

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

Deregulation Roundtable

Boston, MA

13 February 2009

Willett Kempton

Center for Carbon-free Power Integration

College of Marine and Earth Studies

University of Delaware

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

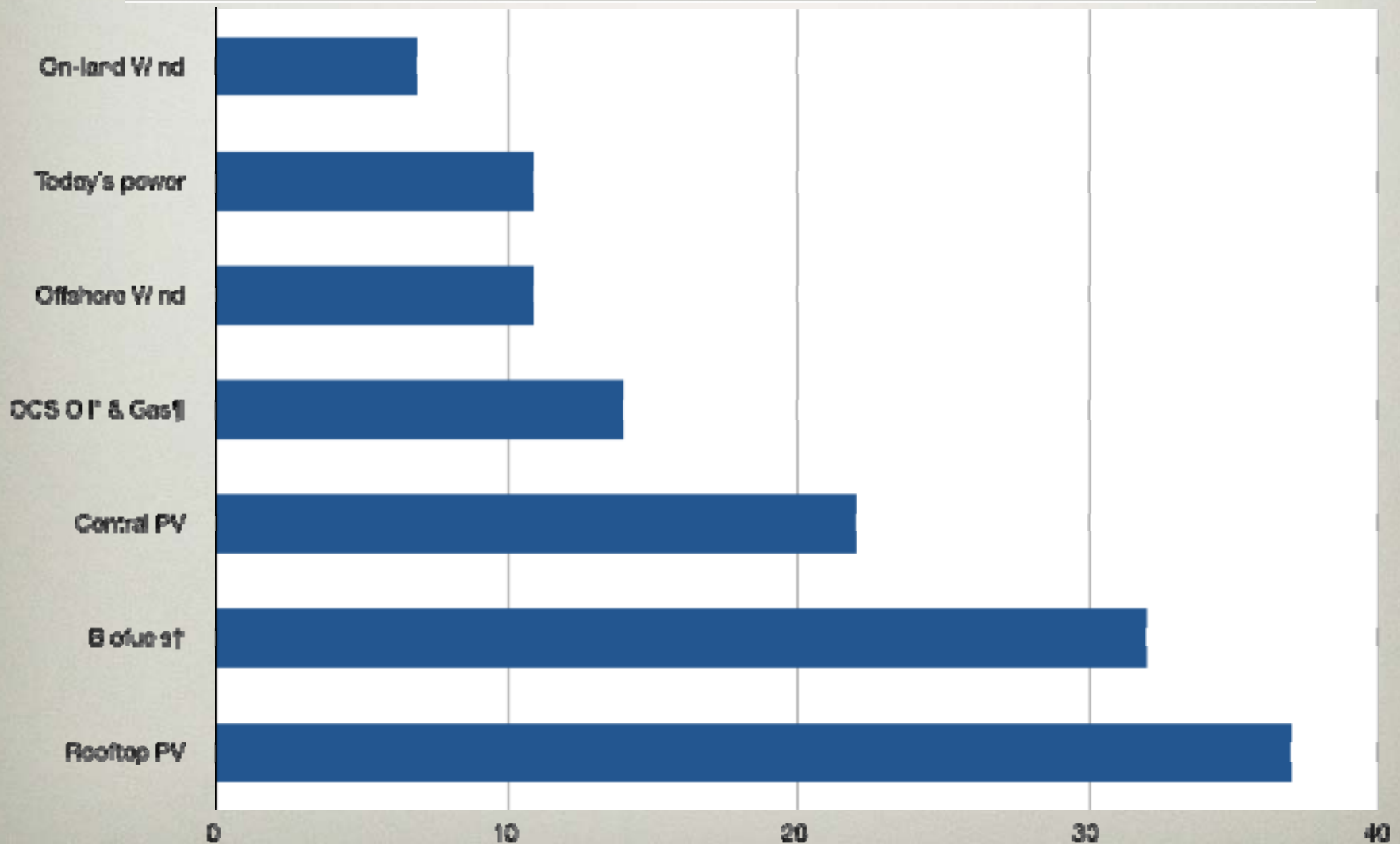
	Ratepayer ¢/kWh	Peak match	Capacity (MW)	Average output (MW _a)
Central PV	22	Good	369	59
Rooftop PV	37	Good	1,797	288
On-land Wind	7	Very poor	50?	15?
Offshore Wind	11	Poor	19,000	7,400
Biofuels [†]	32	Excellent	169+	169
OCS Oil* & Gas [¶]	14	Excellent	250+	250
Today's power	11	Excellent	3,283	1,300

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

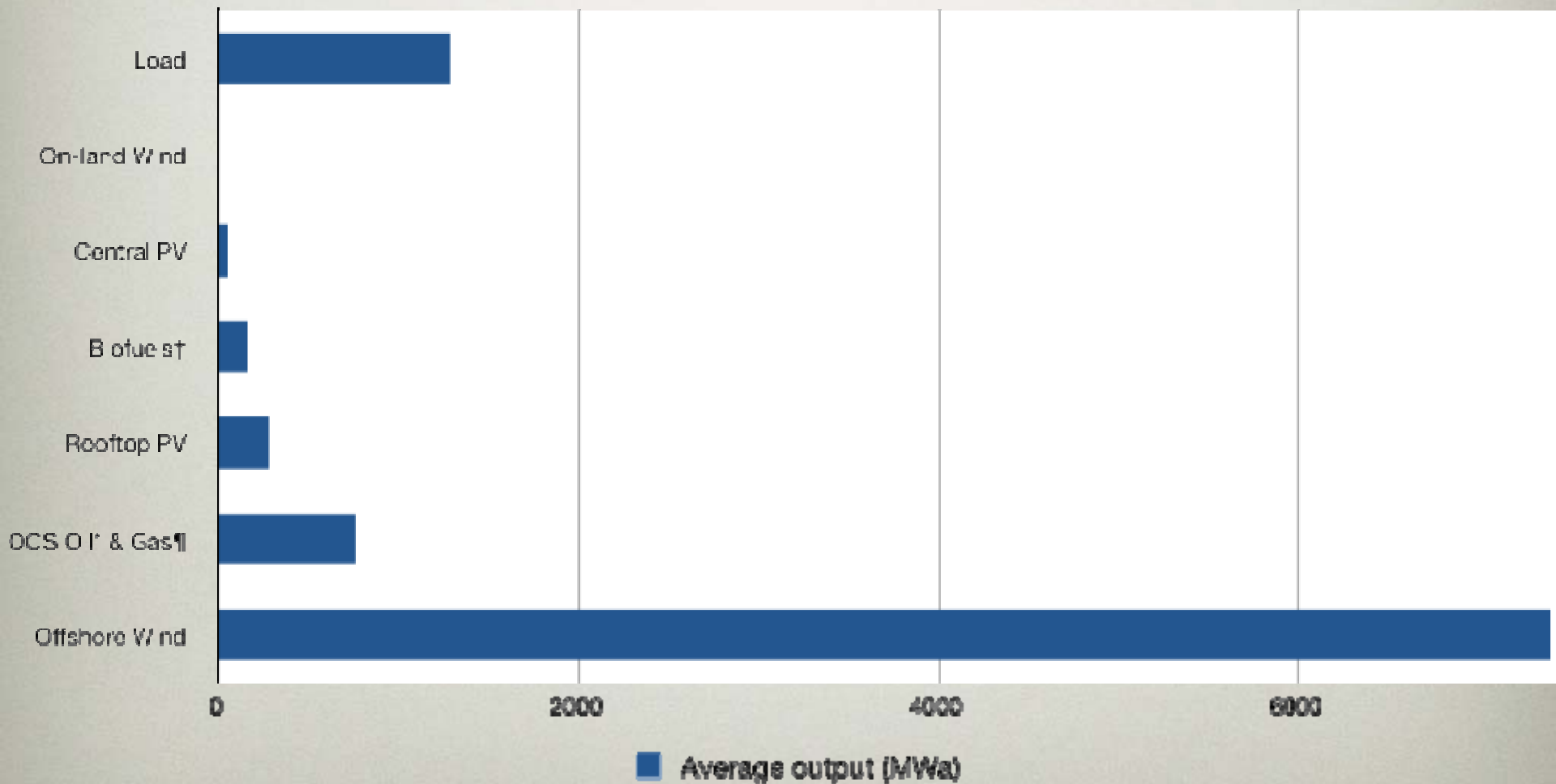
* DE is 1/73 of Atlantic OCS; assuming 20 year burn, 50% efficient conversion to electricity (250MW), \$2 gallon≈22¢/kWh.

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

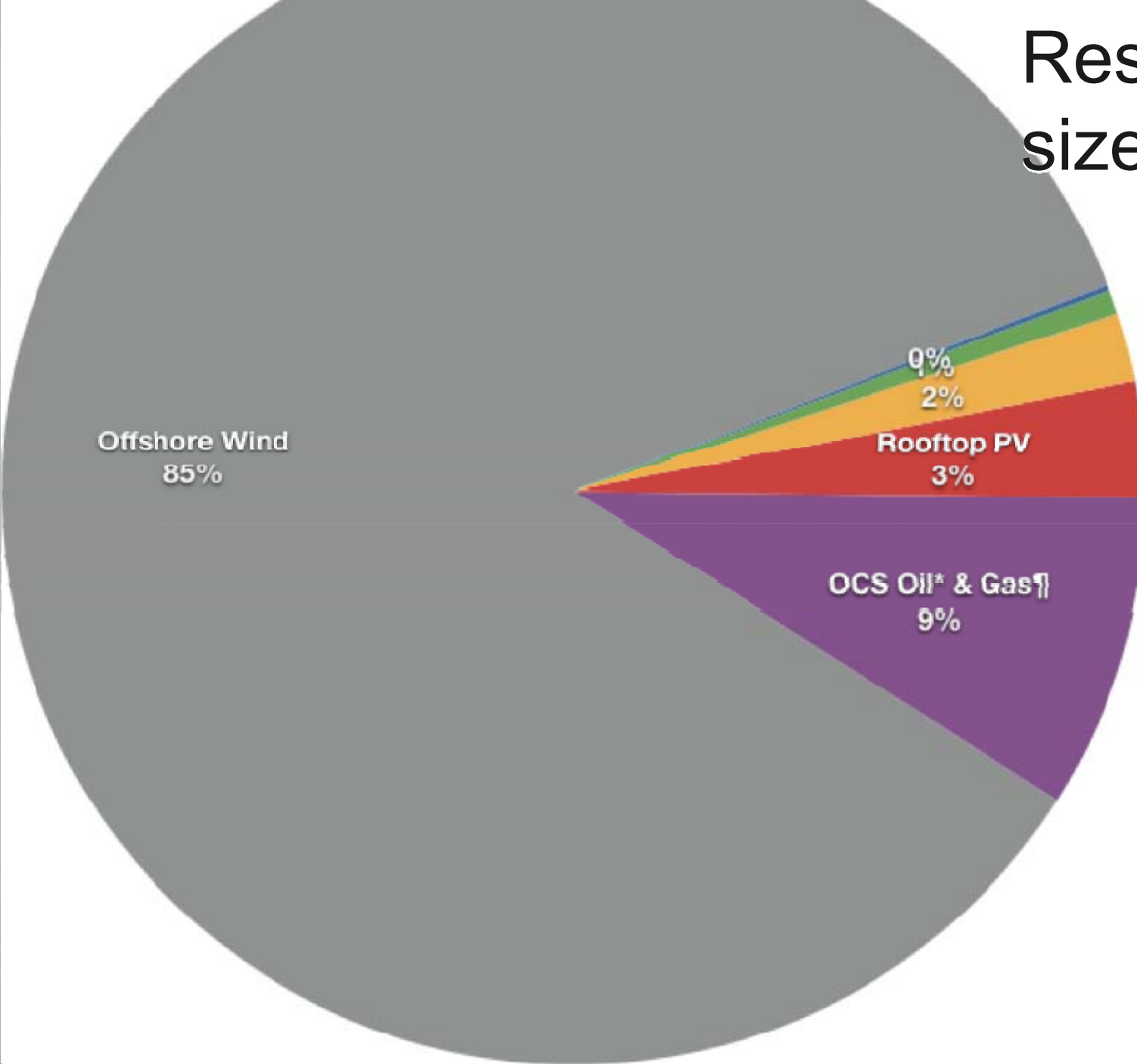
Ratepayer Cost



Resource Size



Resource size



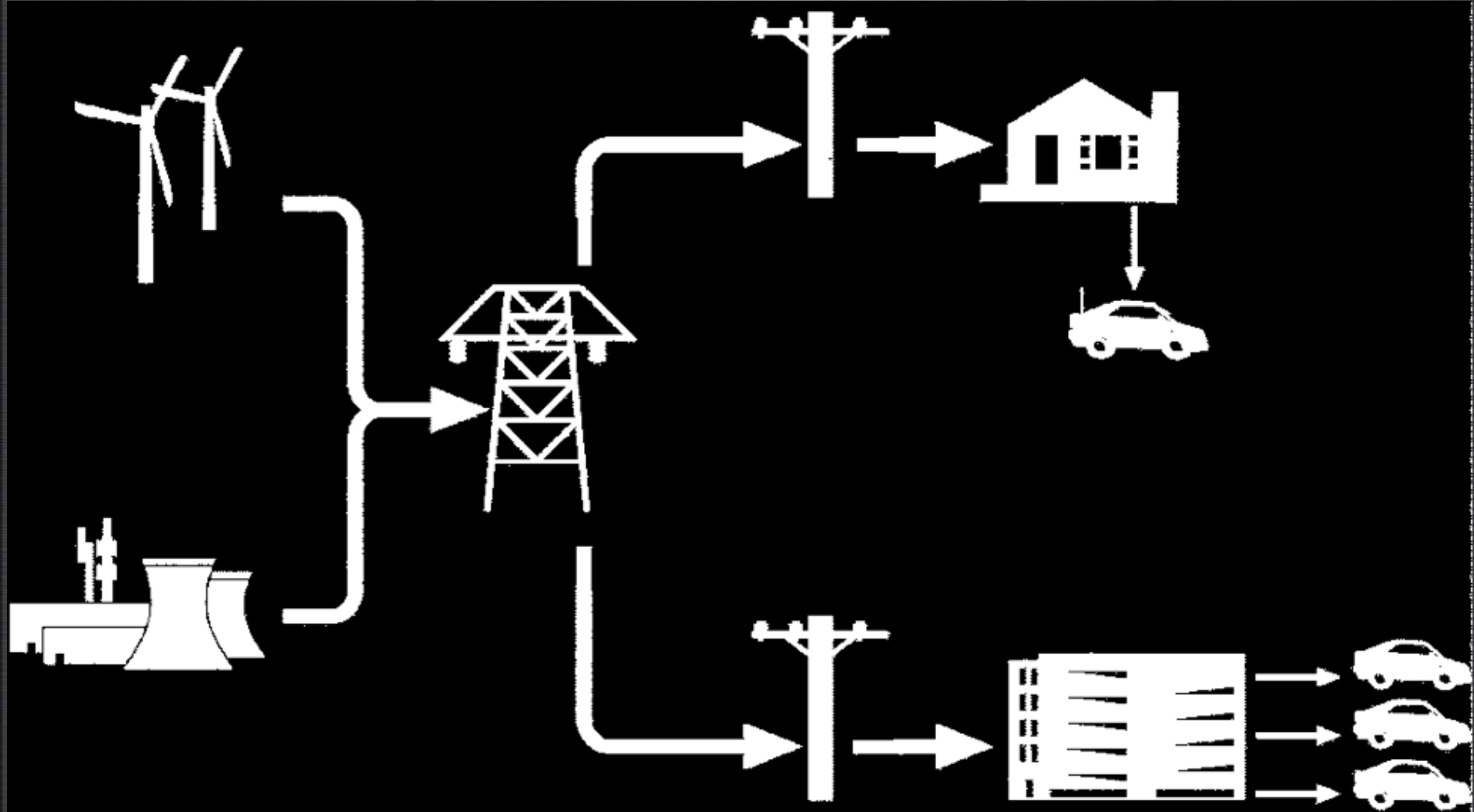
- On-land Wind
- Central PV
- Biofuels
- Rooftop PV
- OCS Oil & Gas
- Offshore Wind

Generalizations

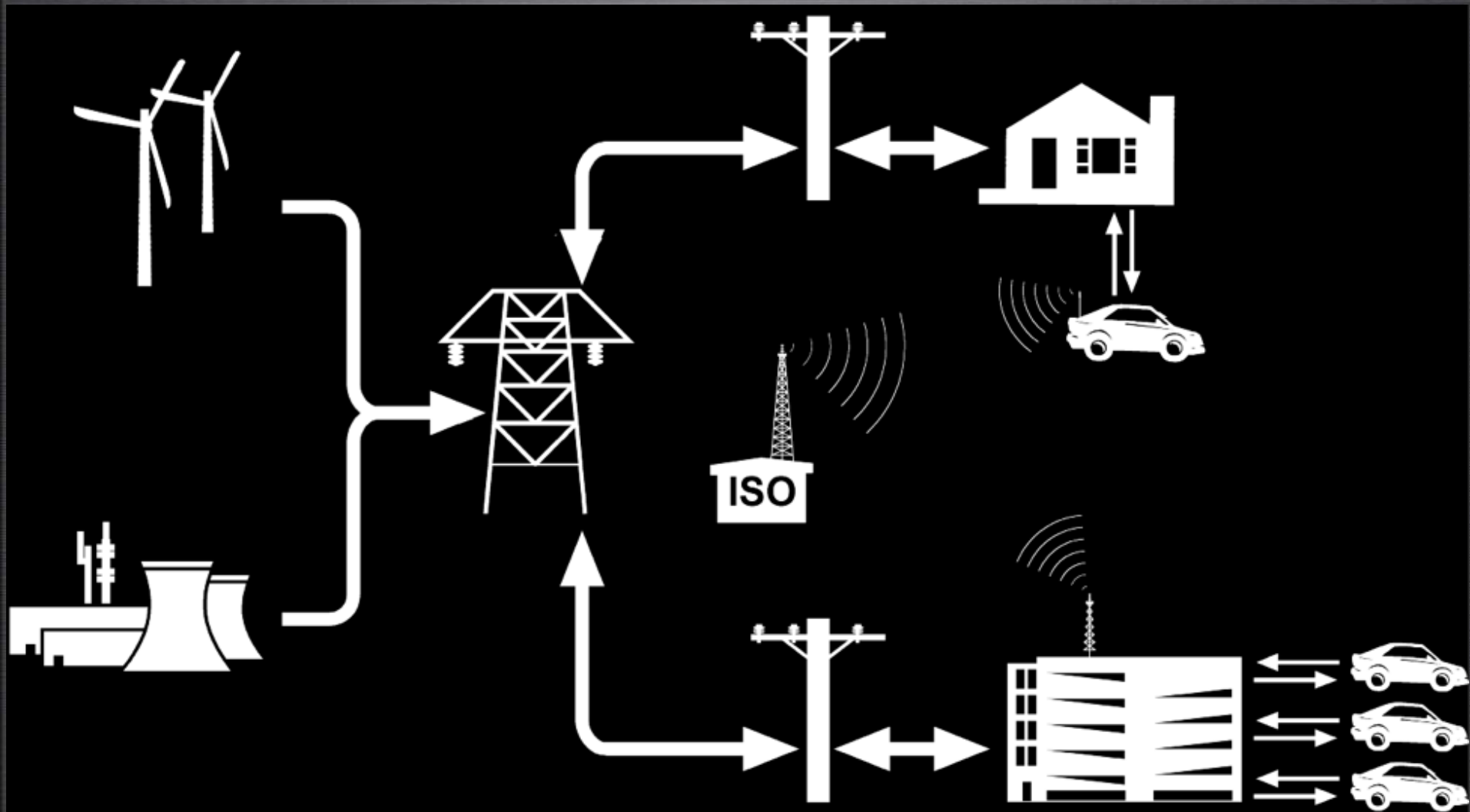
- The resources aren't equal size
- In our example, one is low cost, commercial now, and very large
- But, that one is the worst match to load, a problem at wind penetration $> \sim 20\%$
- So, a path to 80% reduction demands that we solve the wind integration problem

intro to vehicle-to-grid

Plug-in for charging



V2G with ISO Control



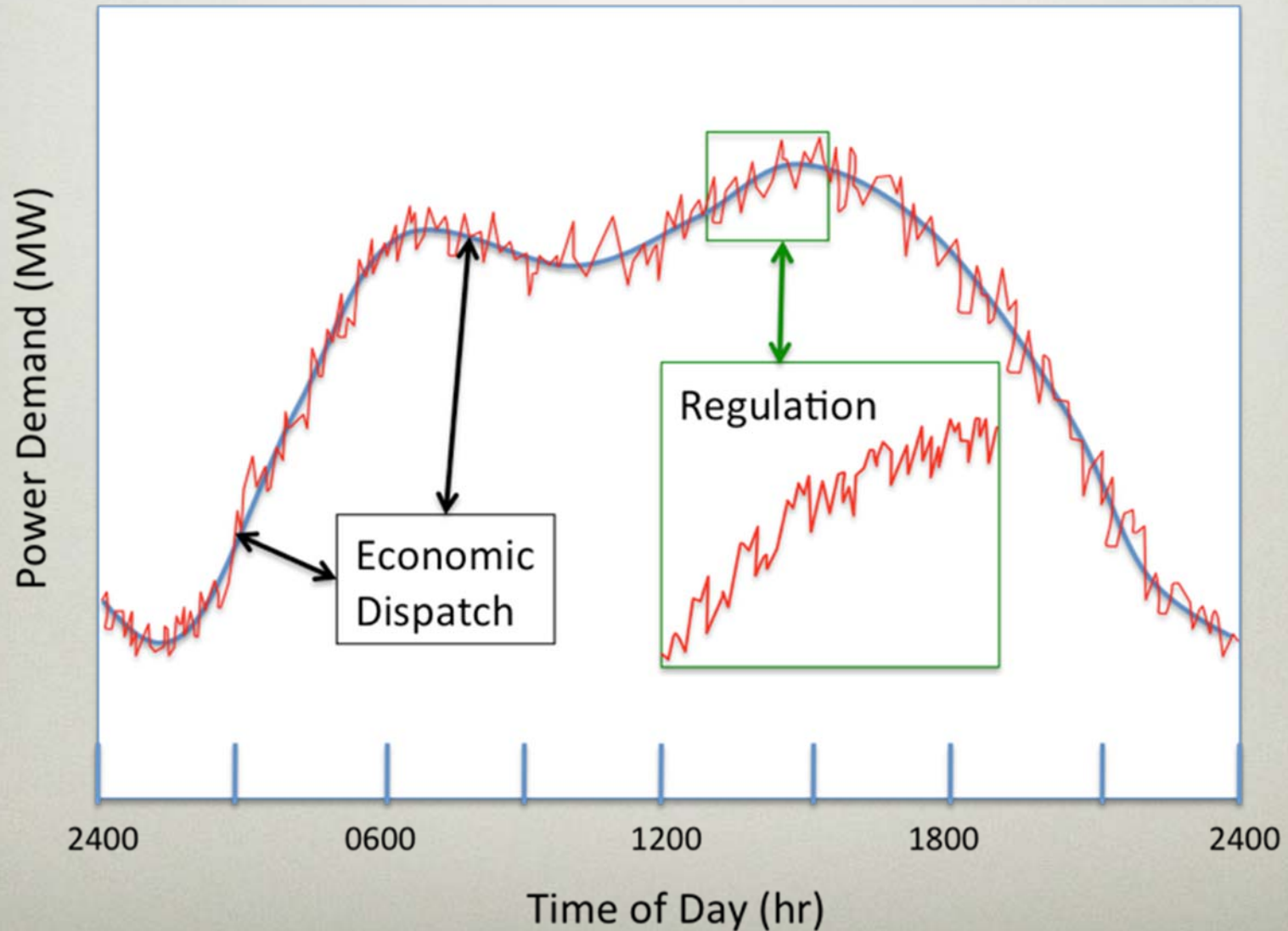
V2G taps an underutilized resource

- 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...

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

Energy Markets

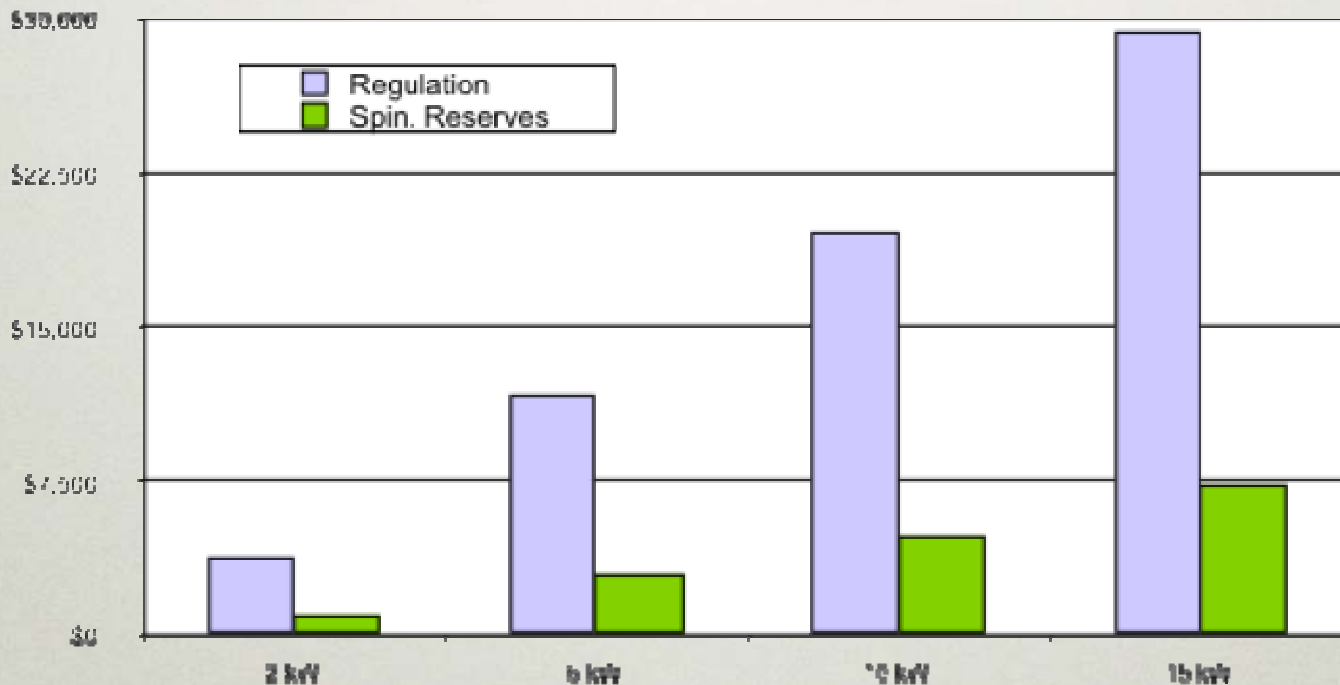


Value of regulation

	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



www.magicconsortium.org

AGC from ISO to Vehicle via PLC



Move ISO link to server



What the ISO sees

scs01awp - Terminal Server Client

Real Time

Spectrum PowerCC

Operations Generation Scheduling Transmission Forecast Energy Data Trading Simulation System Help 12-Oct-07 3:10:39 PM

E - AI 2 E - AI 3 G - AI 1 G - AI 2 W - AI 1 W - AI 2 Tools Displays Communications Logon Logoff Silence Audio Inhibit

<Realtime (RT)> - Runtime Explorer

File View Tools Help

SE_RTS_01 CFE View OPC View ICCP UI Marker Summary All Marker Types

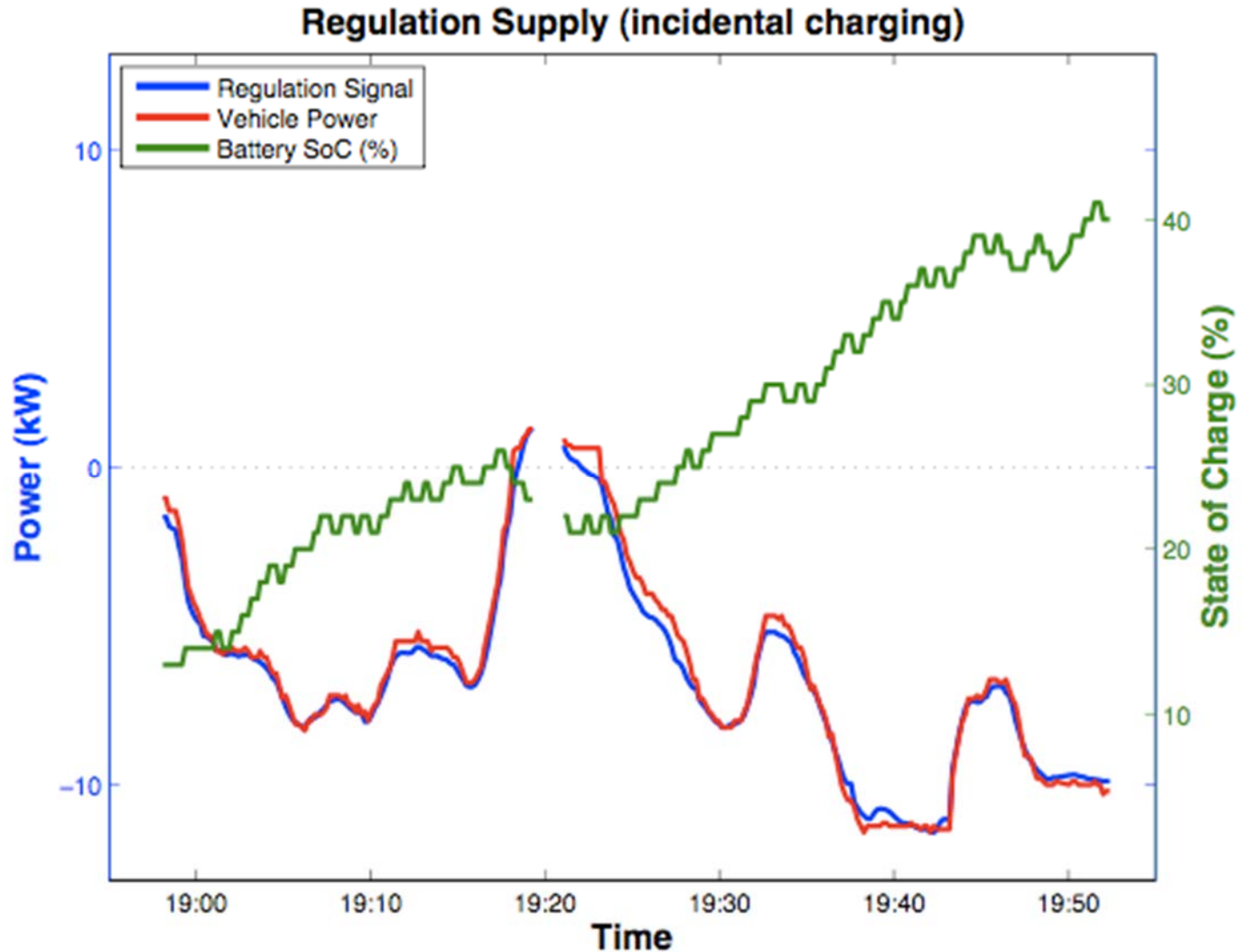
Substation View - Network/Substations/V2GCAR1

Name	Type	Value	Source/Quality
/BATTERY CHARGE STATE	AnalogMeasurement...	60	Telemetered
/COMMUNICATIONS	DigitalMeasurement	Normal	Calculated
/LINE AMPS	AnalogMeasurement...	12	Telemetered
/LINE CHARGE CAPACITY KILOWATTS	AnalogMeasurement...	4.8	Telemetered
/LINE CONNECTION STATUS	DigitalMeasurement	Connected	Telemetered
/LINE DISCHARGE CAPACITY KILOWATTS	AnalogMeasurement...	4.8	Telemetered
/LINE KILOWATTS	AnalogMeasurement...	-3.3	Telemetered
/LINE POWER FACTOR	AnalogMeasurement...	0.5	Telemetered
/LINE VOLTAGE	AnalogMeasurement...	240	Telemetered
/PJM REGULATION SIGNAL	AnalogMeasurement...	-496.0396	Calculated
/PJM REGULATION SIGNAL FEEDBACK	AnalogMeasurement...	-523	Telemetered
/PJM TOTAL REGULATION	AnalogMeasurement...	807.4	Calculated
/PJM TOTAL REGULATION FEEDBACK	AnalogMeasurement...	807.4	Telemetered

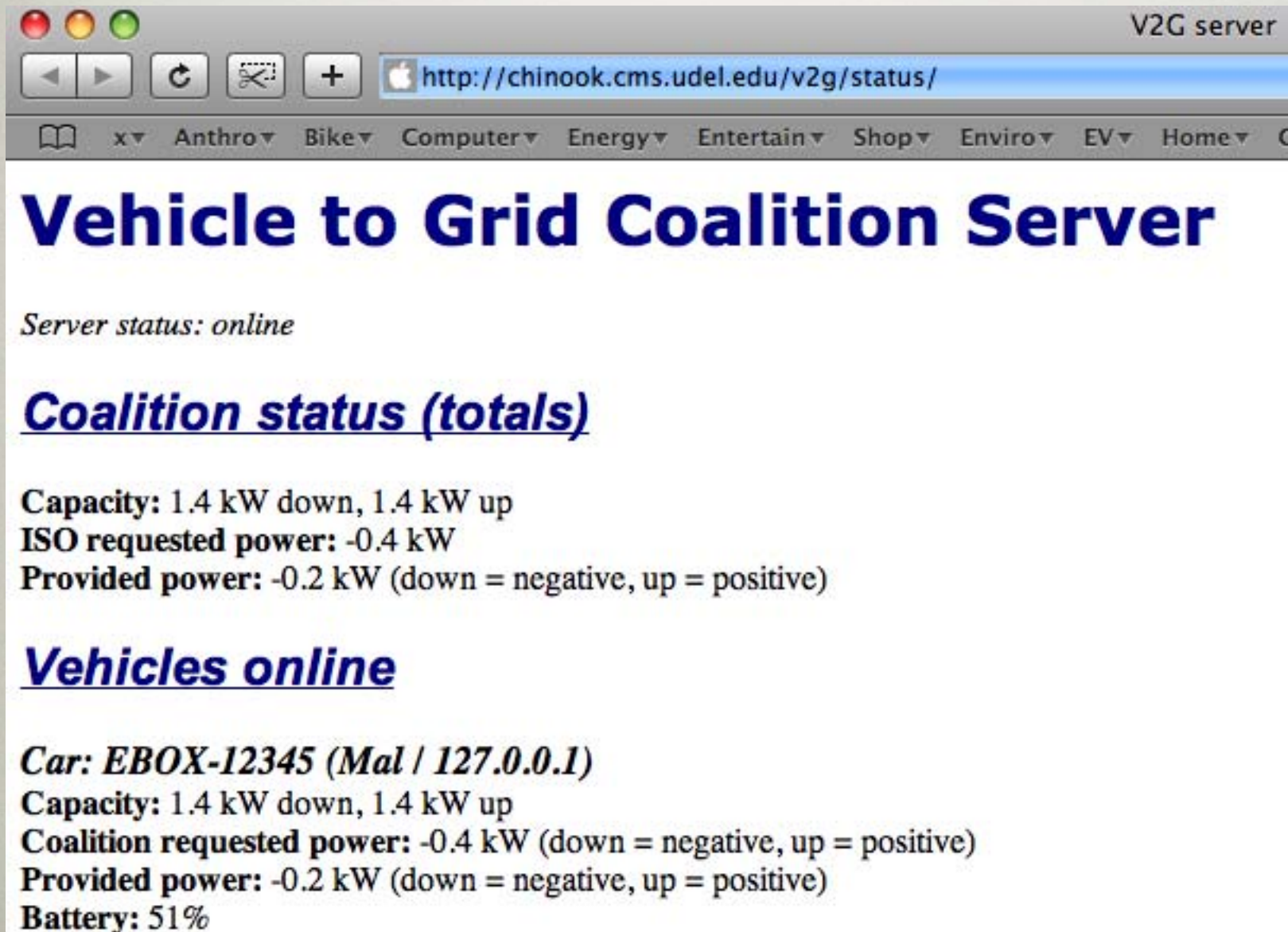
Substation View - Network/Substations/V2GCAR1

- Sub CFE CDC2 A
- Sub CFE D
- Sub CFE DNP30 A
- Sub CFE E
- Sub CFE F
- Sub CFE TG800 A
- Sub CFE TG800 B
- Sub CFE TG8979 A
- Sub CFE TG8979 A_Listen
- Sub D
- Sub E
- SUNBURY
- TEST_EXTERNAL_INTERNET_SUB
- TEST_INTERNAL_INTERNET_SUB
- TEST_PJMNET_SUB
- TEST_WIRELESS_INTERNET_SUB
- THOMPSCR
- V2GCAR1
- VAUGHN
- Warren
- WPSENERG
- Substations 20kV
- Substations DMS
- Substations LC
- PI
- _CFE Common

EVs providing regulation



V2G Aggregator



The image shows a screenshot of a web browser window. The title bar reads "V2G server". The address bar contains the URL "http://chinook.cms.udel.edu/v2g/status/". The browser's menu bar includes "x", "Anthro", "Bike", "Computer", "Energy", "Entertain", "Shop", "Enviro", "EV", and "Home". The main content area displays the following information:

Vehicle to Grid Coalition Server

Server status: online

Coalition status (totals)

Capacity: 1.4 kW down, 1.4 kW up
ISO requested power: -0.4 kW
Provided power: -0.2 kW (down = negative, up = positive)

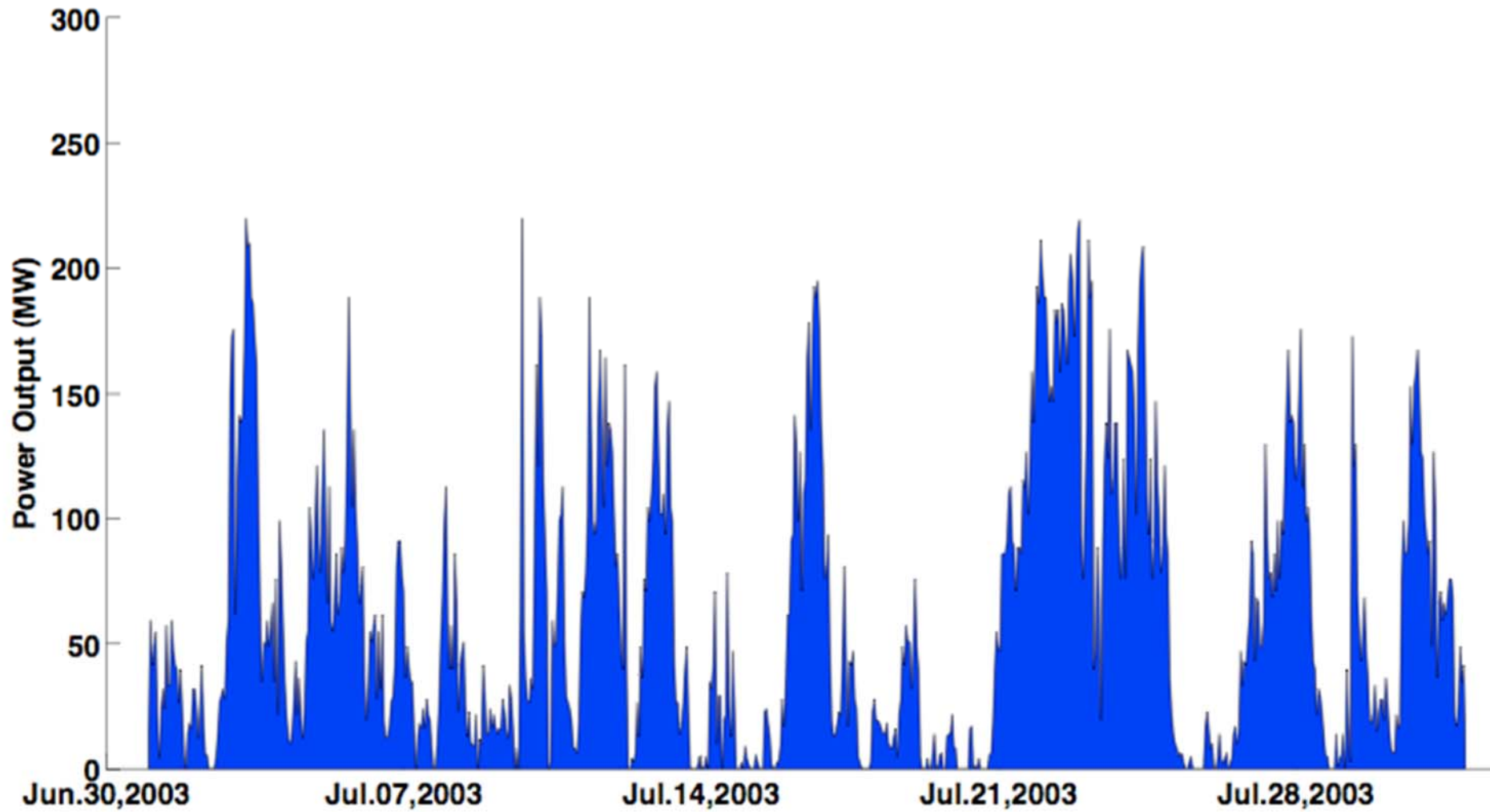
Vehicles online

Car: EBOX-12345 (Mal / 127.0.0.1)
Capacity: 1.4 kW down, 1.4 kW up
Coalition requested power: -0.4 kW (down = negative, up = positive)
Provided power: -0.2 kW (down = negative, up = positive)
Battery: 51%

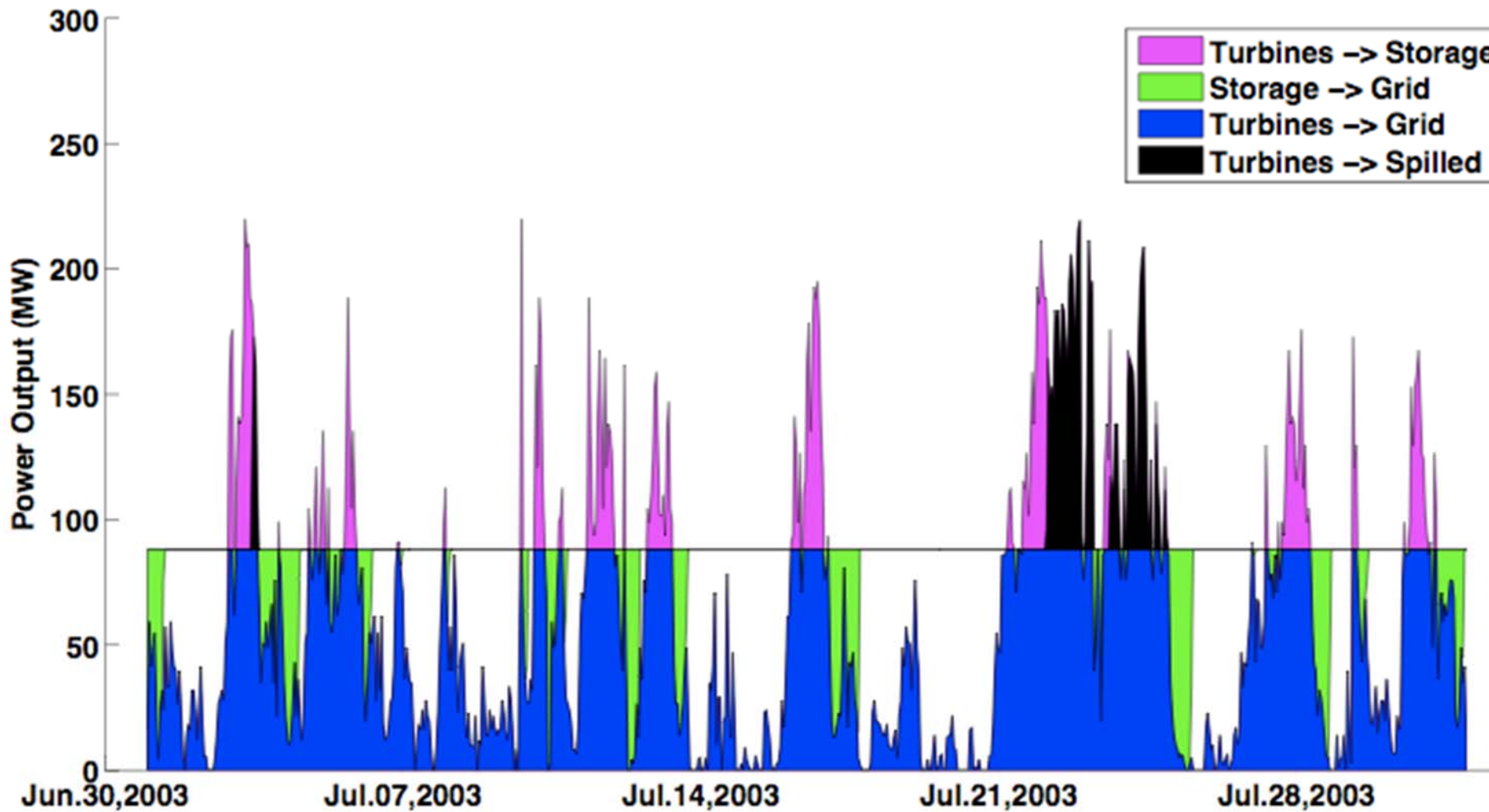
Simple model of V2G for wind leveling

- 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

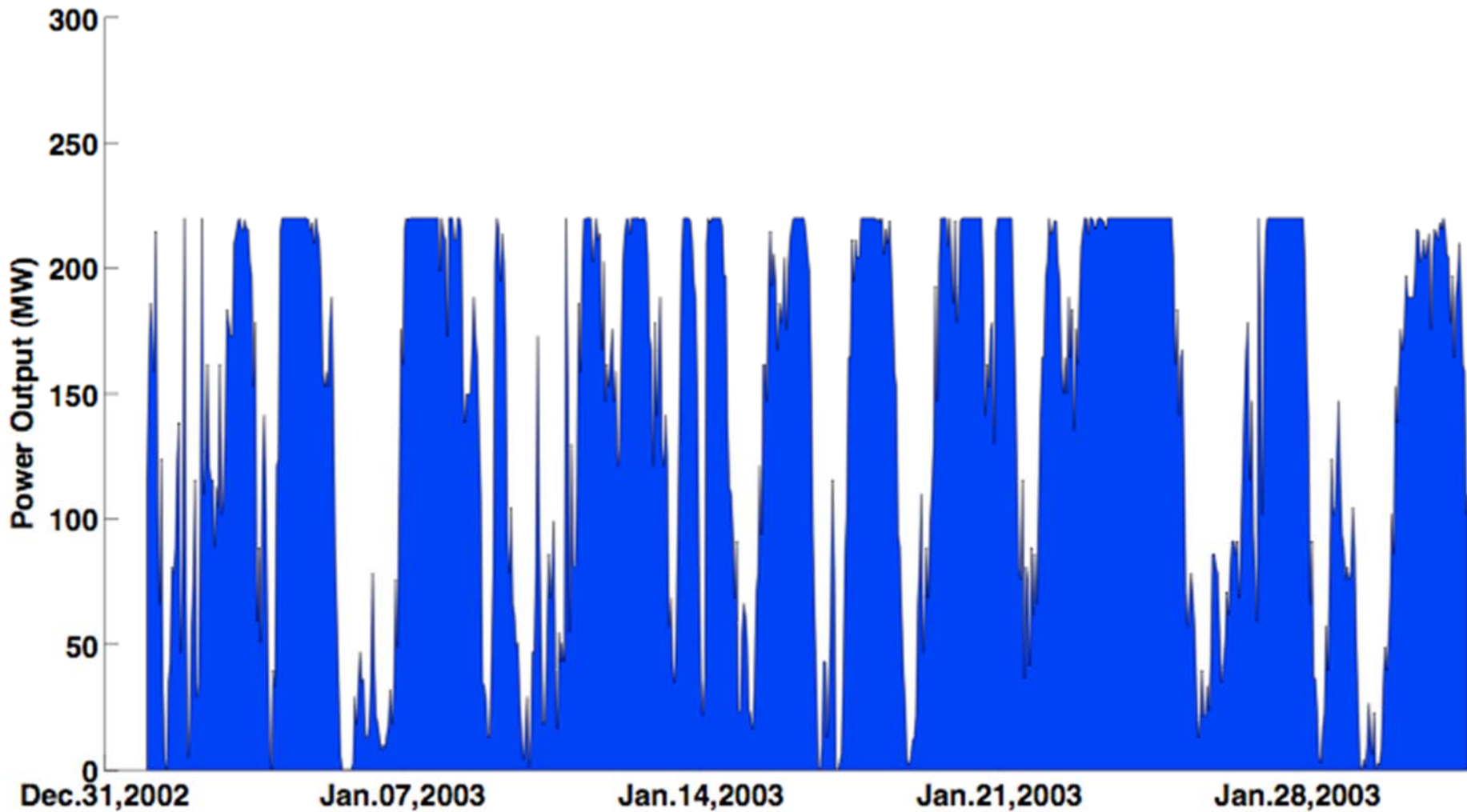
July Wind



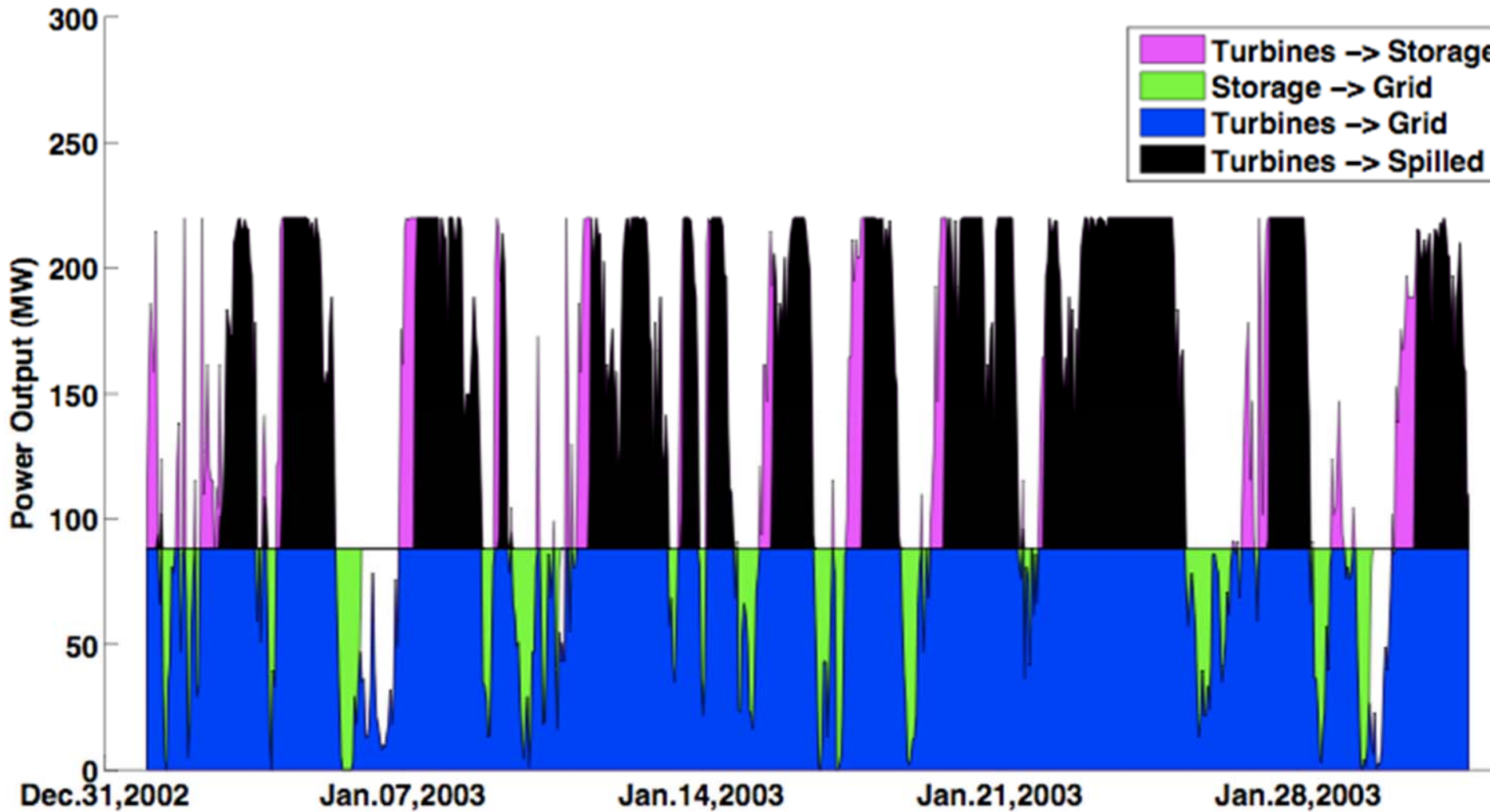
July wind + V2G



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 inherent 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