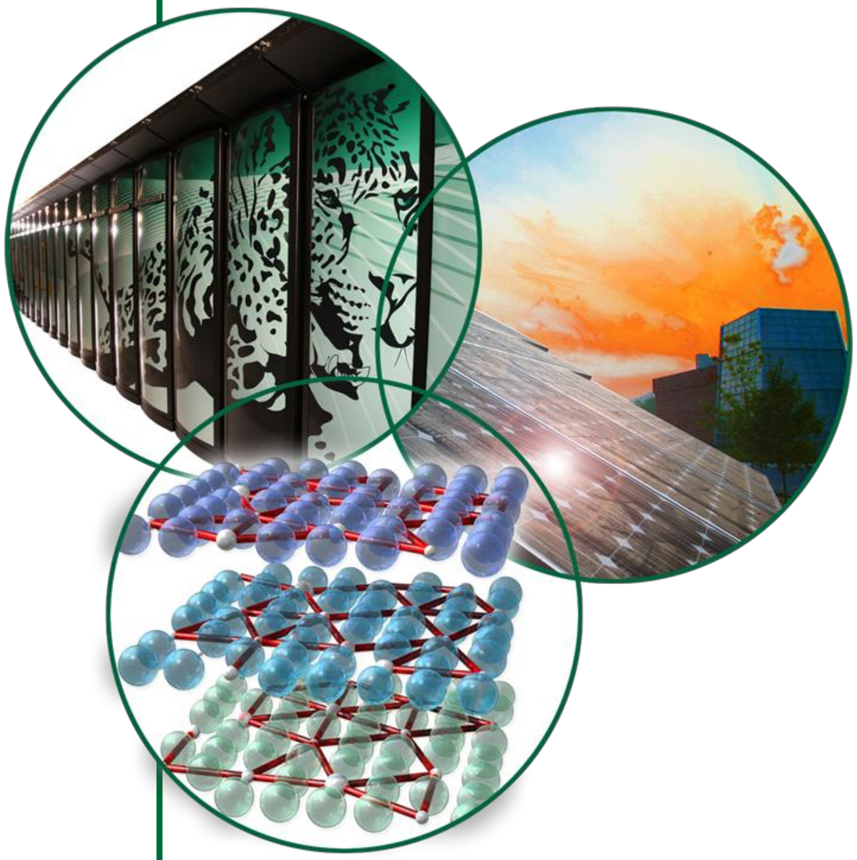
http://secleanenergy.gatech.edu/files/King.pdf

Electrification of Transportation and the Impacts on the Electric Grid

Clean Energy Speaker Series



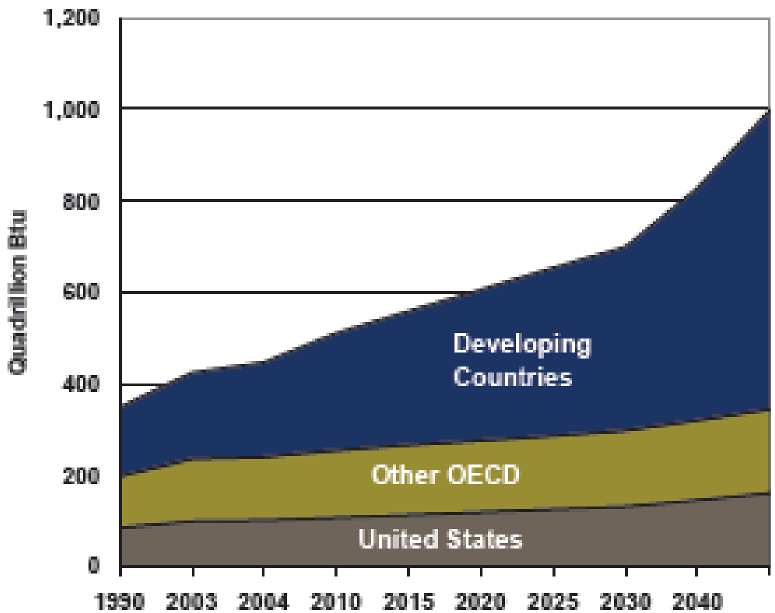
Tom King

Oak Ridge National Laboratory

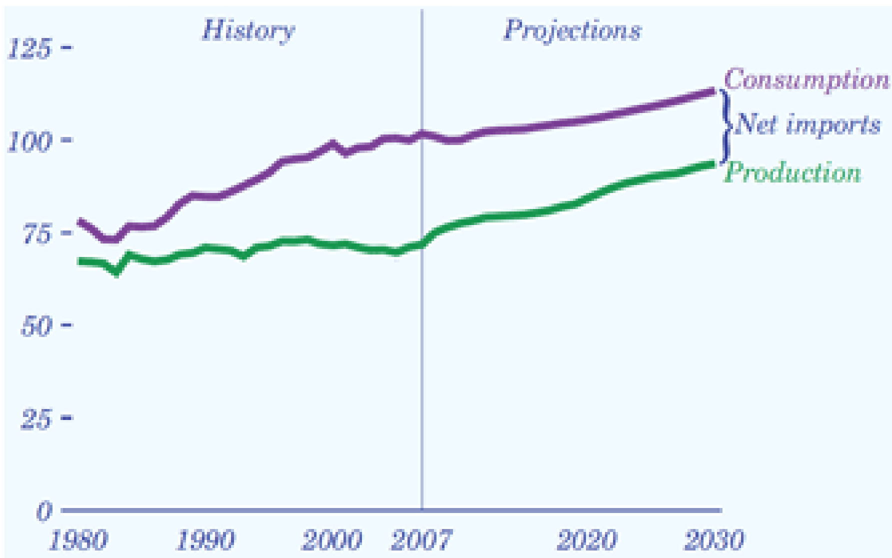
April 27th, 2011

Total energy production and use increasing nationally and internationally

Internat'l Consumption



U.S. Demand and Use
(Quads)



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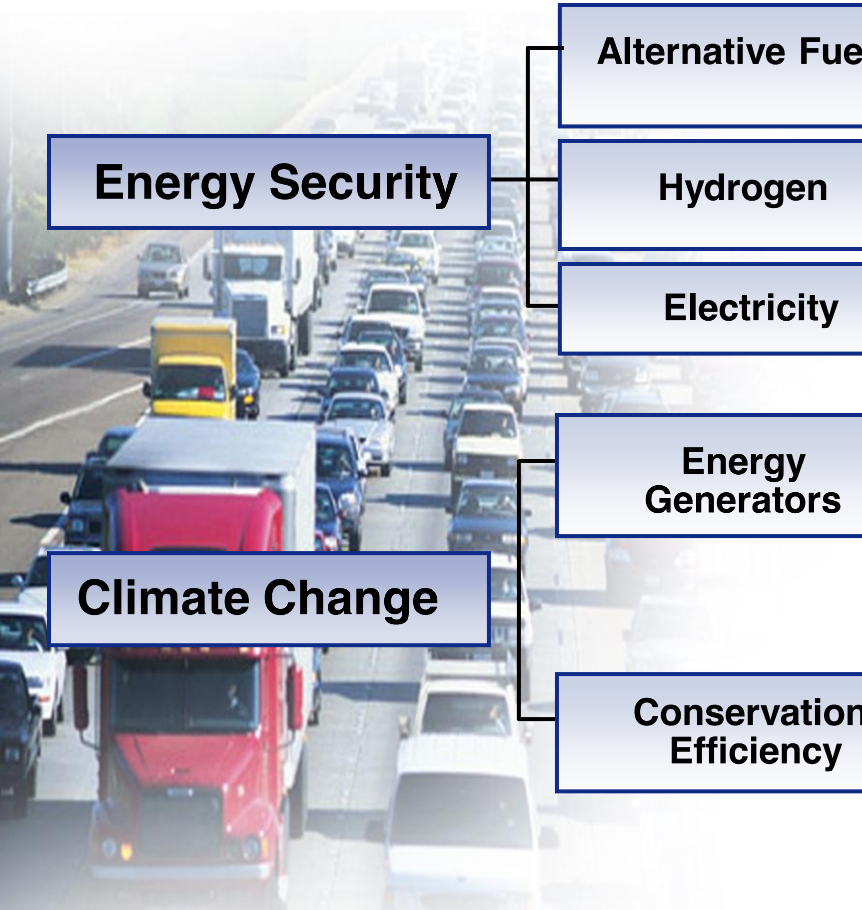
Energy issues can be categorized into two areas – energy security and climate change

Energy Challenge | **Energy Pathway**



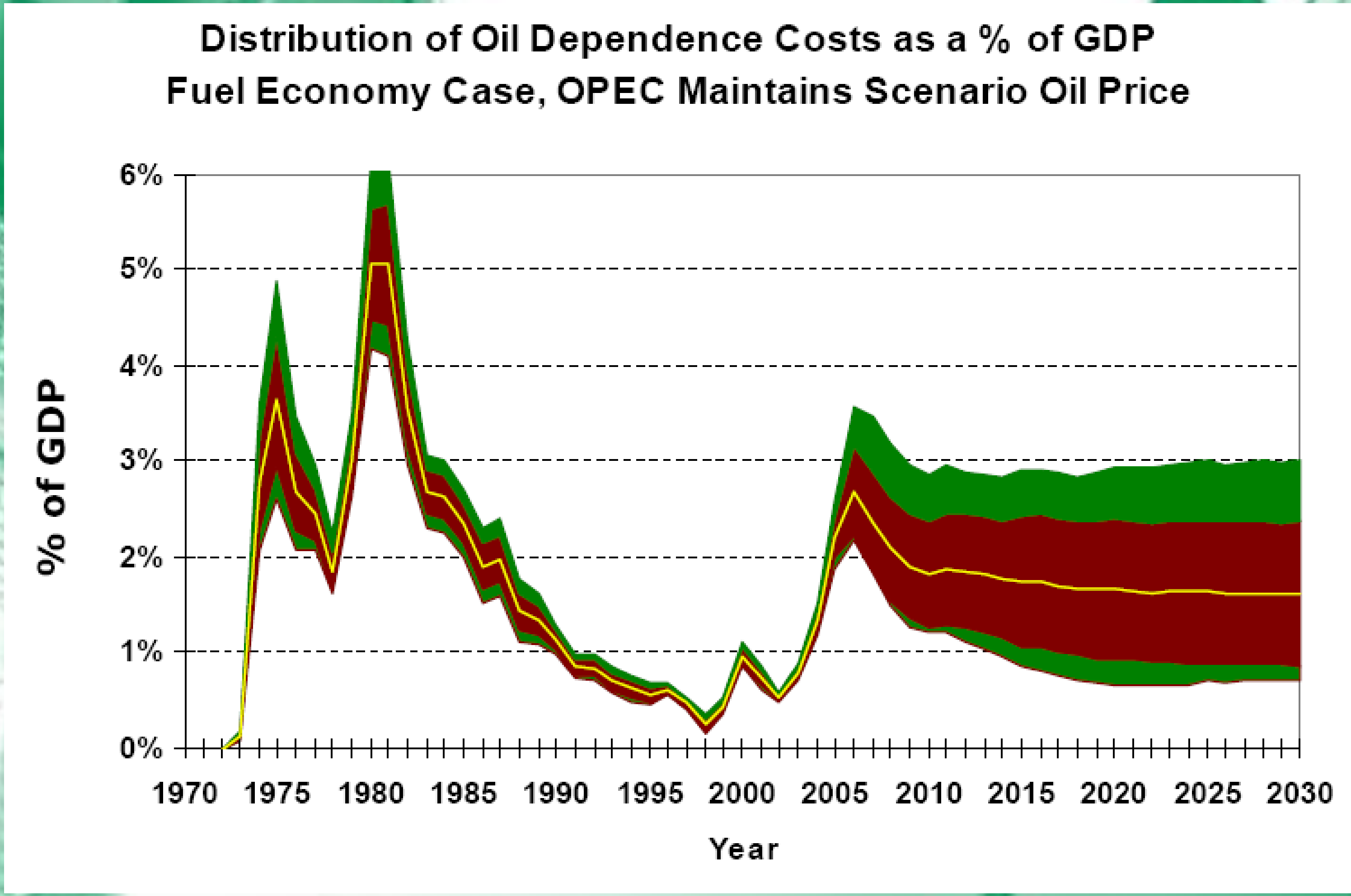
- **Energy Security**
  - Alternative Fuels
  - Hydrogen
  - Electricity
- **Climate Change**
  - Energy Generators
  - Conservation/ Efficiency

The energy solutions for the Nation will place additional burden on the electricity infrastructure

"Electricity, not oil, is the heart of the U.S. energy economy."
Peter Huber, The Million-Volt Answer to Oil

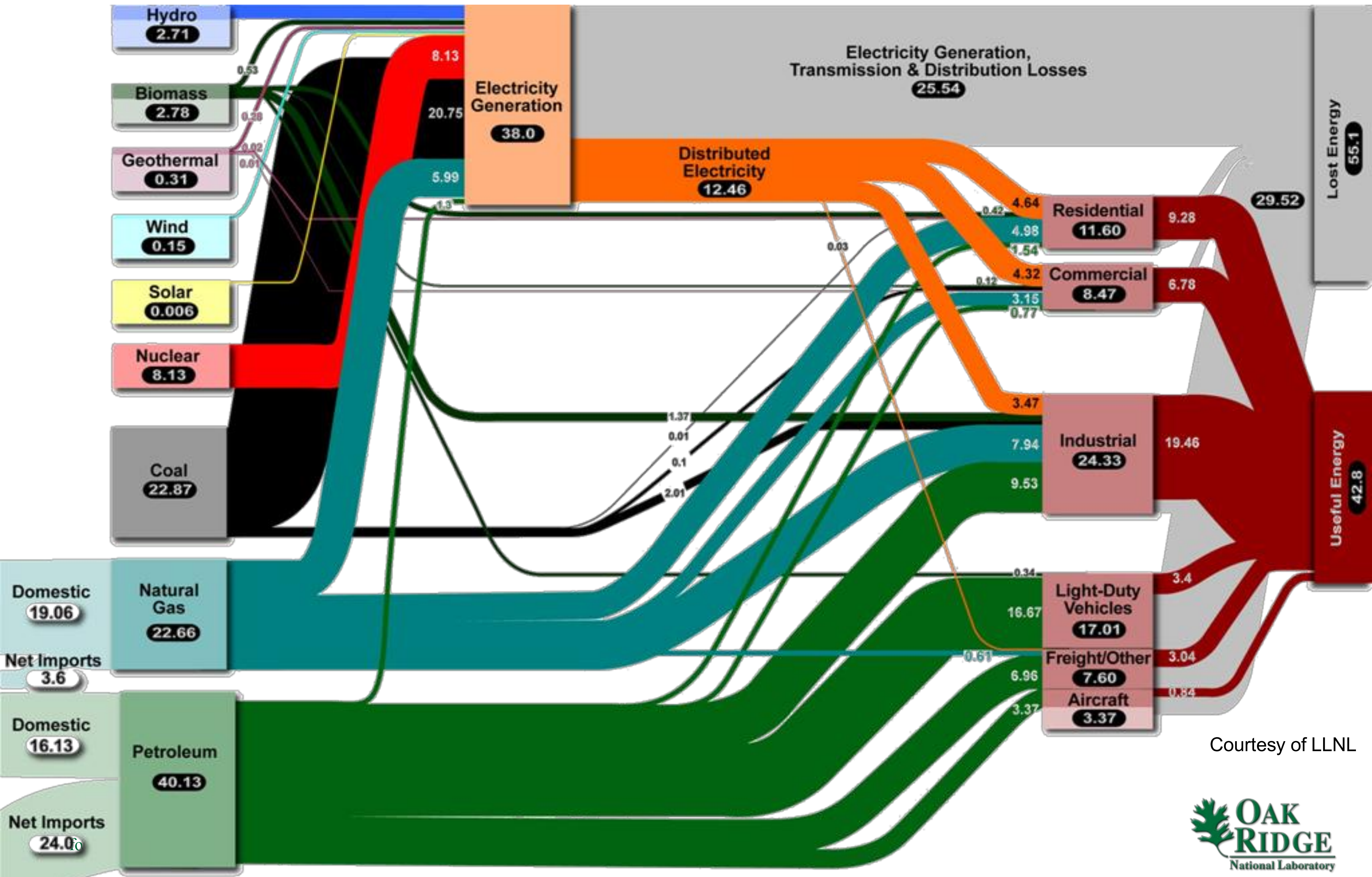
What is energy independence?

"Not subject to control of others"
- Websterian



D. Greene and P. Leiby, Oak Ridge National Lab

National Energy Mix



Courtesy of LLNL

OAK RIDGE National Laboratory

Electricification: Key Infrastructure Issues Remain

- Electricity Operations
  - Utilities have excess generation capacity during off-peak hours
  - Insufficient electricity *distribution* capacity for many PEVs to charge at the same time
  - Vehicle and "grid" communication is necessary to avoid negative impacts to distribution system
- Charging Equipment
  - Customers will typically desire rapid response at home and businesses
  - Installation of L2 charging equipment can be challenging: high cost, lengthy time period, complex interactions among City, Utilities, Contractor
  - Pricing of electricity power is unclear
- "Last Mile" Grid System
  - Transformers must accommodate multiple Evs charging in a neighborhood
  - Public charging not guaranteed

Recovery Act – Infrastructure Activities

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Transportation Electrification Demonstration Projects

The largest-ever U.S. deployment of electric-drive vehicles and charging infrastructure

- Deployment of 13,000 electric-drive vehicles, including light-duty, medium-duty, and heavy-duty passenger and commercial vehicles
- Installation of over 22,000 Level 2 charging sites at residential, commercial, and public locations and 350 (500VDC) Fast Chargers
- Collection of detailed operational data from vehicles and charging infrastructure

10 Grants to establish comprehensive educational and outreach programs focused on electric-drive vehicles

- Funding of the first programs to educate first responders and emergency personnel in how to deal with accidents involving EVs and PHEVs

Courtesy U.S. DOE

Transportation Electrification: EVSE/Vehicle Demonstration Activities

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

* tbd

Transportation Electrification Data Collection

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

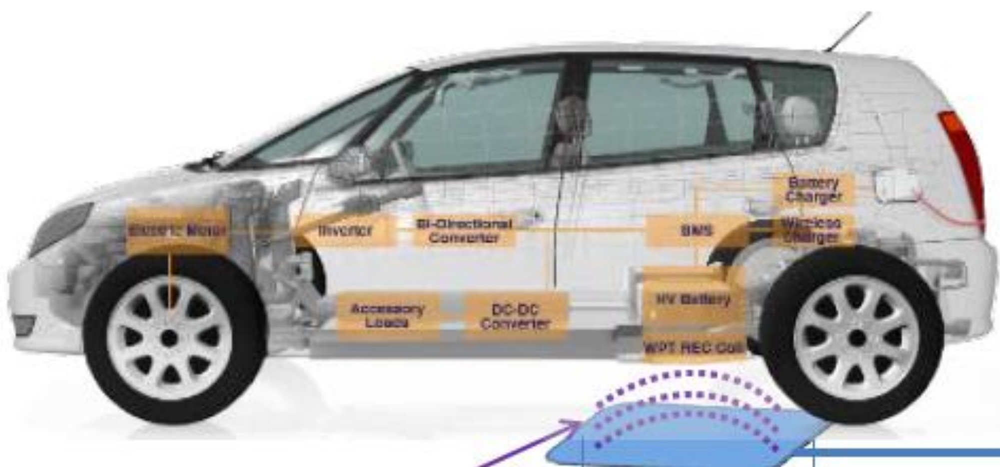
- Charge event data:
  - Connect, start charge, end charge, and disconnect times
  - Average power (kW), max peak power (kW), total energy (kWh), and rolling 15 minute average peak power (kW)
  - Charger ID, event ID, and date/time stamp

- Driving event data:
  - Data recorded for each key on/key off event
  - Event Type (key on/off), date/time stamp
  - Vehicle ID, Odometer, GPS location
  - Battery SOC, Liquid Fuel consumption

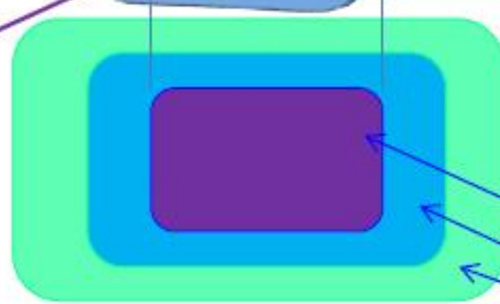
Systems Integration of Renewables

ORNL Vision of PEV Wireless Charging

- **Design a system that focuses on utility to vehicle battery terminal overall efficiency**
  - **SAE J2954 targets plug-battery efficiency >90%**



ORNL developed power inverter to drive resonant antenna pad



WPT resonant antenna system
(2) Dc-dc converter for comm
(3) Traction drive controller
(8) Battery mgm't controller
(9) On-board plug charger-shared
(11) Battery pack and WPT receiver antenna

Zone 1: Active field, ~1m^2, <500uT
Zone 2: 300mm boundary
Zone 3: Field focusing & shielding <62.5mG

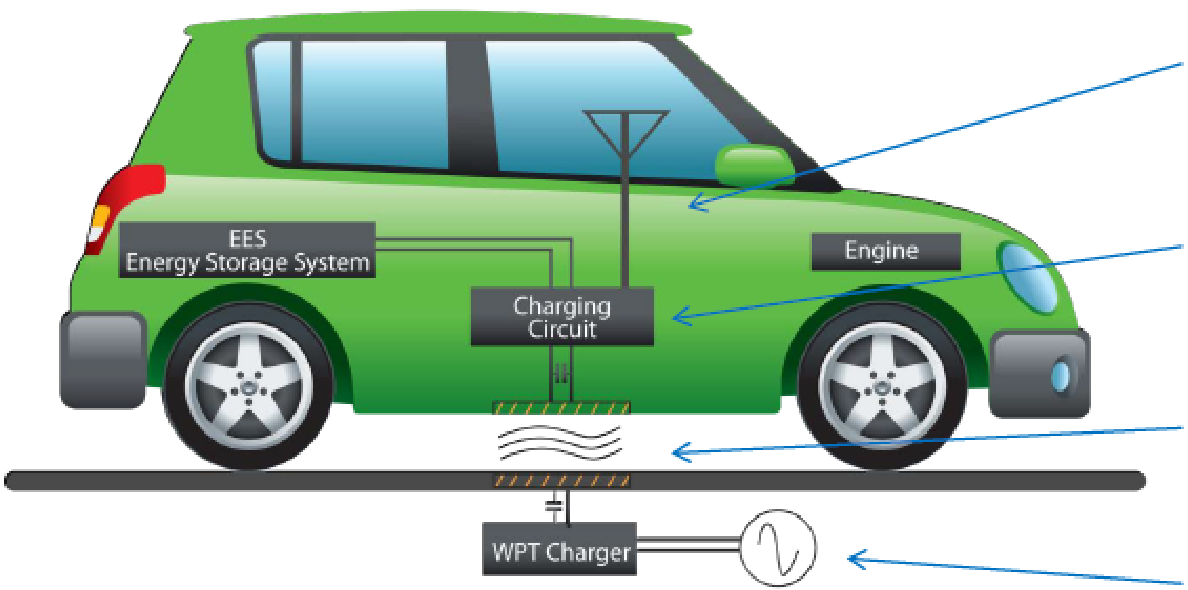
Vehicle graphic: Lindsey Marlar ORNL

Integrating WPT into a PEV

Design and develop antenna system suitable for vehicle integration for stationary, on-road stationary and on-road dynamic charging at high power levels.

Technically: a non-radiating, near field reactive zone power transfer method

Practically: a convenient, safe and flexible means to charge electric vehicles.



Vehicle to WPT communications
RFID localizer for positioning

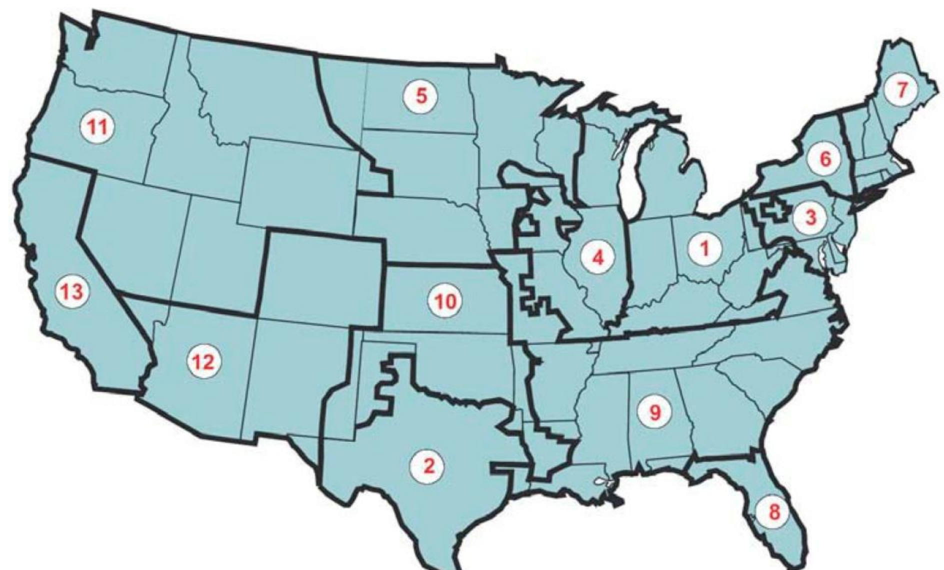
Use existing on-board charger, or dedicated fast-charge and energy management strategy

Active zone field meets international standards (ICNIRP)

Smart grid compliant utility feed and modern power electronics

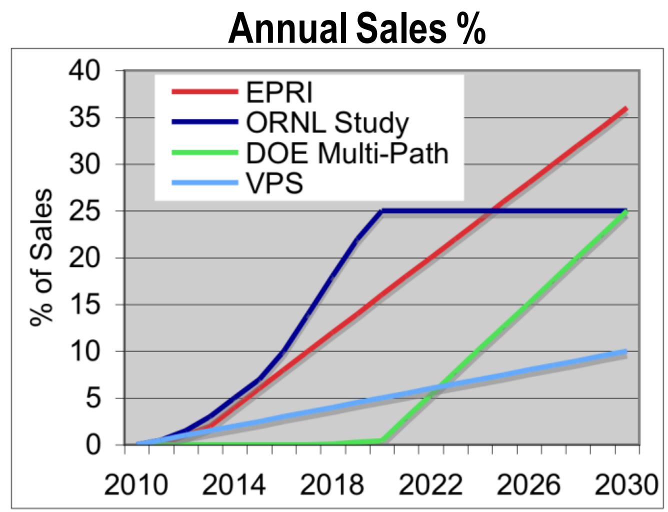
ORNL Regional Study of Grid Impacts

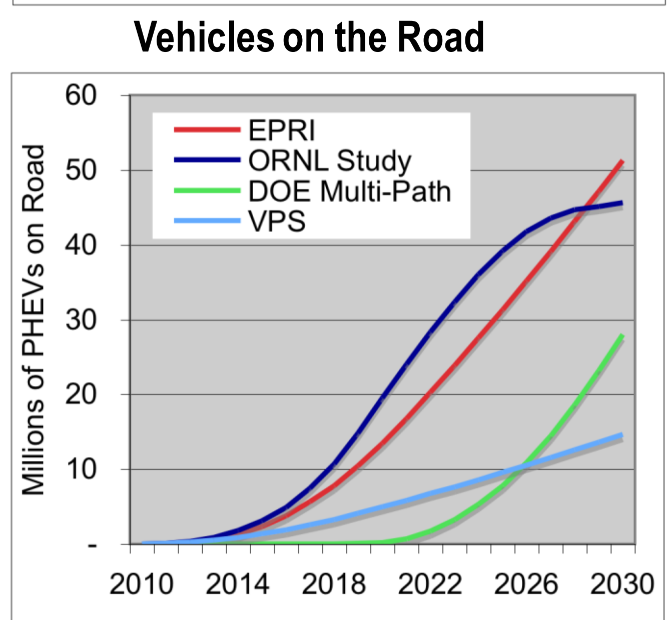
- Electrification of transportation
  - Deployment of high penetration of PHEVs
  - Understand local and regional impacts
- Converse of 2007 PNNL Study (73% of current vehicles can be charged with no new plants if charge only during off-peak)
- Looked at 13 NERC regions covering the U.S.
- Demands and capacity from EIA's Annual Energy Outlook 2007
  - No added capacity for new demands
- Two time periods: 2020 and 2030
- Vary timing of charging
  - When plugged in
  - For how long
- Vary power level
  - Voltage
  - Amperage



How Many Vehicles Will There Be?

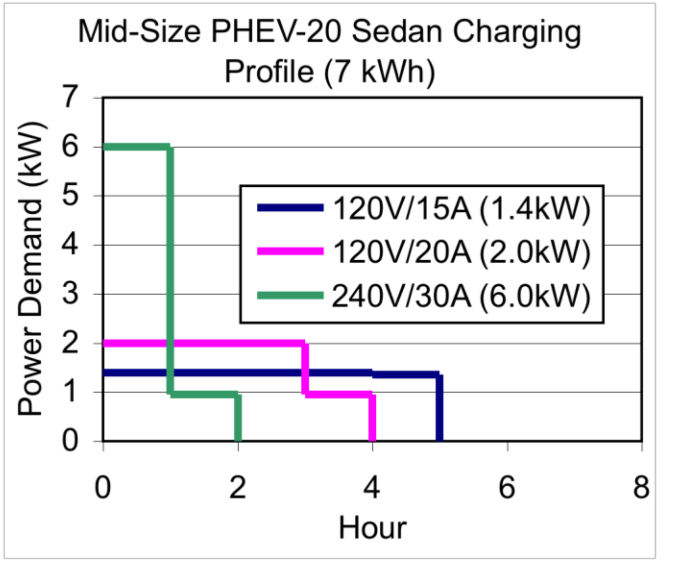
- EPRI target is 10% of sales by 2017, +2%/yr thereafter
- ORNL study assumed 25% by 2020, flat thereafter
- DOE Multi-path study has entry in 2018, growth to 50% by 2040 (PHEV10 and E-REV40)
- Value Proposition Study (E30 PHEV30) used minimum viable market share, 10% by 2030
- Market Introduction Study looked at accelerating growth through policies
  - Span of growth predictions through 2020 roughly tracks the EPRI (high-side) and VPS (low-side) curves





What Power Level Will People Use?

- **120V 15A load ≈ 1.4kW (Level 1)**
  - Allows use of regular wall plug*
  - Slow charging, 5 - 8 hours
  - Low power level has less impact on infrastructure
- **240V 30A ≈ 6kW (Level 2)**
  - Homes require higher cost circuit
  - Significant fraction of house demand
  - Multiple cars/homes could overload equipment
  - SAEJ1772 standard up to 240V 72A ≈ 17kW
- **480V 400A ≈ 192kW (Level 3)**



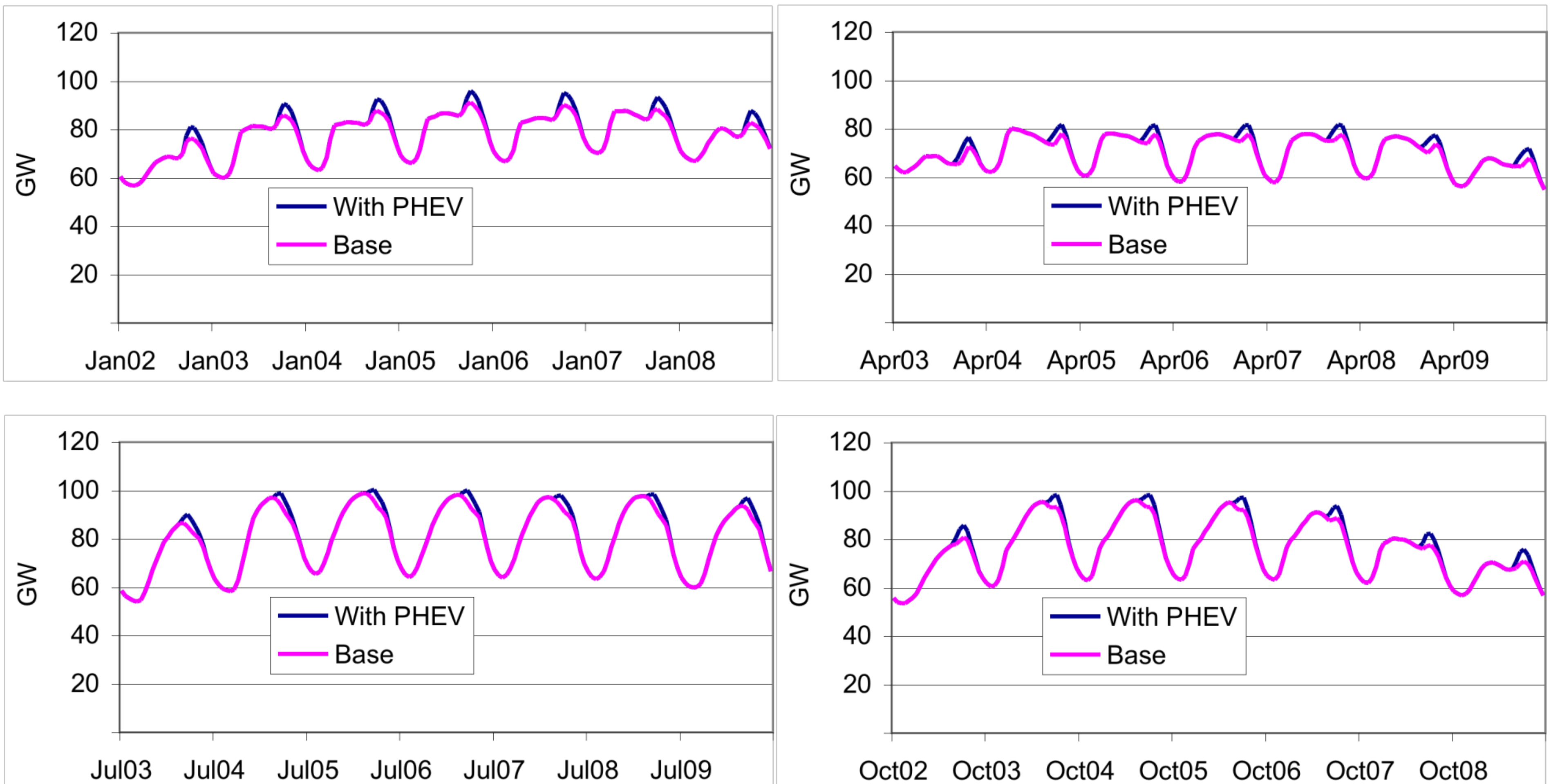
* Electrical code requires separate circuit for electric vehicles

When Will People Charge?

- Charging at night is best for the utility
  - More fully use existing capacity
  - Save on infrastructure expansion
  - Less stress on the grid
- Charging ASAP can be best for customer
  - Convenience
  - If vehicle may be used in evening before off-peak power is available
  - Even peak electric prices may be lower than gasoline
    - 20 ¢/kWh ÷ 4 mile/kWh = 5 ¢/mile
    - $4/gallon ÷ 40 mile/gal = 10 ¢/mile
- Utilities need to incentivize delaying when PHEV plugged in
  - Lower rates during nighttime (e.g., time of use rates, real time rates)
  - Smart Chargers are needed to automate charging optimization

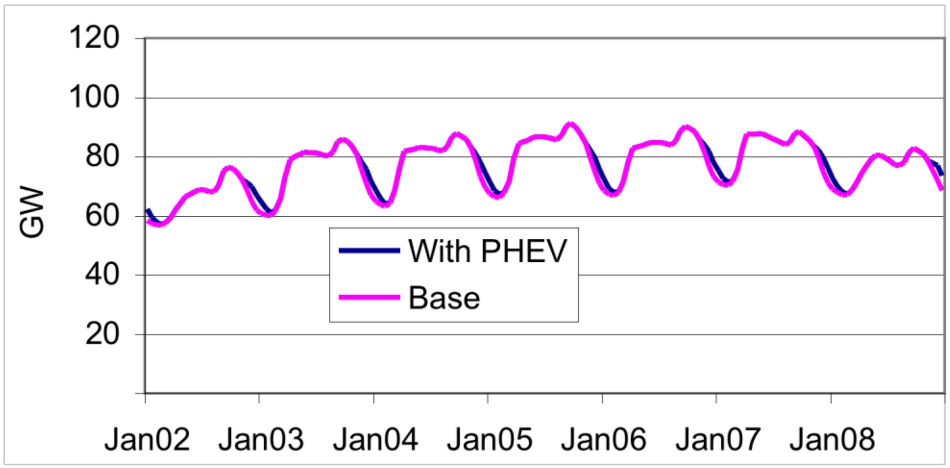
Evening Charging Grid Impacts
(2 kW/vehicle charging rate, ECAR 2020)

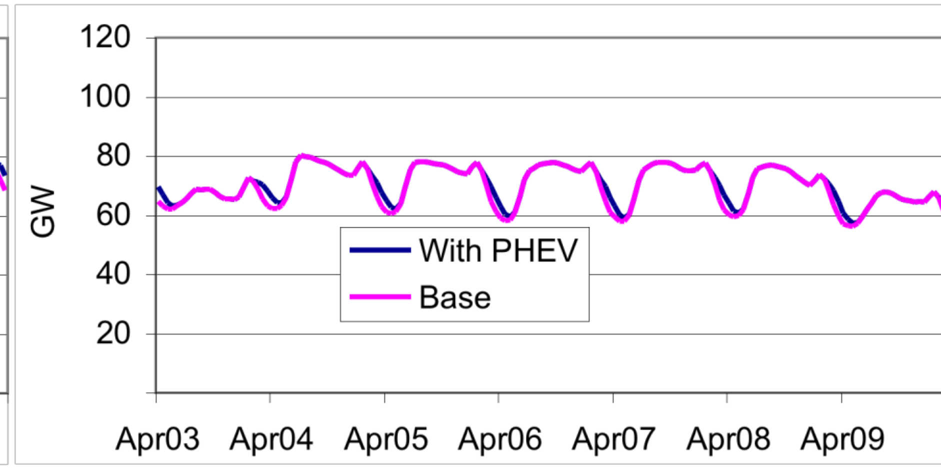
- Evening (5-6 pm) plug-in can hit at peak for most weeks

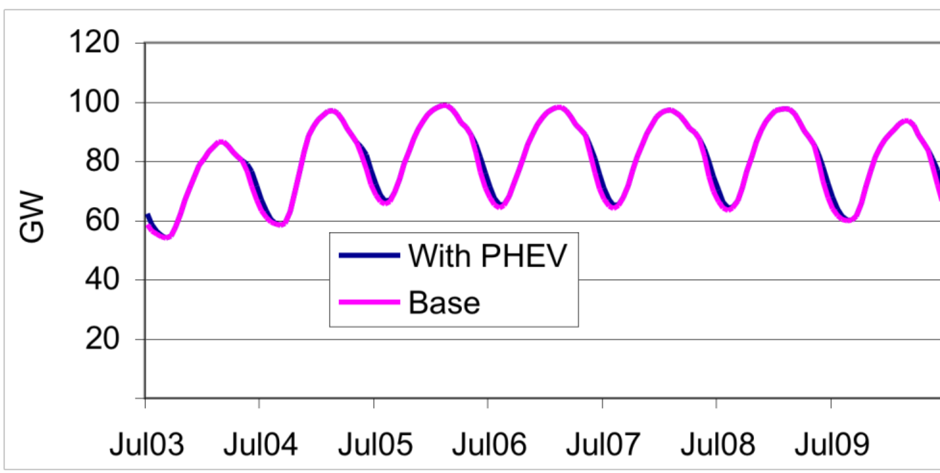


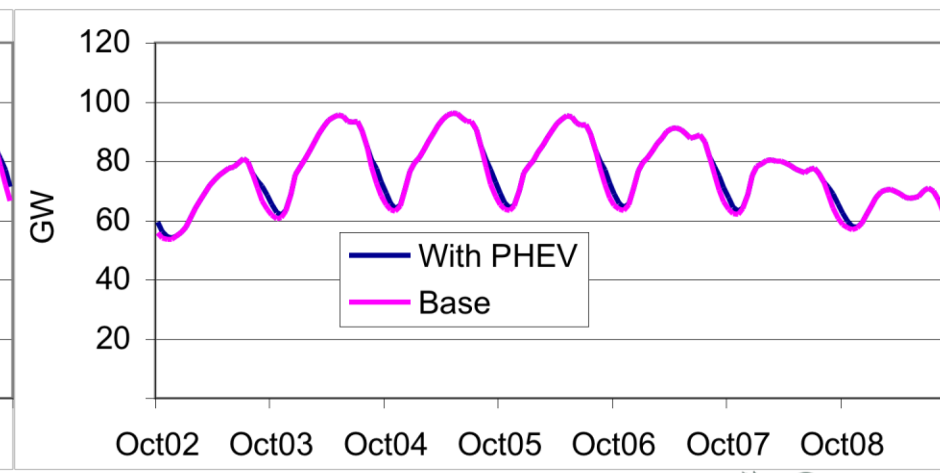
Night-time Charging Grid Impacts
(2 kW/vehicle charging rate, ECAR 2020)

- **Night (10-11 pm) plug-in puts load in the valley**









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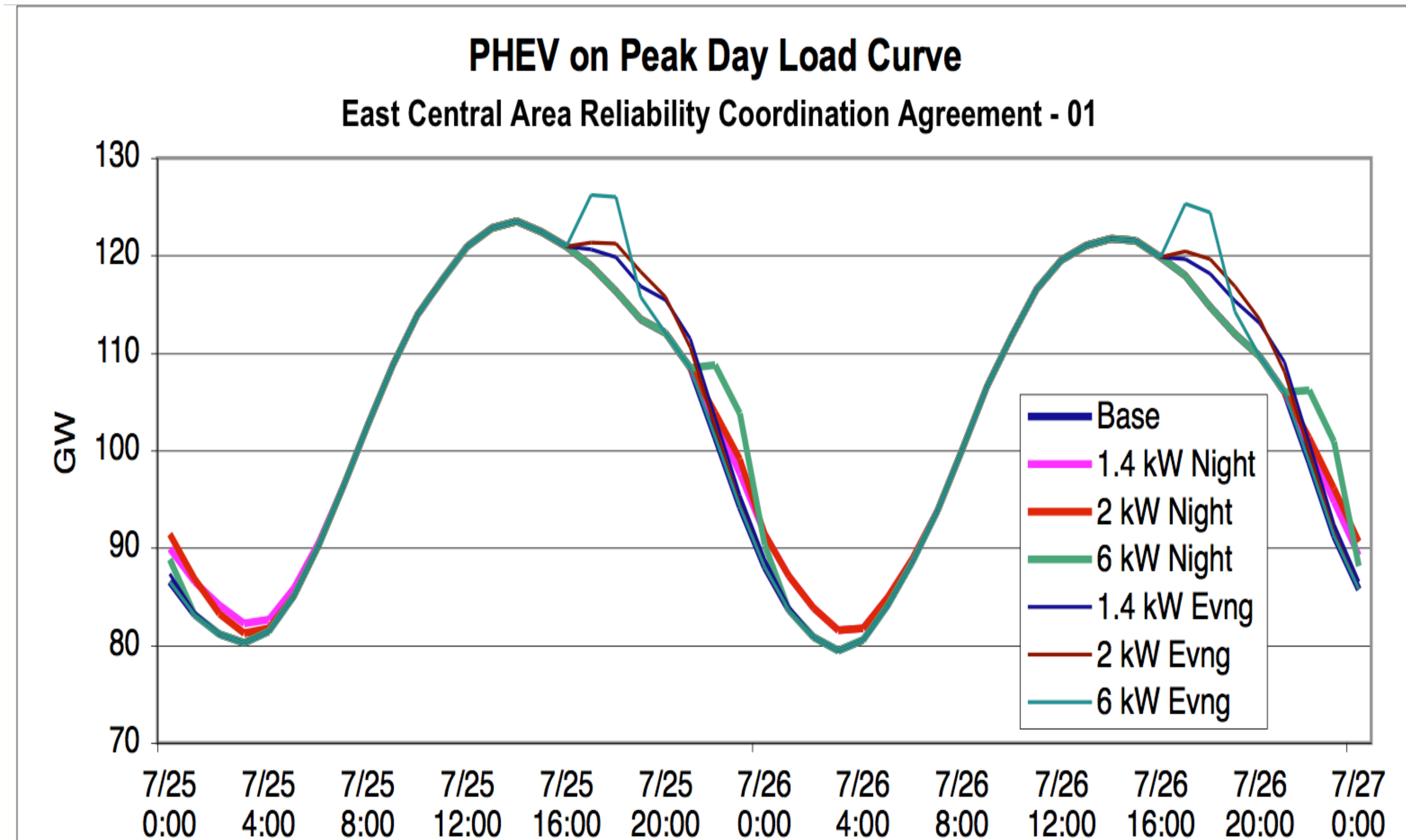
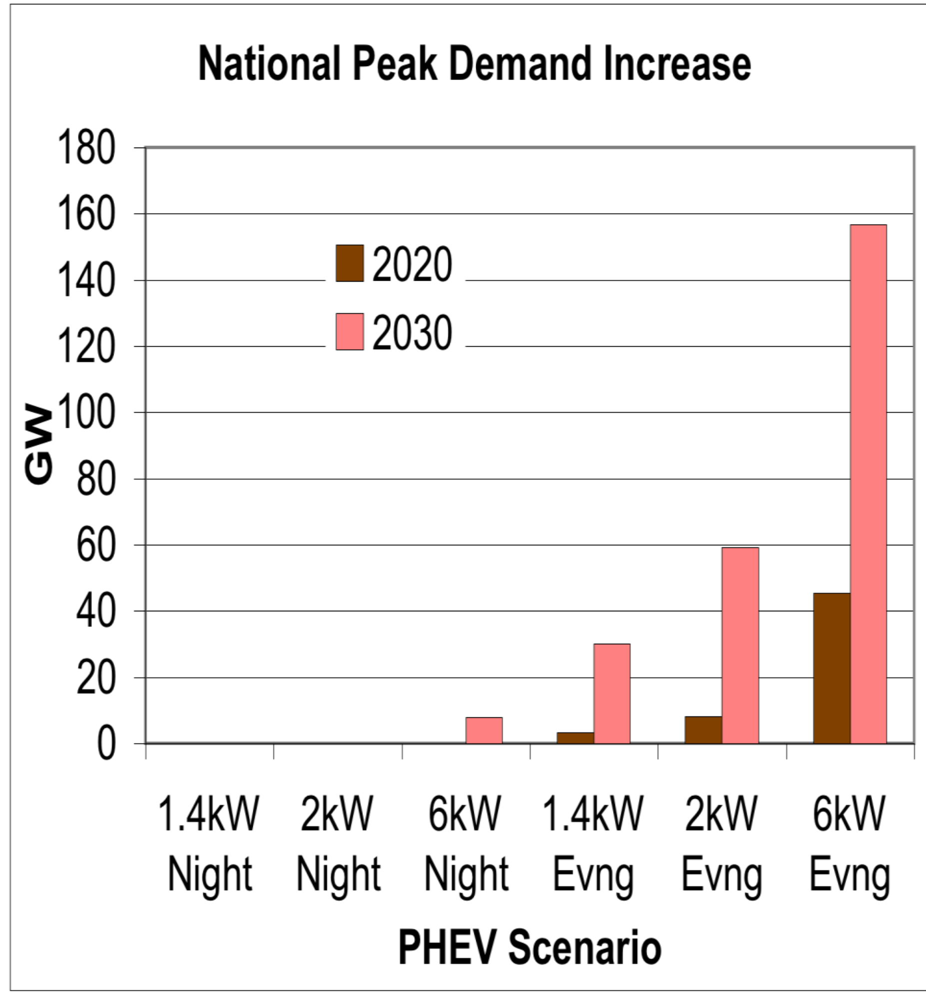
Charging Impact Study

- **Higher power and earlier plug-in time will affect peak production**



Peak Increase can be Significant

- Little or no impact with night charging
  - High power charging can cause new peak from spike
- Evening charging can raise system peaks
  - Even low power charging raises demand



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Distribution Impacts

- Increased load density in existing areas
  - Local peaks may not match system peaks
  - Equipment may require offpeak cool-down
  - One analysis shows a 93% reduction in transformer life
- Charging at home, business, or high-power charging at stations will have different impacts
  - Timing of loads
  - Power level
  - Billing
  - Control of batteries
- Smart-charging allows shaping of load to help the grid

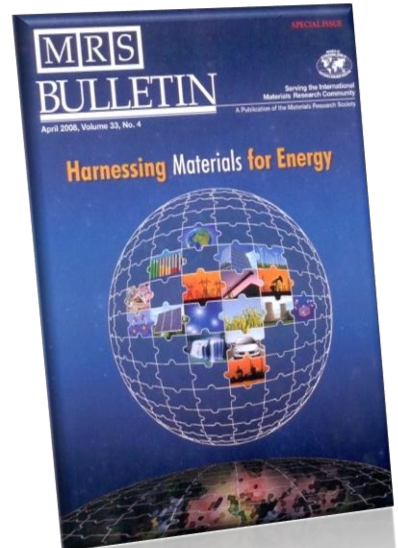
Smart Grid Can Have Varied IQ

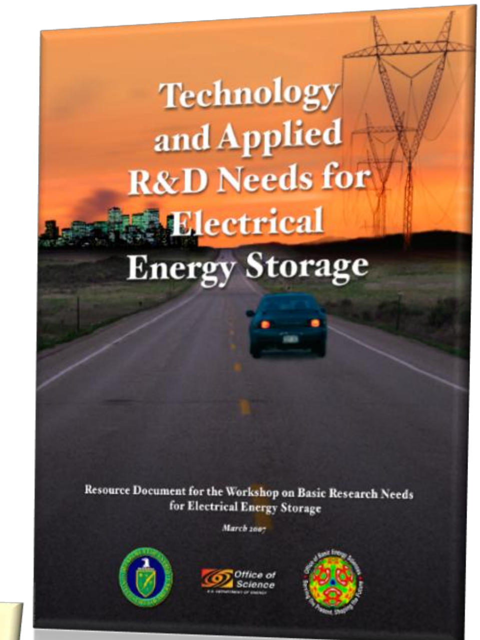
- Simple timer to delay charging
- Price-responsive charging (real-time or TOU)
- Cut-off charging during critical peaks
- Emergency power supply for home or business
- Charging and discharging based on market conditions
- Ancillary services (reactive power, regulation, reserves)

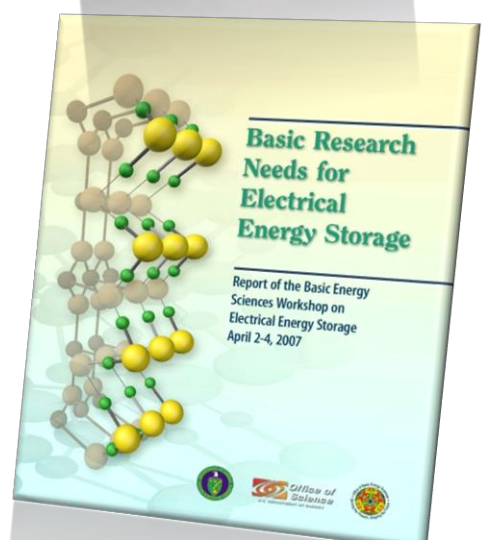
- Utilities may also install distributed stationary storage to shape and control loads

Breakthroughs are needed in energy storage

- Cost reductions
  - raw materials
  - materials processing & manufacturing
  - cell and module packaging
- Performance
  - discharge pulse power limitations at low temperatures
  - capacity and power fading
  - power and energy densities
- Abuse Tolerance / Safety
  - short circuits
  - overcharge, over-discharge
  - fire or high temperatures
  - thermal runaway
  - extended life



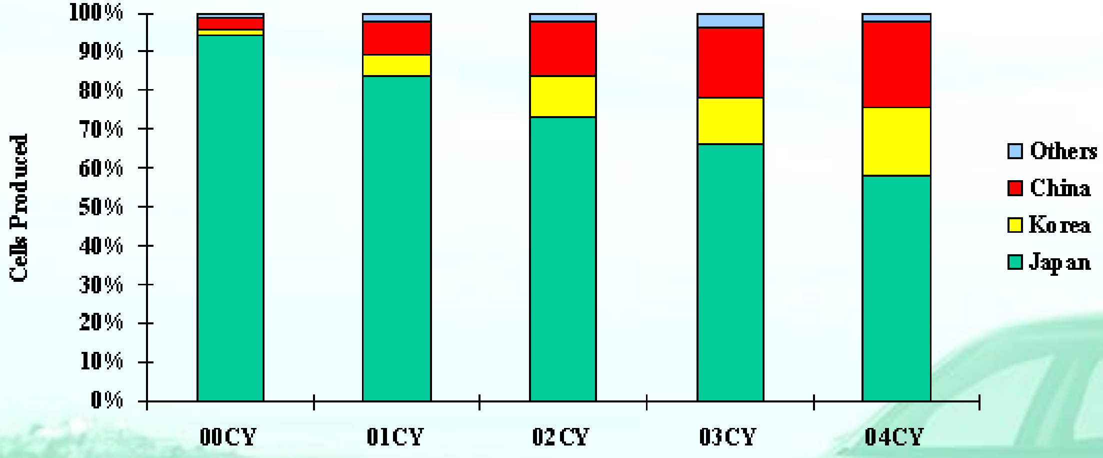




DOE, Energy Storage Research and Development Annual Progress Report 2008

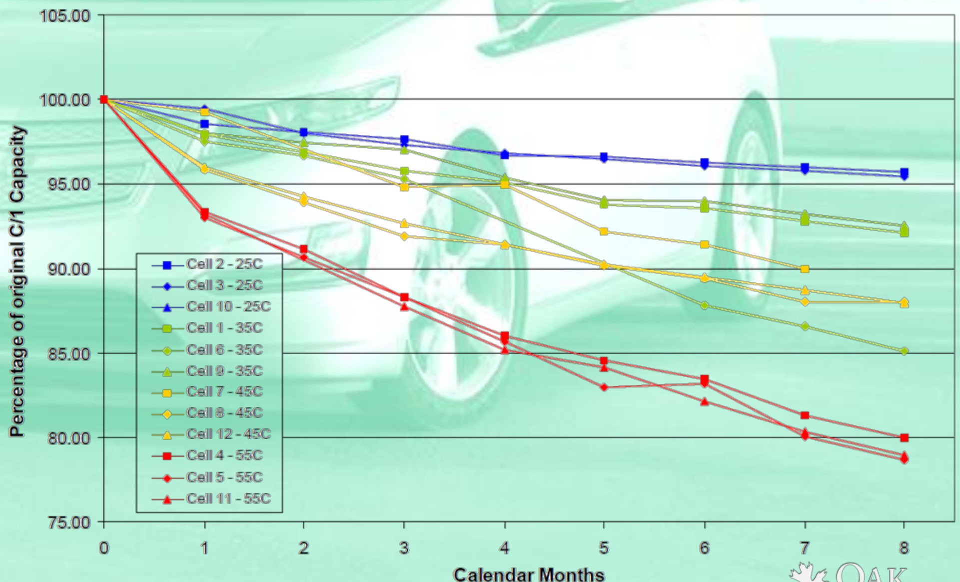
ORNL is addressing two problems:

1. Batteries not being manufactured in the U.S.
2. Batteries not lasting long enough or performing well enough



Work with U.S. battery manufacturers together to make them competitive with their U.S. operations

Study degradation mechanisms and develop new materials and concepts for batteries



Example for ORNL research:

In Situ Microscopy For Battery And Fuel Cell Research At the Nano-scale

Example for ORNL research:
Acoustic emission and other methods to understand degradation mechanisms

Further Information

- **Regional impact of PHEVs on the grid**

http://info.ornl.gov/sites/publications/Files/Pub7922.pdf

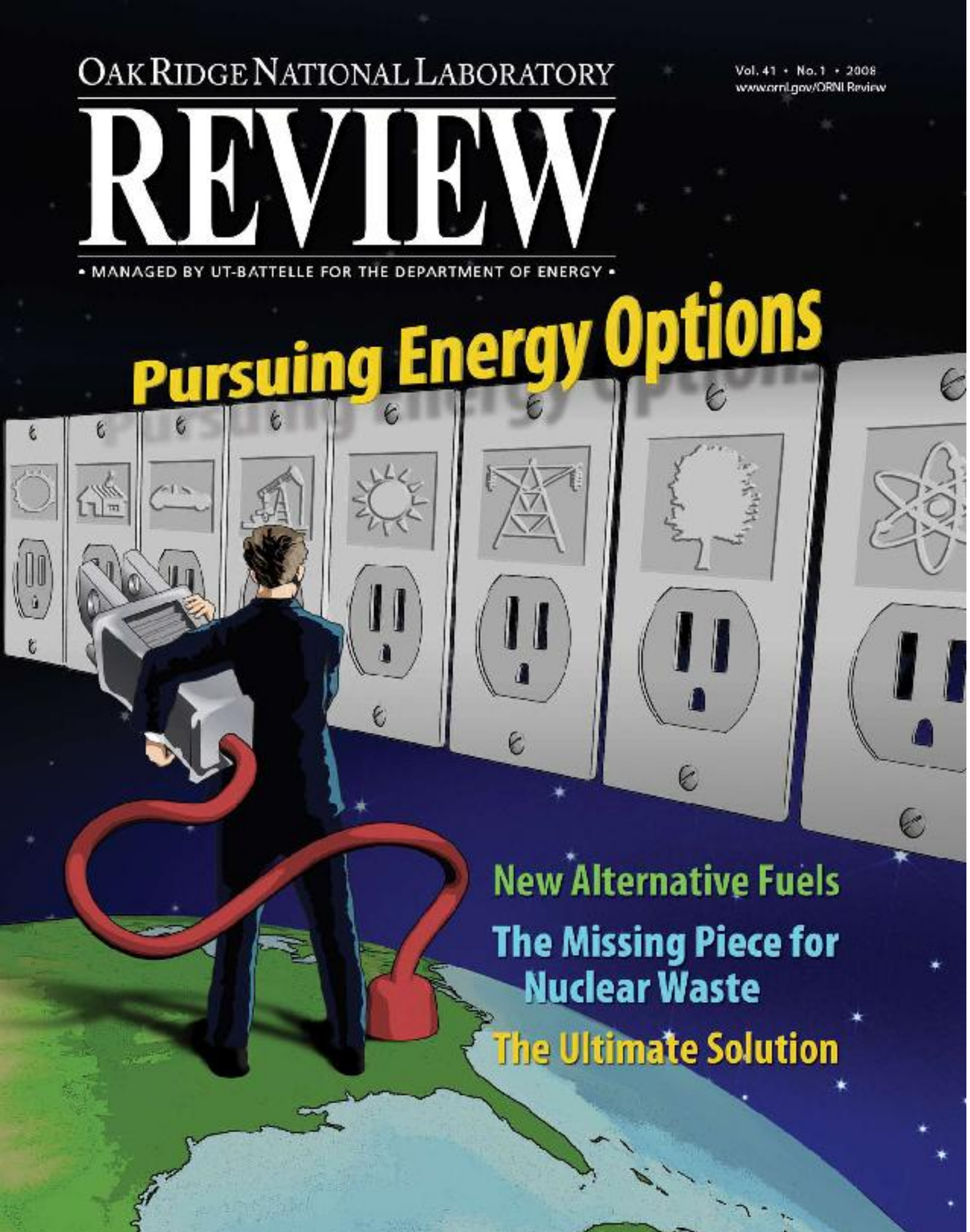
- **Value Proposition Study Final Report**

http://info.ornl.gov/sites/publications/Files/Pub23365.pdf

- **Market Introduction Study**

http://info.ornl.gov/sites/publications/Files/Pub14078.pdf

For further info, contact: hadleysw@ornl.gov 865-574-8018



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