National Renewable Energy Laboratory
Innovation for Our Energy Future

Emission impact of fossil fuel unit cycling

UWIG User Group Meeting

Greg Brinkman

October 12, 2011

Wind impacts on emissions?

Western Wind and Solar Integration Study (WWSIS) (phase 2 plan):

- Understand interaction between wind/solar penetration and thermal unit cycling
- Step-by-step approach to emissions
  - Gather unit-specific data on emissions
  - Characterize impacts of part-load operation, ramping, startups
  - Include these properties in unit commitment and dispatch modeling

EPA Continuous Emission Monitors (CEMs)

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

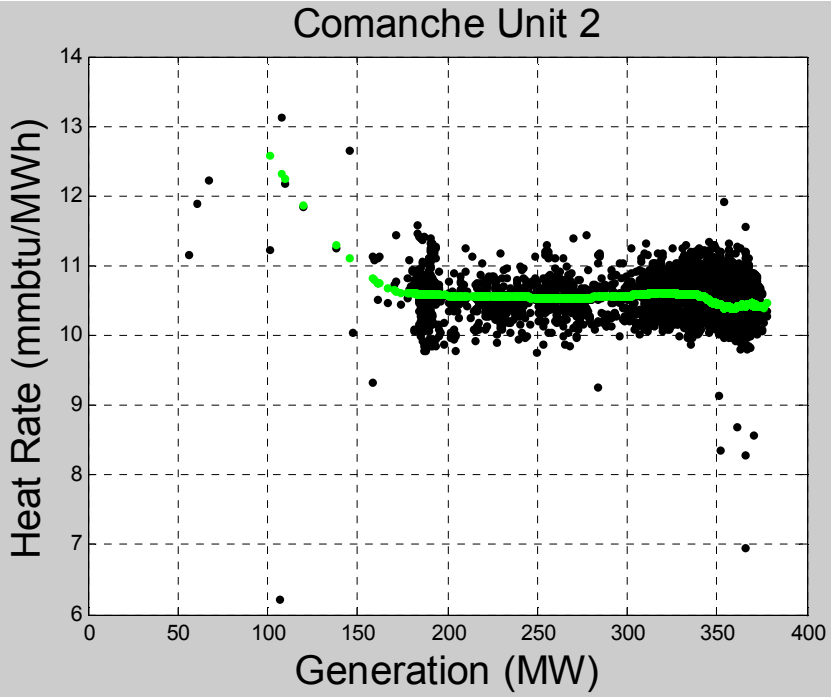
Use CEM data to find unit-specific data

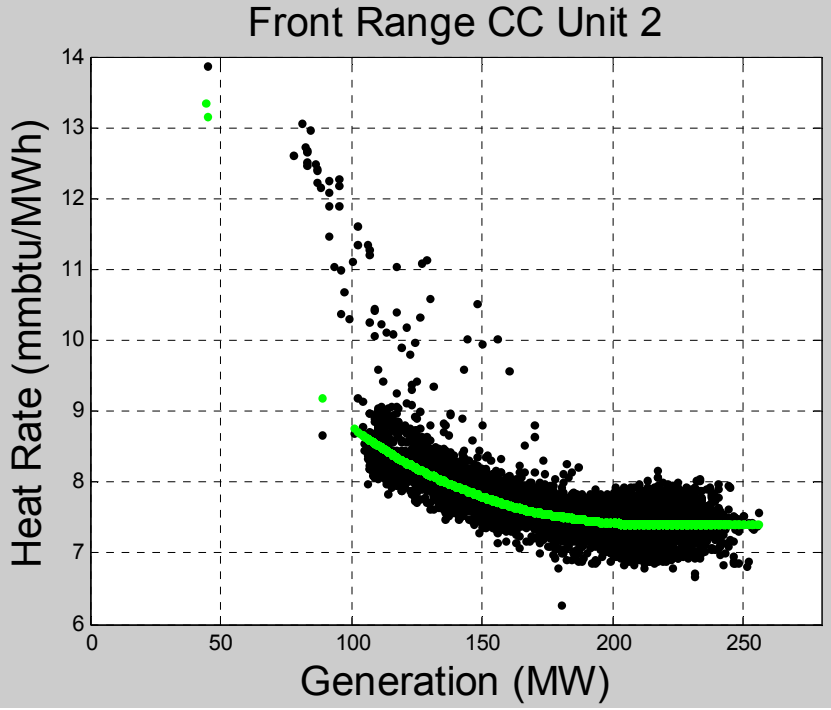
- Heat rate (and CO_2 emissions) as a function of generation
- Emissions (NO_x, SO_2) as a function of generation

Data from year 2008

Heat rate and emission curves

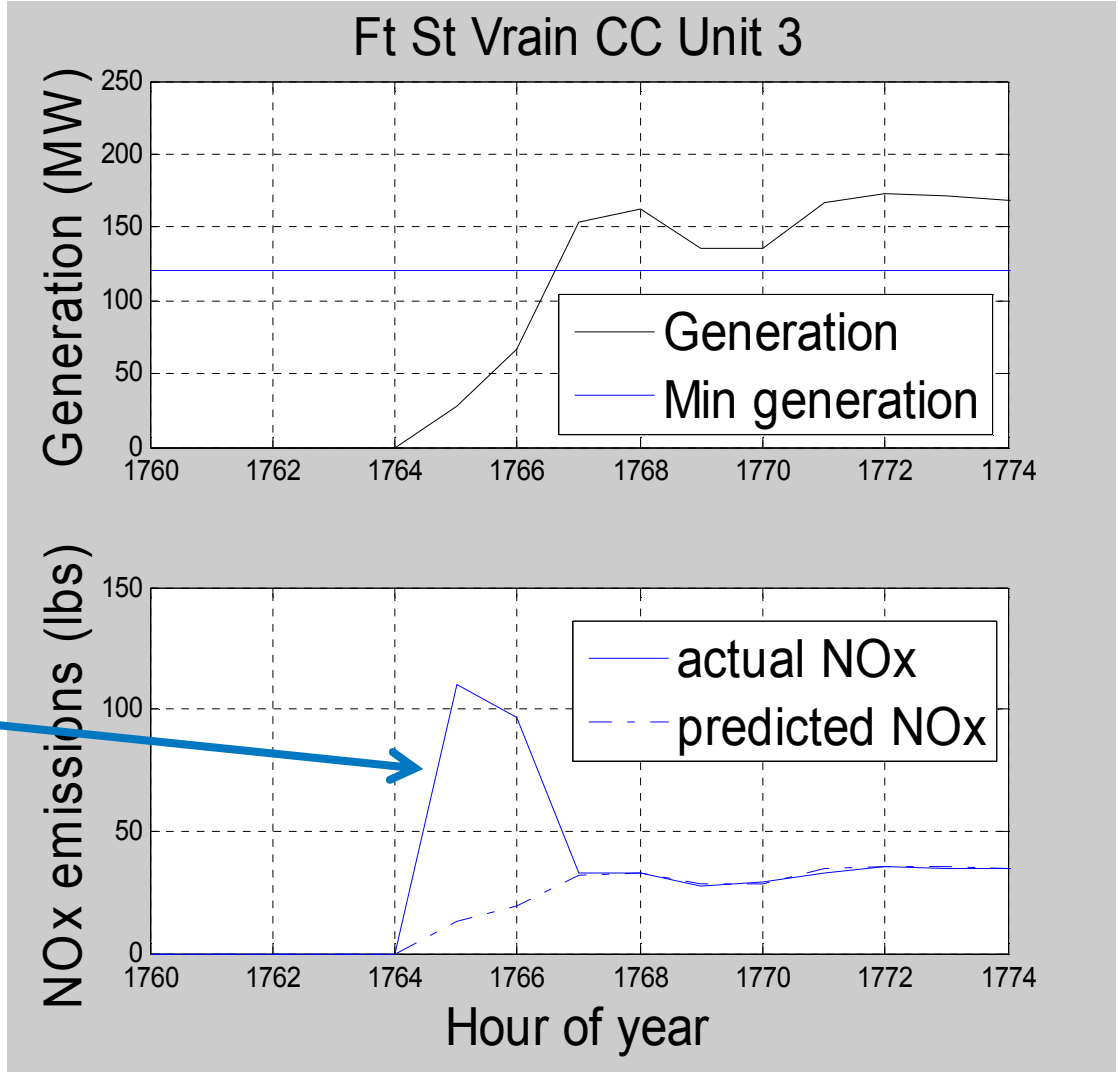
- Local linear fit for every unit
- Residuals used for subsequent analysis
- Eliminate units with obviously clustered data, caused by:
  - Installation of pollution control equipment during year
  - Part-time operation of pollution control equipment
  - Combined cycle units in various modes of operation



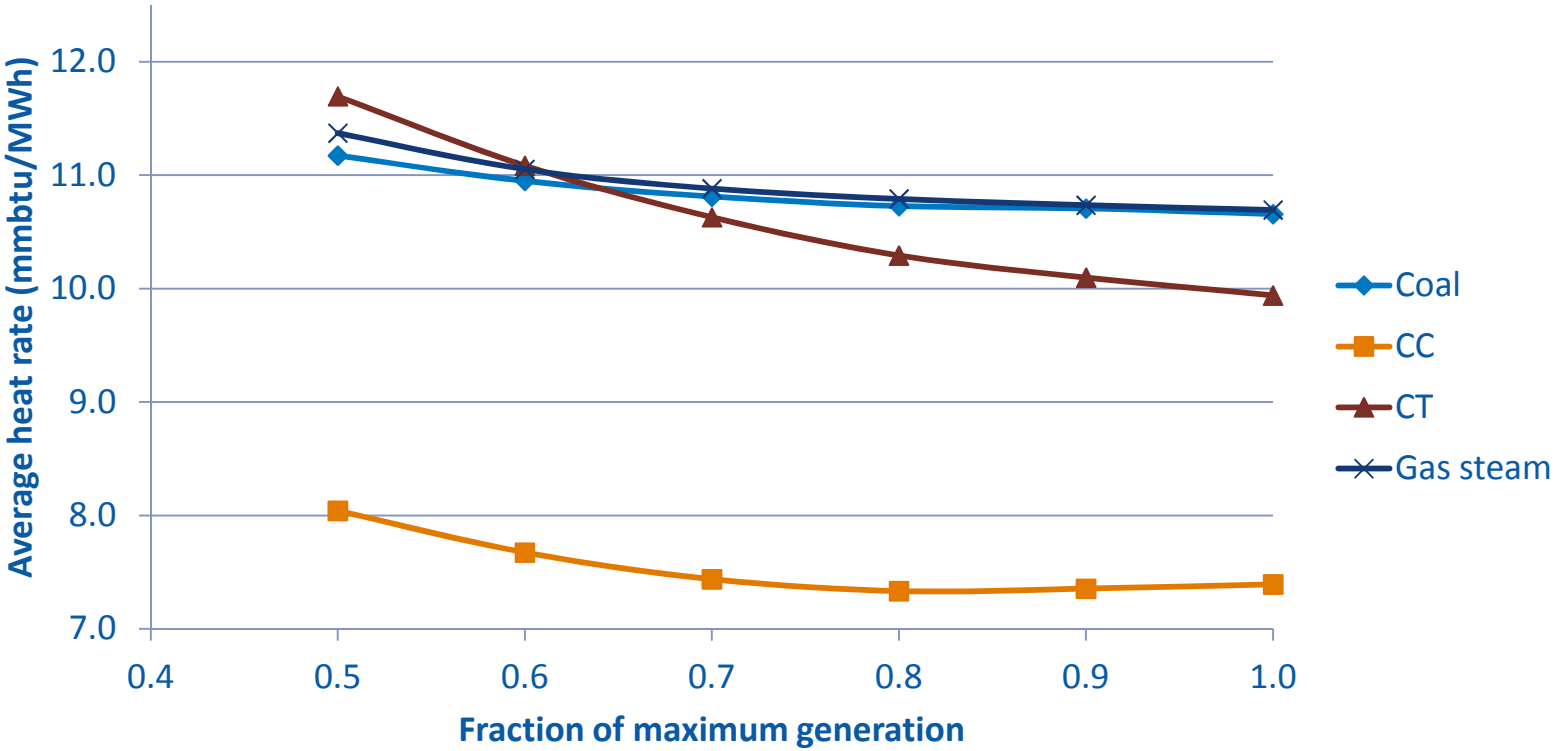


Startup emissions

- 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

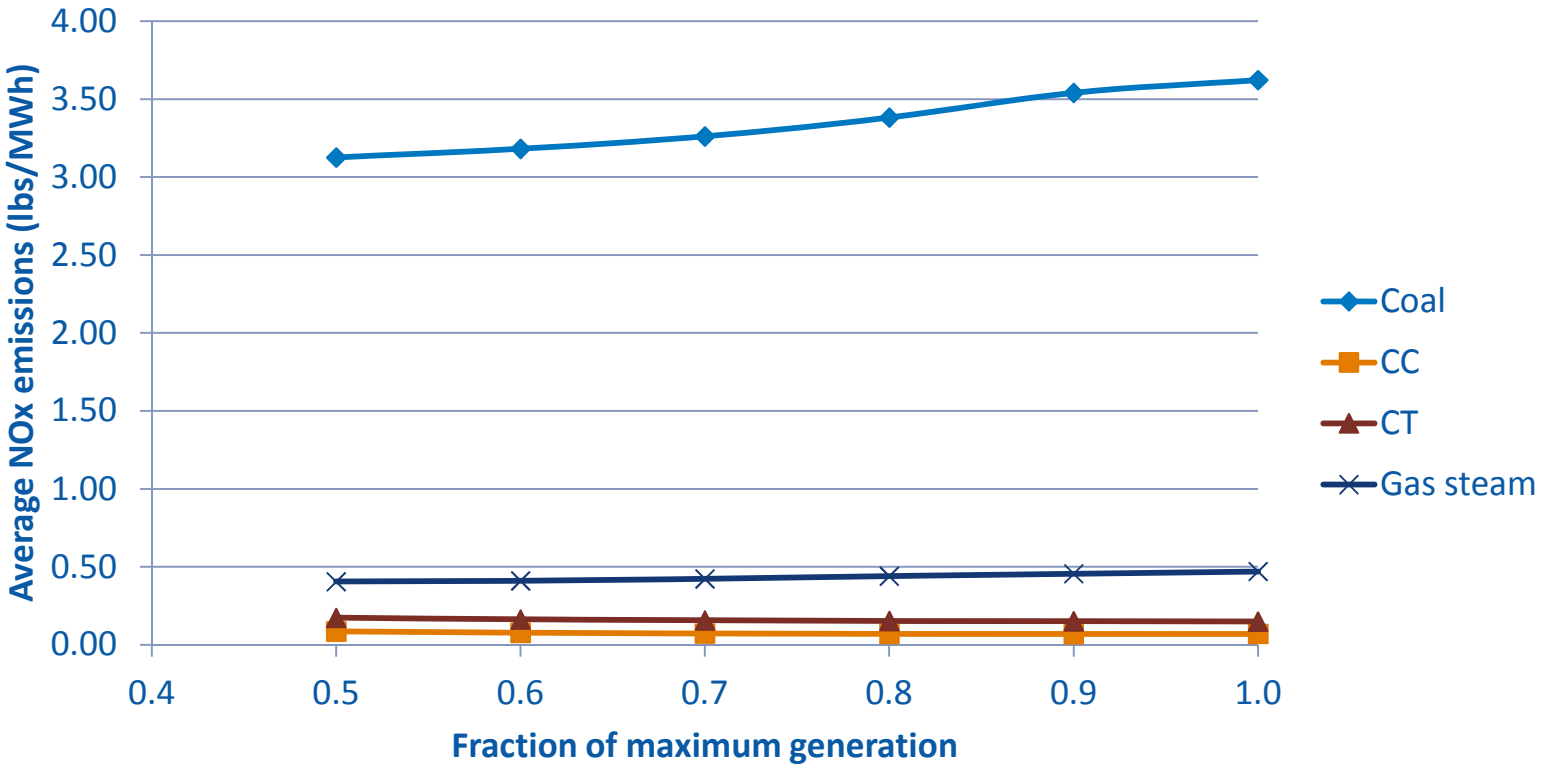


Results (heat input) – WECC averages



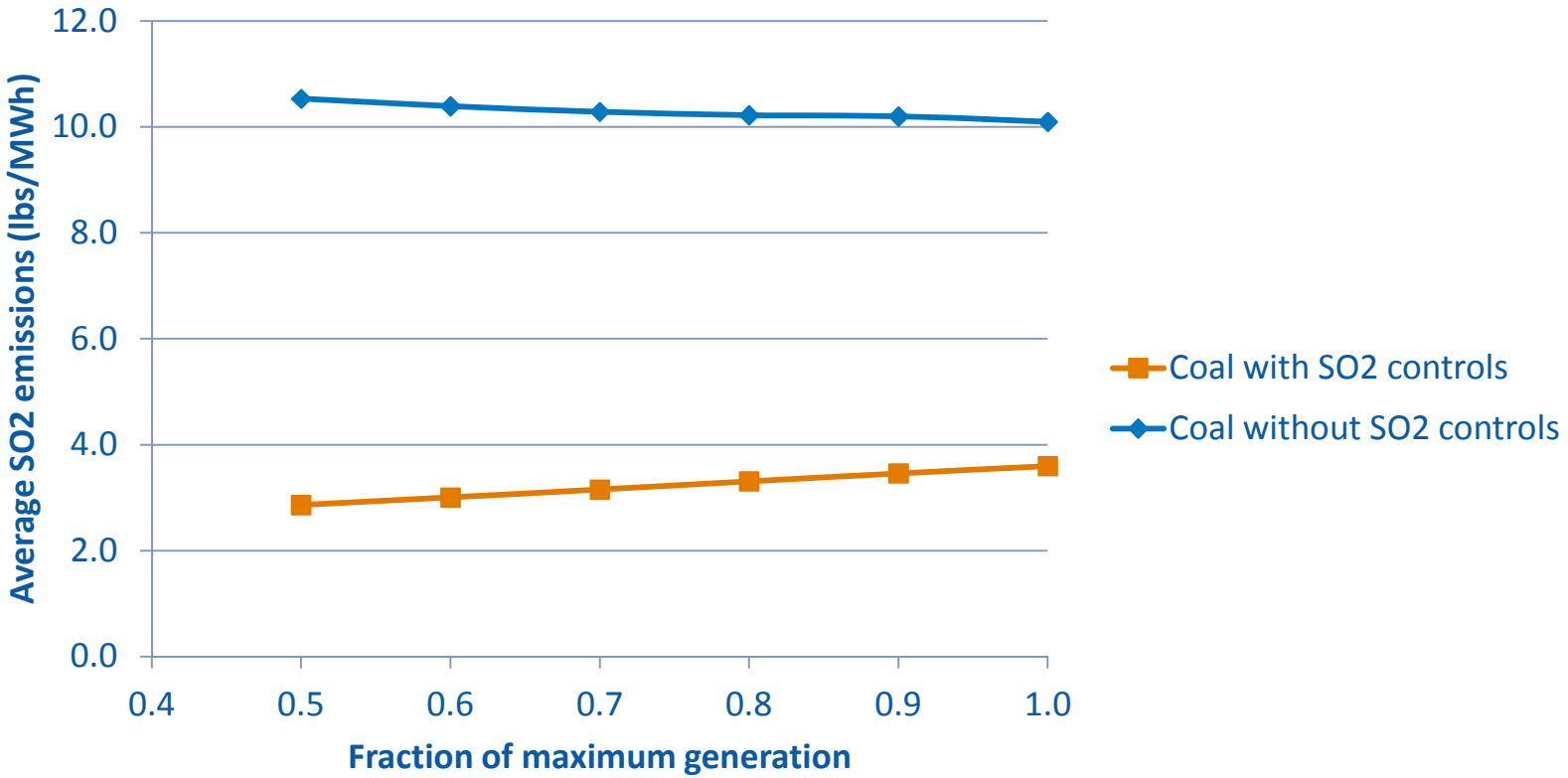
mmbtu/MWh	Coal	Gas CC	Gas CT	Gas steam
US – 50% GDC	10.69	9.07	12.31	11.32
US – 100% GDC	10.12	7.87	10.55	10.70
WECC – 50% GDC	11.17	8.04	11.70	11.37
WECC – 100% GDC	10.66	7.39	9.94	10.69

Results (NOx) – WECC averages



lbs/MWh	Coal	Gas CC	Gas CT	Gas steam
US – 50% GDC	2.66	0.18	0.42	1.86
US – 100% GDC	2.76	0.14	0.36	2.31
WECC – 50% GDC	3.13	0.09	0.17	0.41
WECC – 100% GDC	3.62	0.07	0.15	0.47

Results (SO_2) – Nationwide average



	Coal (controlled)	Coal (uncontrolled)
US – 50% GDC	2.86	10.53
US – 100% GDC	3.60	10.10

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

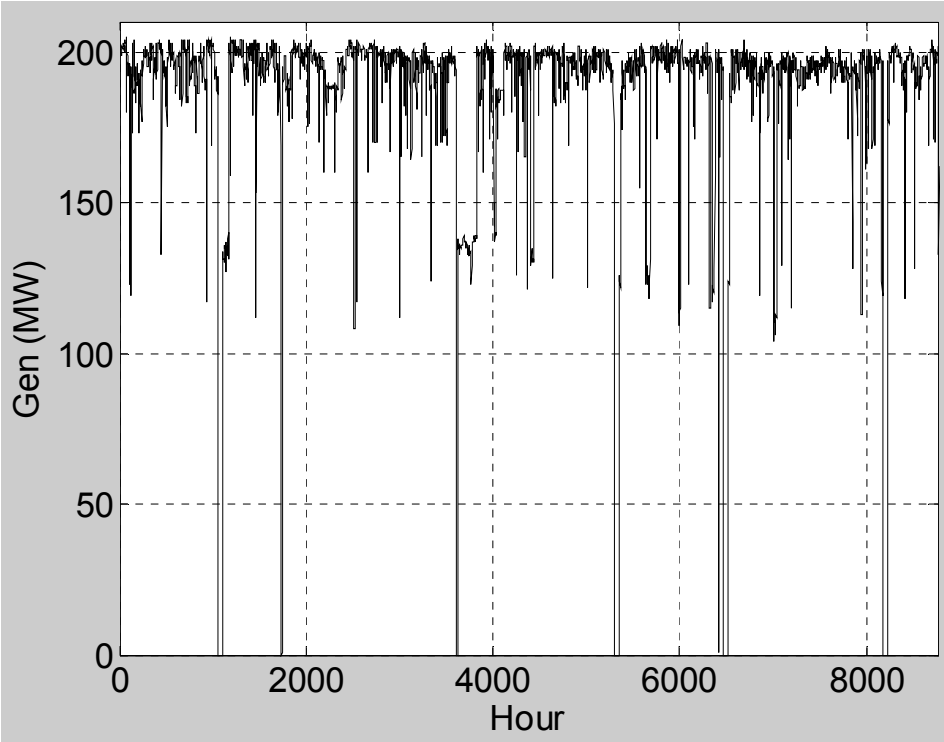
Ramping

Ramping penalty in hours of equivalent full-load operation

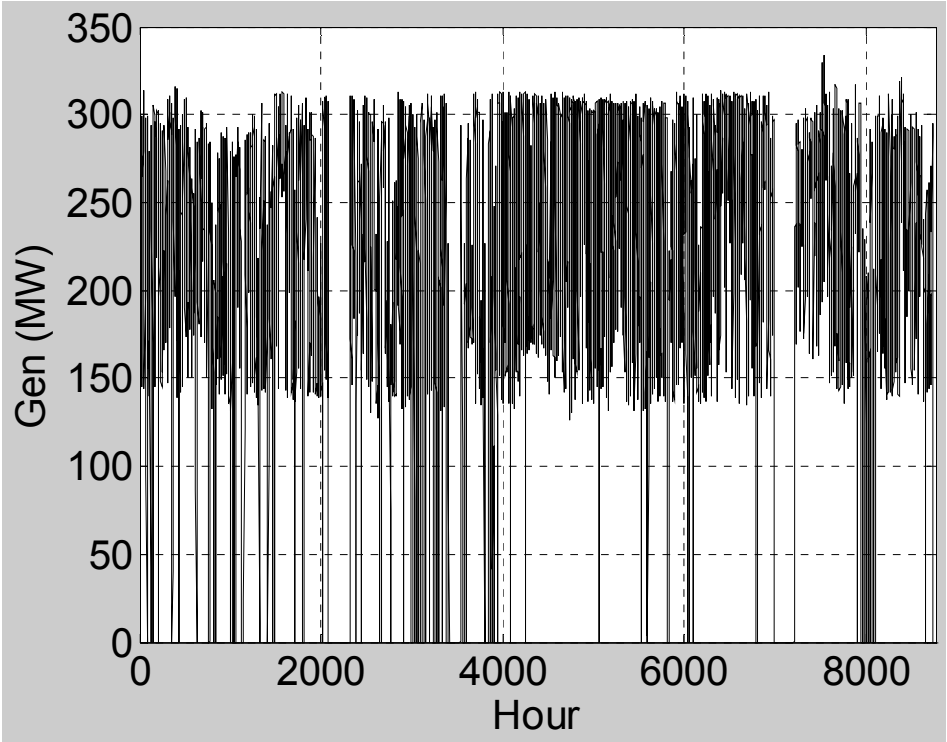
	CO2	NOx	SO_2
Coal	0.03	0.08	0.07
Gas CC	0.01	0.08	n/a
Gas CT	0.01	0.01	n/a
Gas steam	0.01	0.08	n/a

Effects of generation profile on emission rate

Sample base load profile
Hayden unit H1 during 2008
6 startups
8500 hours online
Capacity factor 0.92



Sample shoulder load profile
Rocky Mtn Energy Ctr unit 1
71 startups
7700 hours online
Capacity factor 0.66



Average emissions rate (lbs/MWh) impact of switching a unit from baseload to shoulder load

Unit type	Heat Input	NOx	SO_2
Coal	2.9%	0.0%	2.7%
Gas CC	3.6%	12%	n/a
Gas CT	4.3%	5.0%	n/a
Gas steam	2.4%	-4.8%	n/a

WWSIS re-analysis

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

- Compared to determining which unit is on the margin

Coal units have lower emission rates at part-load relative to full load, and lower startup emissions relative to part-load

- Absolute emissions still larger than CC or CT

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:

Greg Brinkman
gregory.brinkman@nrel.gov
303-384-7390