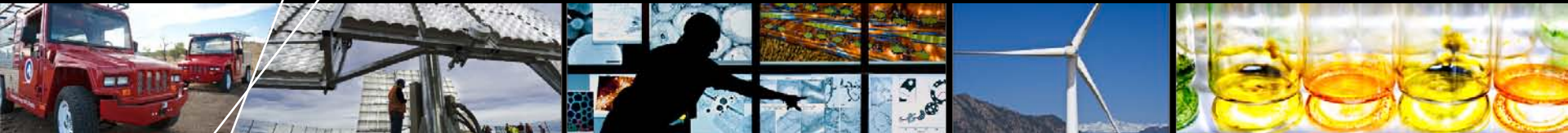


Impacts of Wind on Conventional Generation



**Debbie Lew, Greg Brinkman, Eduardo Ibanez,
Bri-Mathias Hodge, NREL**

Steve Lefton, Nikhil Kumar, APTECH

Gary Jordan, Sundar Venkataraman, GE

Jack King, REPPAE

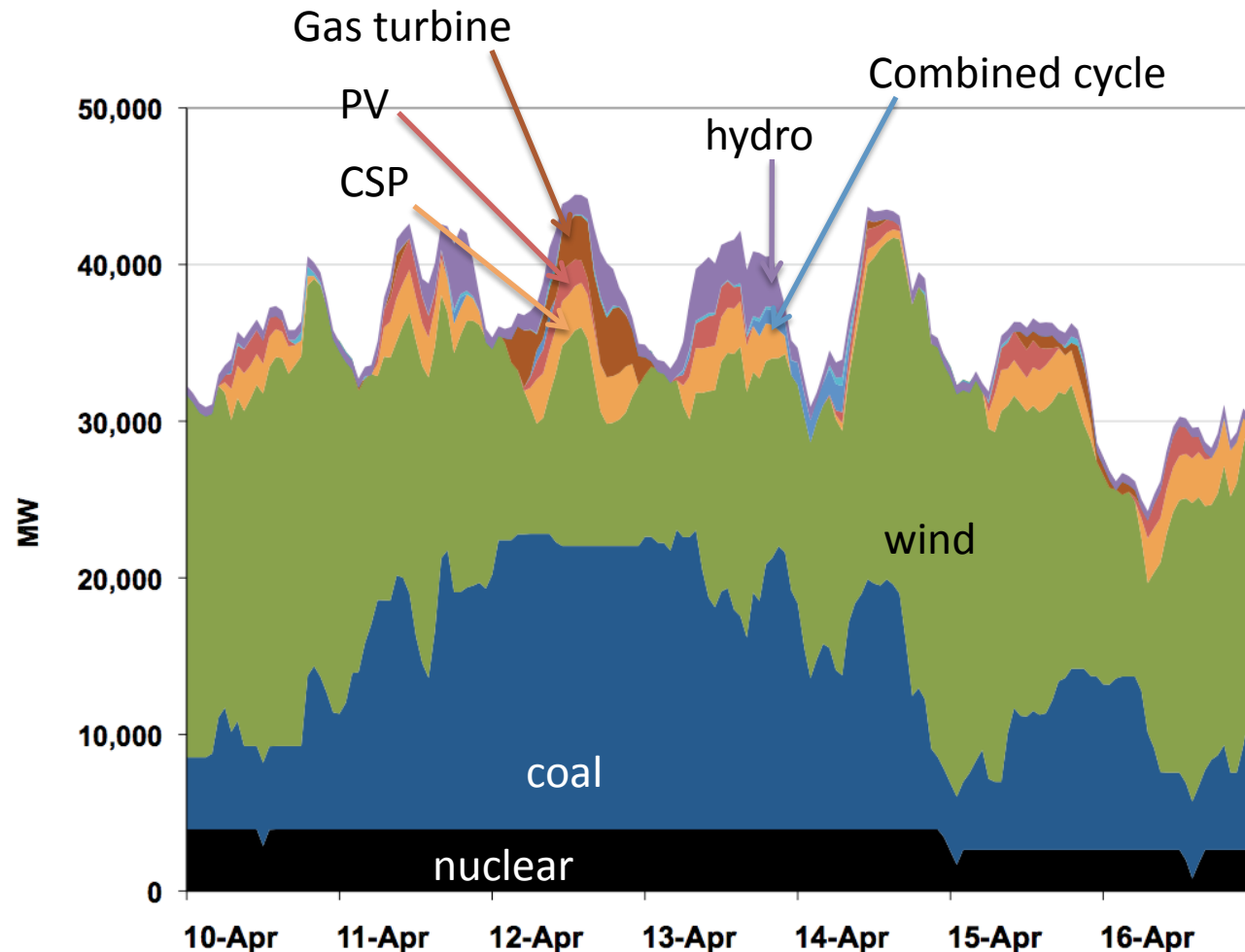
Windpower 2012, May, 2012

Western Wind and Solar Integration Study (WWSIS)

What are the impacts of 35% wind and solar on the power system?

Phase 1 report:

<http://www.nrel.gov/docs/fy10osti/47434.pdf>



The worst week of three years

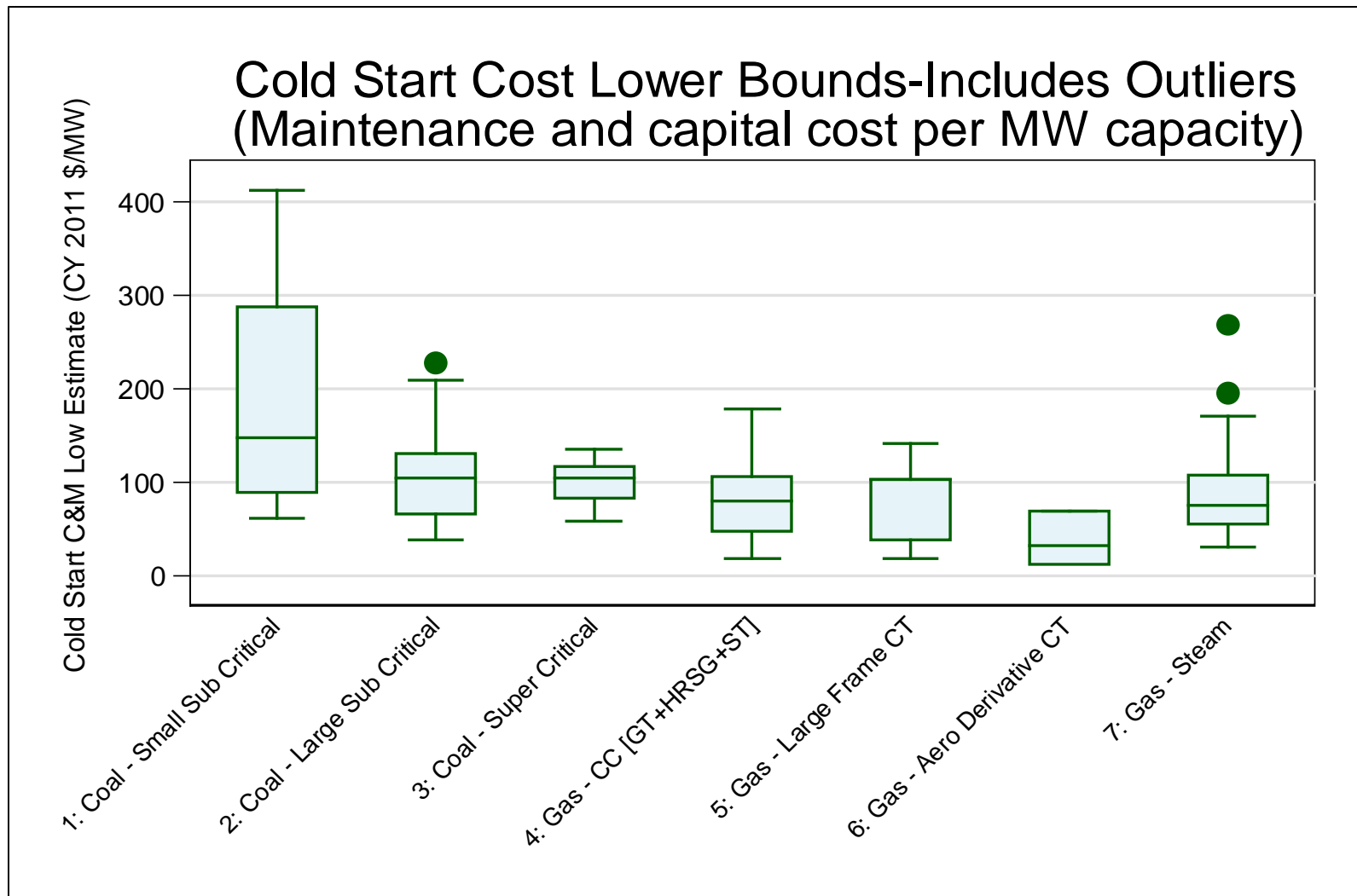
Phase 2 of WWSIS

- **What are the wear and tear costs of cycling and ramping coal and gas plants?**
- **What are the emissions impacts from cycling and ramping of coal and gas plants?**
- **Optimize unit commitment and economic dispatch**
- **Comparing wind and solar**
- **Examine mitigation options including plant upgrades**

Wear and Tear Cost Data

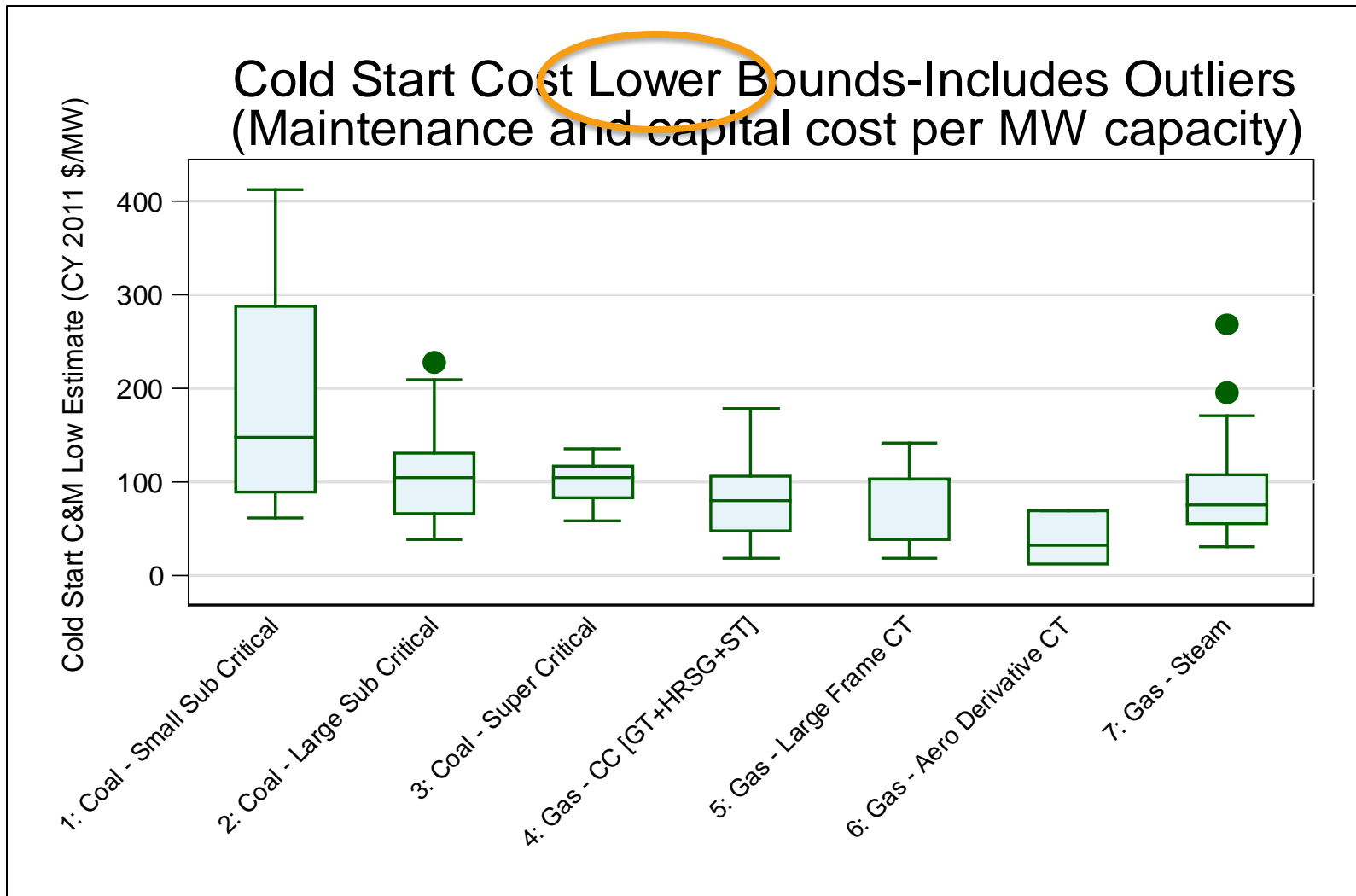
- **Data results from analysis of APTECH on 400 plants:**
 - Costs of hot, warm and cold starts
 - Costs of ramping down to minimum output and back up
 - Forced outage rate impacts
 - Long term heat rate degradation
- **7 types of plants:**
 - Coal – small subcritical, large subcritical, super critical
 - Gas – combined cycle, large frame and aeroderivative combustion turbines, steam
 - *Plus 'best in class' units*
- **What we are not considering in this phase:**
 - Age, vintage, operating history, design

Cost of Cold Start-up



Source: Steve Lefton, Intertek-APTECH, NREL Subcontract.

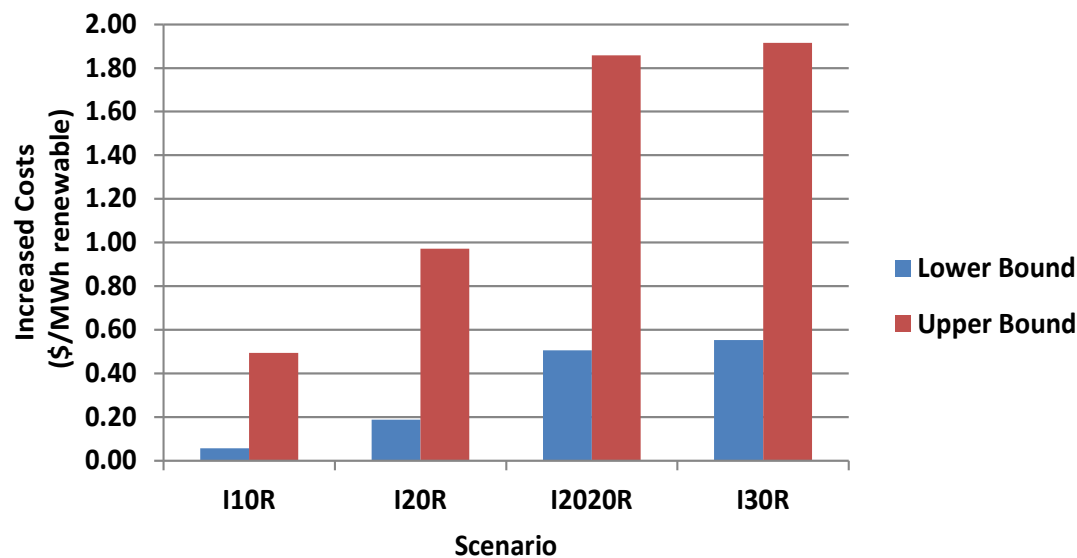
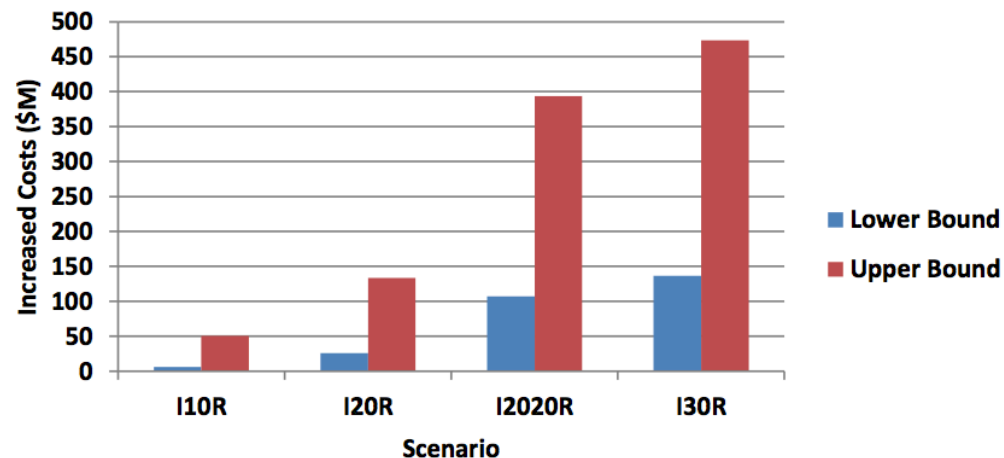
Cost of Cold Start-up



Source: Steve Lefton, Intertek-APTECH, NREL Subcontract.

Ceiling on wear and tear costs

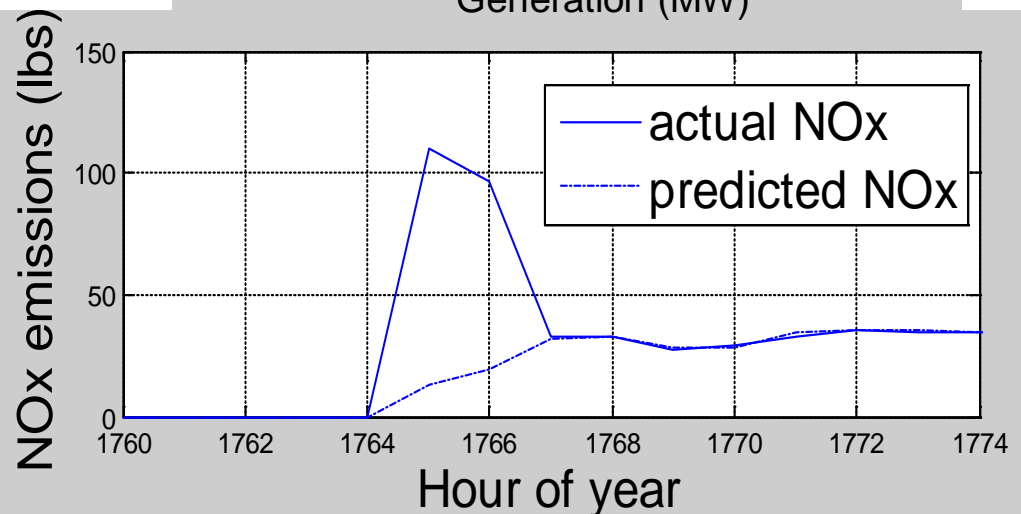
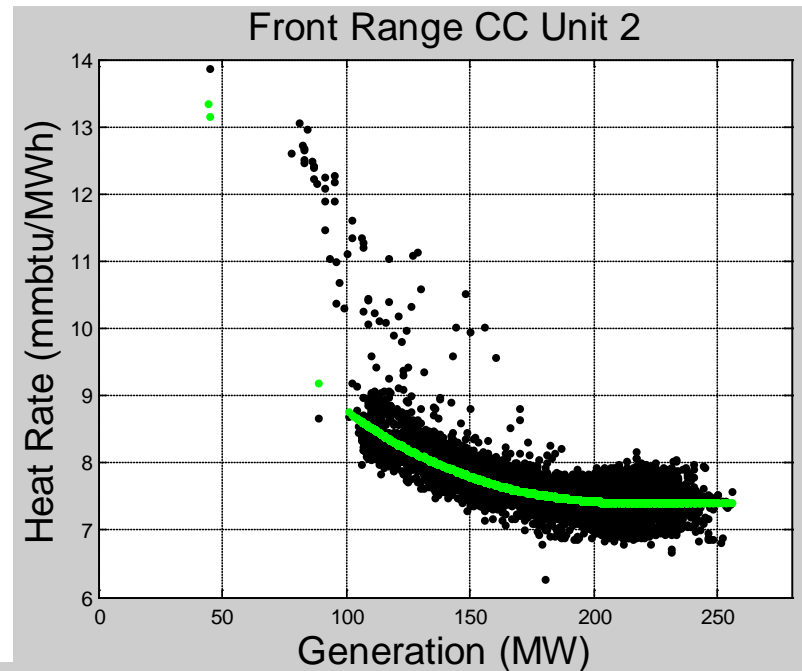
Results show that cycling costs are up to \$2 per MWh of renewables produced, or a reduction in value of the renewables of up to 2.4%



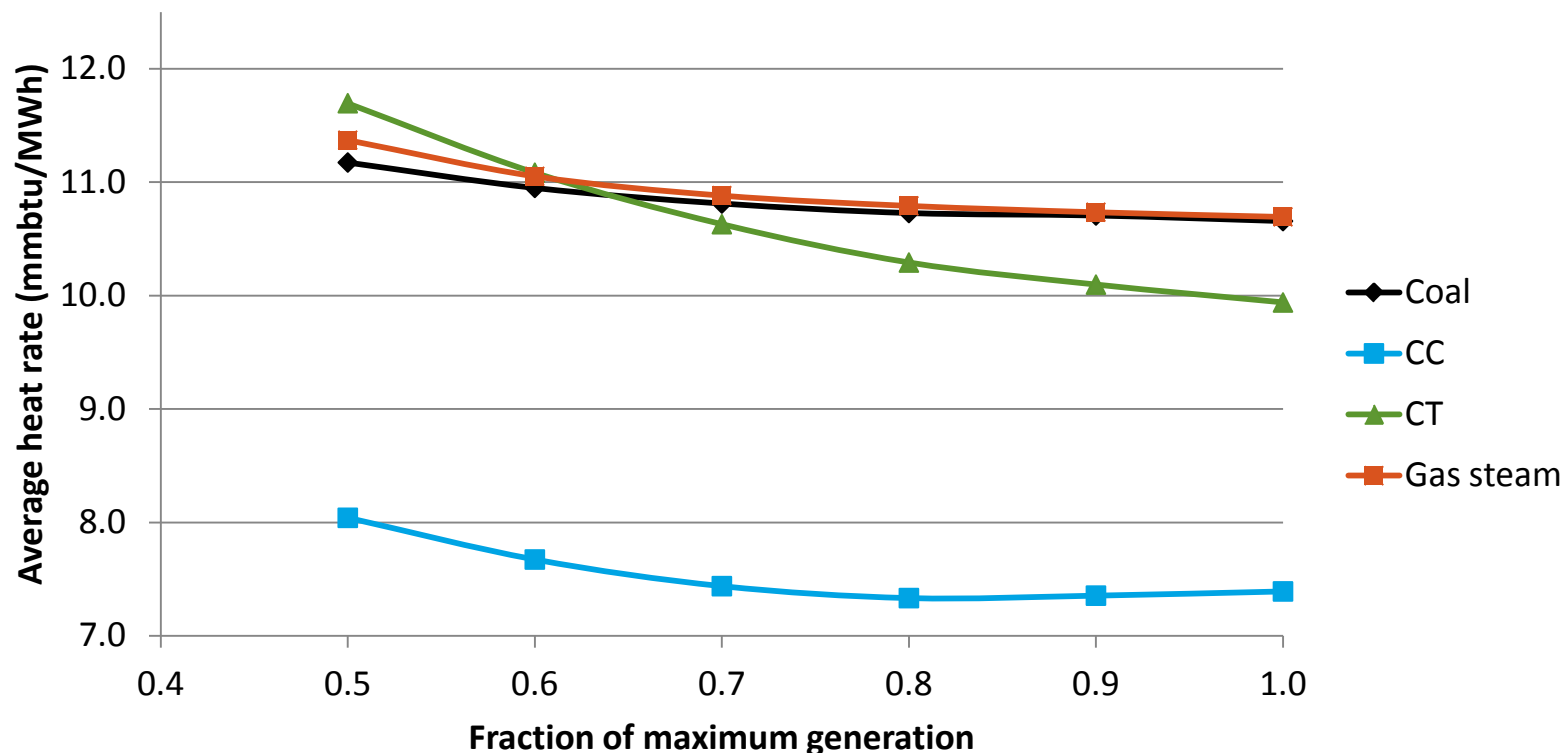
Source: Gary Jordan, GE, NREL Subcontract.

EPA Continuous Emission Monitors

- Use measured hourly emissions from each fossil fuel plant in the U.S. for 2008
- For each plant:
 - Heat rate (and CO₂ emissions) as a function of generation
 - Emissions (NO_x, SO₂) as a function of generation
- Eliminate units with obviously clustered data

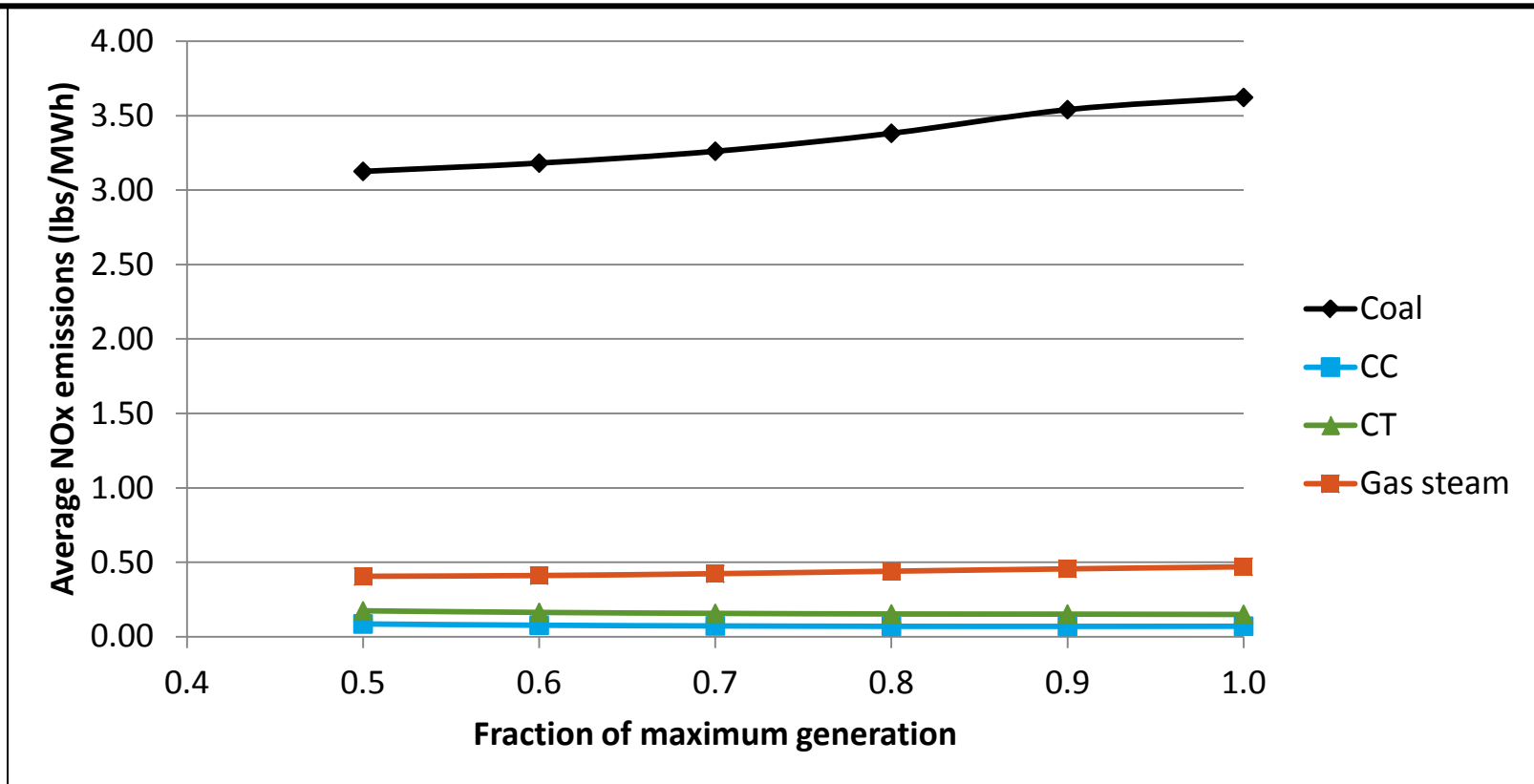


Heat input – WECC averages



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

NO_x – 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

WWSIS1 re-analysis

Avoided emissions per MWh of renewable production

	NO _x (lbs/MWh)	CO ₂ (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%)

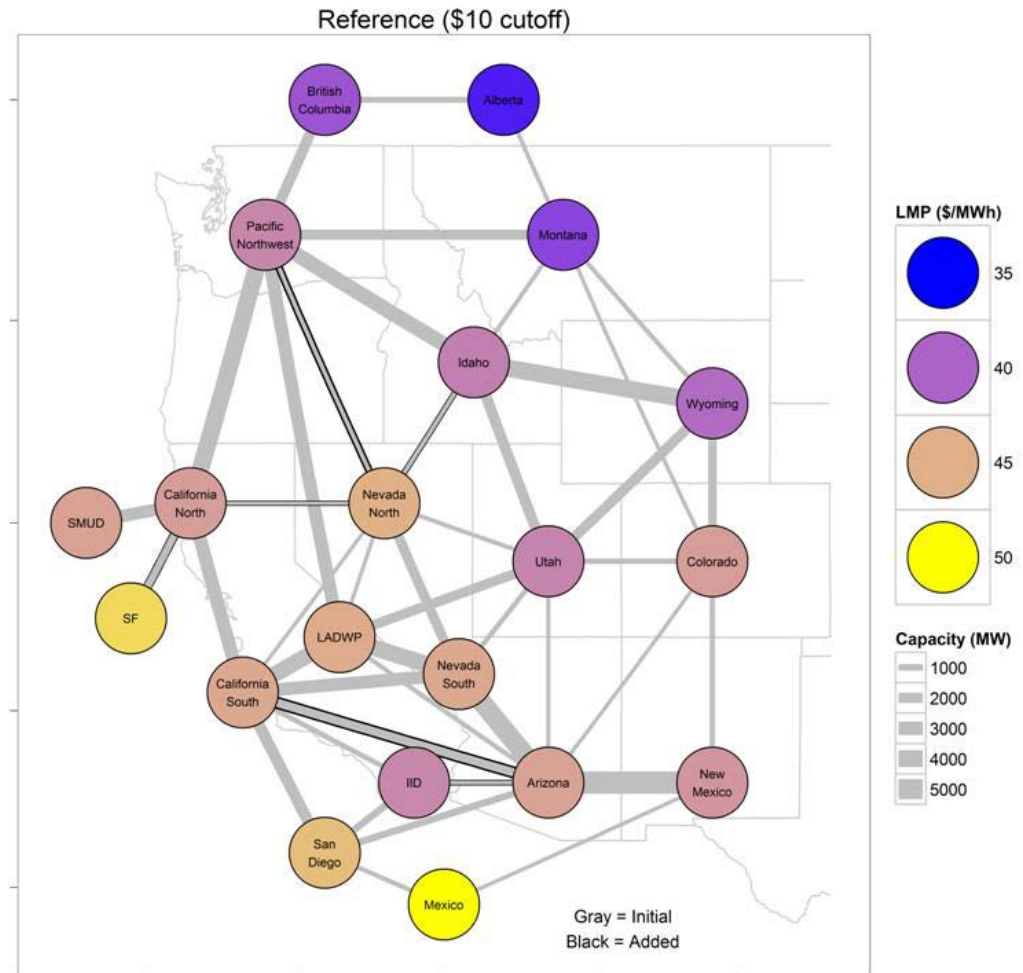
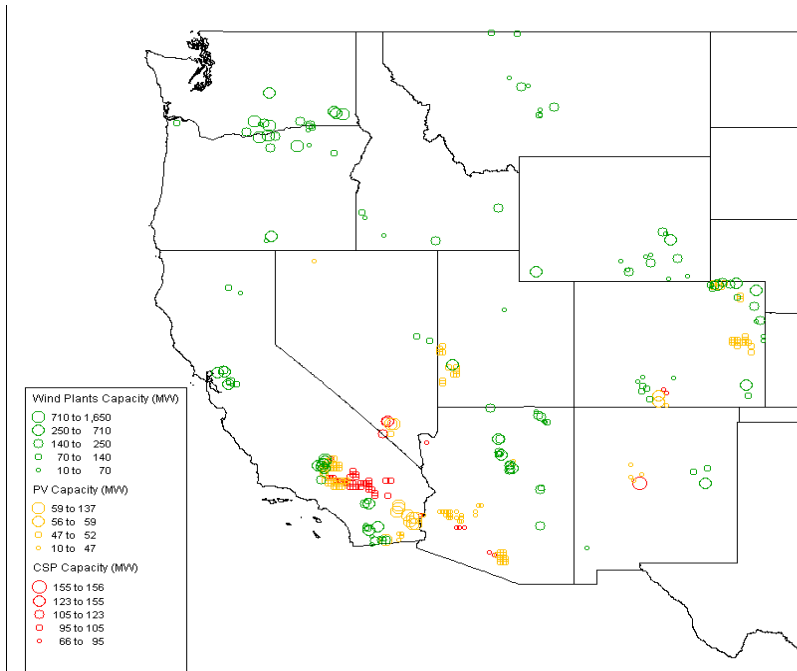
Startups, part-load and ramping have relatively small impact compared to which unit is on the margin

WWSIS2 Scenarios

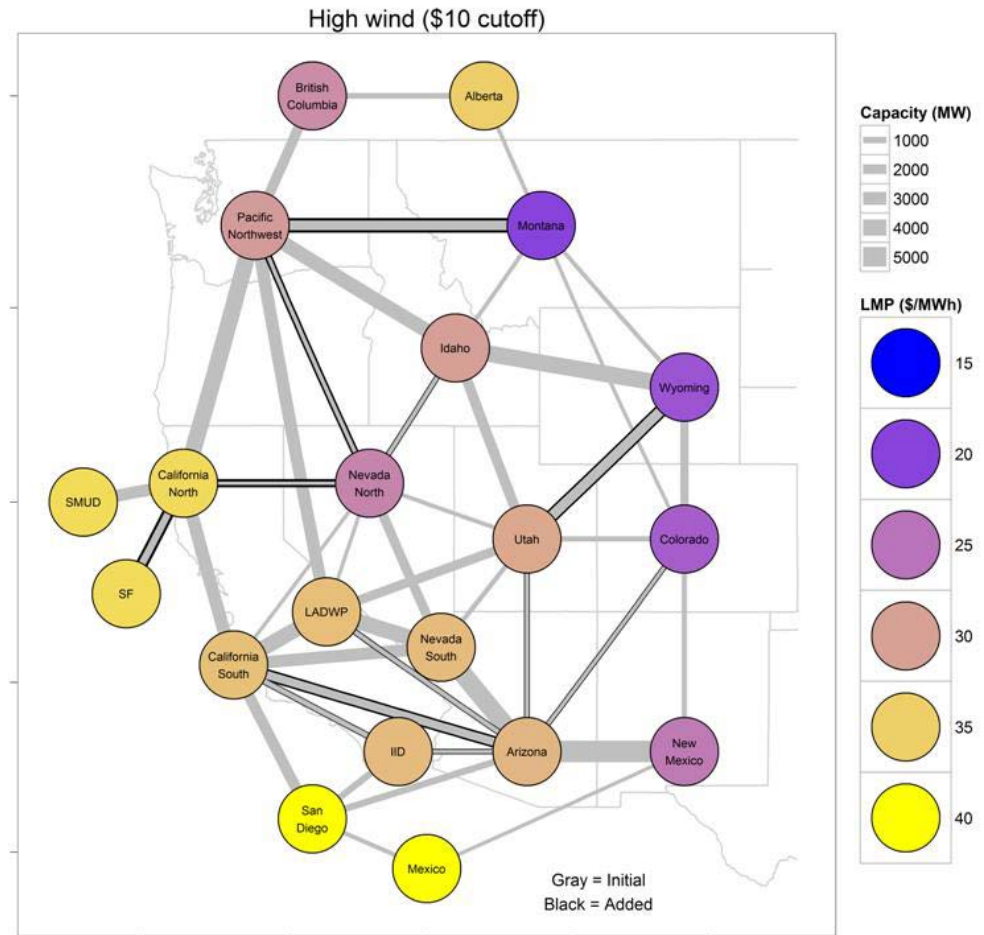
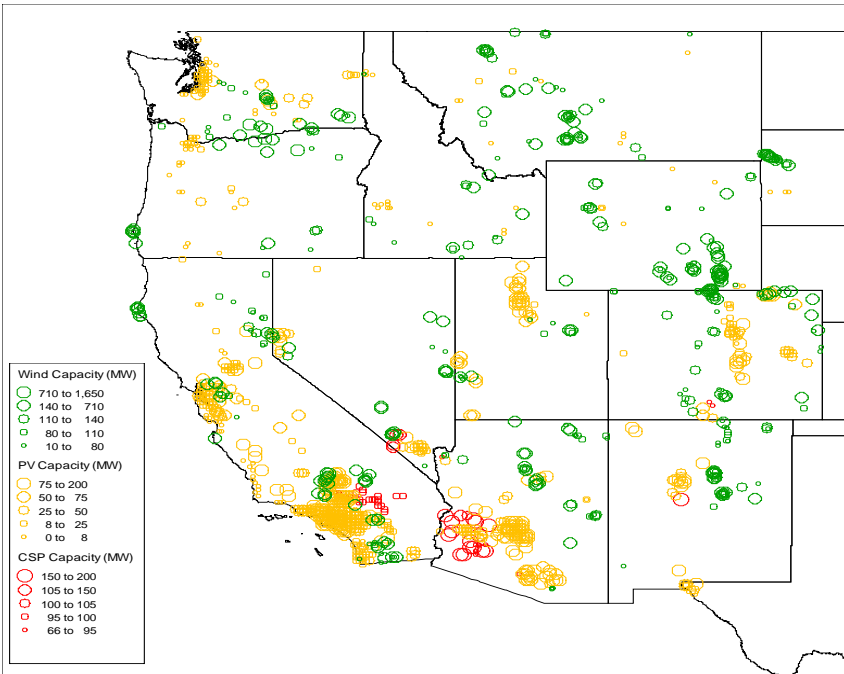
	Wind	Solar
Reference (TEPPC 2020)	8%	3%
Hi Wind	25%	4.8% PV, 3.2% CSP
Hi Mix	16.5%	16.5%
Hi Solar	8%	15% PV, 10% CSP

- CSP has 6 hours thermal storage that Plexos will dispatch
- PV includes utility-scale in remote and urban areas, rooftop
- New emissions and wear and tear cost data

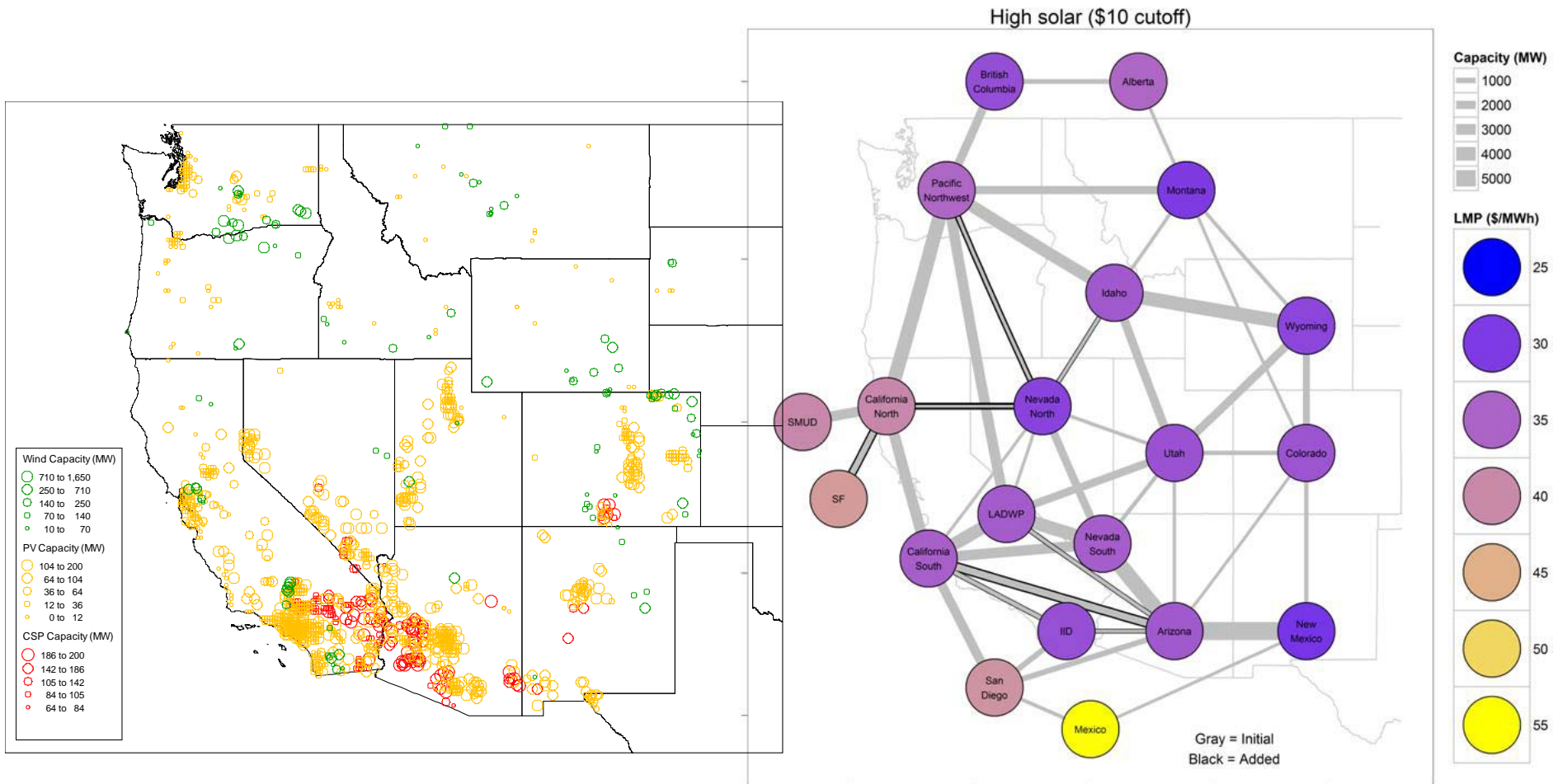
Reference Scenario (8% Wind, 3% Solar)



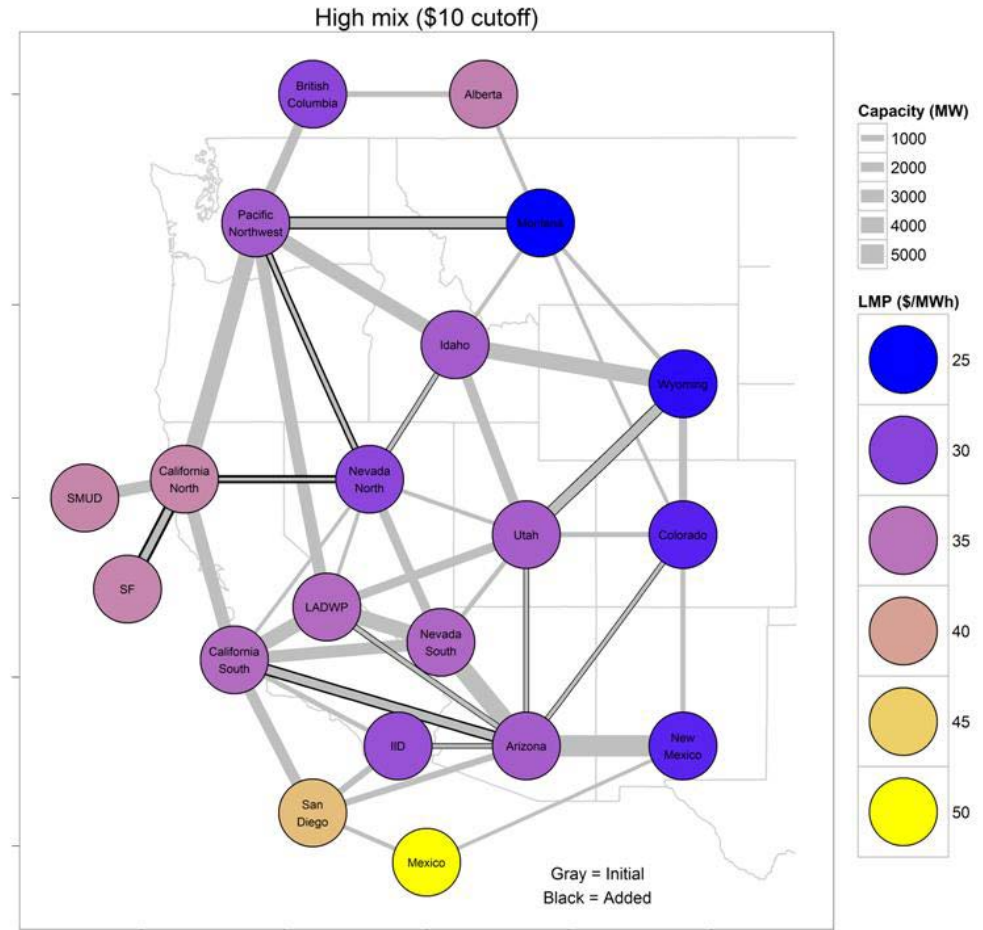
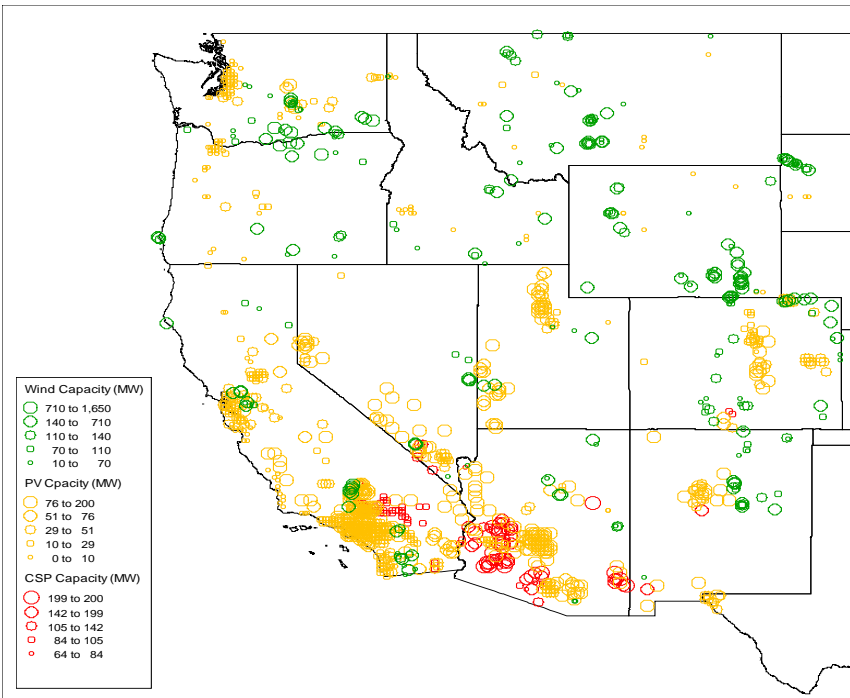
High wind (25% wind, 4.8% PV, 3.2% CSP)



High solar (8% wind, 15% PV, 10% CSP)

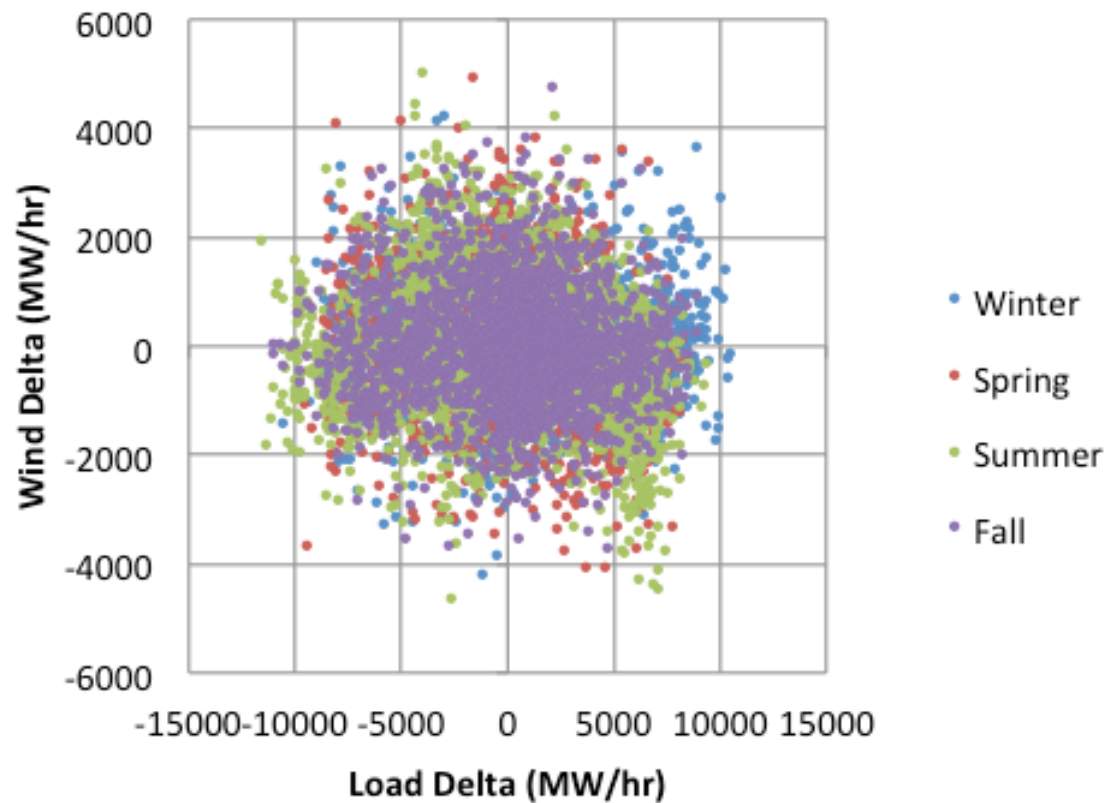


Hi mix (16.5% wind, 9.9% PV, 6.6% CSP)



Hourly Variability

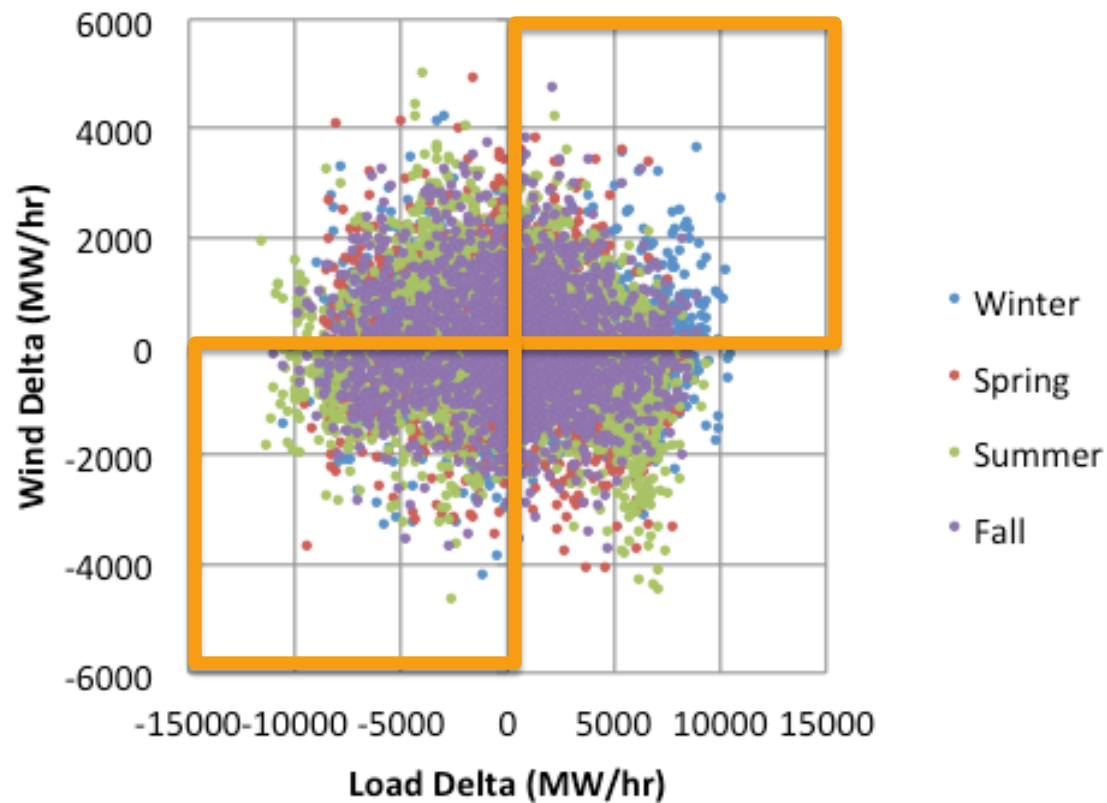
High Wind Scenario Footprint Wind Variability



Source: Jack King, REPPAE, NREL Subcontract.

Hourly Variability

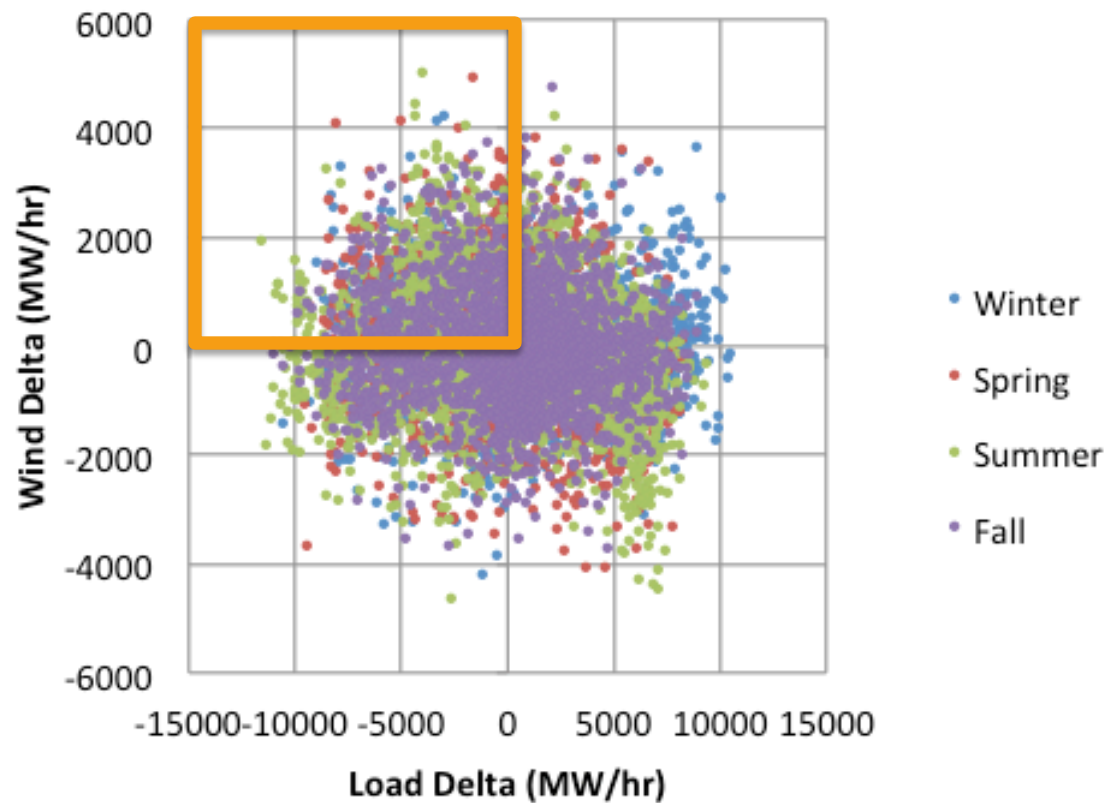
High Wind Scenario Footprint Wind Variability



Source: Jack King, REPPAE, NREL Subcontract.

Hourly Variability

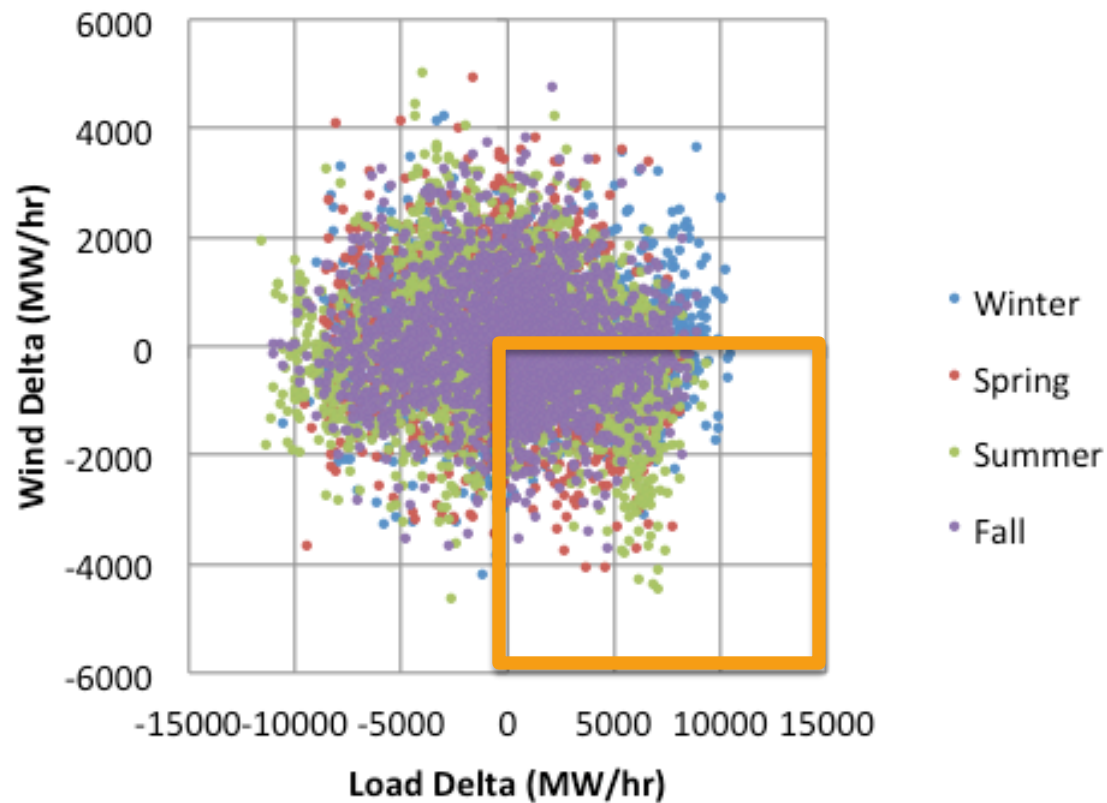
High Wind Scenario Footprint Wind Variability



Source: Jack King, REPPAE, NREL Subcontract.

Hourly Variability

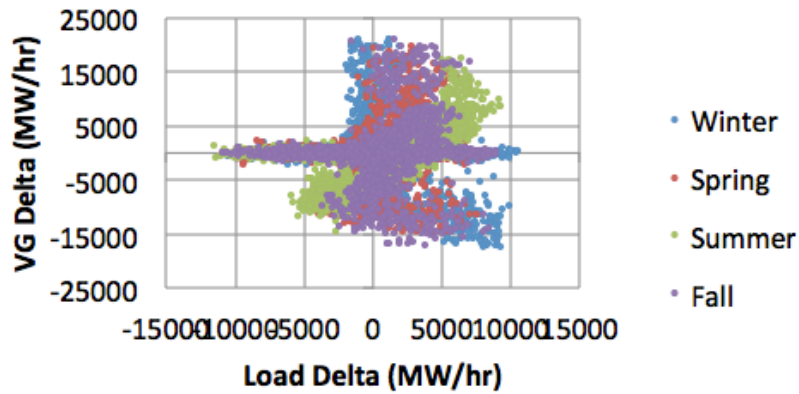
High Wind Scenario Footprint Wind Variability



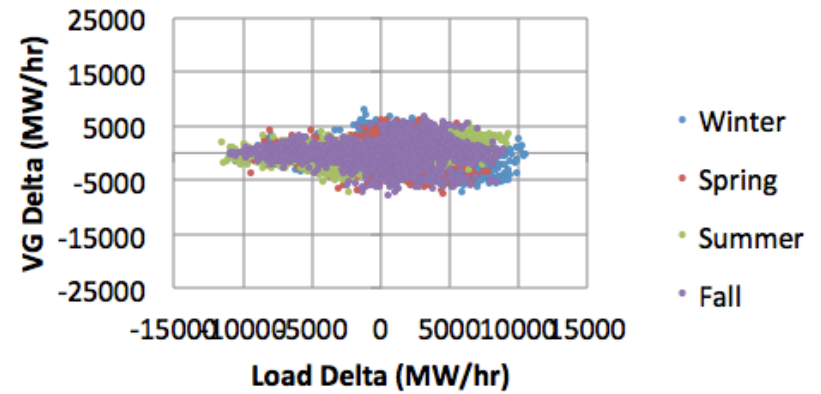
Source: Jack King, REPPAE, NREL Subcontract.

Variability across scenarios

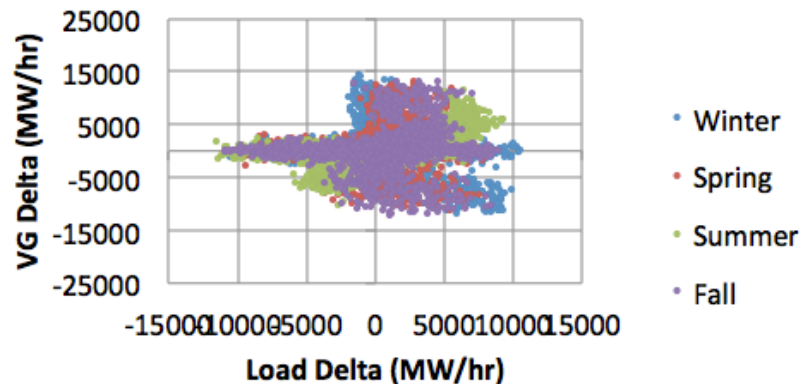
**High Solar Scenario - Footprint VG
Variability (No CSP)**



**High Wind Scenario - Footprint VG
Variability (No CSP)**



**Intermediate Scenario - Footprint VG
Variability (No CSP)**



Source: Jack King, REPPAE, NREL Subcontract.

Thank you!

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<http://www.nrel.gov/wwsis>

