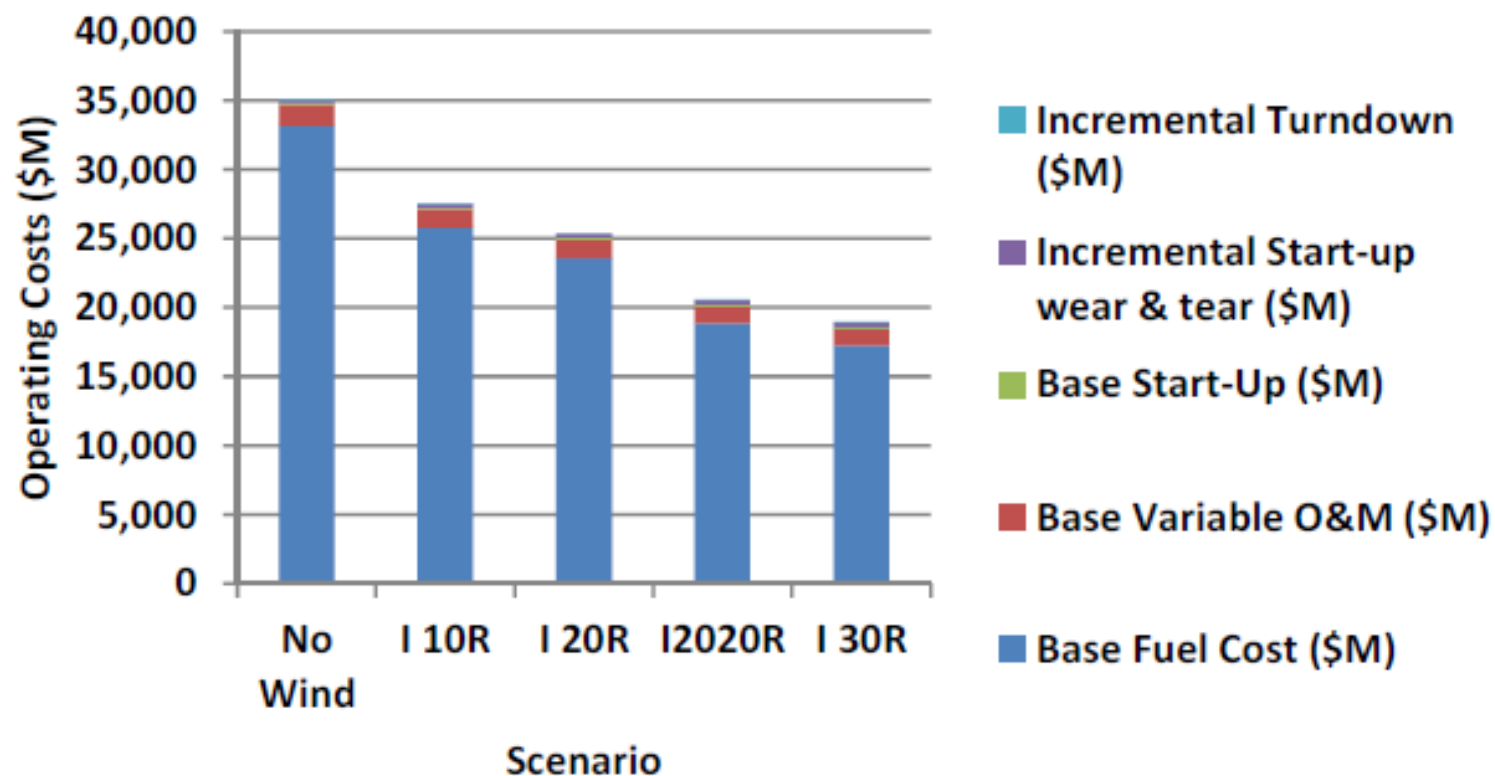
Additional startup costs make up very small portion of total costs (mostly fuel)

Conclusions

- **WWSIS1 found value of wind to be ~$85/MWh**

  – Highly sensitive to gas price assumptions

- **Lower bound cycling cost estimates would reduce that value by 0.1% to 0.7%**

- **Upper bound cycling cost estimates would reduce that value by 0.6% to 2.4%**
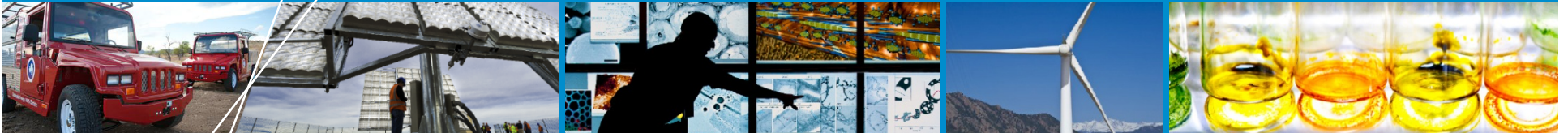
How does cycling impact emissions?

EPA Continuous Emission Monitors (CEMs)

- **Hourly emission measurements on almost all fossil fuel units in the U.S.**

- **Use CEM data to find unit-specific data**
  - Heat rate (and CO_2 emissions) as a function of generation
  - Emissions (NO_x, SO_2) as a function of generation

- **Data from year 2008**

Heat rate and emission curves

- **Local linear fit for every unit**

- **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
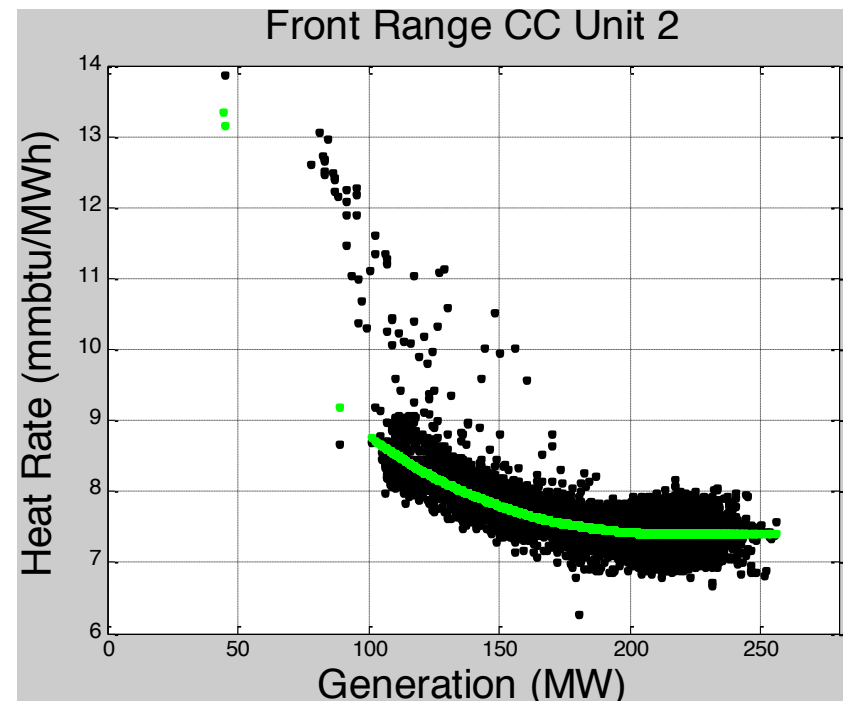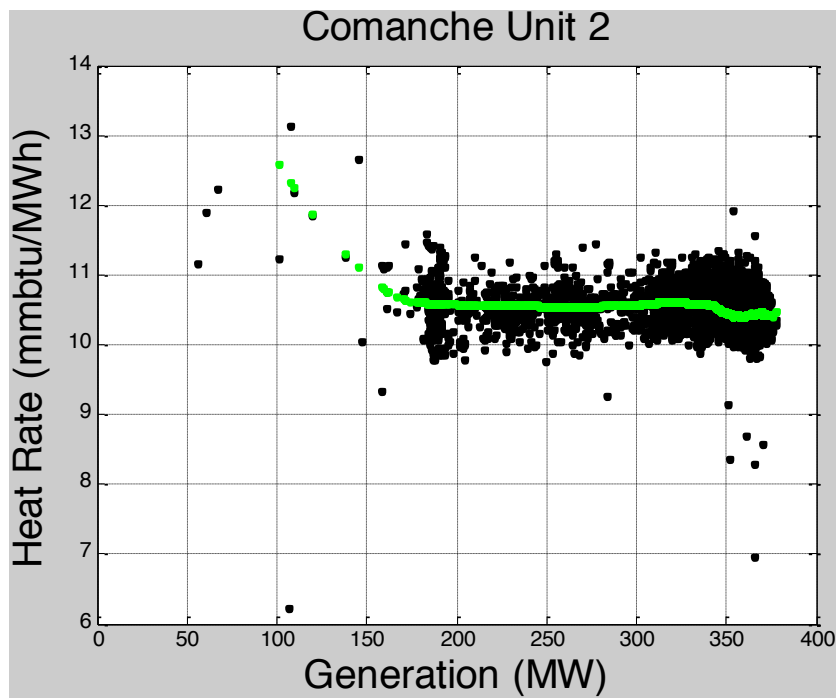
Startup emissions

- **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**

- **Ramping emissions quantified in similar manner**

Ft St Vrain CC Unit 3
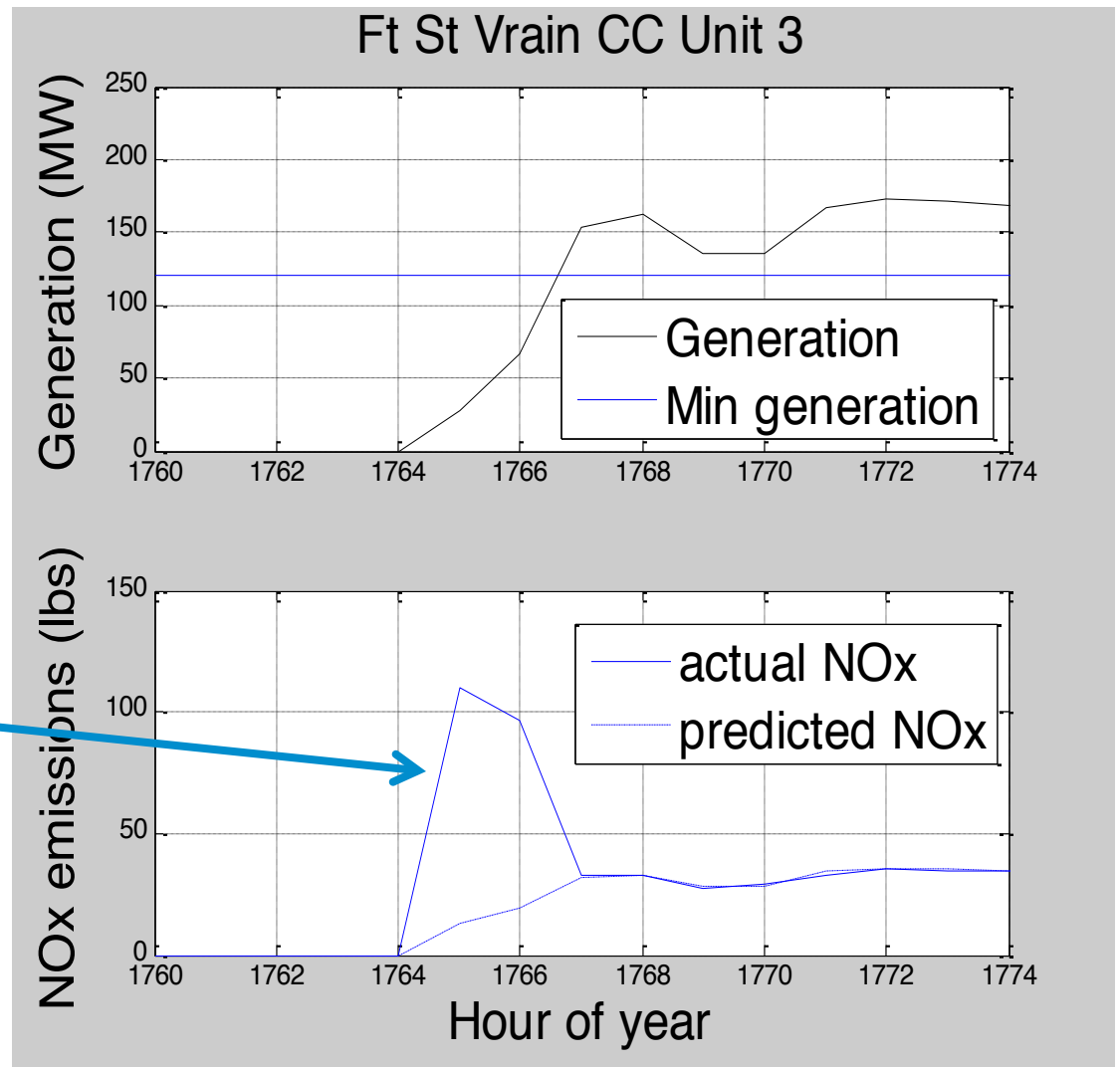
Results (heat input or CO_2)
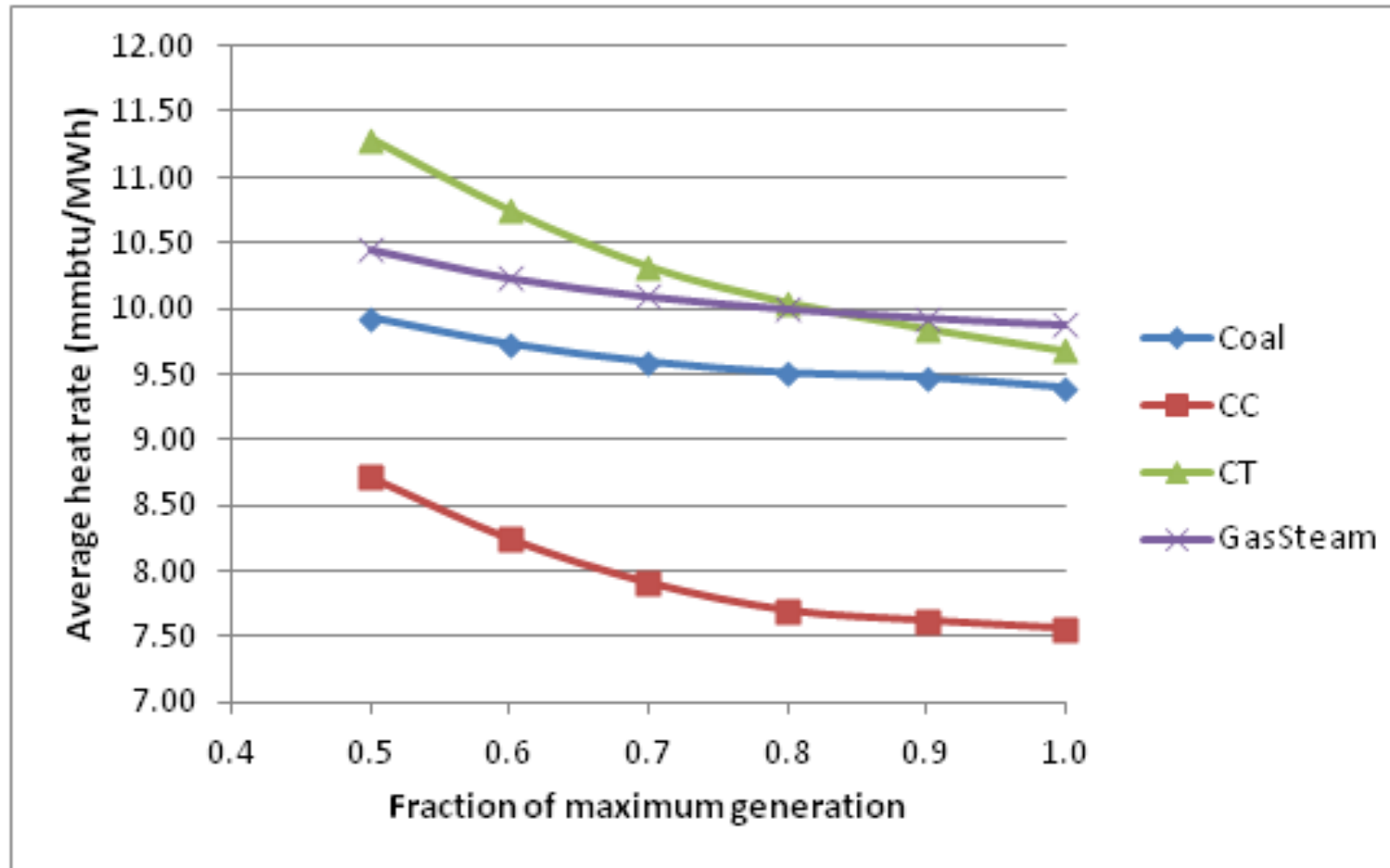
Percentage increase in heat rate at 50% of capacity

Coal	Gas CC	Gas CT	Gas steam
6%	15%	17%	6%

Results (NOx)
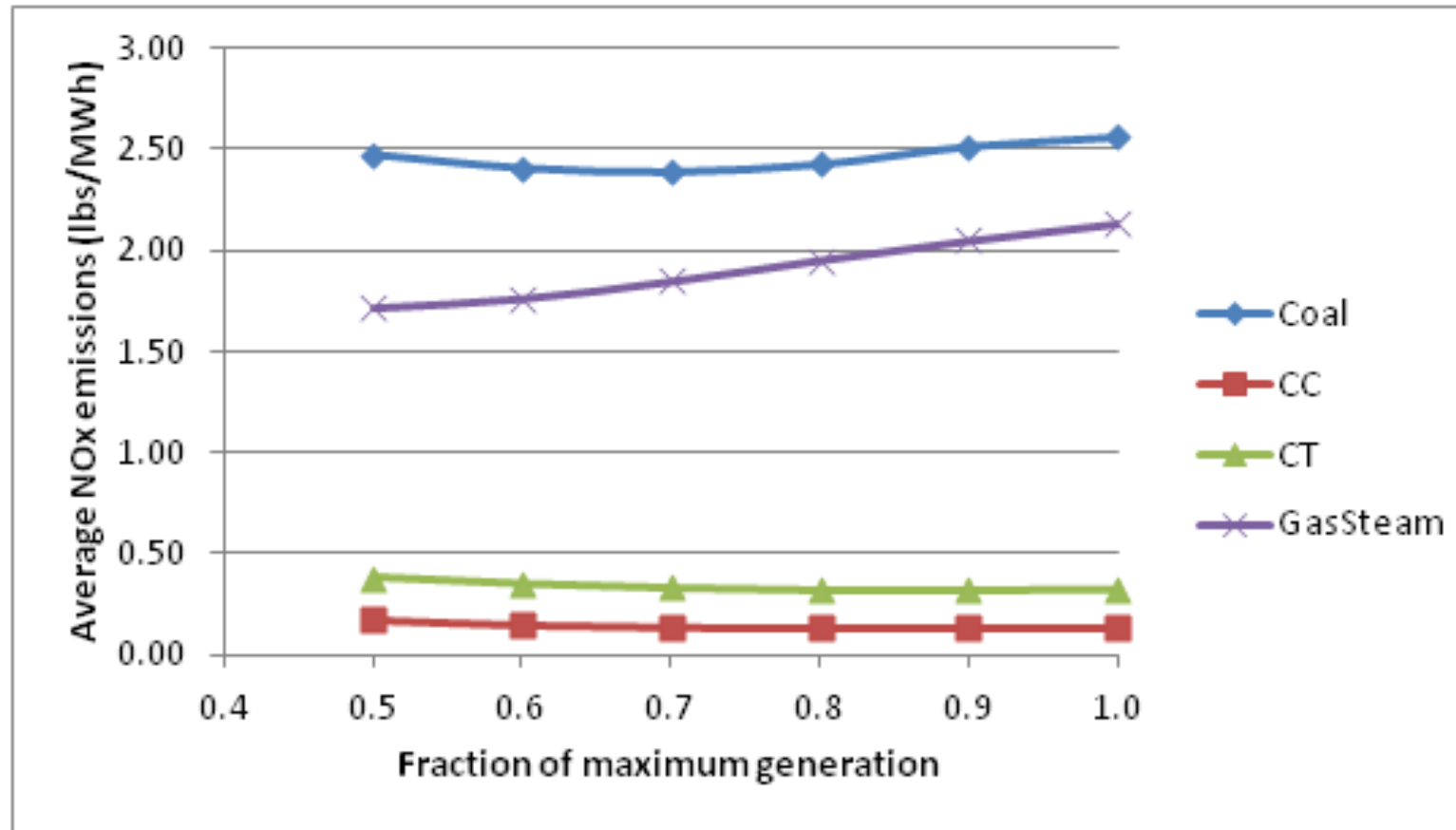
Percentage increase in NOx/MWh at 50% of capacity

Coal	Gas CC	Gas CT	Gas steam
-3%	29%	16%	-19%

Results (SO$_2$)
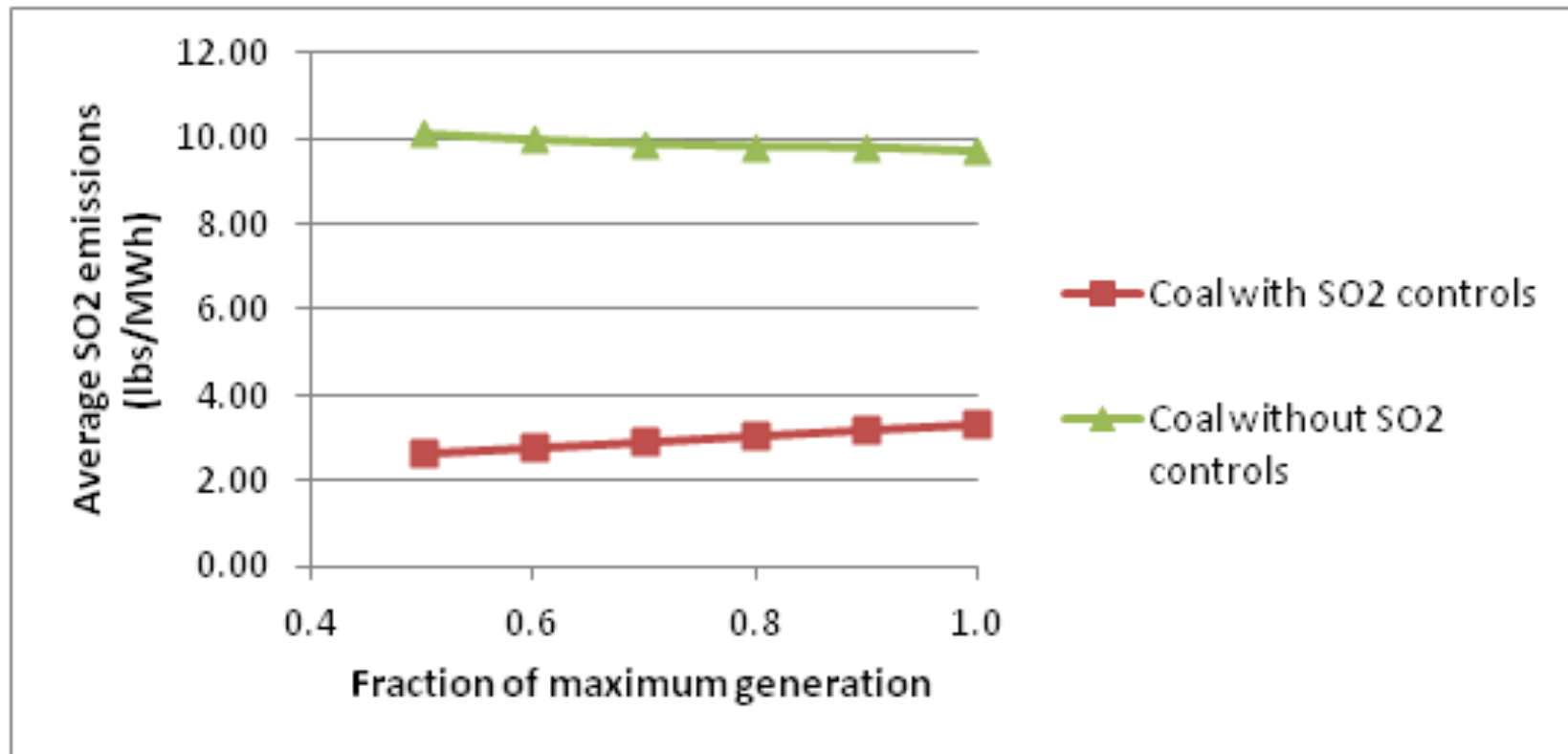
Percentage increase in heat rate at 50% of capacity

Coal (controlled)	Coal (uncontrolled)
-20%	4%

Startups

Startup emission penalty in hours of equivalent full-load operation

	CO2	NOx	SO$_2$
Coal	1.2	1.0	0.8
Gas CC	0.3	6.1	n/a
Gas CT	0.4	1.8	n/a
Gas steam	0.9	0.0	n/a

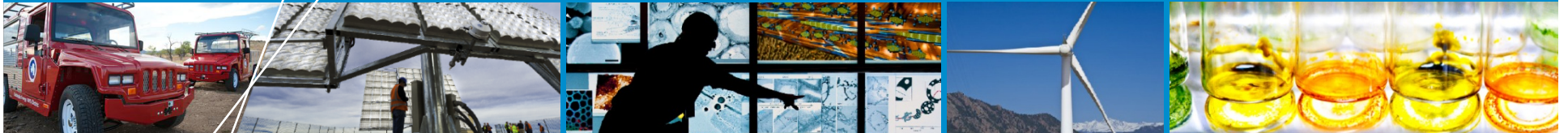Coal units emit more NOx during startup (absolute), but less relative to full-load operation

Ramping

Ramping penalty in hours of equivalent full-load operation

	CO2	NOx	SO$_2$
Coal	0.03	0.08	0.07
Gas CC	0.01	0.08	n/a
Gas CT	0.01	0.01	n/a
Gas steam	0.01	0.08	n/a

Ramping leads to far less emissions compared to startups, but occurs more often

Re-analysis of Western Wind and Solar Integration Study phase 1 results – Cycling impacts on the emission benefits of renewables

WWSIS re-analysis

- **WWSIS1 was re-analyzed for startup, ramping, and part-loading emissions of NO_x and CO_2**

- **Generic emission rates (specific to WECC) applied by category to previously modeled dispatch**

- **Table below shows emissions avoided per MWh of renewable production (reduced fossil-fuel production)**

	Nox (lbs/MWh)	CO2 (tons/MWh)
Assuming flat emission curves	0.422	0.499
+considering part-load emission rates	+0.031 (+7.3%)	-0.006 (-1.3%)
+considering startup emissions	-0.006 (-1.3%)	-0.001 (-0.3%)
+considering ramping emissions	-0.011 (-2.7%)	-0.001 (-0.2%)
Total	0.436 (+3.3%)	0.490 (-1.7%)

Conclusions and future work

- **Startups, part-load efficiencies, and ramping have a relatively small impact on total cost and emissions**
  - Compared to determining which unit is on the margin

- **Cycling may have significant impacts at specific times or places, or for individual generators**

- **How does wind/solar impact emissions?**
  - Type of unit (and emissions performance of unit) on margin more important than "cycling"
  - WWSIS phase 2 will use unit-specific data for these parameters

Questions?

Follow-on questions:

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