2010 Smart Grid Peer Review
Office of Electricity Delivery and Energy Reliability, DOE

Vehicle to Grid Demonstration Project

by
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Purpose & Objectives

- Create the **Grid Integrated Vehicle** (GIV), then operate, permit, and test it
- Analyze vehicle use, our vehicles & large data base of 400 vehicles daily driving
- Analyze market for EVs and V2G
- Develop software to dispatch power from vehicles -> Operate in real time!
- Two-year award, $750,000, close Nov '10

Activities (2-year)

- Research: Driving patterns; economic value; self-learning trip predictions
- Industrial: Facilitate EV retrofit operation
- Purchase vehicles for UD; leverage for State Govt. (five new vehicles total)
- Development: In-vehicle computer; EVSE (on-wall) information and channel; central capacity aggregation and dispatch
- Policy and law
- Tech transfer and licensing

Why do GIV and V2G make sense?

Basic GIV/V2G Math

- US car used 1 hour/ day, parked 23 h/ d
- Battery 100 mi, daily travel = 30 mi, thus
- Drive train output = 100 kW
  - Practical power via US grid = 10 - 20 kW
- Cars as significant power capacity?
  Compare:
  - US generation ~1000 GW, avg. load ~450 GW
  - US light vehicles: 200 million
  - At 15 kW/ vehicle: 3,000 GW
    - **Cars: 3x generation, 6x average load**

Applications Niche

- Storage at the low-voltage end of the distribution system
- 15 kW & 30 kWh means ~1 hr discharge thus capacity markets, not energy
- Second use of customer equipment, thus capital costs are controls
- Operating cost is payment to driver as incentive to stay plugged in, plus compensate any added battery wear

Capital Cost of Distributed Capacity and Storage

- Capital cost is on-board intelligence plus communications, now ~$400
- For example, an EV with 15 kW, 30 kWh
- Capacity cost: $27/ kW
- Storage cost: $13/ kWh

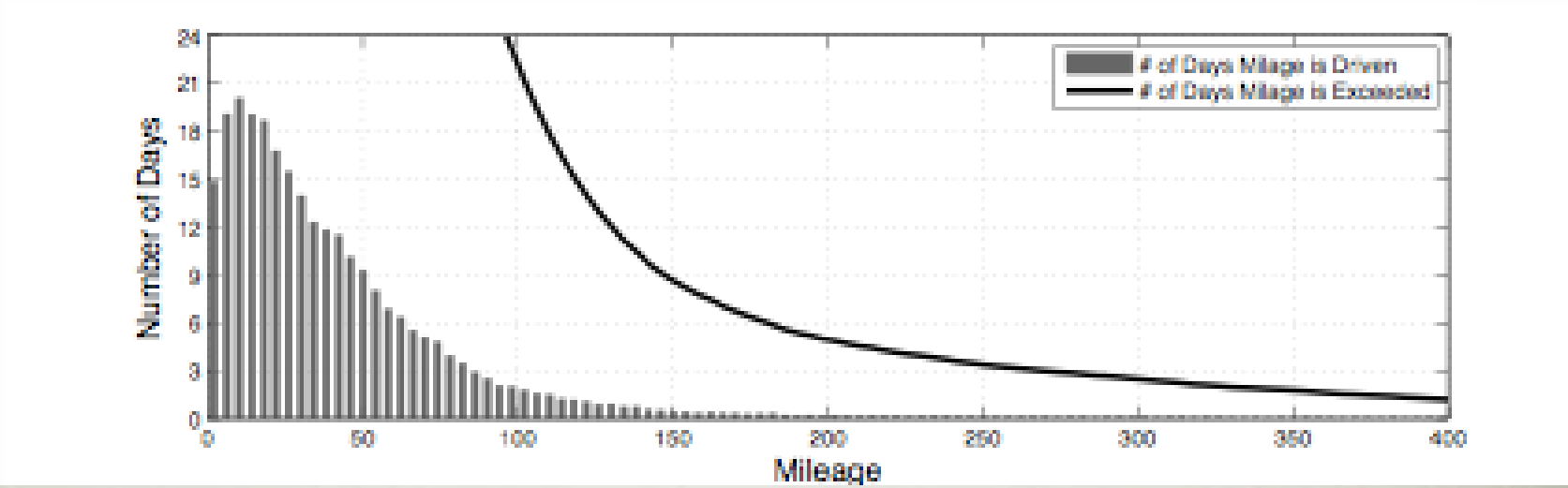
Analysis:
Driving patterns

Driving Patterns

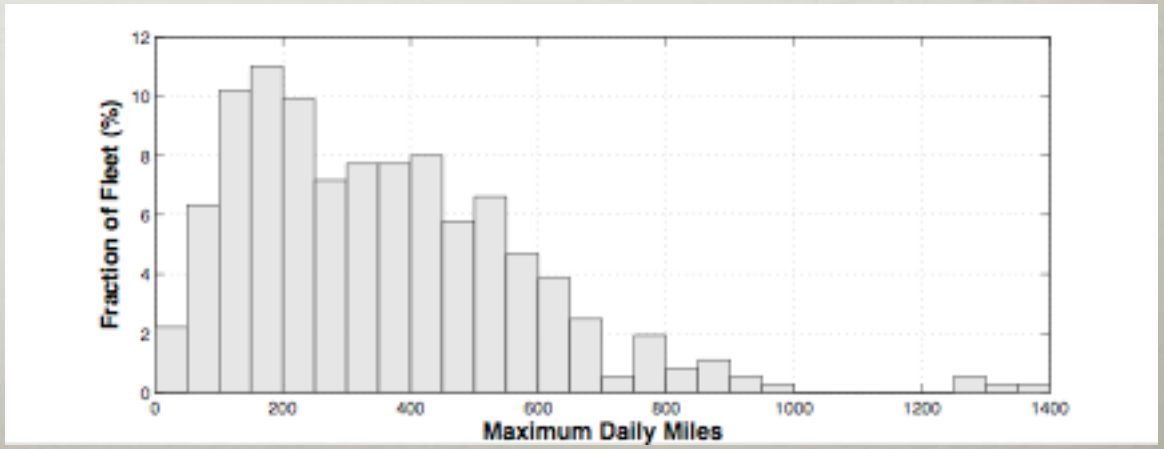
- Large vehicle data base analyzed
- 1 Hz-resolution, year-long, 400 vehicles
- Example results on following graphs
- Reference: Pearre, Kempton, Guensler, Elango, "Electric Vehicles: How Much Range is Required for a Day's Driving?" (Revised **manuscript**, submitted with revisions, Oct 2011)

Finding: A segment that doesn't drive far

Vast majority of driving is << 100 miles/ day



Longest trip of year: 8% *never* go > 100 miles/ day; 18% *never* > 150



Analysis:
Market for EVs

Analysis of market

- EV market: what is value of EV attributes needed for V2G and GIV?
- Survey of 3029 adult car buyers
- Contingent valuation, value of individual EV attributes: range, charging speed, V2G contract, etc, etc
- Segment into gasoline (GV) and electric vehicle (EV) classes, roughly 60% - 40%

Findings: Value of EV Attributes

WTP for range, relative to 75 miles range.

Range	GV-class	EV-class
75 mi	0	0
150 mi	$3,894	$7,349
200 mi	$5,723	$12,757
300 mi	$7,670	$17,748

Source: Hidrue, Parsons, Kempton & Gardner, "Willingness to pay for electric vehicles and for their attributes", U Delaware, **manuscript** submitted for publication, Nov 2010.

Findings: Value of EV Attributes

WTP for faster charge of 50 miles, relative to 10 hours.

Charge Time	GV-class	EV-class
10 hours	0	0
5 hours	$4,720	$971
1 hour	$5,900	$7,626
10 min.	$6,490	$11,093

Source: Hidrue, Parsons, Kempton & Gardner, "Willingness to pay for electric vehicles and for their attributes", U Delaware, manuscript submitted for publication, Nov 2010.

Implications for GIV/V2G

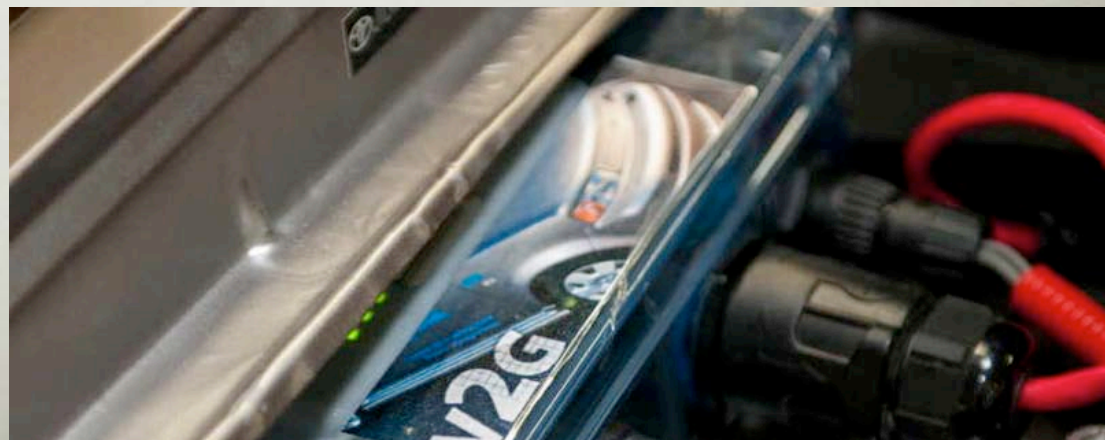
- Market for 100 mile range EVs -- today
- Drivers will want 10 - 20 kW charge rate, do-able with 40 - 80 amp 240 volt
- With ~15 kW charge, ancillary services can gross ~$3,000/ year in high value markets

Manufacturing

Production: EV with GIV

vehicles made with integrated GIV and V2G built in

Capacity: 5 - 1,000 per year



UD Developed GIV components

Three Components of GIV

- VSL: Vehicle Smart Link (in car)
  - Control charging, report to server
  - Knows or predicts next trips and times
- EVSE: Electric Vehicle Supply Equipment
  - Grid location, internet portal, power connection, interconnect permit
- Aggregation Server
  - Real time operation of a set of vehicles

Vehicle Smart Link (VSL)

Vehicle Smart link (VSL) in Car

- No moving parts, fits under dash; automotive grade
- Gets grid location and authorizations from EVSE
- Reports capacity to aggregator
- Attempt to predict next use of car (time, distance)
- Well-defined interfaces to OEM systems

EVSE

Design Criteria for EVSE

- Comply with SAE J1772
- Store on EVSE: Authorization, *grid* location (distribution transformer, feeder, etc)
- For backfeeding, need 100% reliable grid location
- Direct wire: car to EVSE (e.g. CAN or serial)
- Single utility visit, inspector puts an encrypted authorization in EVSE
- Also provide communications channel to internet

EVSE prototype now being field tested

EVSE prototype now being field tested

With EV simulator

Vehicle Aggregation Server

Design of Aggregator

- Provides a single, large, stable and reliable power source
- TSO does not see details of single cars, only sees aggregate
- Aggregator bids capacity in TSO market
- Dispatches dispatch requests to vehicles
- Reports actual power dispatched

Aggregator software manages complexity

- Insure each vehicle is has enough charge for next trip, then...
- Calculate how much remaining capacity to offer in the market
- Dispatch ISO/ TSO regulation service requests
- And other services ...


pjm
UNIVERSITY of DELAWARE
COM 1
COM 0
POWER
RUN
STAT
CHINOOK

Results: Aggregator

Vehicle to Grid -- Coalition Server
University of Delaware

Coalition Status

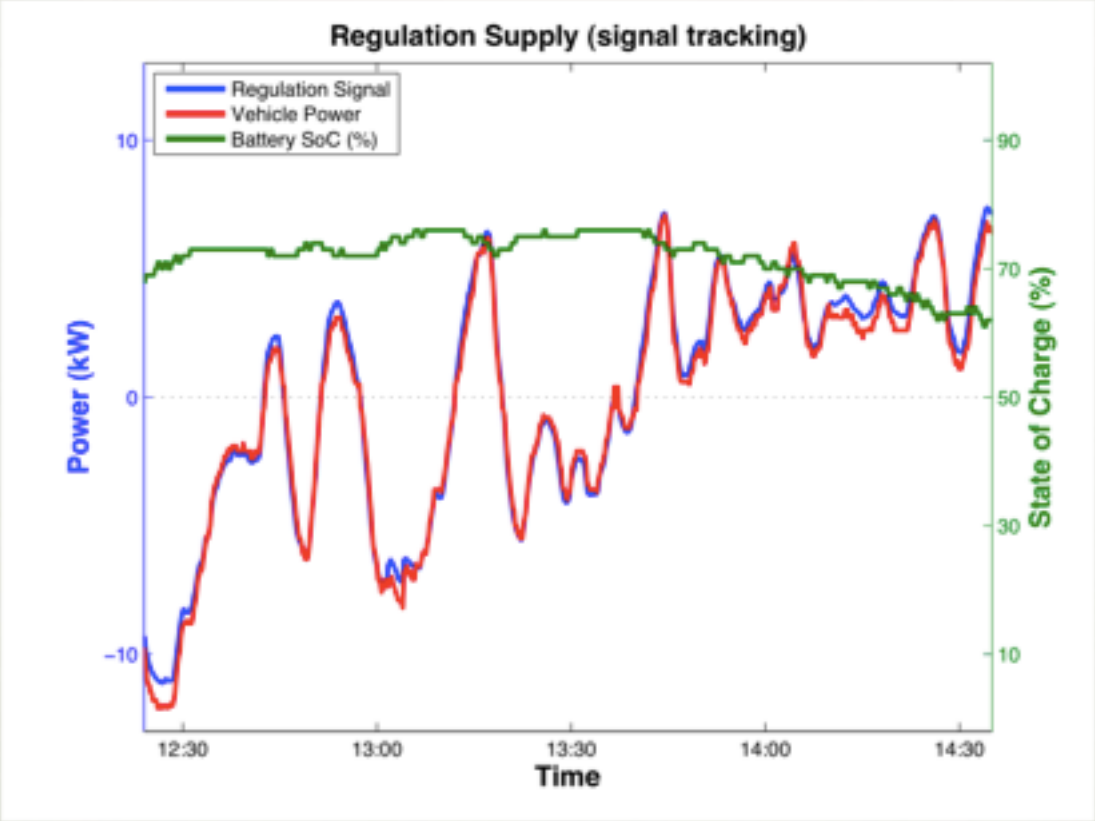
ISO	Power Capacity Up (kW)	Power Capacity Down (kW)	Power Requested (kW)	Power Provided (kW)	Energy Charge (kWh)	Energy Empty (kWh)	Number of Cars
PJM	49.37	49.37	-14.80	-15.81	104.30	35.70	4
CAL-ISO	0.00	0.00	0.00	0.00	0.00	0.00	0
Simulated-ISO	0.00	0.00	0.00	0.00	0.00	0.00	0

Hide Charts | CAL-ISO | Simulated-ISO | PJM

Individual Vehicle Status

Car Name	Power Capacity Up (kW)	Power Capacity Down (kW)	Power Requested (kW)	Power Provided (kW)	Energy Charge (kWh)	Energy Empty (kWh)	Miles	Volts (V)	Amps (A)	Monthly Credit ($)
UD-296	0.00	0.00	0.00	0.00	29.05	5.95	91.30	211	22.5	33.17
UD-170	11.23	11.23	-3.36	-3.95	12.60	22.40	39.60	234	16.9	76.31
DEState5205	10.70	10.70	-3.21	-2.05	33.25	1.75	104.50	214	9.6	21.73
DEState0000	17.36	17.36	-5.21	-5.70	31.50	3.50	99.00	248	23	24.59
UD-210	10.08	10.08	-3.02	-4.09	26.95	8.05	84.70	210	19.5	23.38

Results: Very fast response



- Power response is very close to command signal.
- Far higher fidelity than any rotating equipment.

Interconnect Policy

Permitted by Load-Serving Entity (local utility)

City of Newark Generator Interconnection Application -Short Form

(For Use with Generators 25 kW or Less)

An applicant (Generator Owner) makes application to the City of Newark to install and operate a generating facility of 25kW or less interconnected with the City of Newark utility system.

Section 1. Applicant Information

Name: UNIV OF DELAWARE

Mailing Address: 222 S. CHAPEL

City: NEWARK State: DE Zip Code: 19716

Facility Location (if different from above): 401 Wyoming Rd

Telephone (Daytime): Area Code 302 Number 831-4907 (Evening) Area Code 302 Number 893-2148

City of Newark Electric Account No.: 08000002497-00 Pole Number: _____

Section 2. Generator Technical Information

NEM – Net Energy Metering

Is Generator powered from a Renewable NEM Qualifying Energy Source: [X] Yes [ ] No

Type NEM Qualifying Energy Source (if applicable): [ ] Solar [ ] Wind [ ] Hydro [X] Electric Vehicle

Generator (or solar collector) Manufacturer, Model Name & Number: AC Propulsion eBox (Battery System) Output Power Rating in kW: 120 kW

Inverter Manufacturer, Model Name & Number (if used): AC Propulsion AC-150 Rating in kW: 19.2 kW

NEWARK DELAWARE

delmarva power

Permitted by Load-Serving Entity (local utility)

Will a generator disconnect device, accessible to the City of Newark, be installed?: ☐ Yes ☒ No

If the Generator Owner elects not to install a manual disconnect device accessible to the City of Newark, the Generator Owner assumes all risks and consequences when a service meter must be "pulled" to disconnect the generator thereby also interrupting all utility electric service to the Customer site.

Will an automatic transfer switch be used? ☐ Yes ☒ No

Supply specifications for the transfer switch showing UL listing and "Break before Make" contacts.

Section 3, Generator/Equipment Certification

~~Generating systems that use utilize inverter technology must be compliant with IEEE 929 and Underwriters Lab. UL 1741.~~ **By signing below, the Applicant certifies that the installed generating equipment meets the appropriate preceding requirement(s) and can supply documentation that confirms compliance.** *

Signed (Applicant): _____ Date: 1/8/09

* Documentation has been provided to the City certifying that the AL-150 inverter meets IEEE 1547 standards.

"meets IEEE 1547 standards"

Law to codify interconnects, net metering for V2G

SPONSOR: Sen. Simpson & Rep. Kowalko
Sen. McDowell; Rep. Hocker

DELAWARE STATE SENATE
145th GENERAL ASSEMBLY

SENATE BILL NO. 153

AN ACT TO AMEND TITLE 26 OF THE DELAWARE CODE RELATING TO CUSTOMER SITED ENERGY RESOURCES.

BE IT ENACTED BY THE GENERAL ASSEMBLY OF THE STATE OF DELAWARE (Two-thirds of all members elected to each house thereof concurring therein):

Section 1. Amend §1001, Title 26 of the Delaware Code by adding two new definitions reading as follows, and renumbering existing definitions alphabetically.

"(1) 'Aggregator' means any person or entity who contracts with an electric distribution company, electric supplier or PJM Interconnection (or its successor) to provide energy services, which facilitate battery storage systems for grid-integrated electric vehicles and related technologies.

(14) 'Grid-Integrated Electric Vehicle' means a battery-run motor vehicle that has the ability for two-way power flow between the vehicle and the electric grid and the communications hardware and software that allow for the external control of battery charging and discharging by an electric distribution company, electric supplier, PJM Interconnection, or an aggregator."

Define:

Aggregator

Grid-integrated electric vehicle

law to codify interconnects

Section 2. Amend §1014, Title 26 of the Delaware Code by adding a new subsection to read as follows:

(g) A retail electric customer having on its premises one or more grid-integrated electric vehicles shall be credited in kilowatt-hours (kWh) for energy discharged to the grid from the vehicle's battery at the same kWh rate that customer pays to charge the battery from the grid, as defined in (e)(1) of this section. For electric customers with time of use rates, the kWh rate for charging and discharging shall be the rate in effect when charging or discharging occurs. Excess kWh credits shall be handled in the same manner as net metering as described in (e)(1) of this section. To qualify under this subsection, the grid-integrated electric vehicle must meet the requirements in (d)(1)a., (d)(1)b. and (d)(4) of this section. Connection and metering of grid integrated vehicles shall be subject to the rules and regulations found in (e)(2), (e)(3), and (e)(4) of this section.

Net metering for V2G

Net is at rate at time of use

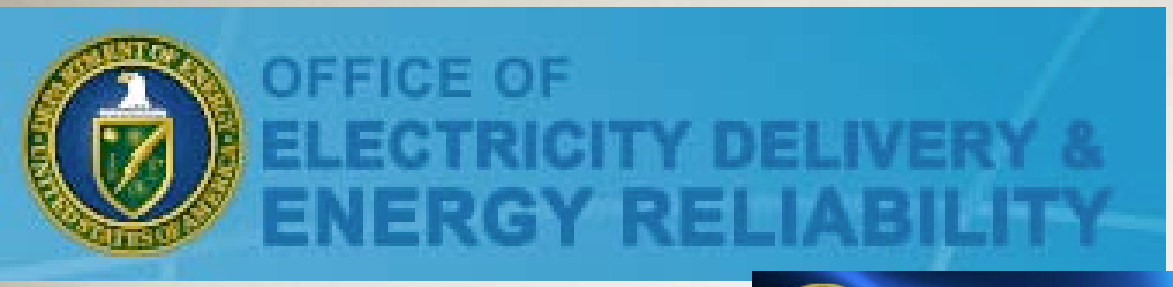
Interconnection requirements, etc same as distributed renewables

Patents

Patents

- Patent Applications, 2007-2010:
  - U.S. Patent Application Publication Nos. 2007/ 0282495 A1 "System and Method for Assessing Vehicle-to-Grid (V2G) Integration" filed May 2007 (UD; Kempton and Tomic)
  - U.S. Patent application publication No. "Hierarchical Priority and Control Algorithms for the Grid-Integrated Vehicle", filed March 2009, (UD; Kempton)
  - Three US and PCT applications in 2010, Electric Vehicle Station Equipment for Grid-Integrated Vehicles; Electric Vehicle Equipment for Grid-Integrated Vehicles; Aggregator Server for Grid-Integrated Vehicles. Filed Sept 2010 (UD; Kempton and co-inventors)
- One signed license for VSL, in license negotiations for EVSE and for aggregator

Thanks to our sponsors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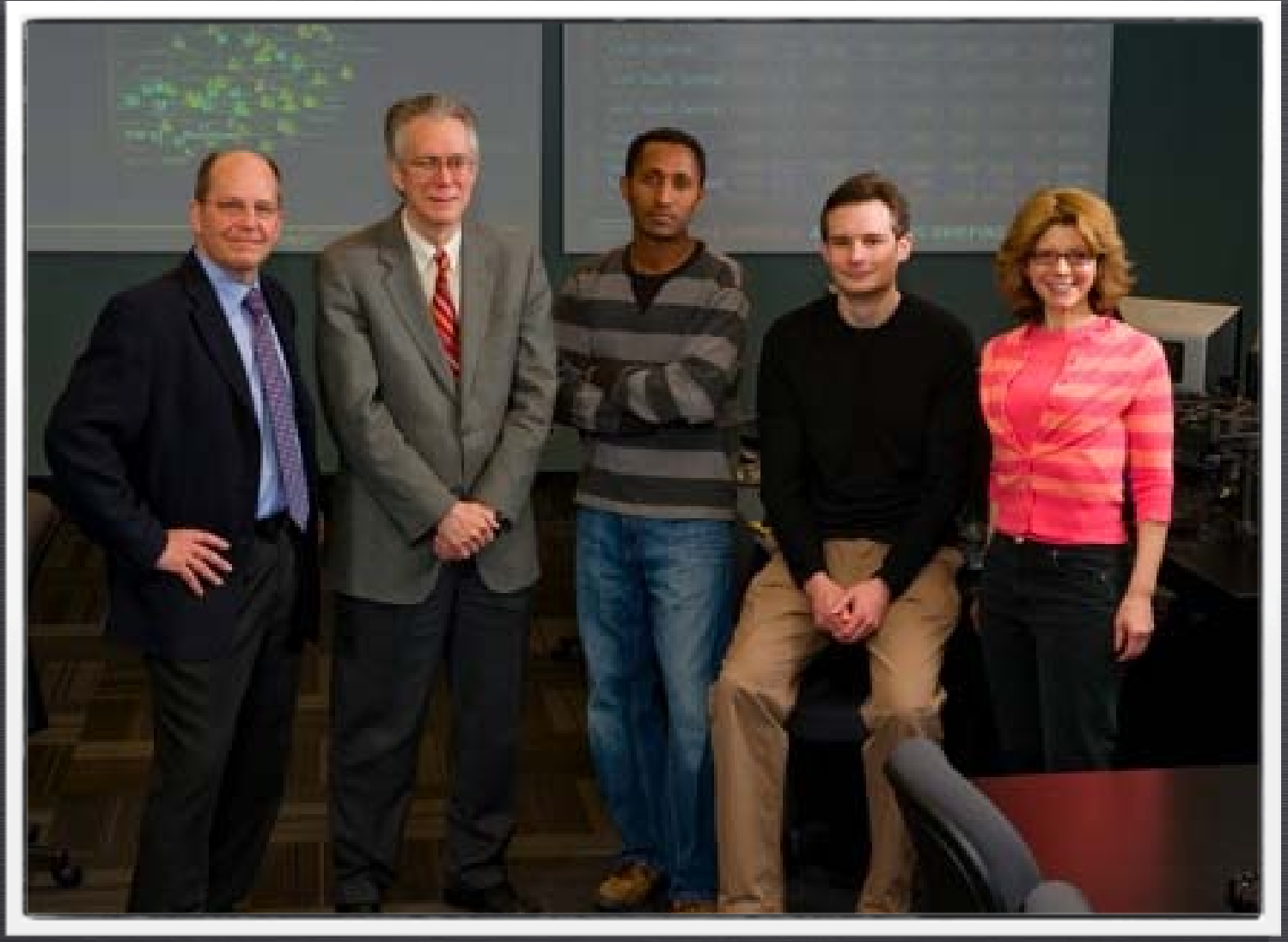
AIR RESOURCES BOARD

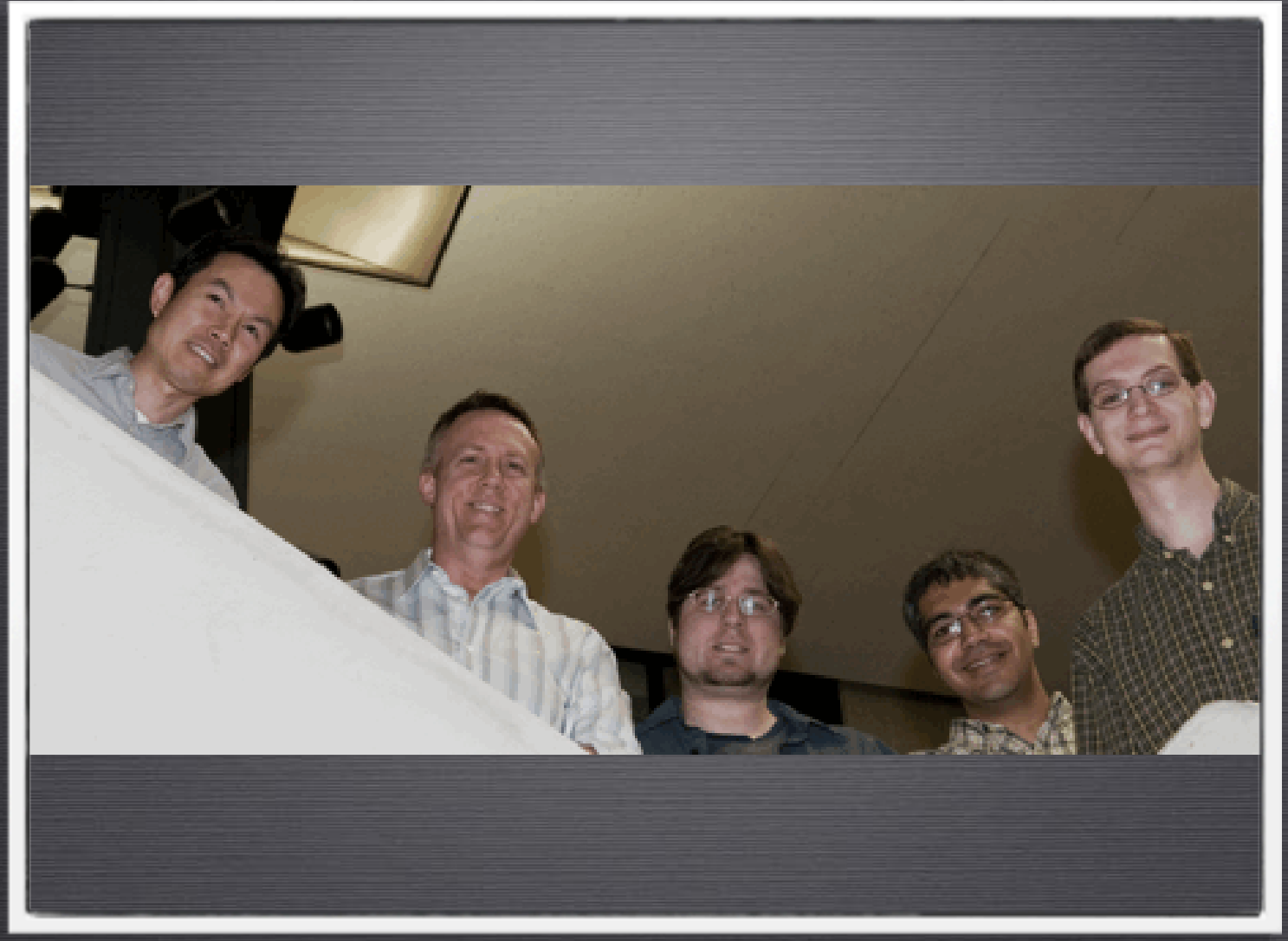
Thanks to the UD Teams that did all this

Policy, Partnerships, System Analysis

Electrical Engineering



Economics and Marketing



Computer & Information Systems

END

More information:

www.udel.edu/V2G

www.magicconsortium.org