Grid Integration of large fluctuating power generation with plug-in vehicles

Deregulation Roundtable
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Outline

- Need for more fundamental analysis
  - Wedges (Pacala and Socolow), versus
  - Resource inventory for a state or region
- Today: Carbon-free power fluctuates
- Vehicle-to-grid as a bridging technology

The Basics

- Reductions of 80% force a rethinking
- What is our carbon-free inventory?
- Problem: Natural flows are not controlled, so need storage or flow management
  - Electric Vehicles will be one large storage resource

Delaware Power Resources

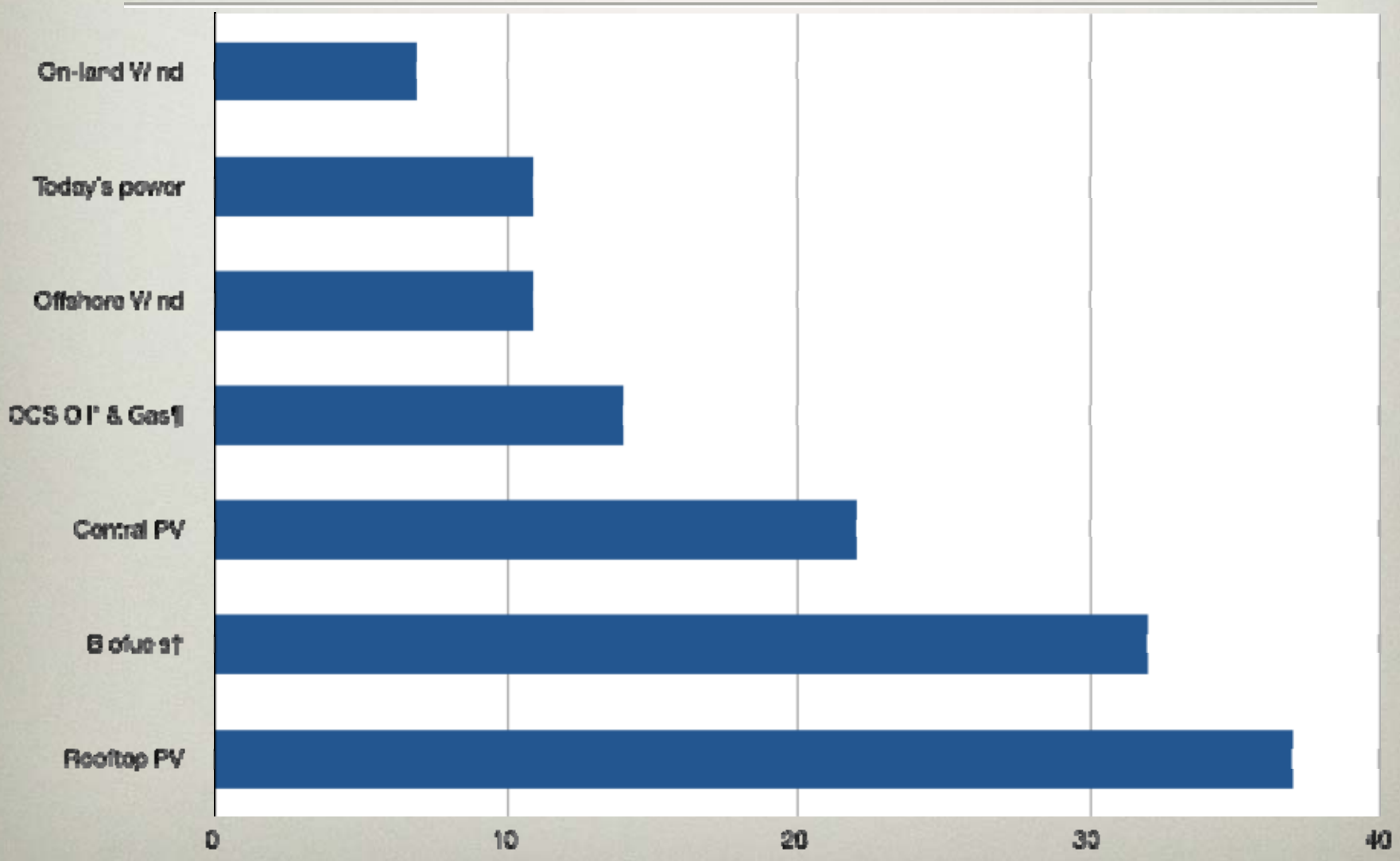
	Ratepayer ¢/kWh	Peak match	Capacity (MW)	Average output (MW_a)
Central PV	22	Good	369	59
Rooftop PV	37	Good	1,797	288
On-land Wind	7	Very poor	50?	15?
Offshore Wind	11	Poor	19,000	7,400
Biofuels†	32	Excellent	169+	169
OCS Oil* & Gas¶	14	Excellent	250+	250
Today's power	11	Excellent	3,283	1,300

† 8-10¢/kWh as fuel energy content, but 2/3 to 4/5 loss to use

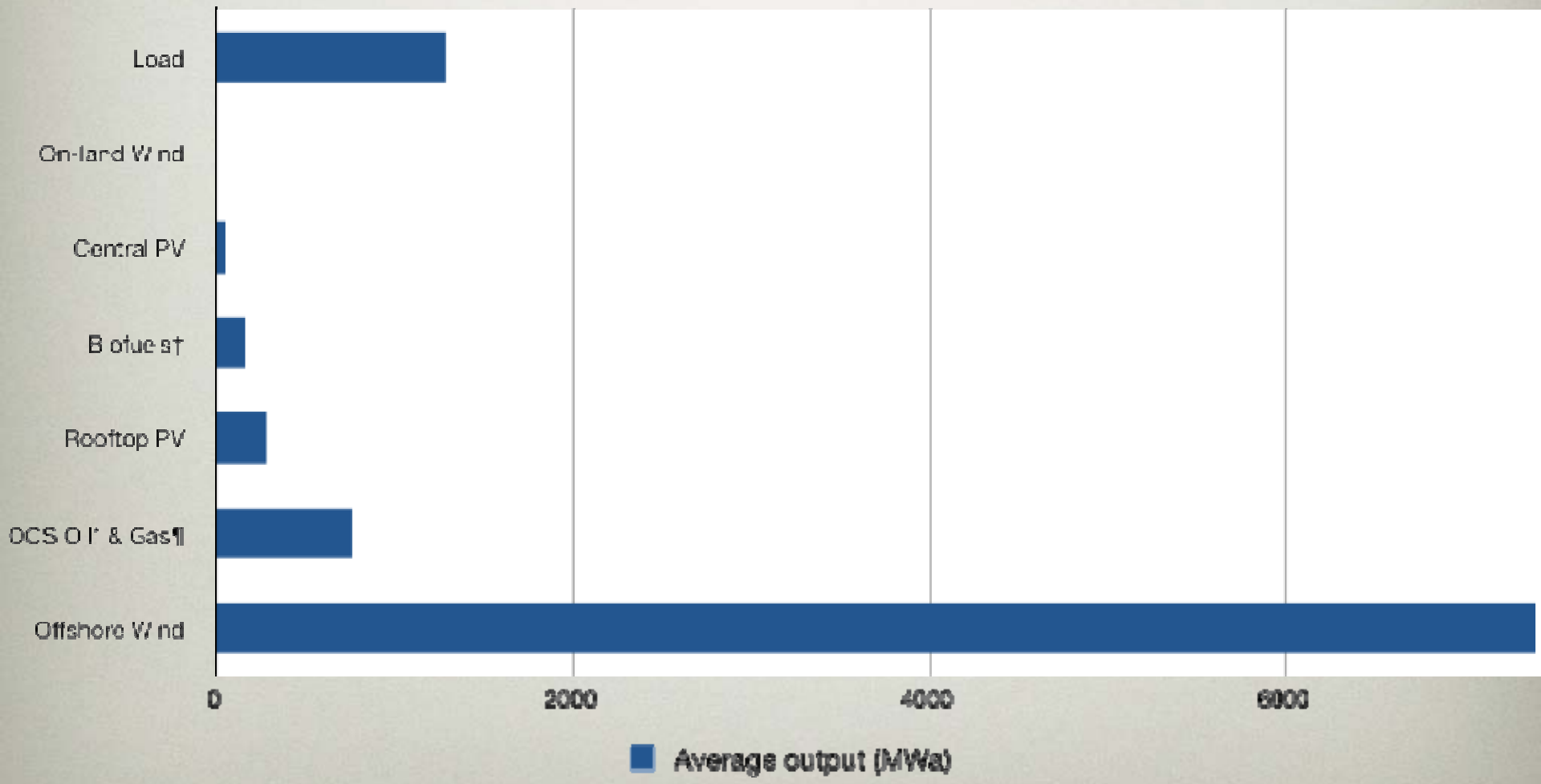
* DE is 1/73 of Atlantic OCS; assuming 20 year burn, 50% efficient conversion to electricity (250MW), $2 gallon≈22¢/kWh.

¶ Gas, assume 20 year burn, 60% efficient convert to electric (520MW), current wholesale market of 10¢/kWh.

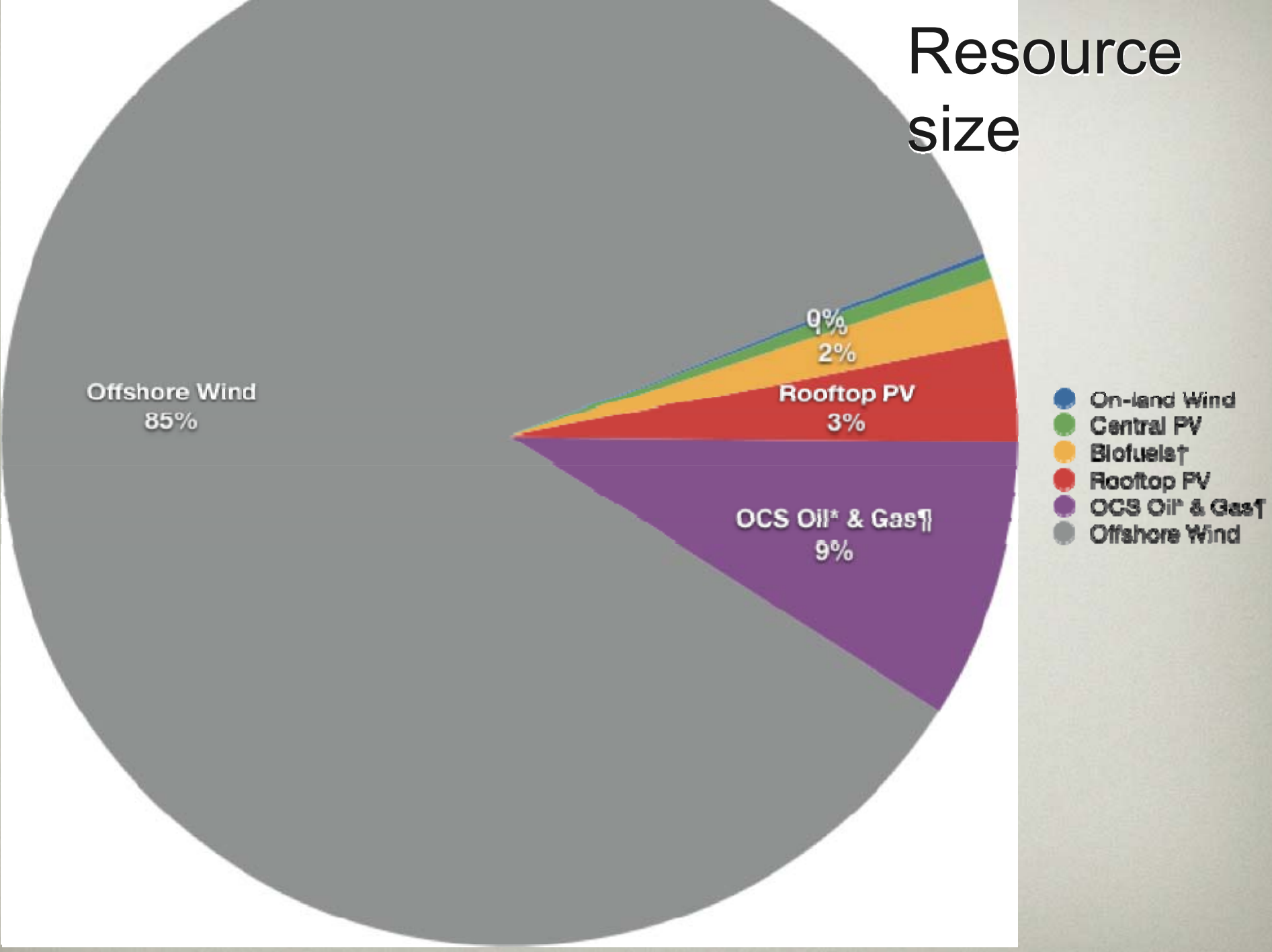
Ratepayer Cost



Resource Size



Resource size

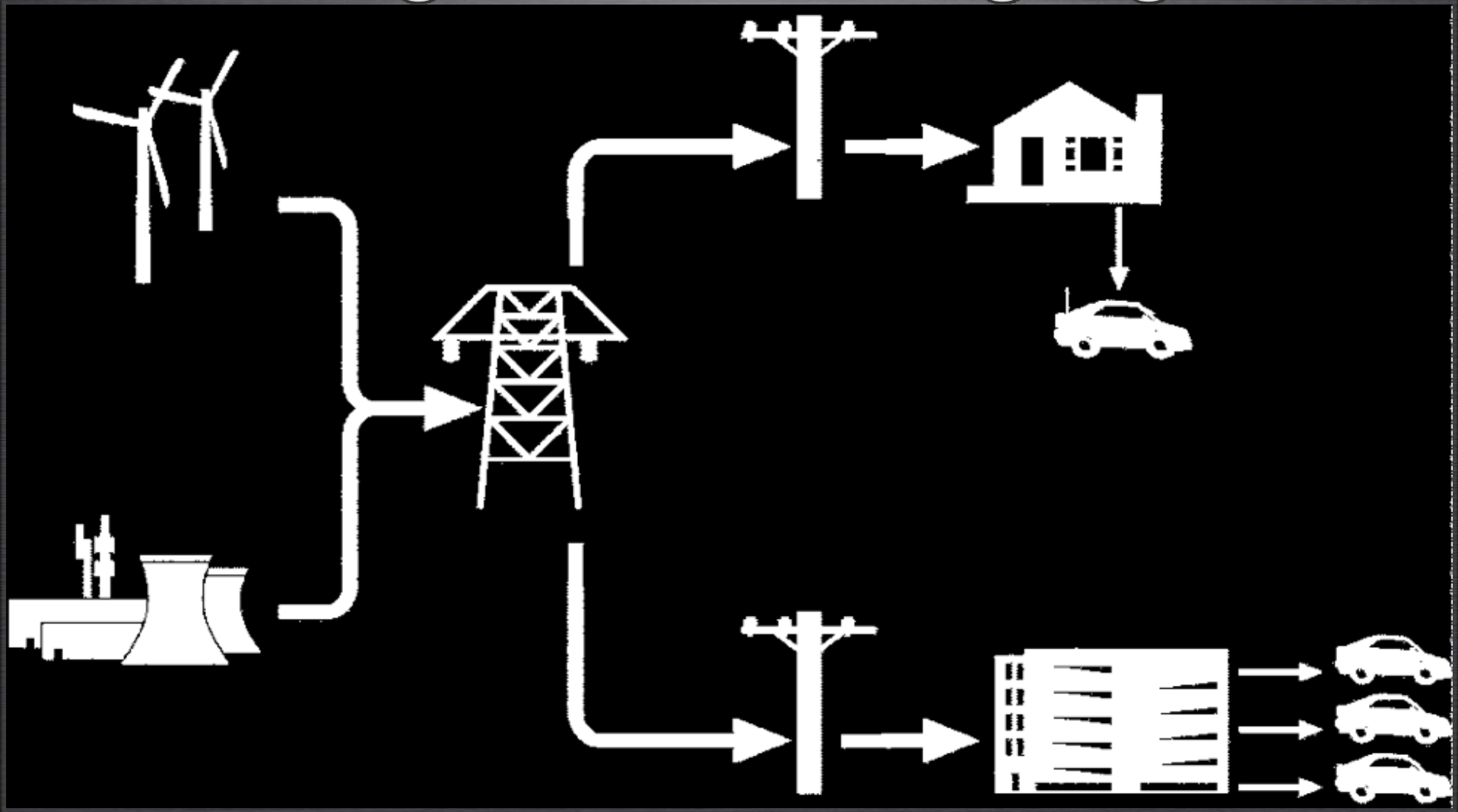


Generalizations

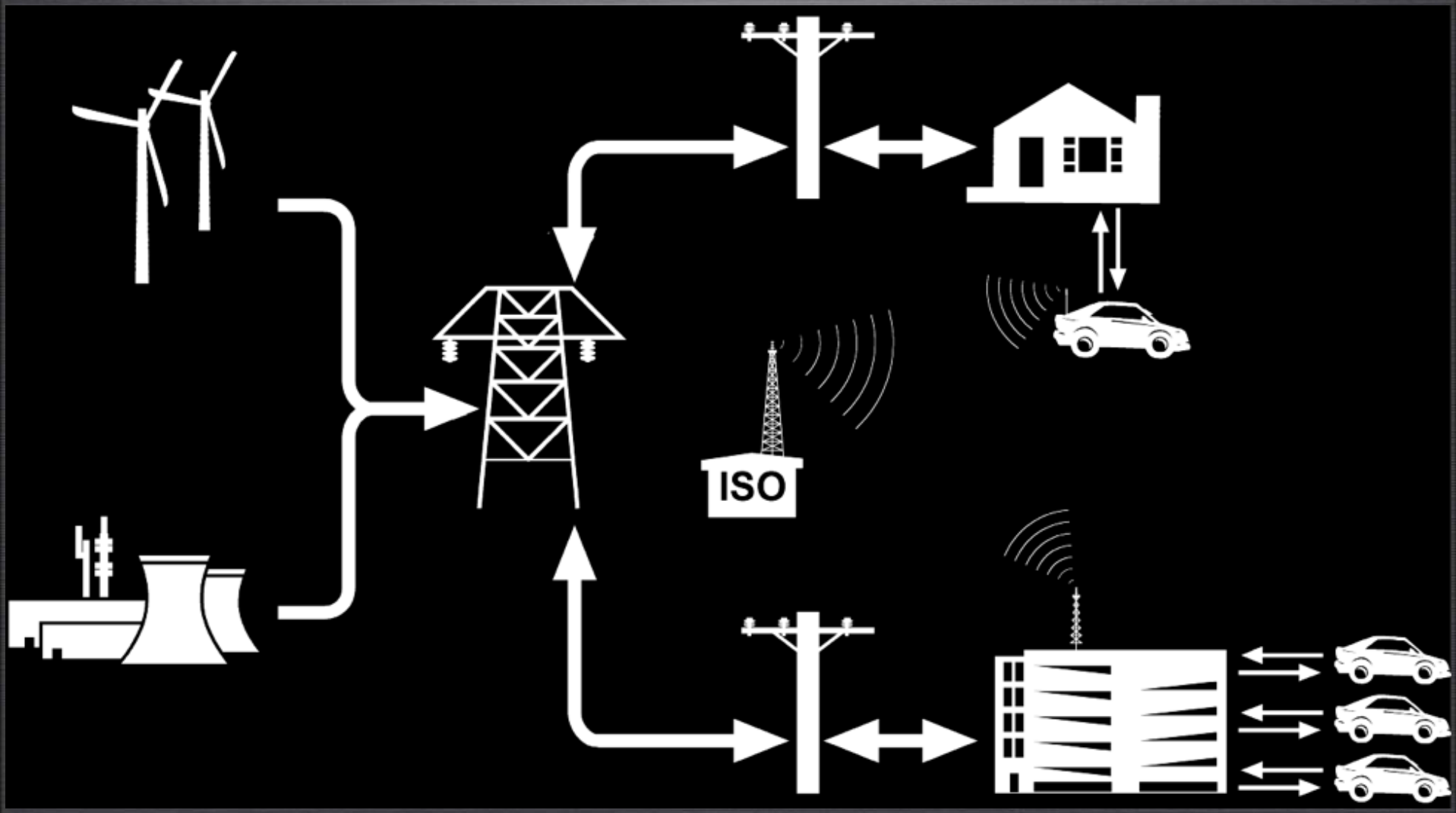
- The resources aren't equal size
- In our example, one is low cost, commercial now, and very large
- But, that one is the worst match to load, a problem at wind penetration > ~20%
  - So, a path to 80% reduction demands that we solve the wind integration problem

intro to vehicle-to-grid

Plug-in for charging



V2G with ISO Control



V2G taps an underutilized resource

- US car used 1 hour/day, parked 23 h/d
- Average daily travel = 32 miles, thus **most storage unused most days**
- Practical power draw from car: 10 - 20 kW
- US power: generation=978 GW; load=436 GW avg (EIA 2005)
- US 241 million cars (FHWA 2005) x 15 kW = 3,615 GW, thus...

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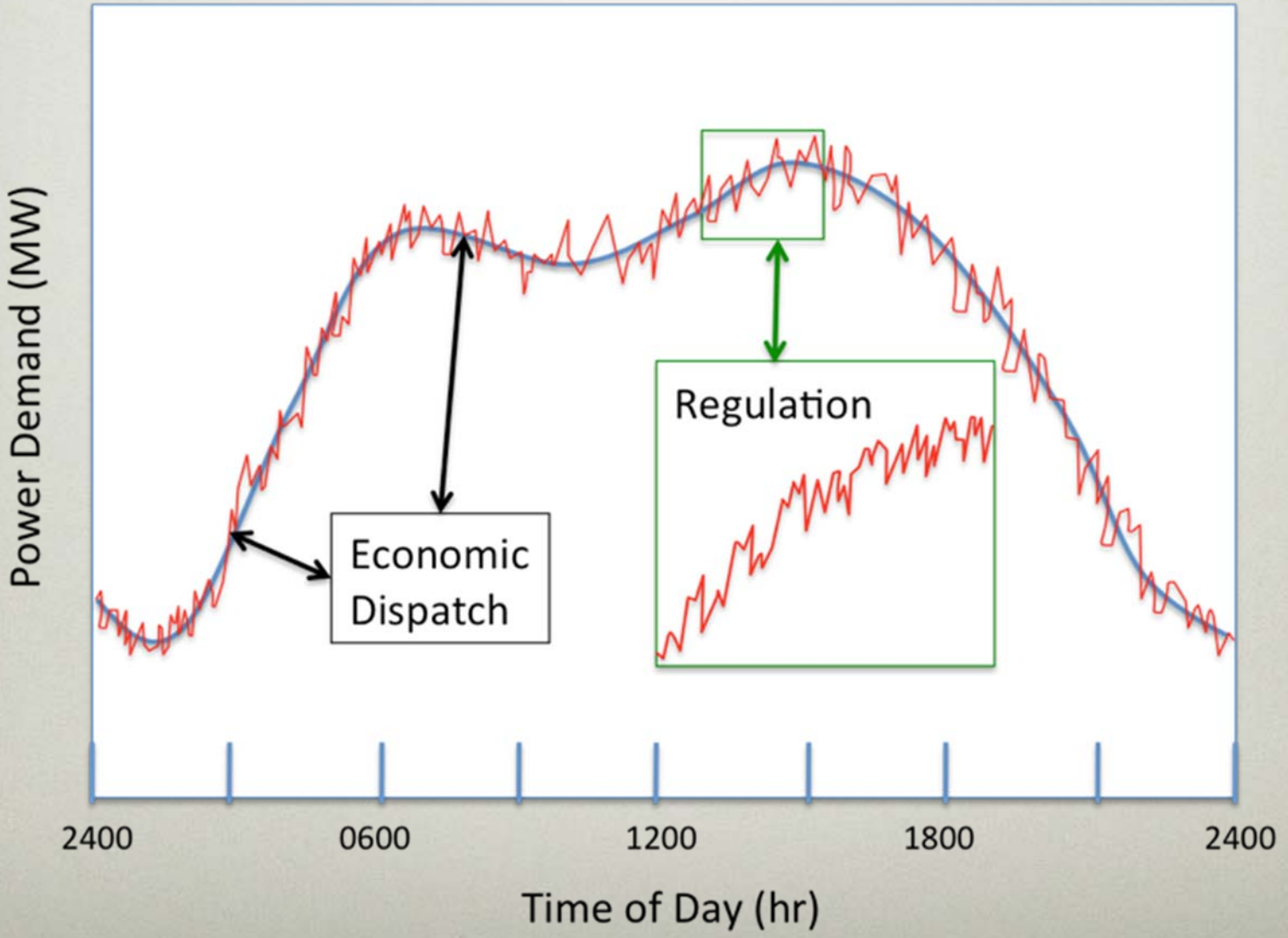
- **Power of fleet is >3x generation; >8x load!**

Energy Markets

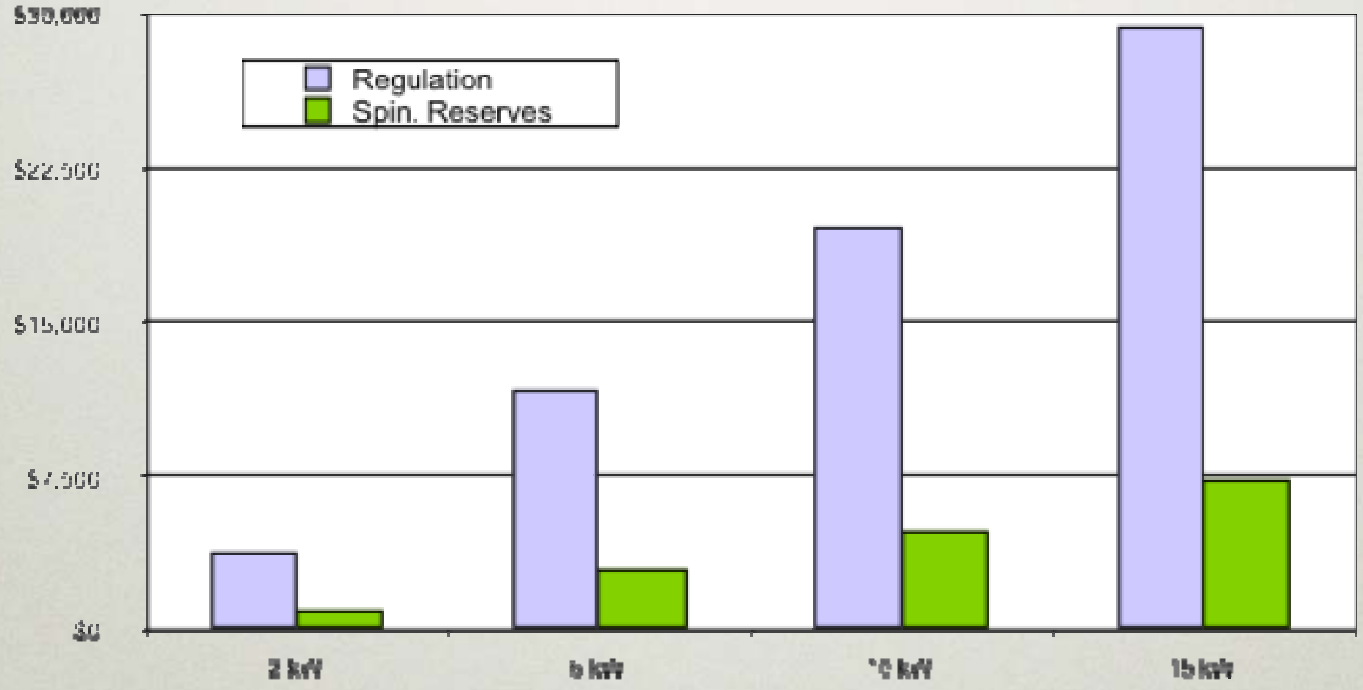


Value of regulation

	Average Annual Market Clearing Price ($/MW-h)		
	2004	**2005**	**2006**
PJM	$42.75	$49.73	$32.69
RTO-NE	$28.92	$30.22	$24.02
NY ISO	$22.59	$39.21	$51.26
ERCOT	$22.66	$38.07	n/a
CA ISO	$29.00	n/a	$36.04

Basic per Vehicle Values

10 –Year Present Value V2G Revenue Potential



Assumptions: 80% availability, Reg. $40/MW-h, Spin. $10/MW-h, 7% discount rate, example calculations

Sequence of Markets

- Initial, high-value markets, are A/S
  - Regulation
  - Spinning reserves
- Later, larger markets with lower value per kW:
  - Defer upgrades to distribution feeders, transformers
  - Peak load reduction, valley filling
  - Power factor correction
  - Balancing wind, shifting solar peak

MAGICC: Mid-Atlantic Grid-Interactive Cars

Mid-Atlantic Grid-Interactive Car Consortium (MAGICC)

- Partners
- Univ. of Delaware
- PHI: Delmarva Power, Atlantic Electric, PEPCO, etc
- PJM Interconnect
- AC Propulsion
- ACUA

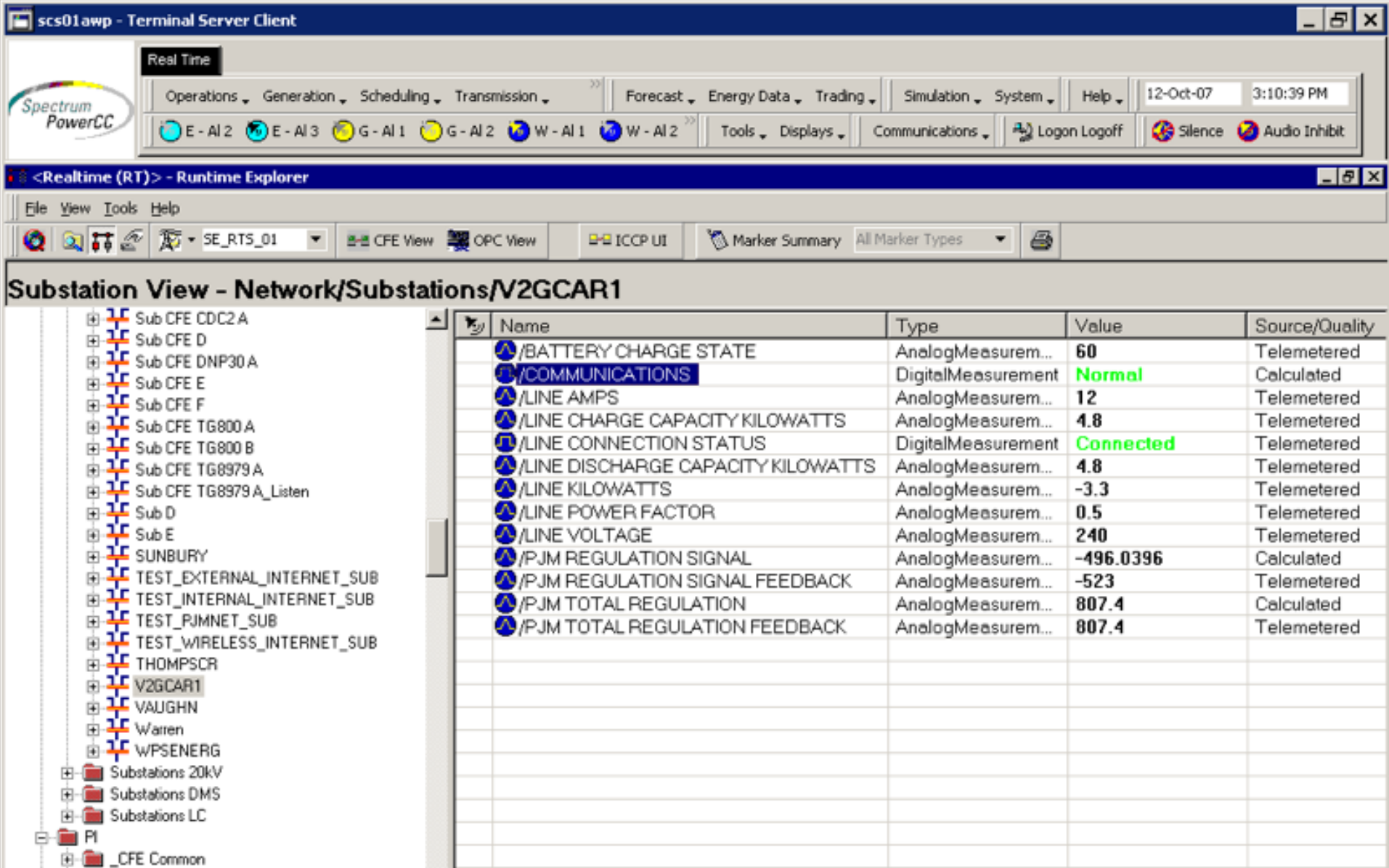
MAGICC
Mid-Atlantic Grid Interactive Cars Consortium

www.magicconsortium.org

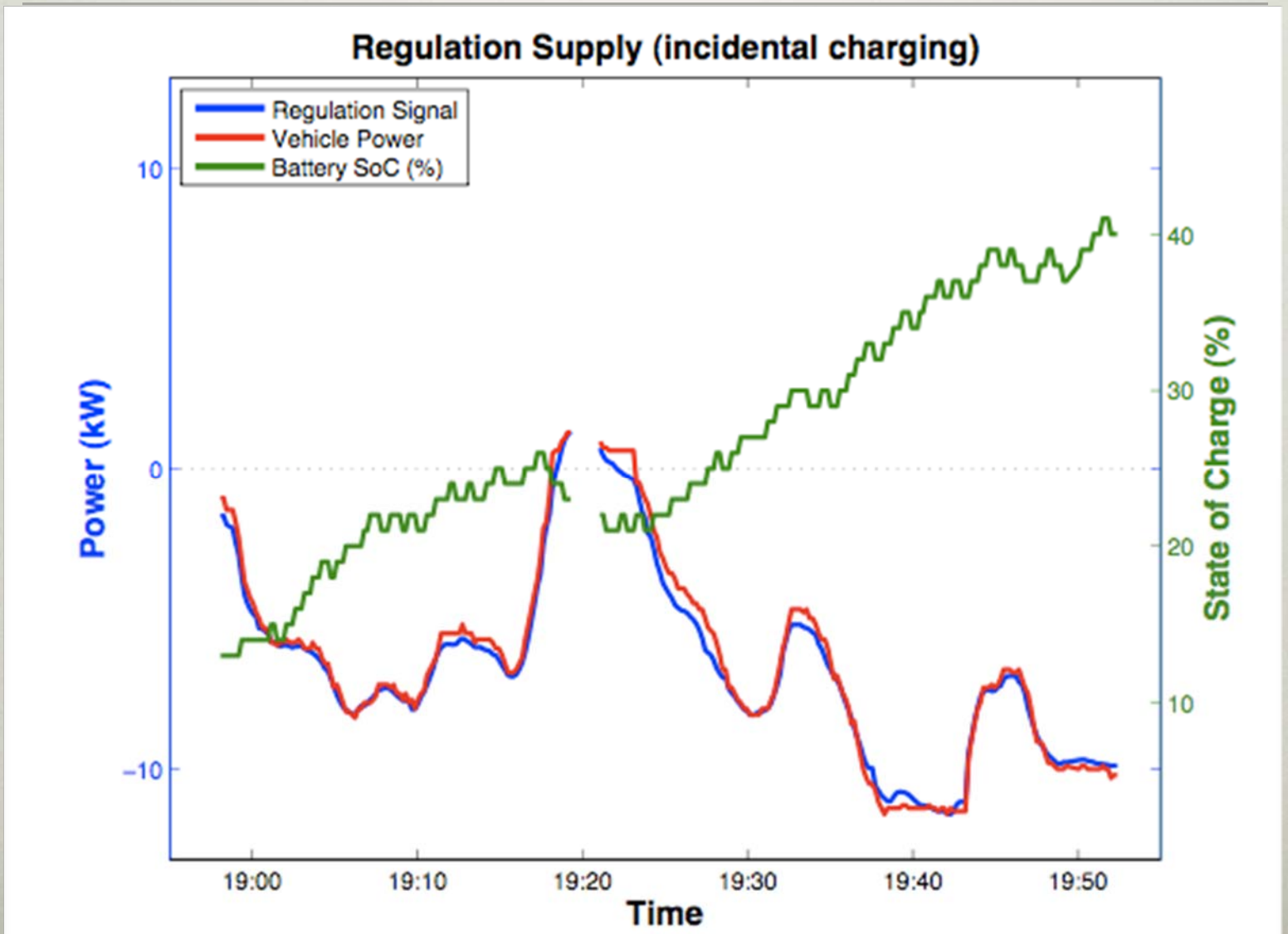
AGC from ISO to Vehicle via PLC

Move ISO link to server

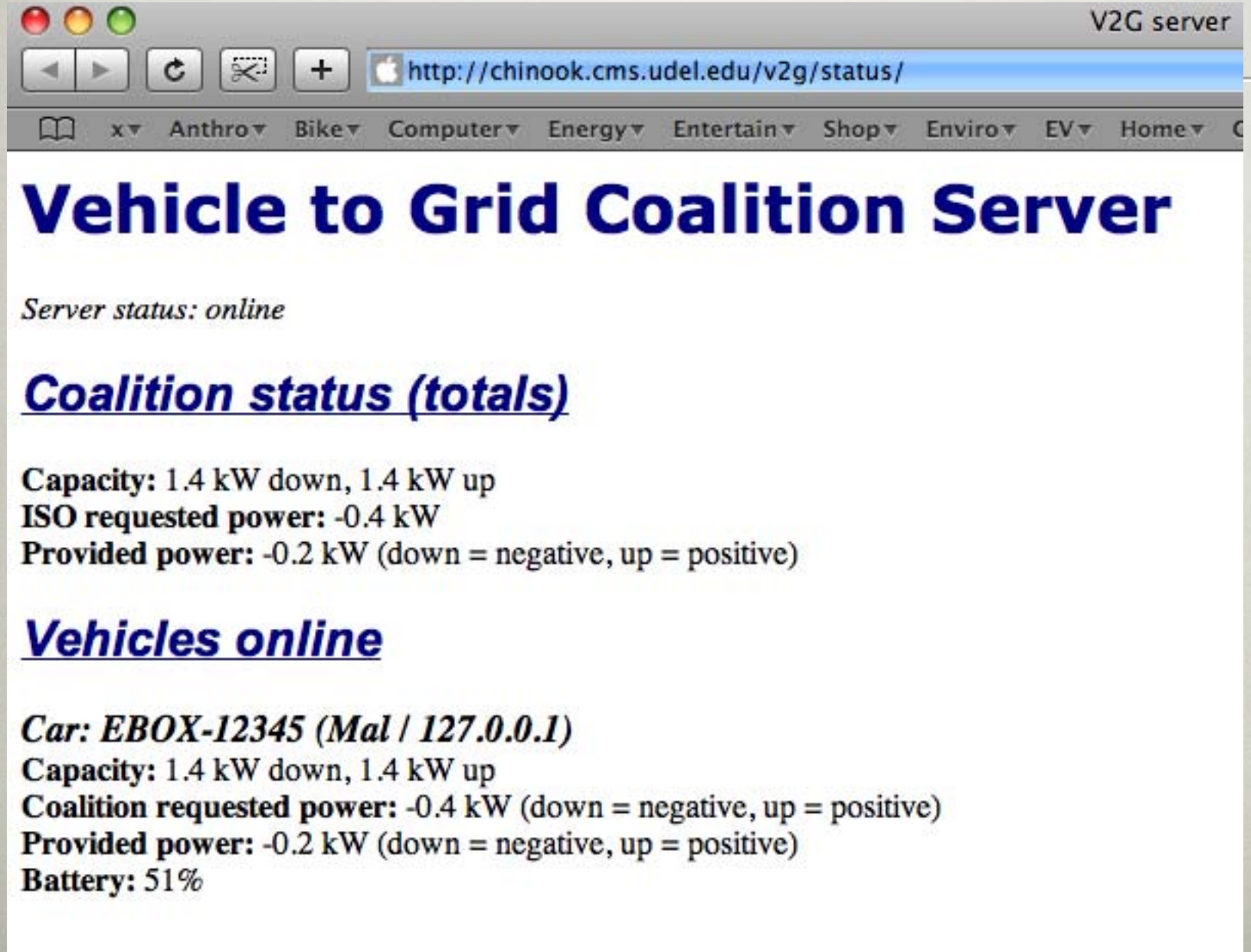
What the ISO sees



EVs providing regulation



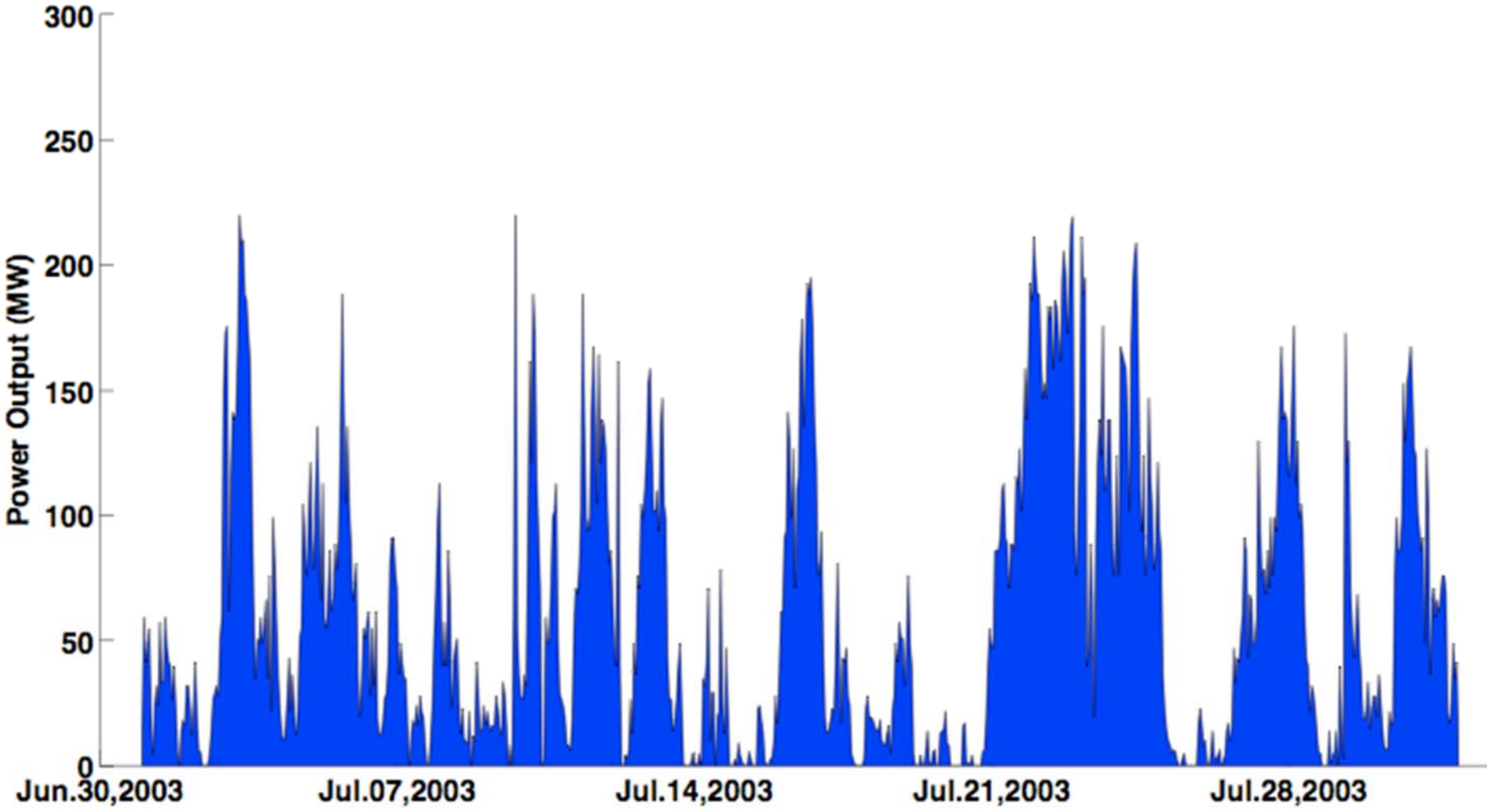
V2G Aggregator



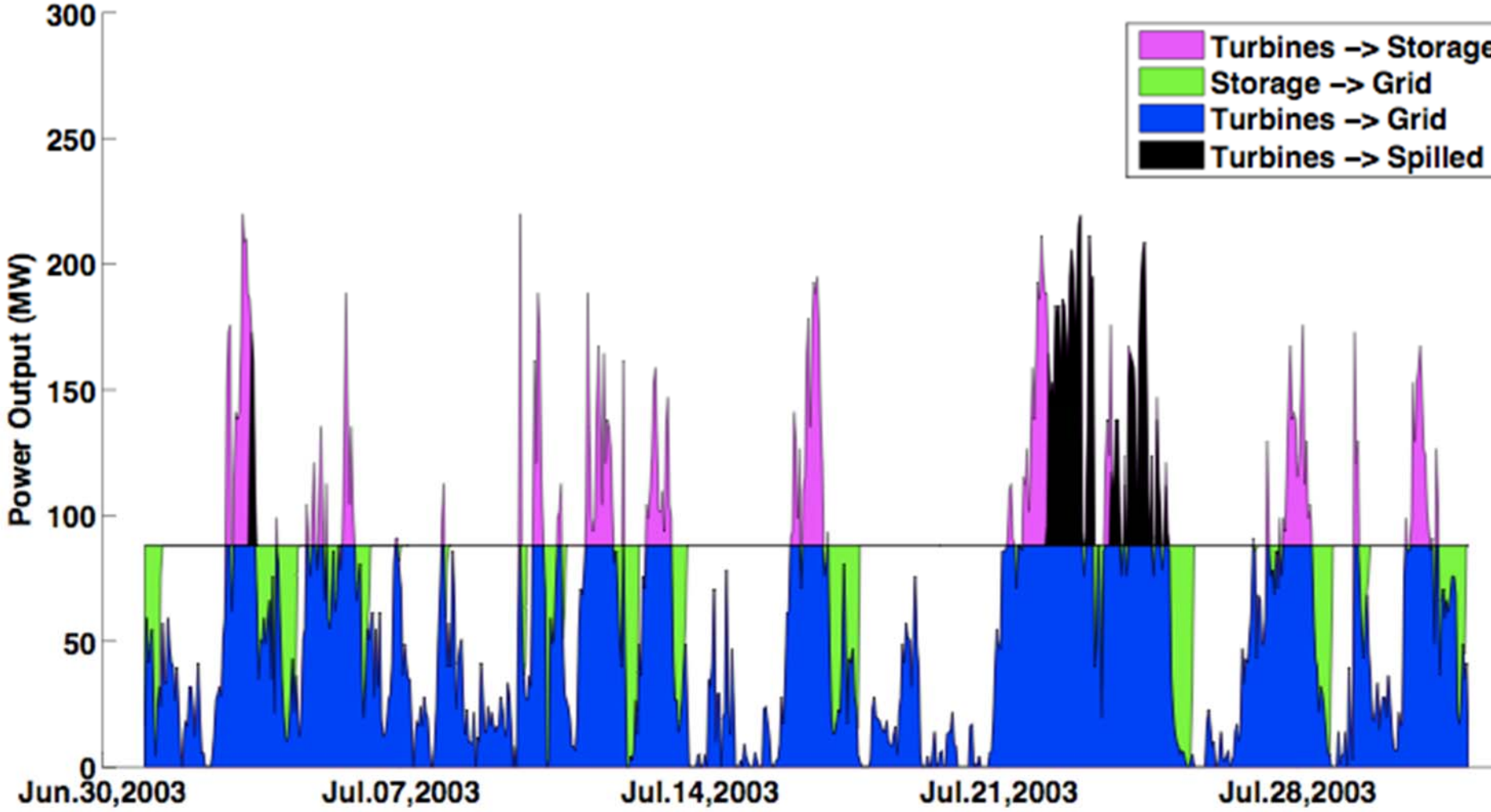
Simple model of V2G for wind leveling

- 220 MW offshore wind power (modelled from buoy 44009)
- Leveling target at 88 MW (40% of nameplate or 14% of average DE load), equal to 8760 average output
- Use storage of 1000 MWh (1 GWh) to level
  - Storage from just under 30,000 EVs (28571 eBoxes), about 4% of DE fleet
- Simplifying assumptions: no other end use storage, no distribution power limits, driving compromised during a few long wind lulls/year
- Equivalently, 3,250 MW capacity (100% of DE electricity) and 58% of fleet

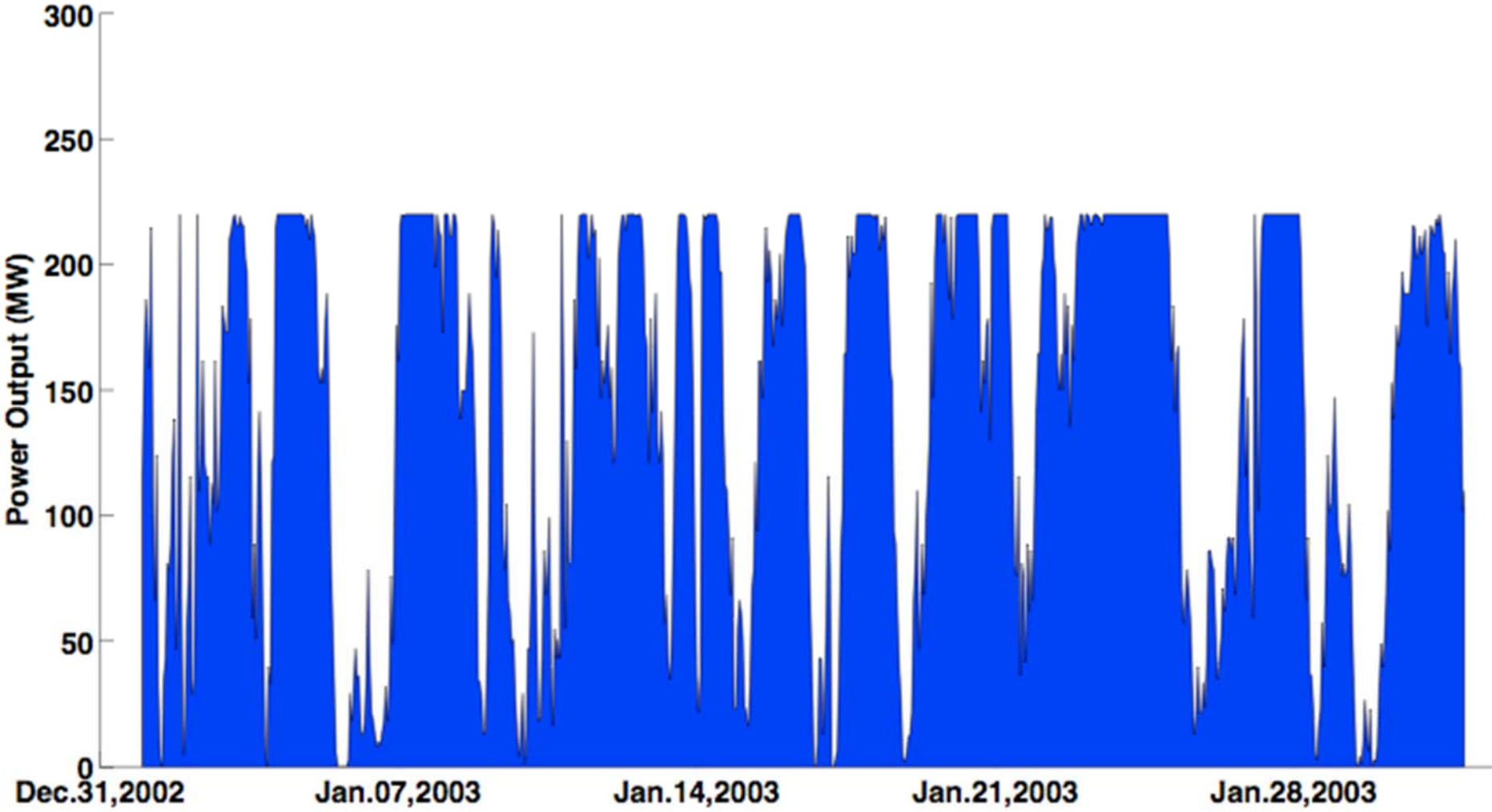
July Wind


300
250
200
150
100
50
0
Power Output (MW)
Jun.30,2003
Jul.07,2003
Jul.14,2003
Jul.21,2003
Jul.28,2003

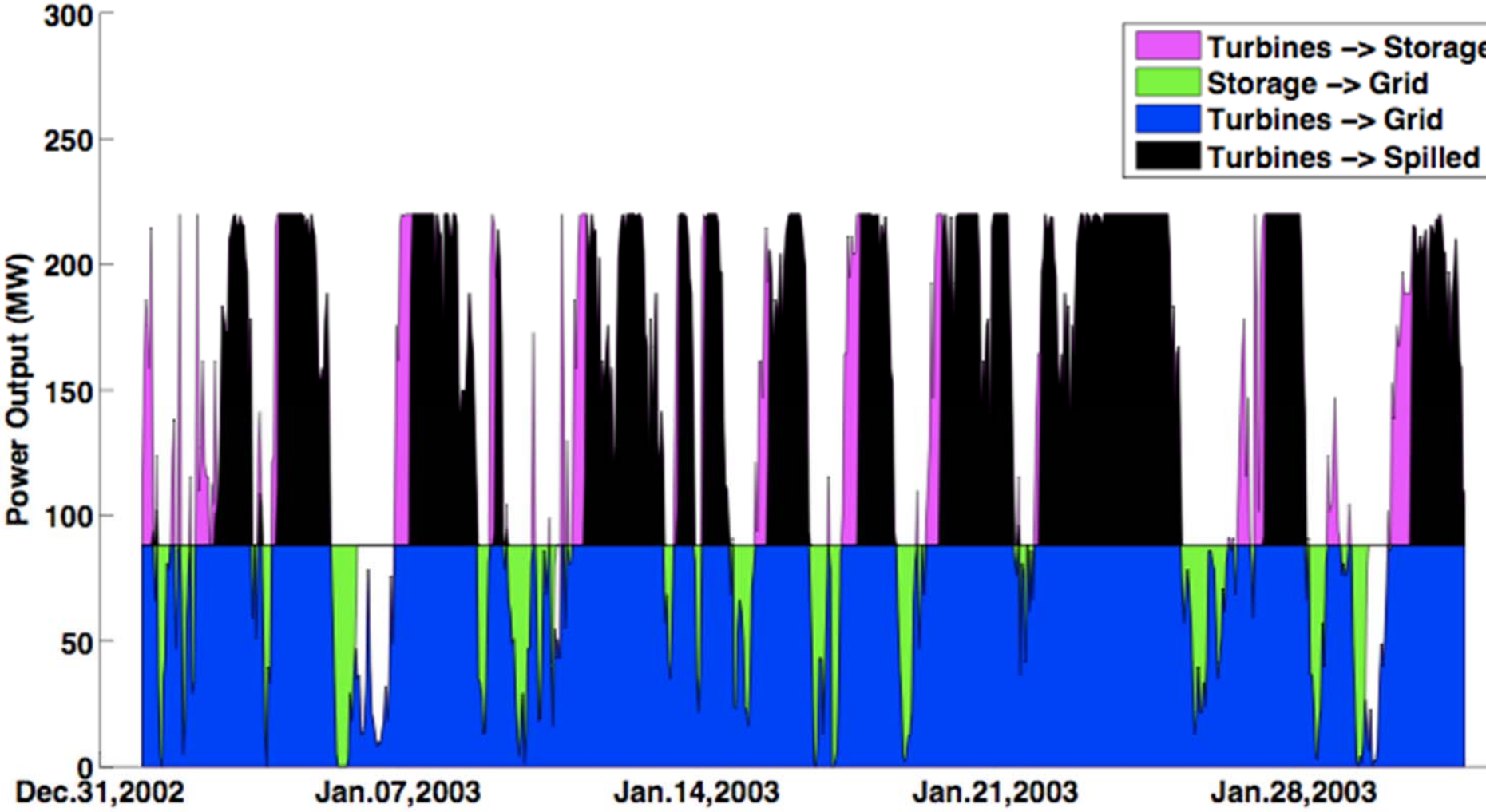
July wind + V2G



January Wind



January wind + V2G



V2G as wind leveling

- Good to reduce ramp rate, fill short gaps (up to 6 hours? one day?)
- Not suitable for multi-day wind lulls
  - Still need fossil or some other backup
  - Long term solutions, non-surface or intherent storage
- Half of fleet serves very roughly 100% electric -- needs model with load, etc

Next V2G Steps Underway

From car-as-generator to fleet as generator

- AGC signal to a server used by aggregator
- Server runs an agent-based coalition manager, dispatches individual vehicles
- Learning module on each vehicle learns pattern of use of that vehicle, predicts ability to dispatch
- Vehicle module acts reasonably when communication lost (e.g. night charge)

Experimental Fleet

Current Fleet

- AC Propulsion eBoxes (one in DE, one in CA)

- UD Fuel Cell Bus

Fleet expansion

- Need to dispatch > 2 vehicles
- To test aggregator, need multiple vehicles
- OEMs not building grid-oriented cars
- DOE award cost-share matched with 2 Delaware agencies + utility
  - Add 4 cars in state fleet, V2G dispatch
  - Test software on real vehicle use
- V2G market test: 300 cars (not yet funded)

Fleet expansion

Fleet expansion

Summary

- Large-scale CO2-free power fluctuates
- Now doing individual vehicle dispatch under AGC; simple model of wind fill-in
- Work underway
  - Software for aggregator & vehicle
  - Market research for V2G contracts
  - Dispatch on small fleet (~6 cars)
  - Fleet for A/S contract (~300)

END

More information:

www.carbonfree.udel.edu