Data Driven Wind Power Integration
Yesterday -Today-Tomorrow
Carnegie Mellon University
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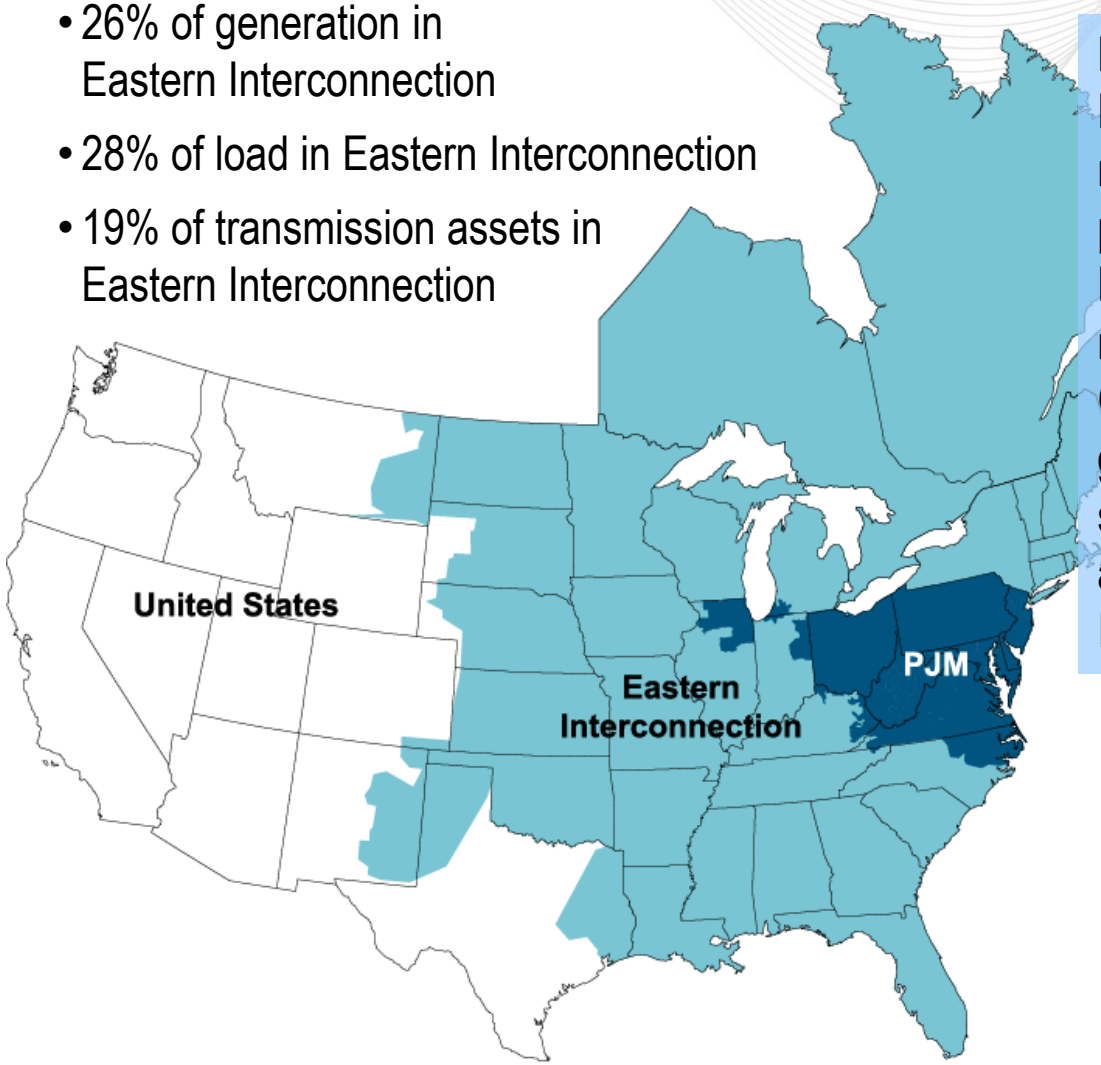
PJM

PJM as Part of the Eastern Interconnection

- 26% of generation in Eastern Interconnection
- 28% of load in Eastern Interconnection
- 19% of transmission assets in Eastern Interconnection



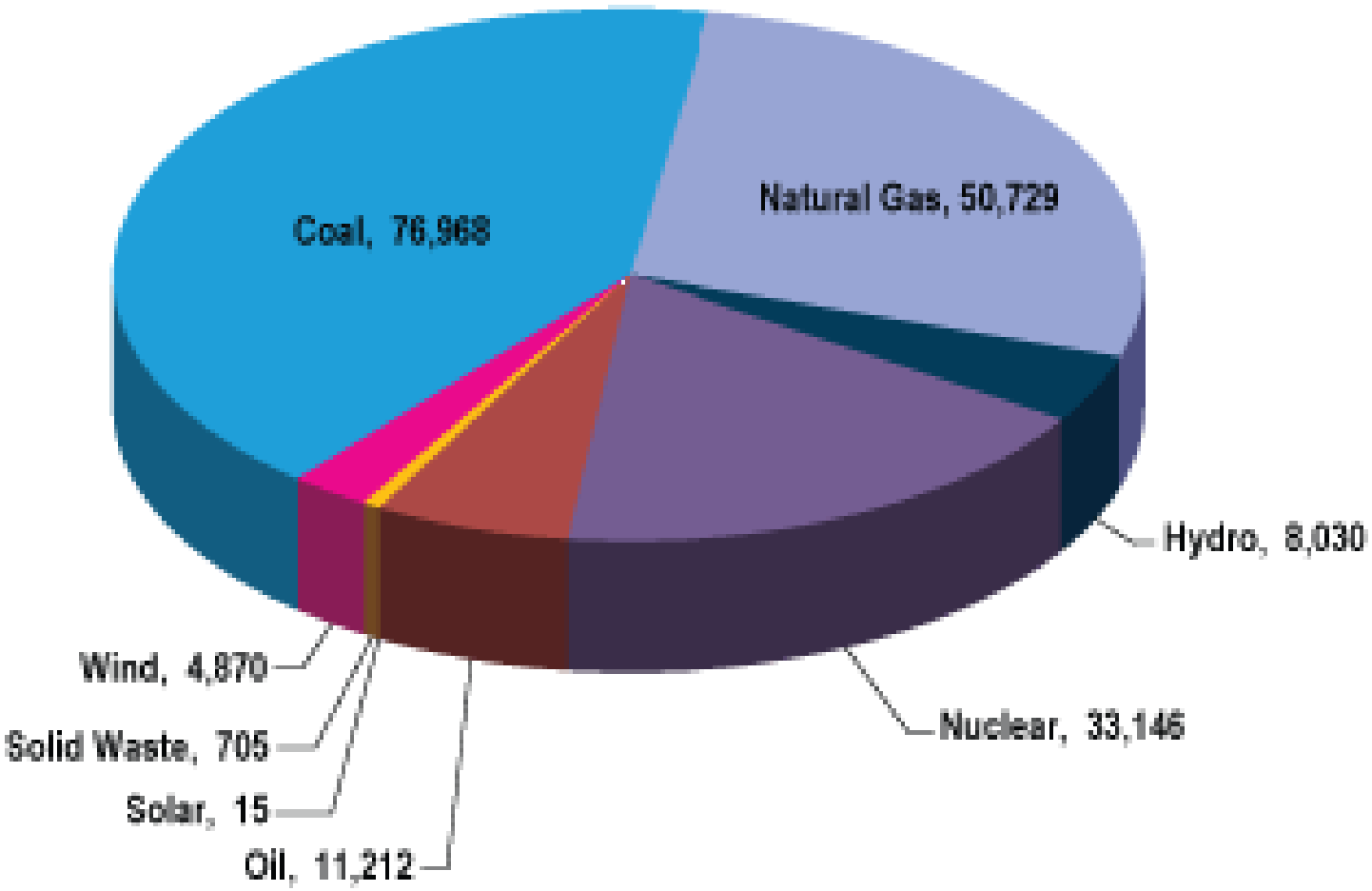
KEY STATISTICS

PJM member companies	750+
millions of people served	60
peak load in megawatts	163,848
MWs of generating capacity	185,600
miles of transmission lines	65,441
GWh of annual energy	832,331
generation sources	1,365
square miles of territory	214,000
area served	13 states + DC
Internal/external tie lines	142

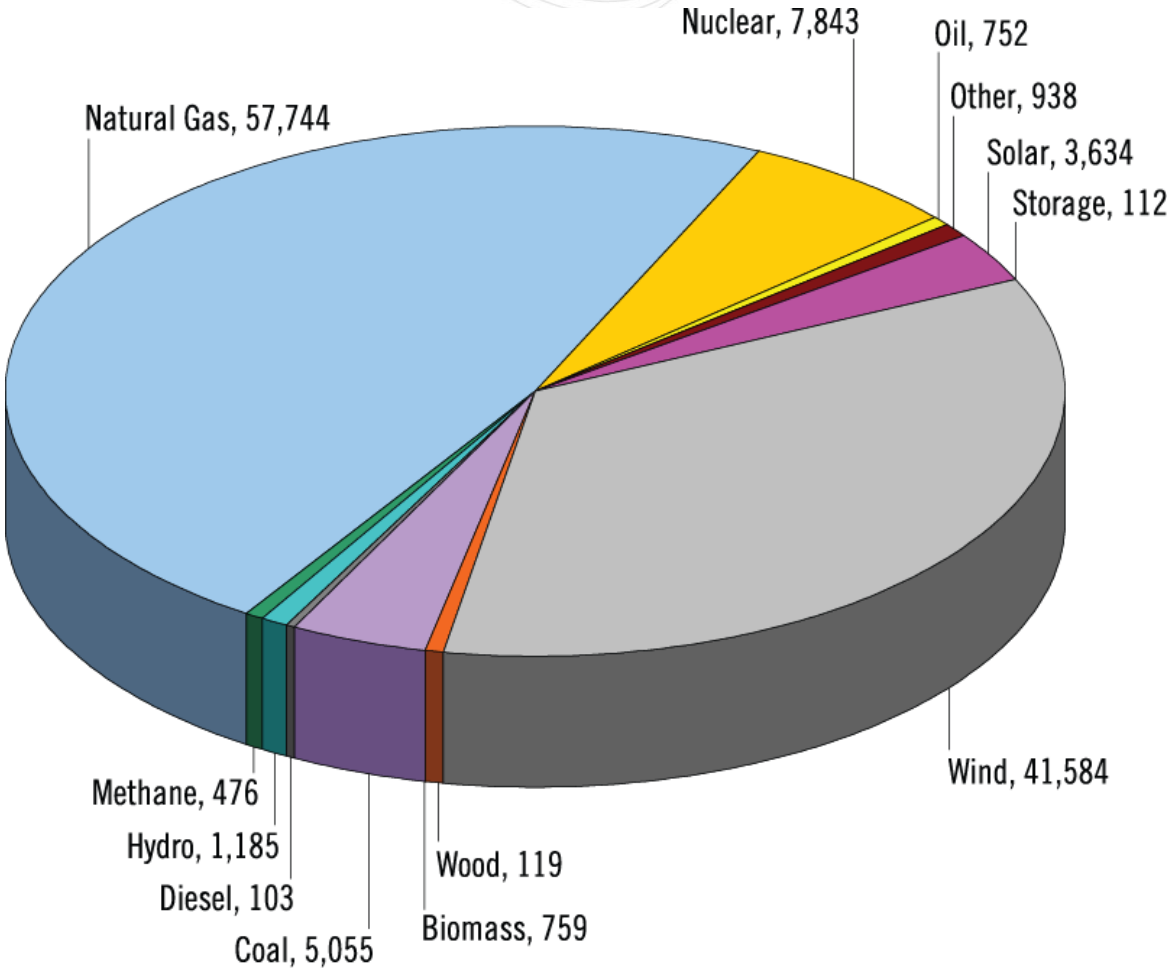
21% of U.S. GDP produced in PJM

As of 1/4/2012

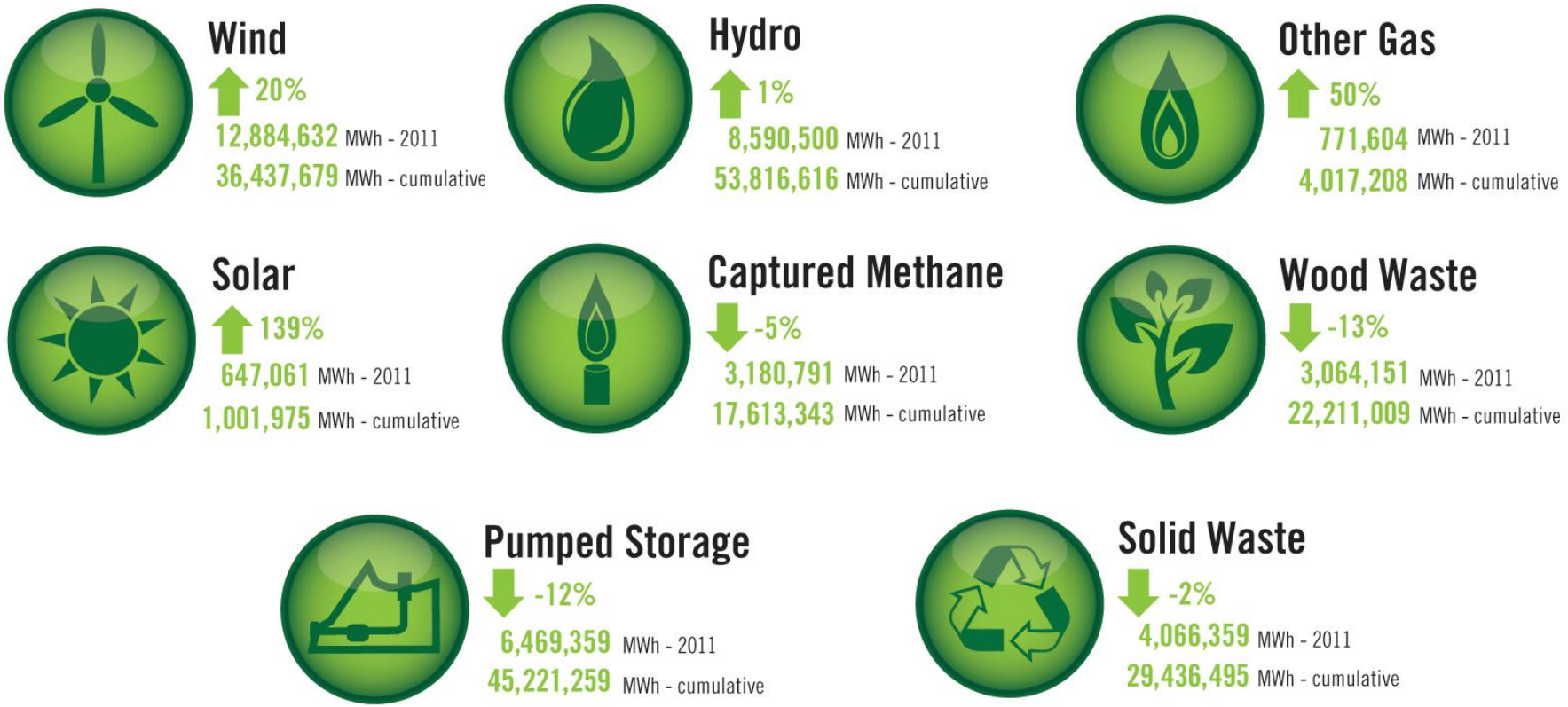
PJM Fuel Mix - Today



Fuel Mix of All Queued Generation – Tomorrow?

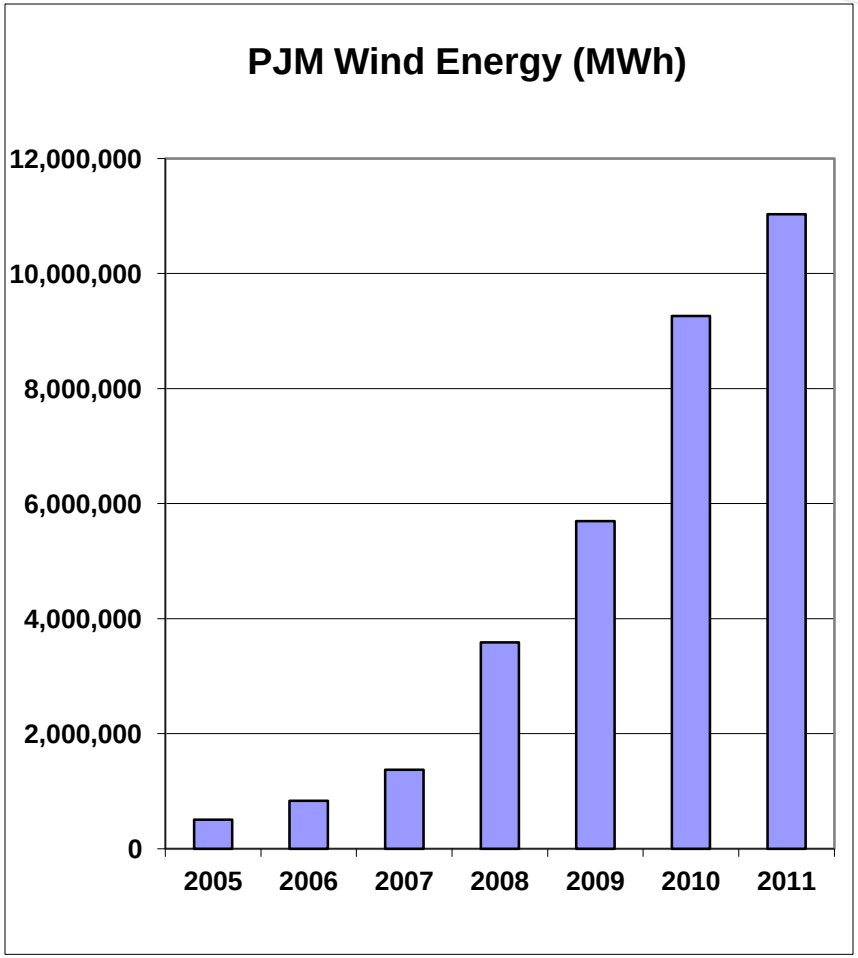


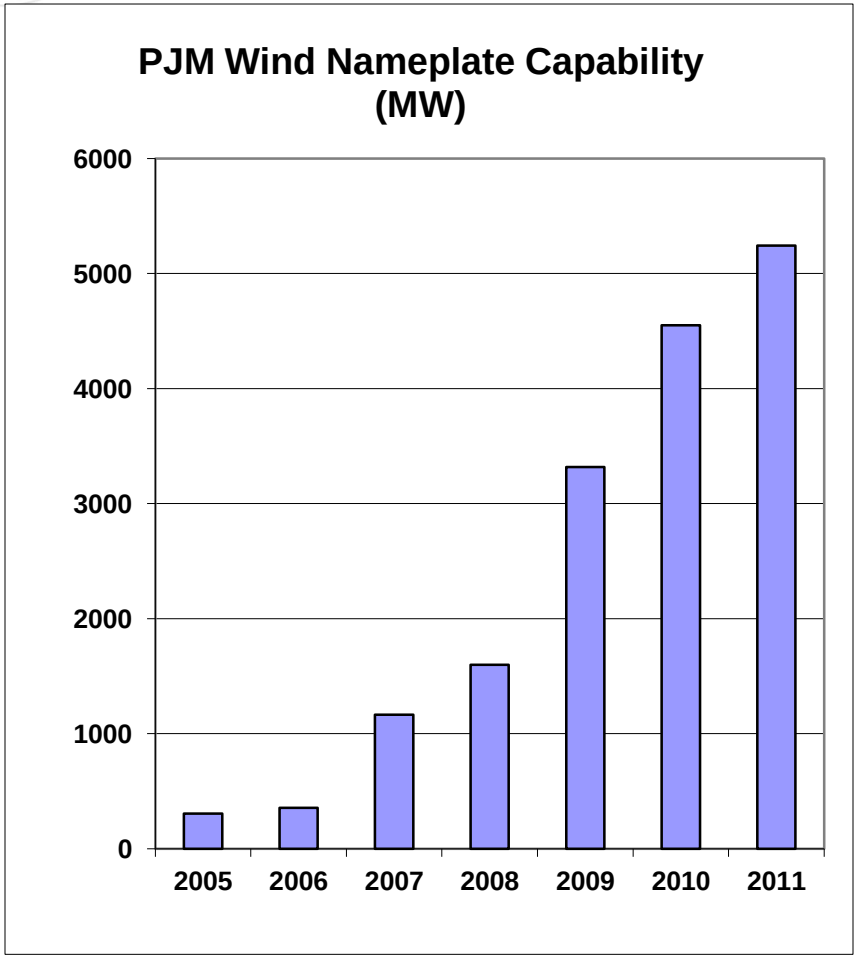
The Greener Grid



This slide shows how many megawatt-hours of renewable energy were produced in 2011 and cumulatively since tracking began in 2005. It also shows the percent change between 2010 and 2011.

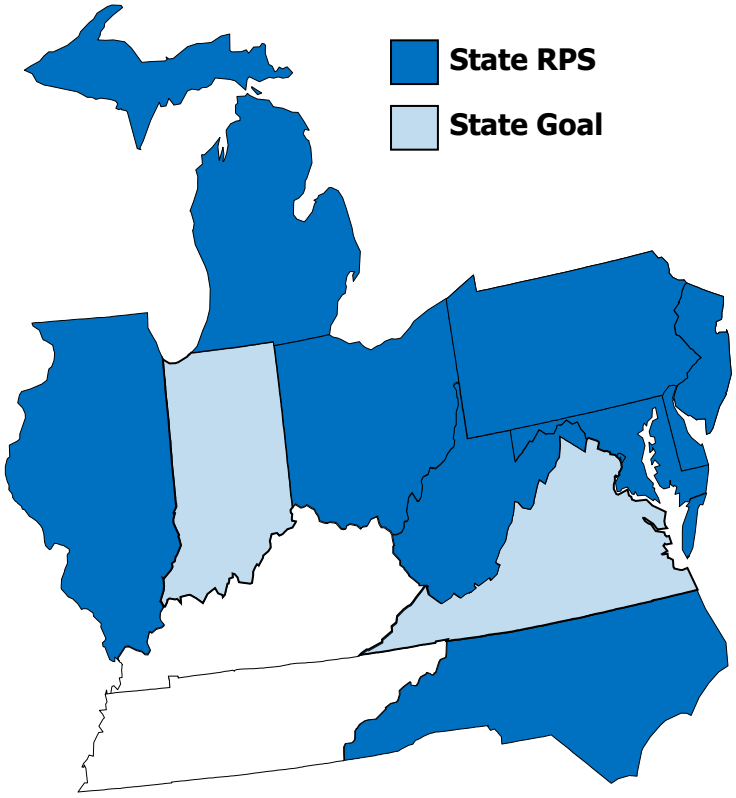
Increasing Wind Penetration in PJM





PJM States with RPS

State Renewable Portfolio Standards (RPS) require suppliers to utilize wind and other renewable resources to serve an increasing percentage of total demand.



DSIRE: www.dsireusa.org December 2011

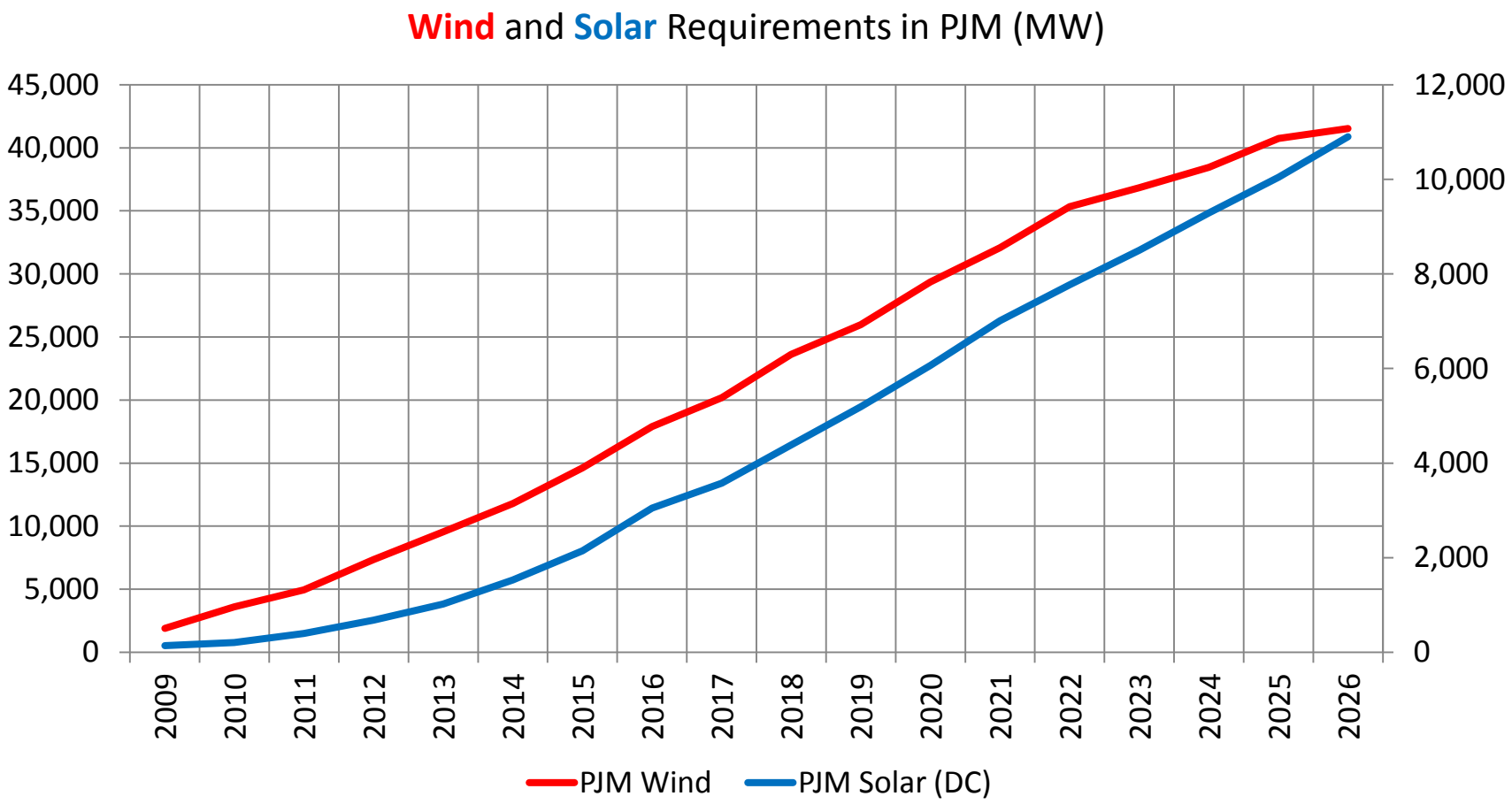
State RPS Targets:

- ☼ NJ: 22.5% by 2021
- ☼ MD: 20% by 2022
- ☼ DE: 25% by 2026
- ☼ DC: 20% by 2020
- ☼ PA: 18%** by 2020
- ☼ IL: 25% by 2025
- ☼ OH: 25%** by 2025
- ☼ NC: 12.5% by 2021 (IOUs)
- WV: 25%** by 2025
- MI: 10% + 1,100 MW by 2015
- VA: 15% by 2025
- IN: 10% by 2025

☼ Minimum solar requirement
** Includes separate tier of "alternative" energy resources

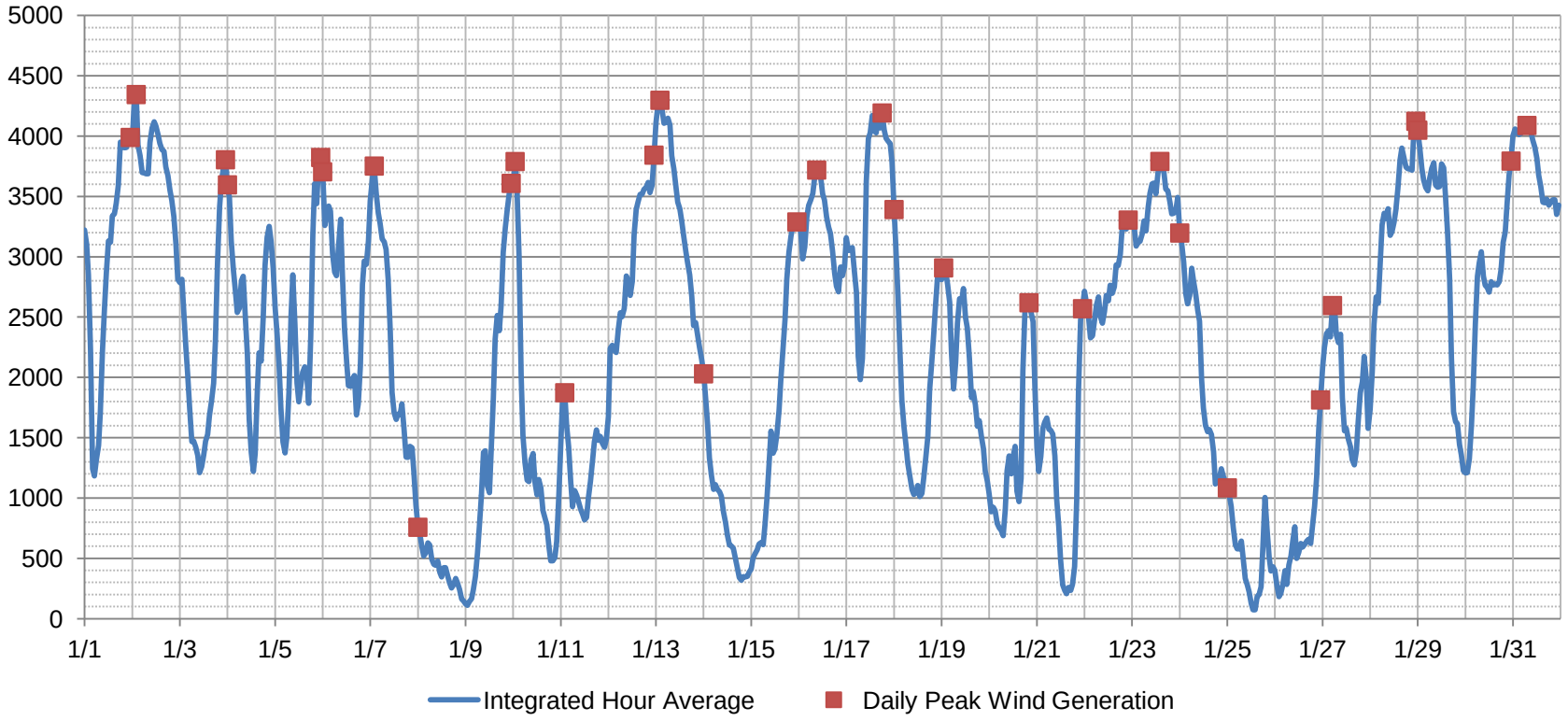
Projected Renewable Energy Requirements in PJM

By 2026: **135,000 GWh** of renewable energy, 14% of PJM annual net energy (**42 GW** of wind and **11 GW** of solar)



January 2012 Wind Generation

January Integrated Hourly Wind Generation (MW)



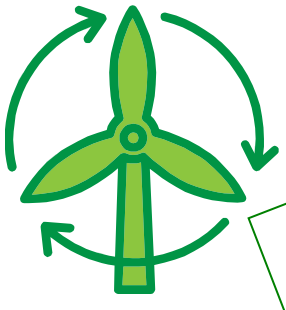
Relying on information from wind resources, PJM forecasts wind conditions. The goal of this forecasting effort is to:

1) Augment real-time reliability decisions by PJM operators

2) Accurately schedule generation in the Day-Ahead and Reliability Analysis unit commitment

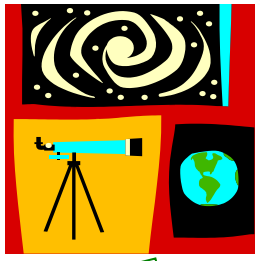
Met Mast

Inputs to Wind Power Forecast

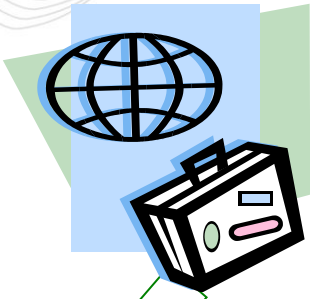


Power Data

Unit Availability



Terrain



Global

Wind Farm

Data

Exchange

PJM

Data

Exchange

Forecaster

Met Data

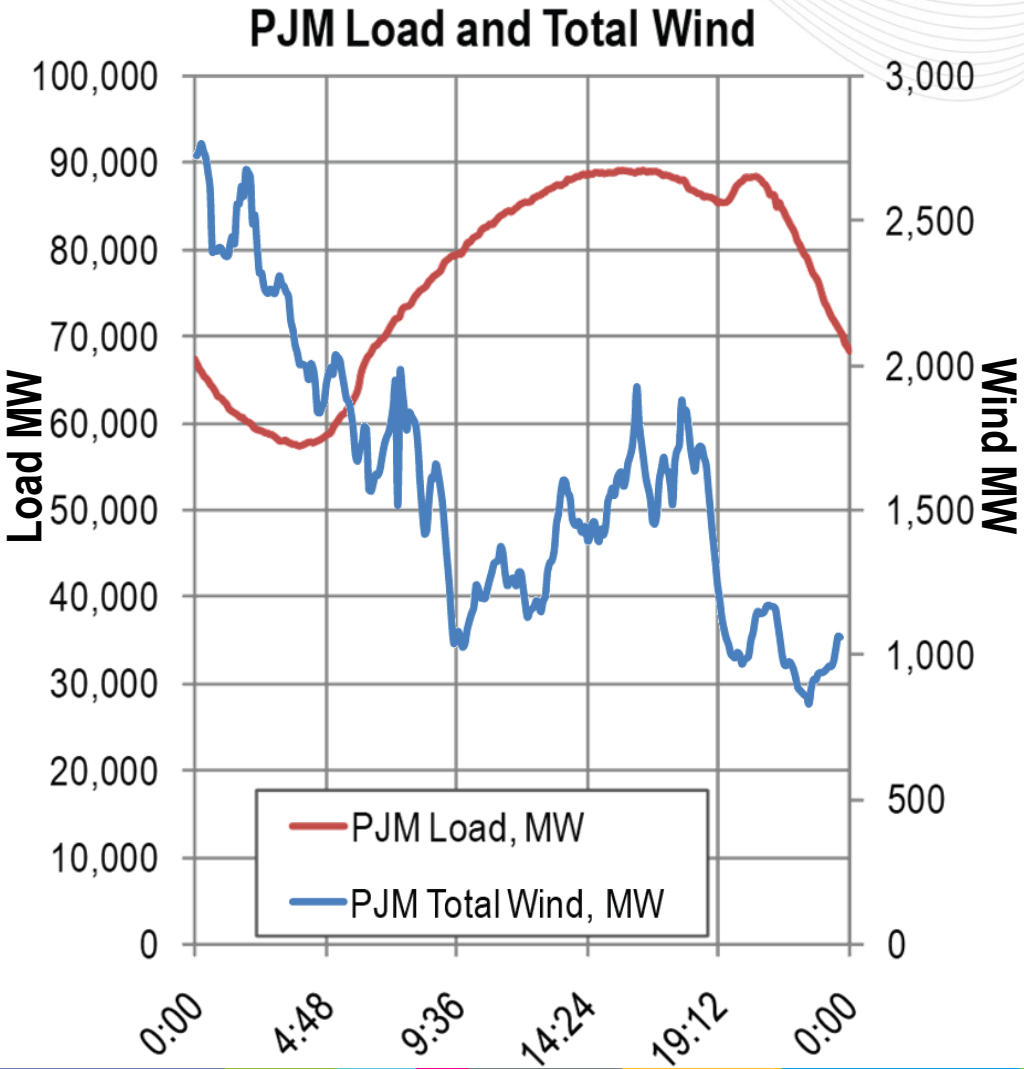
Historical Data

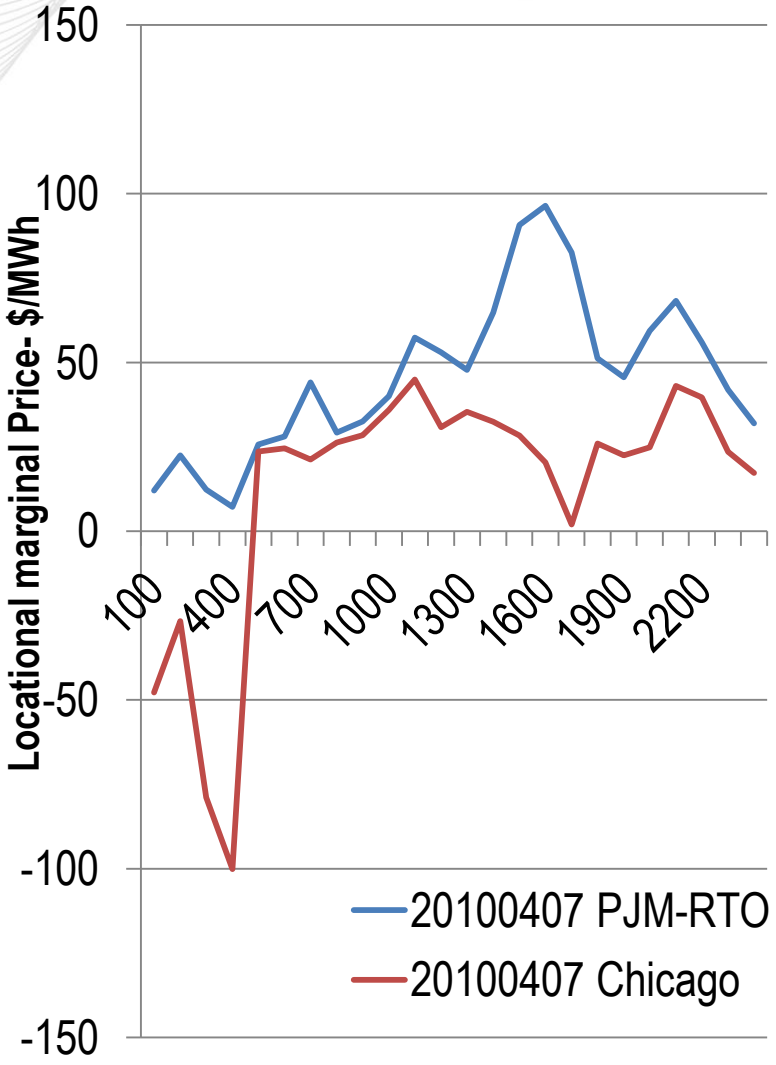
Regional

The Fine Print on Renewables

- Wind is coming, but not on the peak hours (13% available at the time of peak)
- Energy Storage is needed to ensure renewables achieve their potential

PJM Load and Wind Resources

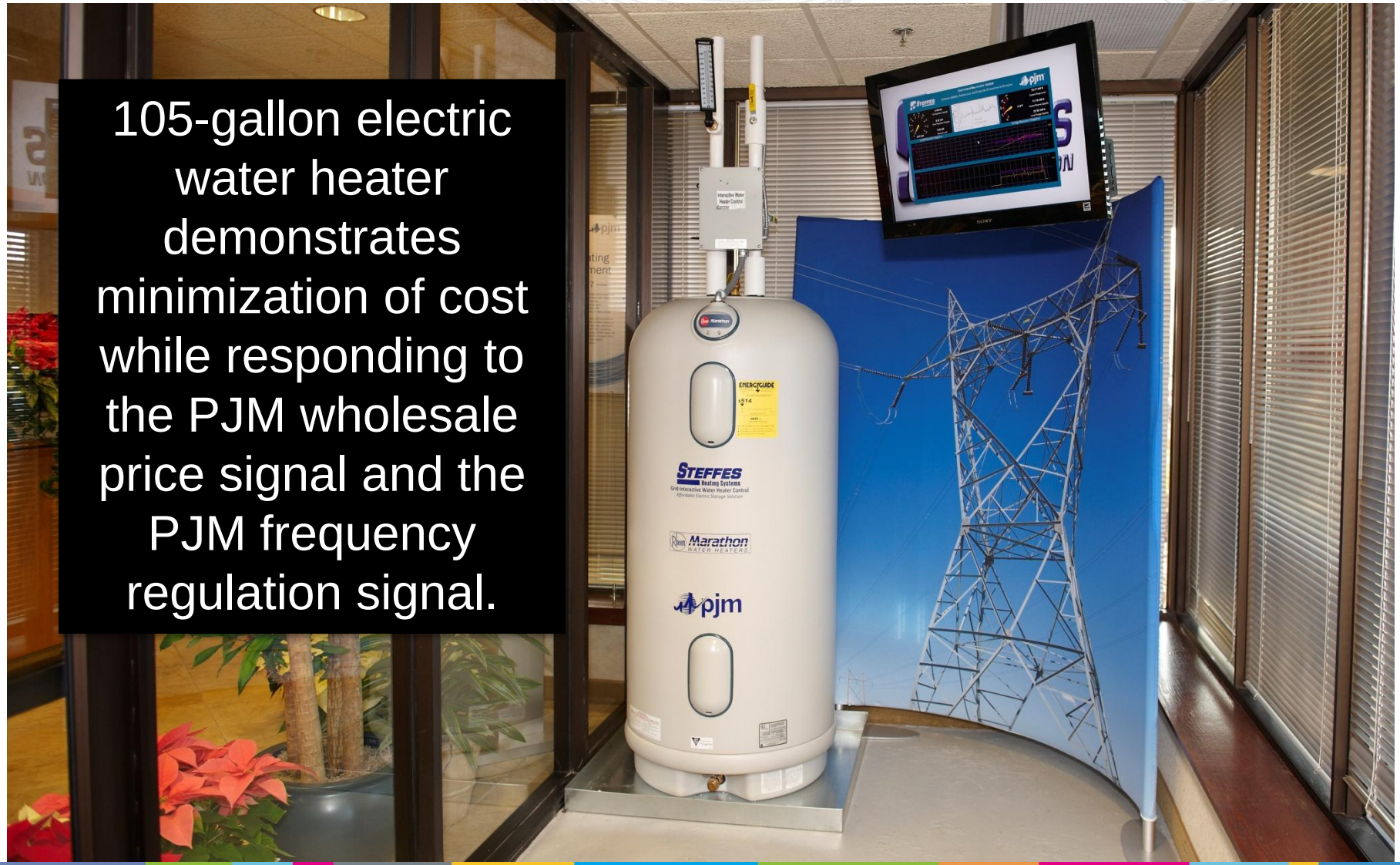




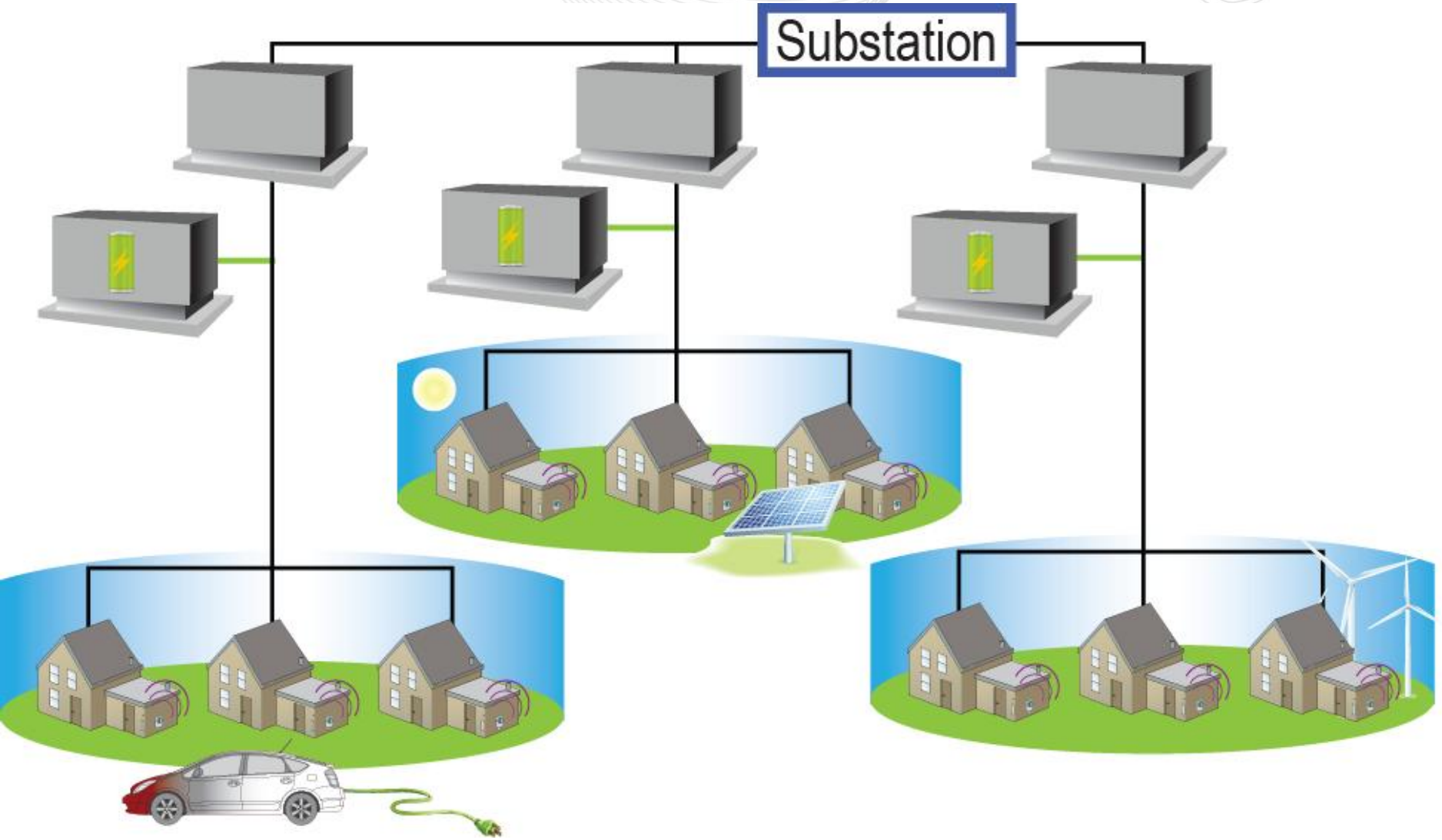
Grid-Scale Energy Storage System – 32 MW Battery

Laurel Mountain
Wind Farm
98 MW
61 turbines
Battery Storage
Lithium-ion (A123)
Power 32 MW, Energy 8 MWh

Water Heater



Community Energy Storage



Effects on Reserve Requirement:

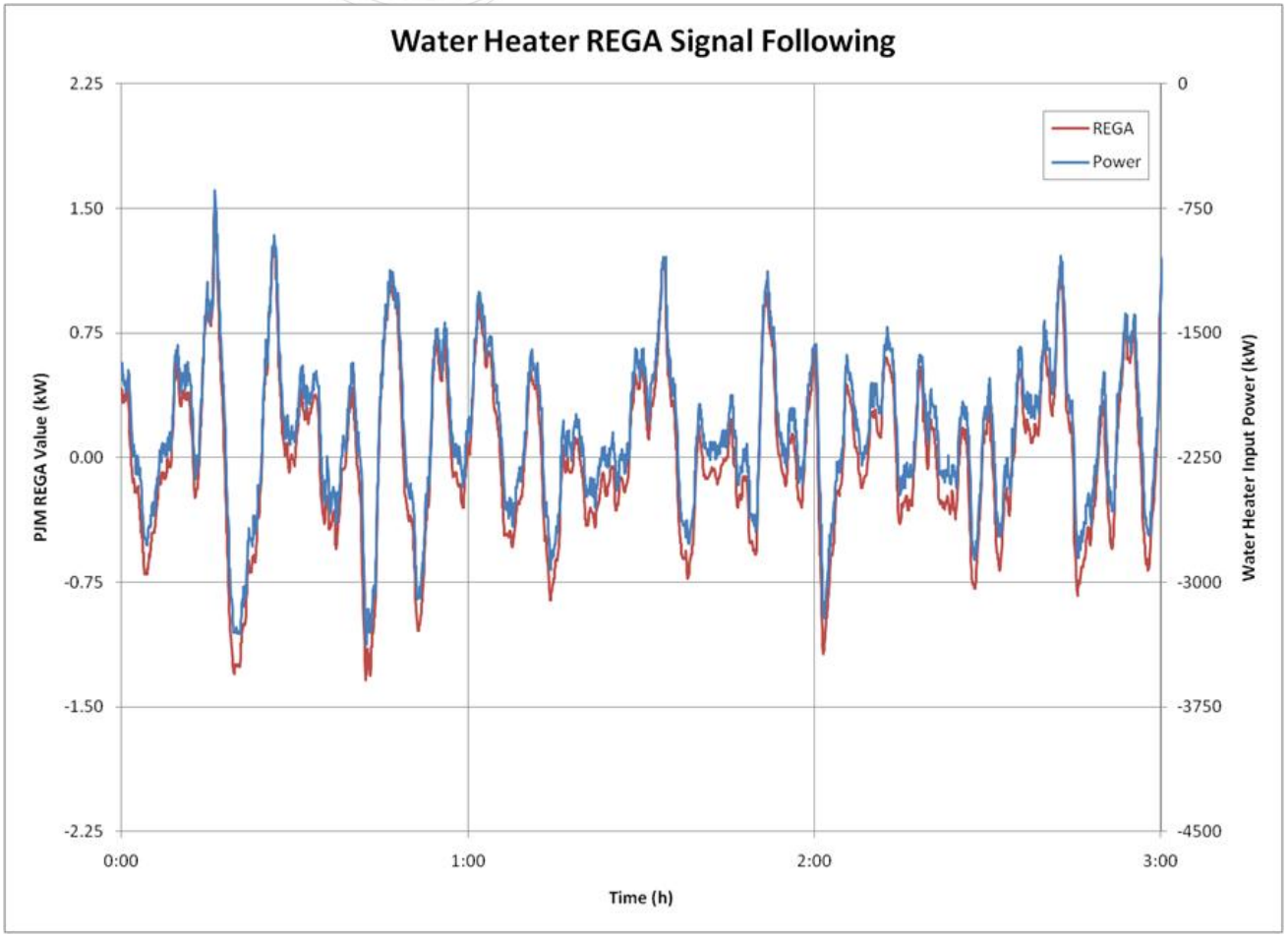
Higher wind generation mean higher variability and faster Rates of Change of Frequency

To mitigate these effects, Grid requires Higher amounts of reserves as well as faster responding reserves

Fast Regulation: Speed Matters…

- PJM Frequency Regulation Signal

- Water heater power consumption +/- 2.25 Kw base point



PHEV: Benefits to Markets

Its really going to happen this time.

--Photo: EPRI

PHEVs: The Momentum Builds

Battery Electric Vehicles

2010 Coda Automotive Sedan
2010 Mitsubishi iMiEV BEV
2010 Nissan LEAF
2010 Ford Battery Electric Van
2010 Tesla Roadster Sport EV
2011 Peugeot Urban EV*
2011 Renault Kangoo Z.E.
2011 Renault Fluence Z.E.
2011 Tesla Model S
2011 BYD e6 Electric Vehicle
2011 Ford Battery Electric Small Car
2011 Opel Ampera Extended Range BEV*
2012 Fiat 500 minicar

1902 Lohner-Porsche PHEV

2009 BWM MINI E

Battery Electric Vehicles

2012 Renault City Car*
2012 Renault Urban EV*
2012 Audi e-tron
2013 Volkswagen E-Up*
2016 Tesla EV

Extended Range Electric Vehicles

2010 Chevy Volt Extended Range

Plug-in Hybrid Vehicles

Fisker Karma S Plug-in Hybrid
2010 Toyota Plug-in Hybrid
2011 BYD F3DM Plug-in Hybrid
2012 Bright Automotive IDEA Plug-in Hybrid
2012 Ford Plug-in Hybrid
2012 Volvo Plug-in Hybrid

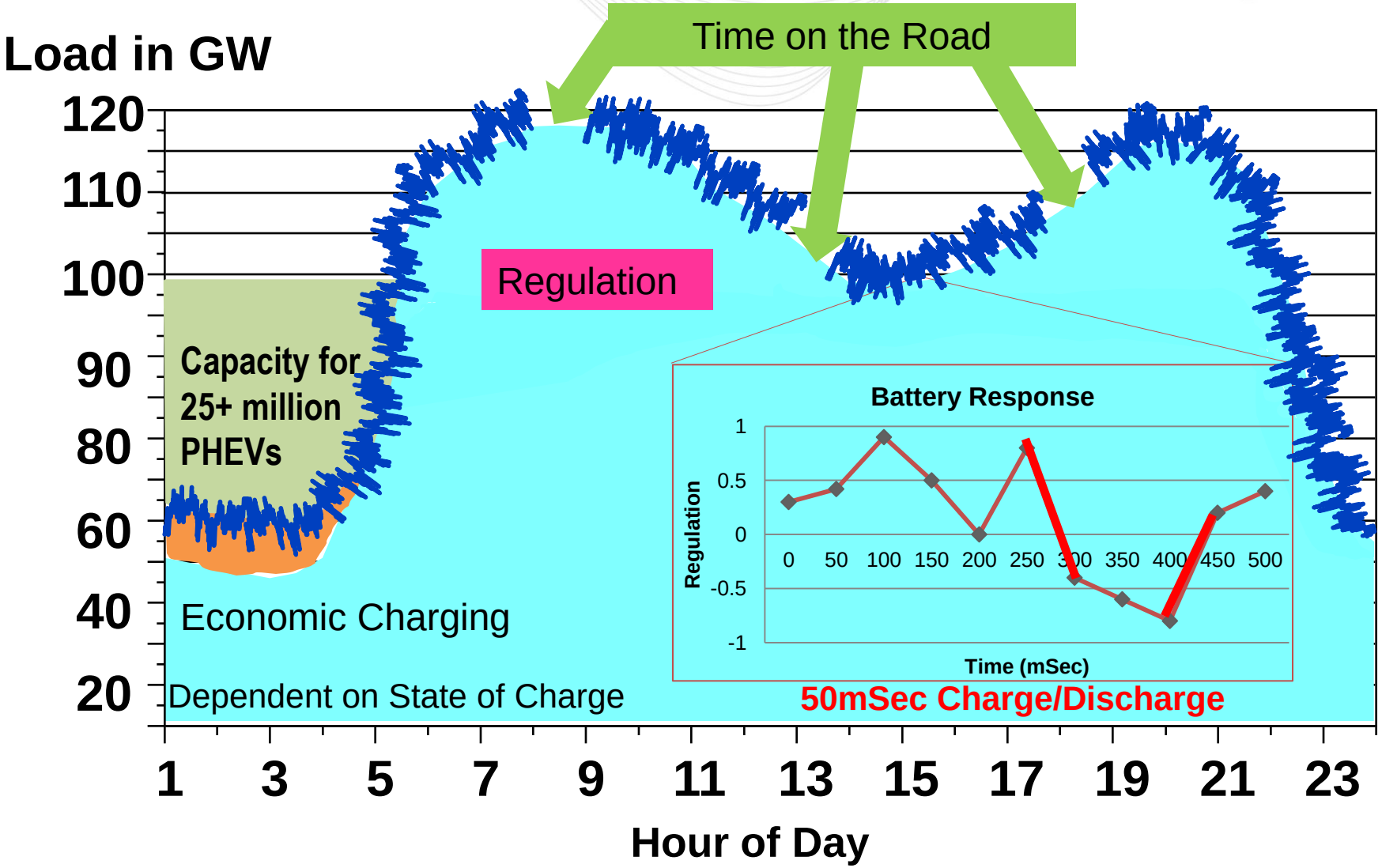
3/31/2010

Pony Under the Christmas Tree?

60¢ (PJM Off-peak Price)

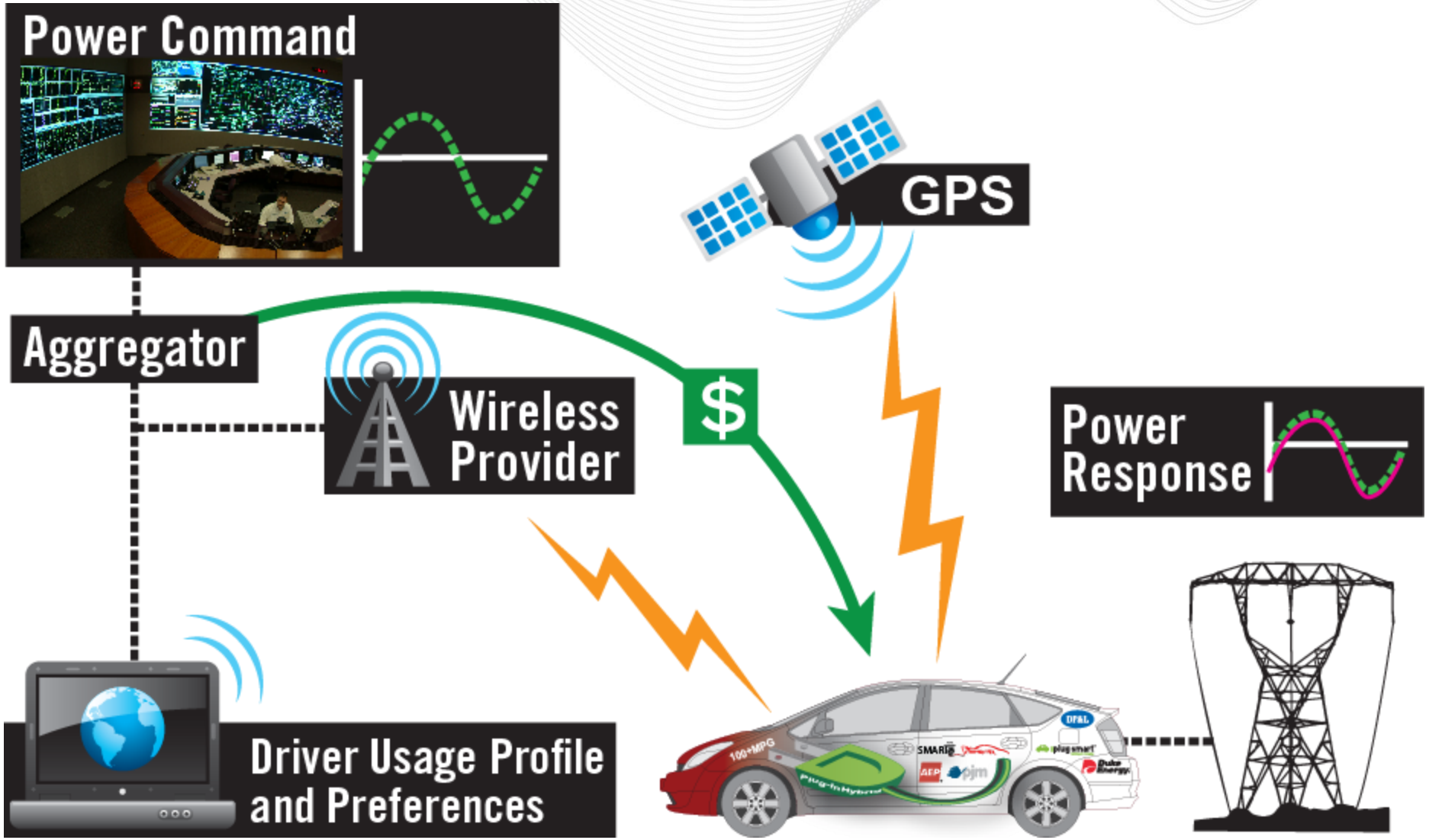
~~75¢~~ per "Gallon"

Grid Benefits – Regulation vs. Economic Dispatch

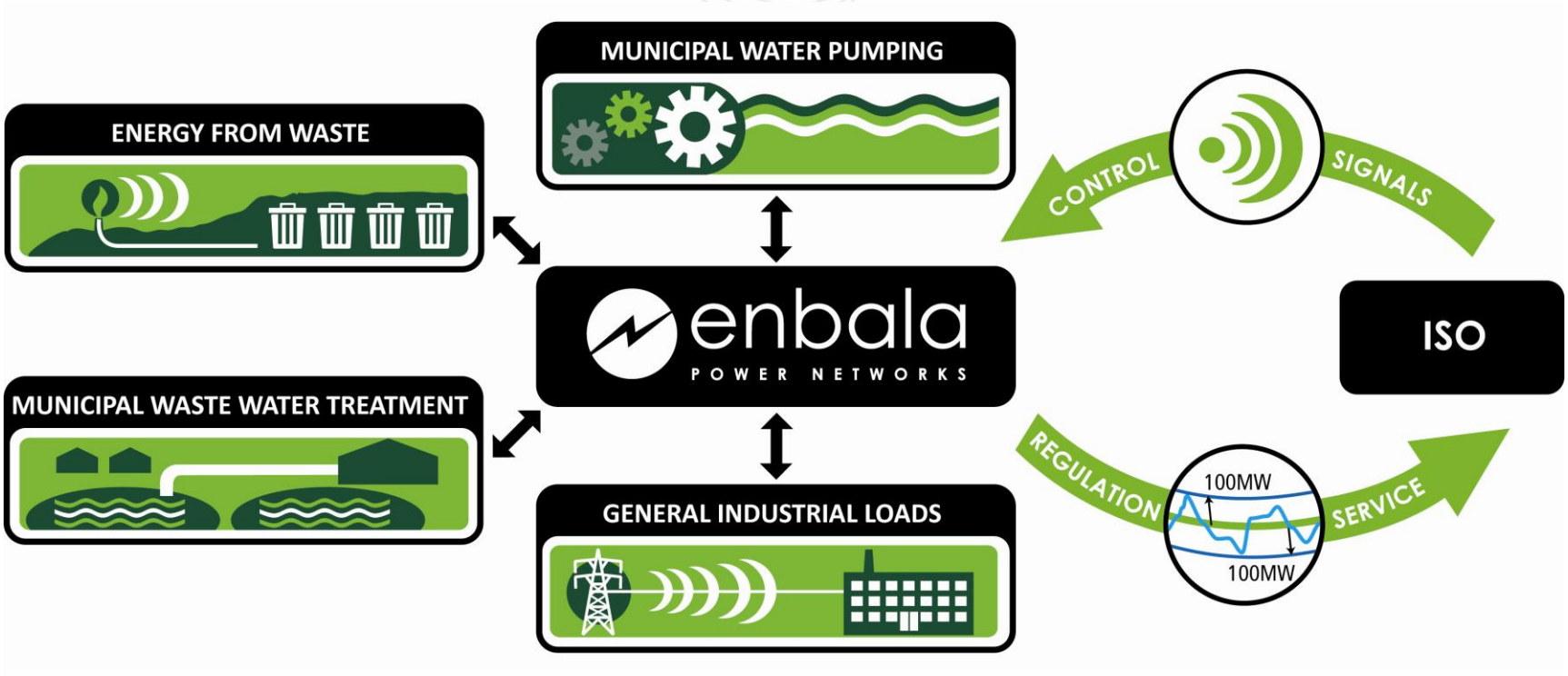


Available for Summertime Work

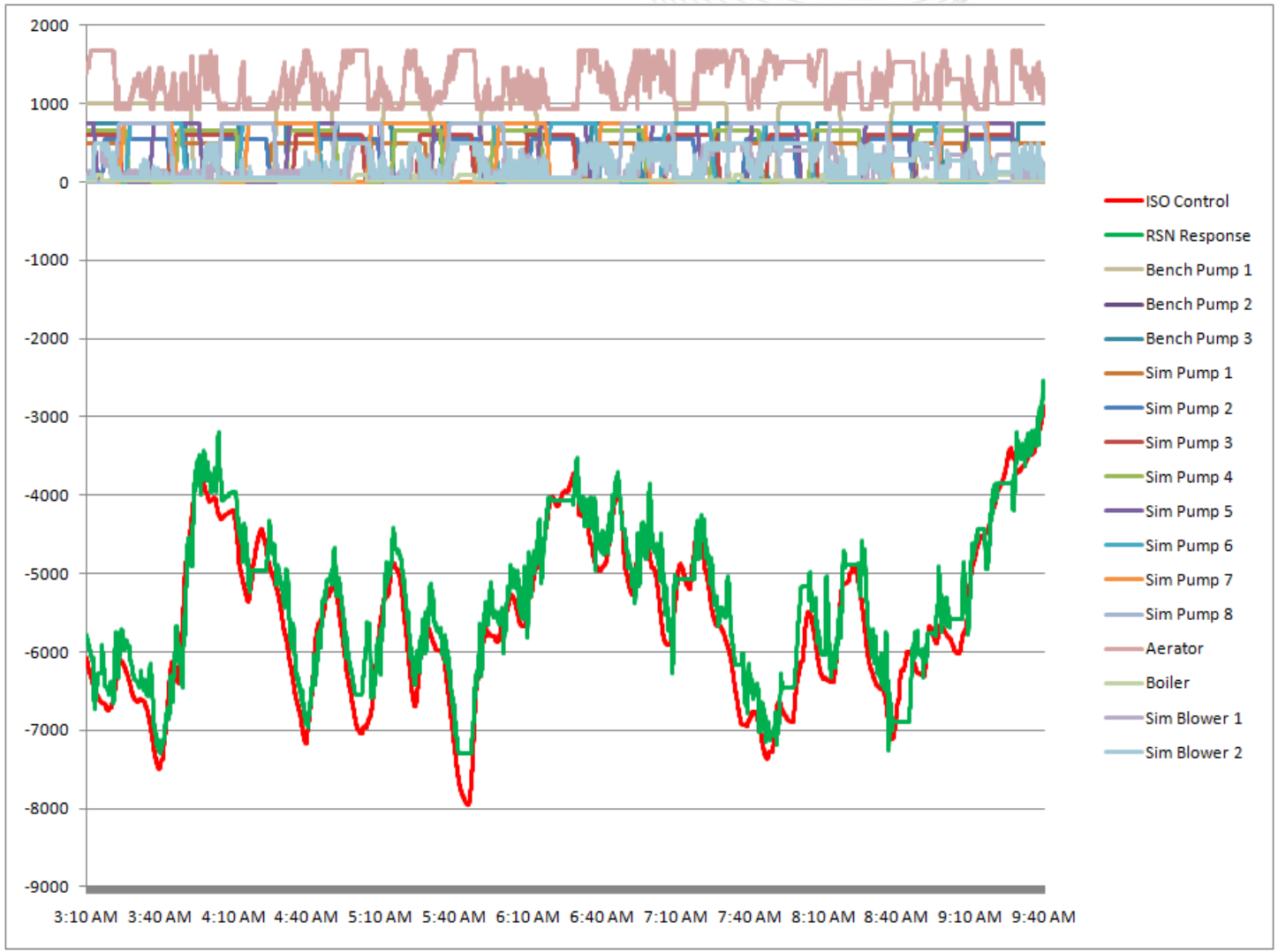
Smart@Car-a connection to the grid



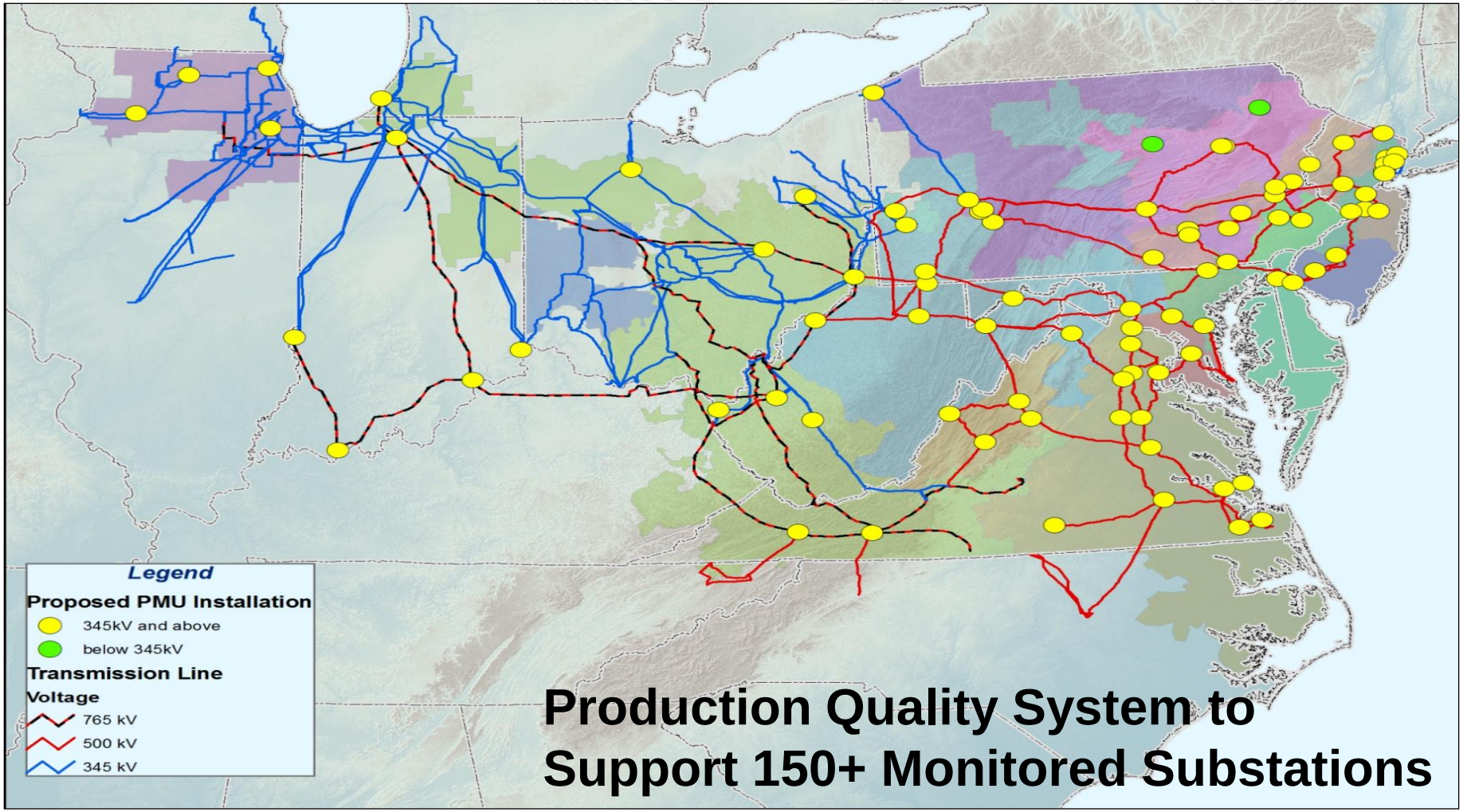
ENBALA's Power Network (EPN)



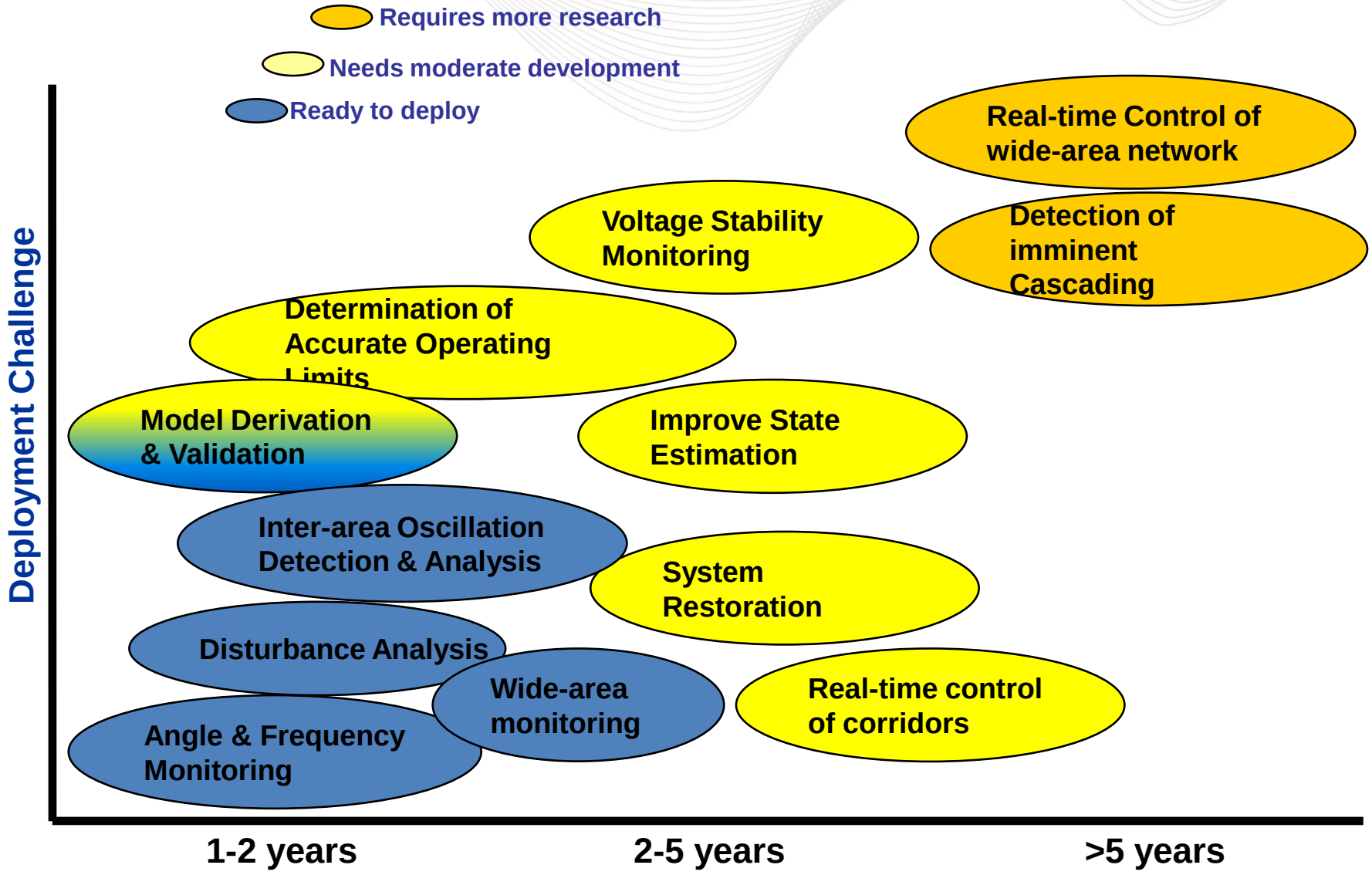
Operational Performance – Aggregation of 16 water pumps:



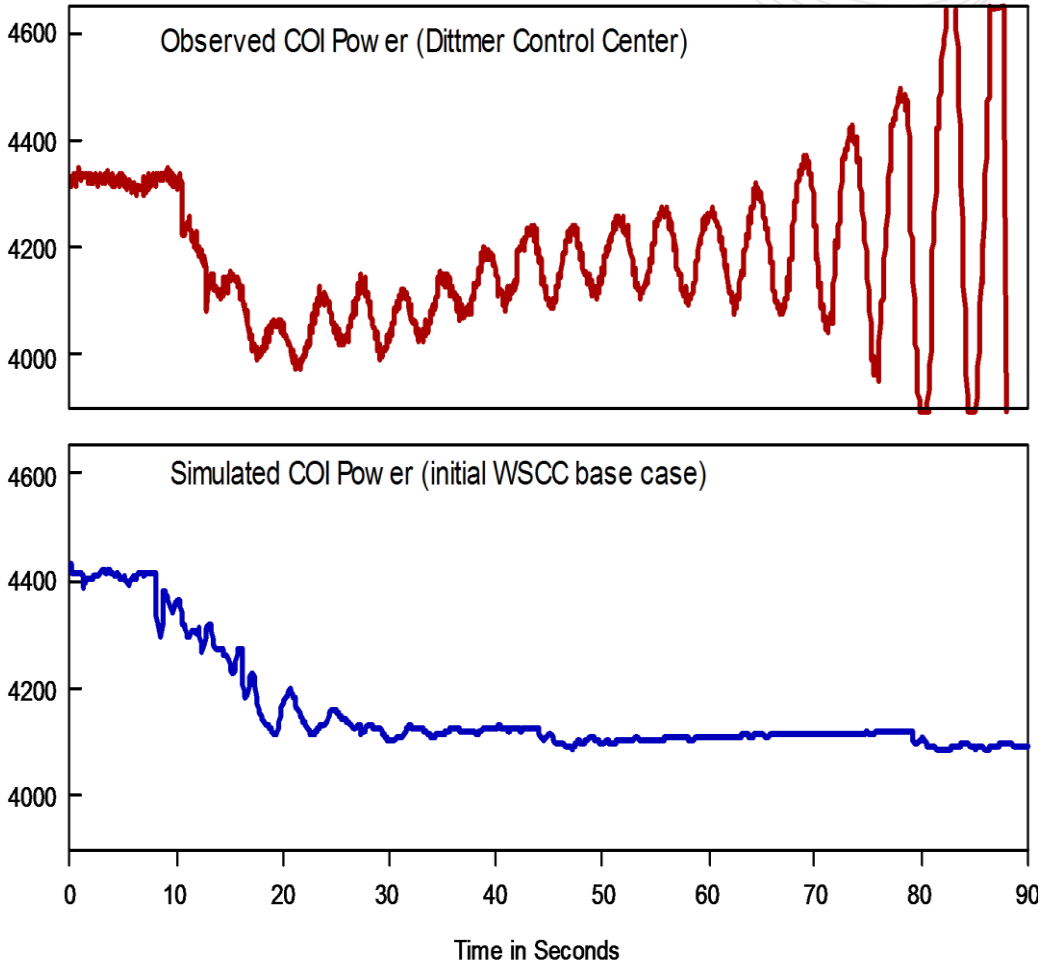
PJM SynchroPhasor Deployment Project



SynchroPhasor Applications

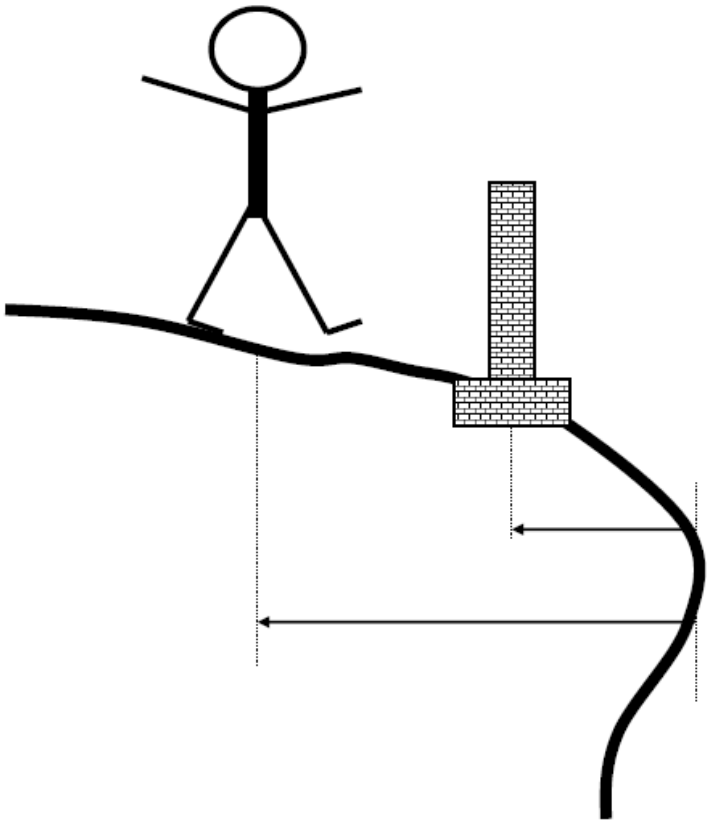


Off-line Applications



Phasor data measures system dynamic behavior during disturbances that simulations can't yet accurately predict

Wide-area situational awareness



Measurements give us current system states:

For true situation awareness we need to know;

- **Where the edge is**
- **How close to the edge we can safely (reliably) operate**

Baselining studies of phasor angles are required for understanding system behavior

- For more information about PJM's initiatives:
  - Exploring Tomorrow's Grid: New developments and technologies to advance the grid:
    http://www.pjm.com/about-pjm/exploring-tomorrows-grid/smart-grid.aspx
  - Renewables Dashboard: See how PJM is working to bring renewable energy to the grid:
    http://www.pjm.com/about-pjm/newsroom/renewable-dashboard.aspx