Grid Analysis for Transforming the Transportation Sector from Fossil Fuel to Electricity

Michael Kintner-Meyer, Ph.D., PNNL
Clint Gerkensmeyer, PNNL
Ye Li, Ph.D., PNNL
Tony Nguyen, Ph.D., PNNL

Zoran Filipi, Ph.D., University of Michigan
Richard Curtin, Ph.D., University of Michigan
John Sullivan, Ph.D., University of Michigan
Walter McManus, Ph.D., University of Michigan
John Lee, Ph.D., University of Michigan

RDSI Program Review
October, 2008

Contact: email: Michael.Kintner-Meyer@pnl.gov
phone: 509.375.4306

Pacific Northwest
NATIONAL LABORATORY

PNNL-SA-63164

Vision

The U.S. grid could become the energy delivery system of the transportation sector with a clean and diversified fuel source, thus, addressing our dependence on foreign oil

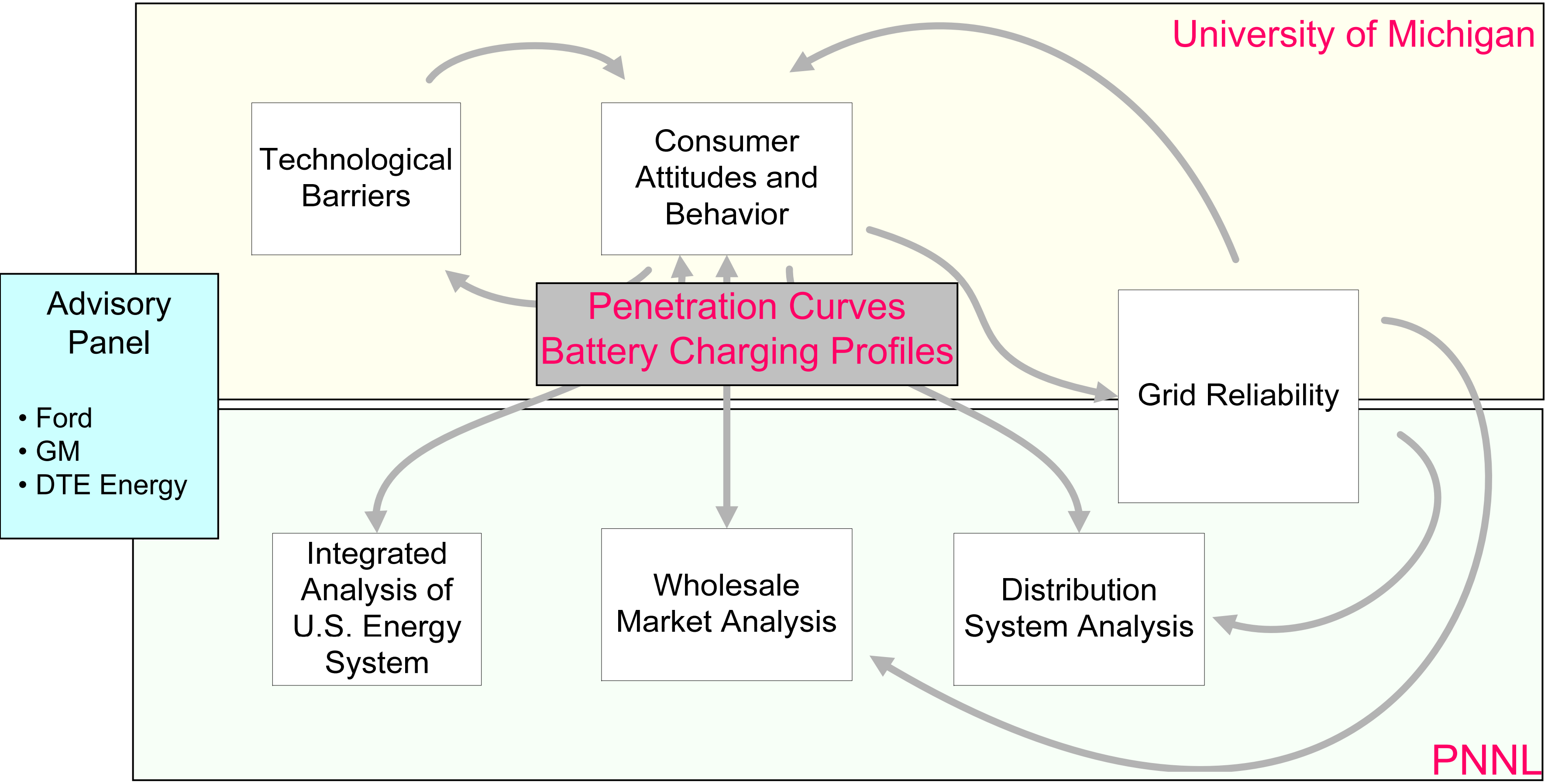
Key questions being addressed:

- What is the customer acceptance of PHEVs?
- What are the technological and cost barriers?
- What are impacts of PHEVs to the grid and the environment?
  - What are impacts in the distribution system in terms of adequacy and reliability
  - What are the impacts to the bulk transmission system in terms of production cost and emissions
  - What are the impacts to the entire U.S. energy system from an integrated energy assessment point of view.

Pacific Northwest
NATIONAL LABORATORY

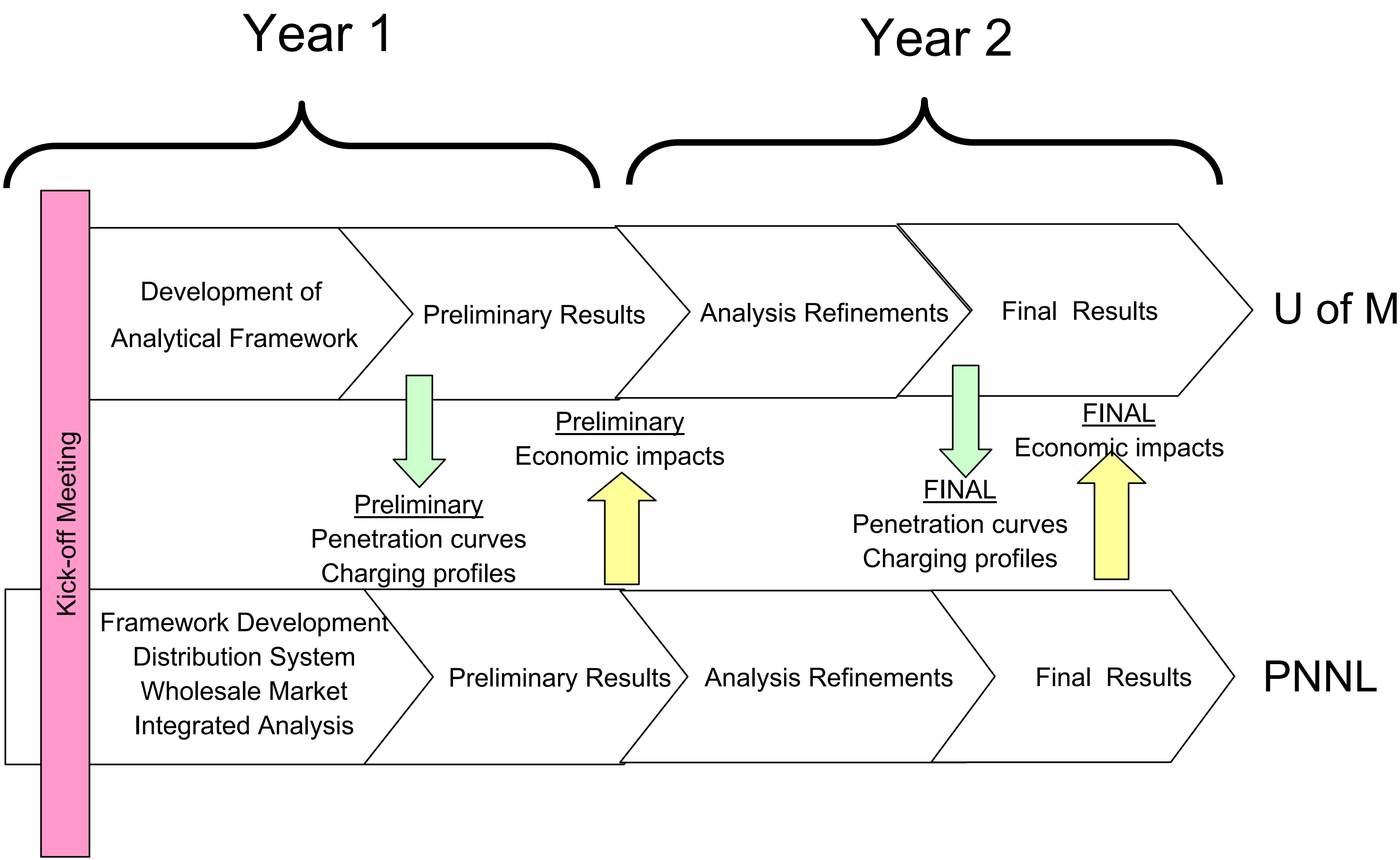
PNNL – University of Michigan Collaboration

Jointly funded by DOE/OE and DOE/EERE



Pacific Northwest NATIONAL LABORATORY

Execution of Project



Pacific Northwest
NATIONAL LABORATORY

Distribution System Analysis

PI: Michael Kintner-Meyer, PNNL

Key issues

- At what level of PHEV penetration do feeder upgrades become necessary?
- Will the PHEV load growth occur uniformly in the service area or will there be areas of PHEV concentrations (early adopters)?
- How will the budget for asset replacement be affected by PHEV load growth
- How can the new load be managed and what is the value?

Key challenges

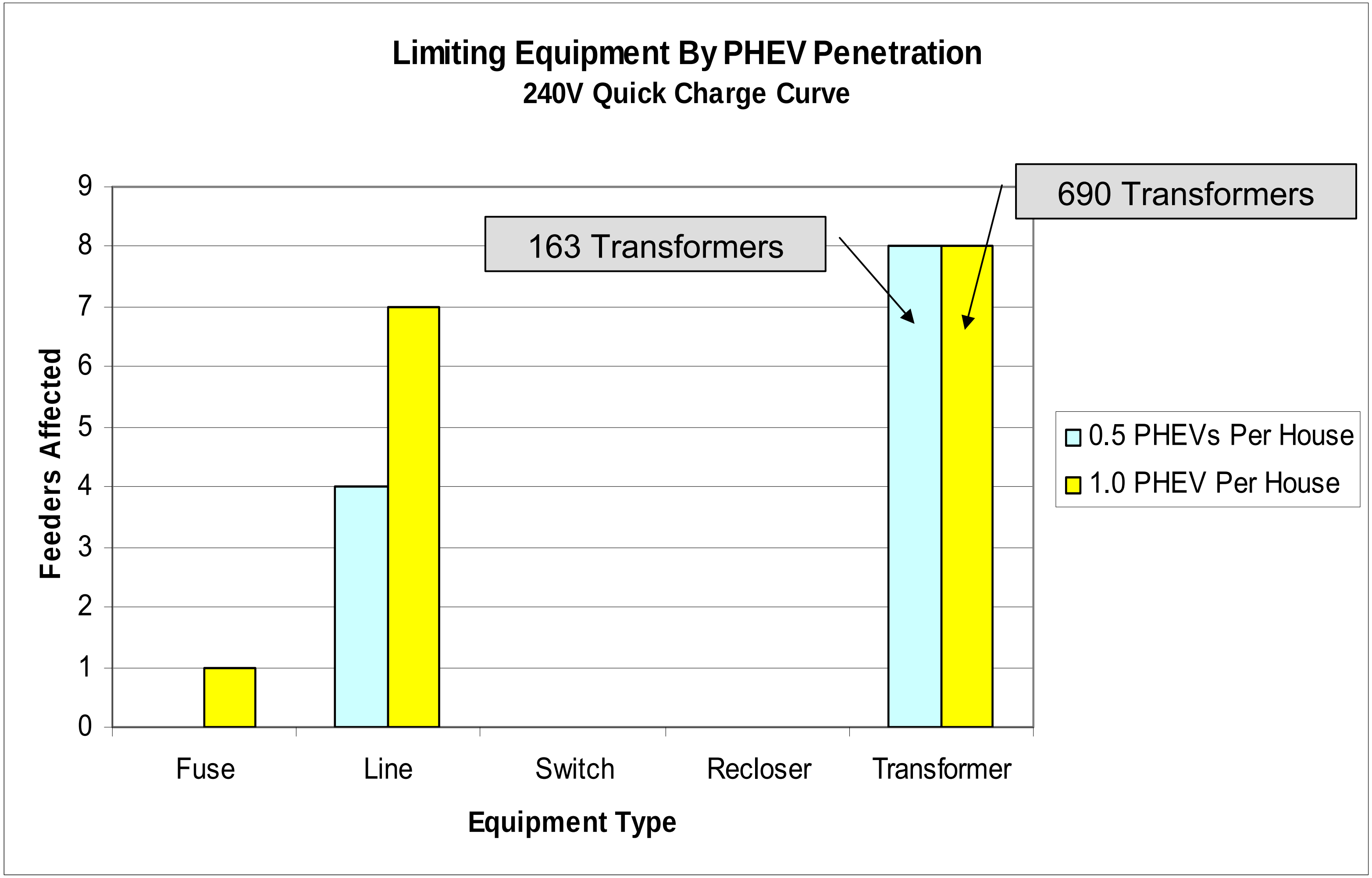
- Large diversity in distribution system (in terms of utilities design and sizing criteria, vintage, topology, length) makes it difficult to develop assessment in a national context
- Many parameters determine the outcome of the analysis

Methodology

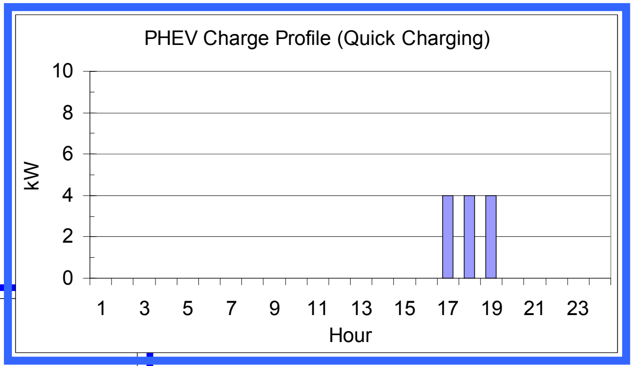
- Develop assessment framework Using distribution planning tools (SynerGEE™, DEW) to test for loading conditions in radial feeders
- Perform selected case studies with PNW utilities and DTE Energy

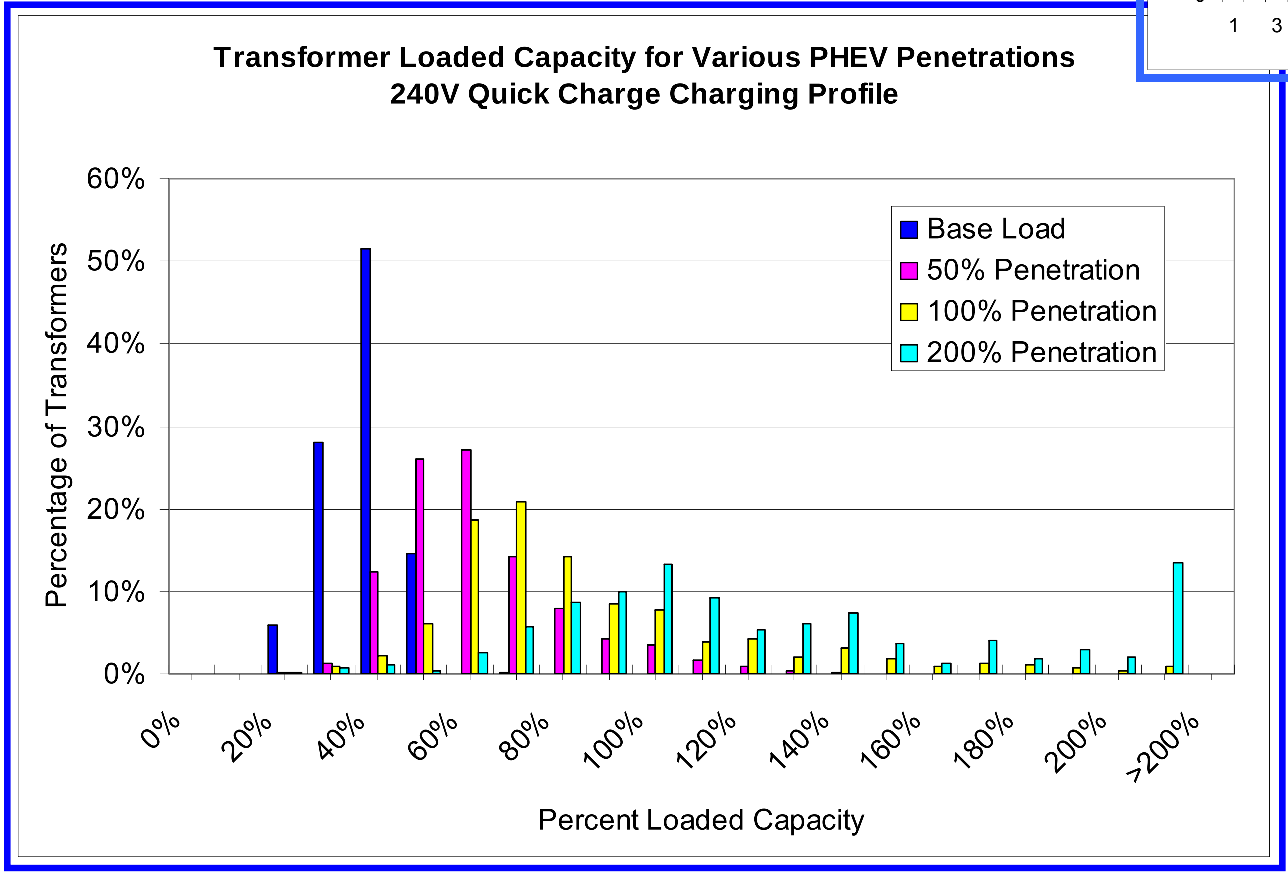
Pacific Northwest NATIONAL LABORATORY

Components Exceeding Rated Capacity Quick Charging (Selected Utility in PNW)



Secondary Transformer Loading (Selected Utilities in PNW)





Pacific Northwest
NATIONAL LABORATORY

Results, Next Steps, and Outcomes

Preliminary results

- Design and component sizing guidelines are important
- Vintage of distribution system appears important
- Results so far showed significant reserves in distribution systems

Next steps

- Re-run scenarios with revised PHEV charging profiles
- Assess effort to perform analysis with DTE Energy data

Products and expected outcomes

- IEEE Paper, presented at PES General Meeting, Pittsburgh July 20, 2008
- Report on feeder reserves and supply curve of feeder upgrades as a function of PHEV penetration
- Outcomes
  - Distribution analysis framework can be readily used for any utilities with distribution system data (SynerGEE format)

Pacific Northwest
NATIONAL LABORATORY

Impacts of PHEVs on Distribution System Reliability

PI: John C. Lee, University of Michigan

Key issues

- What are the PHEV load-dependent reliability impacts on distribution systems?
- Specifically, what are the reliability impacts on transformers with high penetration of PHEV?

Objectives

- Develop a stochastic reliability model for distribution system
- Use results from the stochastic model to suggest improvements to current DTE Energy practice for equipment replacements and upgrades

Methodology

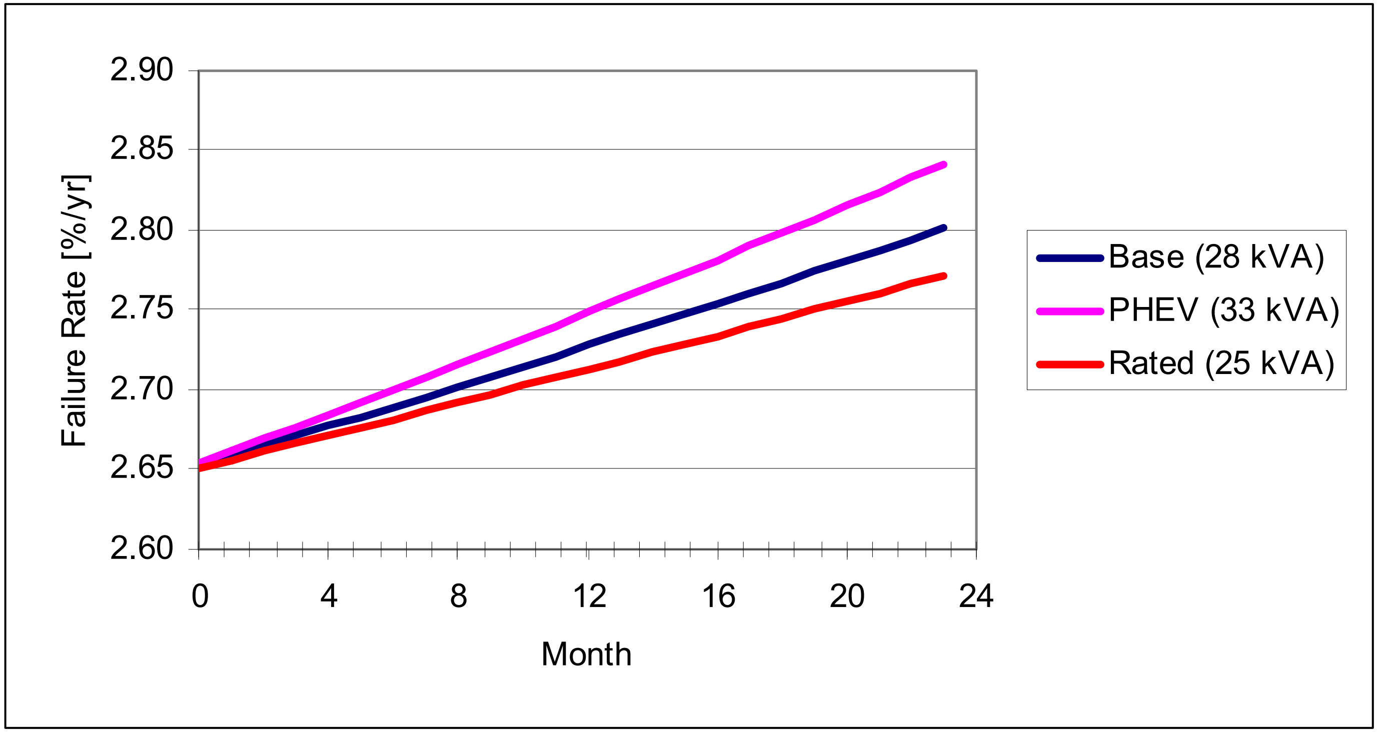
- Develop dynamic event and fault trees (DET/DFT) model for selected DTE Energy distribution feeder
- Determine temporal evolution of failure probability of transformers and other components as a function of load history
- Calibrate model to DTE Energy’s SAIFI, CAIFI statistics

Products and outcome

- Report
- Incorporate methodology into Distribution Engineering Workstation (DEW)

Pacific Northwest NATIONAL LABORATORY

Preliminary Result from Transformer Load Study



- Load-dependent failure rate calculation is based on IEEE C57.91-1995
- PHEV load increases failure rate by an additional 0.02% per year

Pacific Northwest
NATIONAL LABORATORY

Bulk Transmission System Analysis

PI: Michael Kintner-Meyer, PNNL

Key issues

- How will the growing PHEV load affect the wholesale electricity markets?
  - Production
  - Emissions

Objectives

- Determine plant capacity expansions to meet 2030 load
- Perform product cost modeling (security constrained unit commitment and optimal power flow) to determine:
  - LMP
  - Average Cost
  - Emissions

} As a function of PHEV charging profiles

Methodology

- Develop plausible PHEV charging profiles
- Using state-of-the-art production cost and expansion planning model (PROMOD, MarketPower by Ventyx)
- Perform analysis for 3 US interconnects (WECC, ERCOT, Eastern Interconnect) considering regional RPS laws

Products and expected outcome

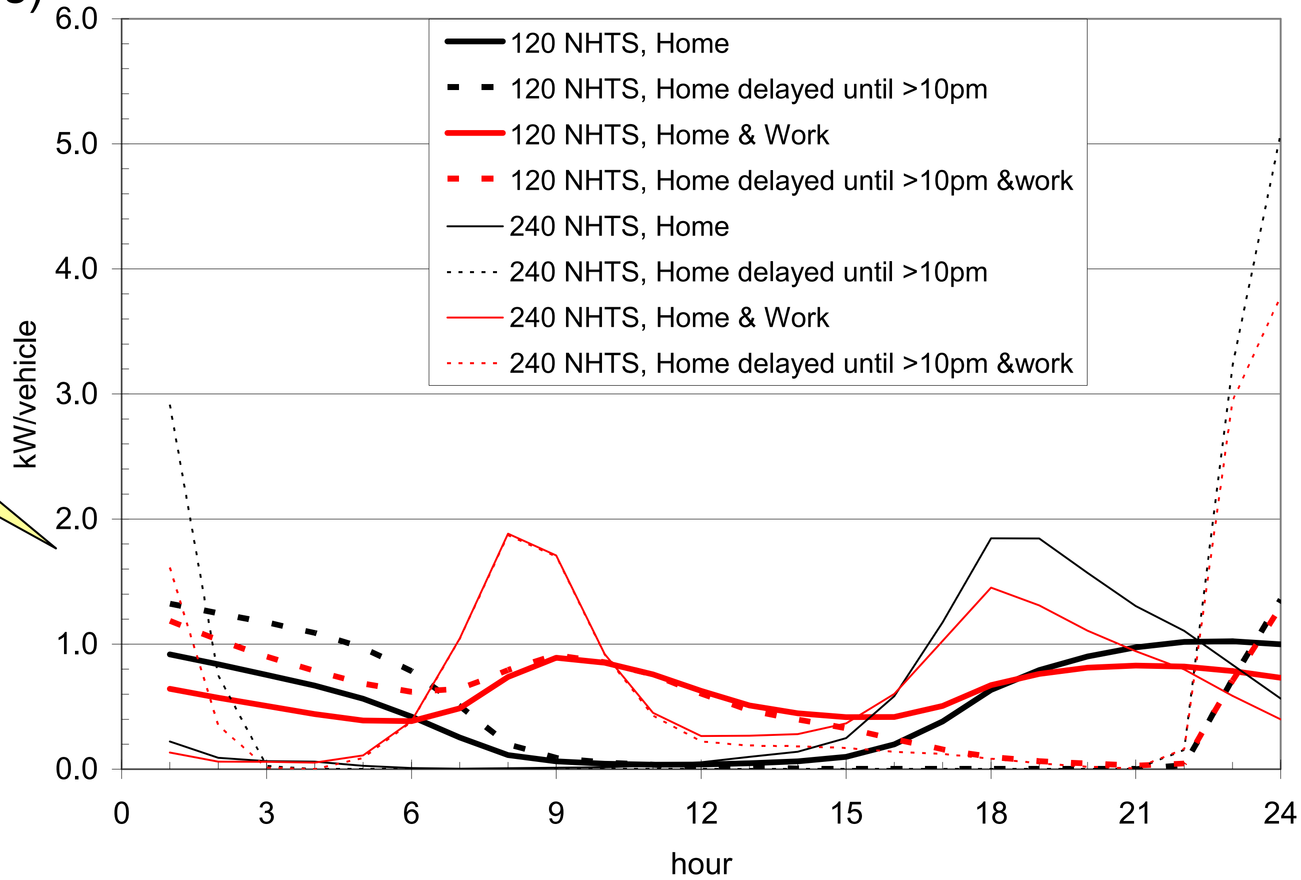
- Report, various papers
- Dissemination of results to the regional policy makers (Western Governors Ass., NWPPC, and others)

Pacific Northwest NATIONAL LABORATORY

Developed Plausible PHEV Charging Profiles

- Need for PHEV charging profile
  - Most researchers use EPRI "W" shaped profile based on notion of 120V/12A charging
- Refined PHEV profile with DOT 2001 National Household Travel Survey to reflect "resting periods" of vehicles
- Considered both 120V and 240V charging (automakers announced 240V charging capabilities)

Diversified average charging profiles for PHEVs



Results and Next Steps

Preliminary results

- Validated PNNL's 2007 results for the WECC that today's grid is capable to support up to 73% of the US light-duty vehicle fleet (using detailed nodal model)
- Models for WECC and ERCOT completed

Next steps

- Fine tune WECC and ERCOT models
- Establish Eastern Interconnect model
- Evaluate U of Michigan's PHEV penetration results as input for analysis

Integrated Analysis using National Energy Modeling System (NEMS)

PI: Michael Kintner-Meyer, PNNL

Key issues

- How do PHEV compete against other advanced vehicles?
- What will the generation mix look like with new PHEV load?
- What are the impacts on consumers' electric rates?
- What are the synergies between the PHEV storage and growing renewable resource utilization?
- What are the impacts on energy prices (e.g. natural gas, coal, gasoline, diesel)?

Objectives

- Perform integrated assessment of PHEV penetration scenarios on the US energy system using NEMS

Methodology

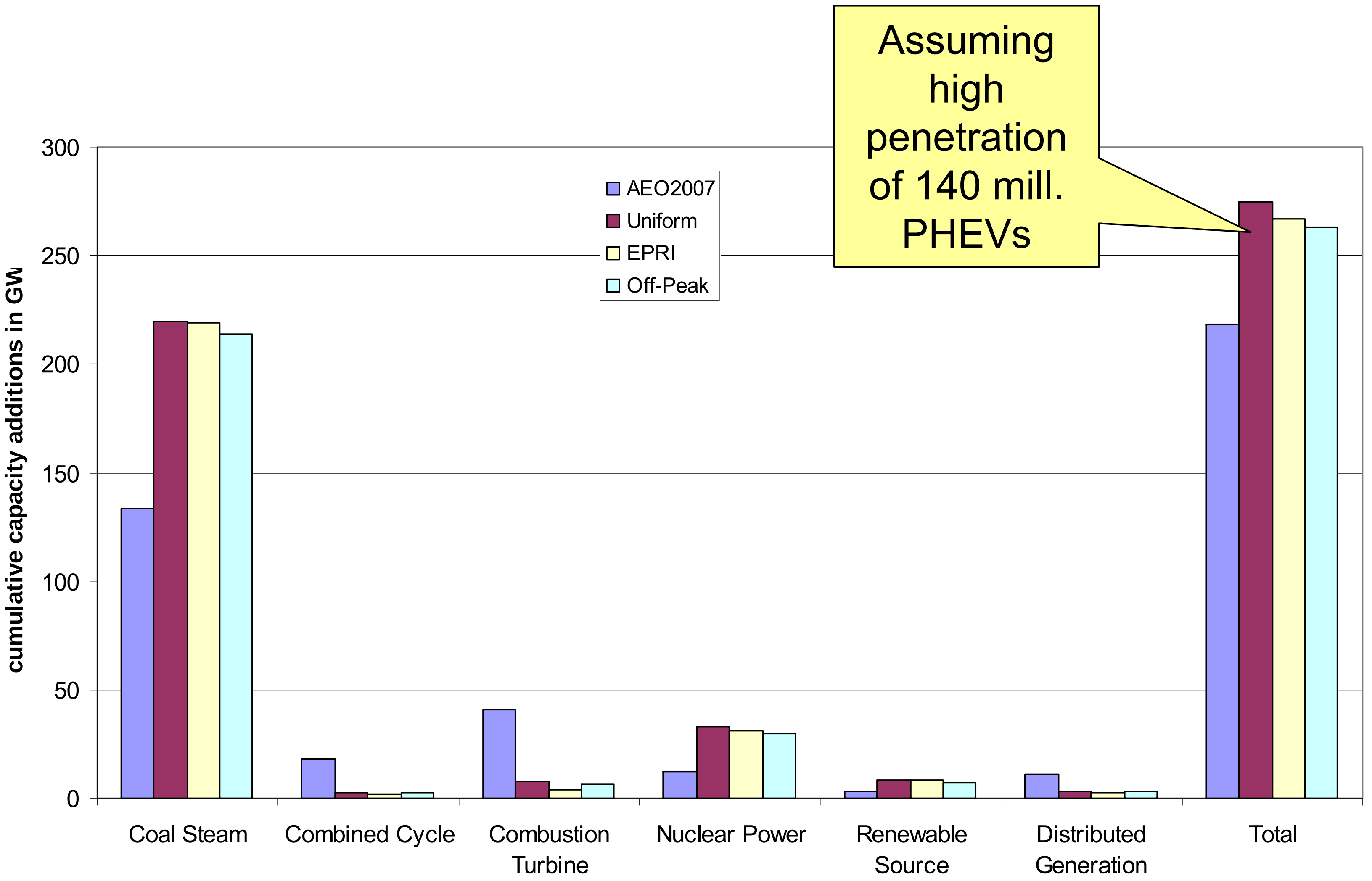
- Enhance NEMS (electric market model) model to represent different PHEV load shapes
- Assess if EERE's PHEV penetration model can be utilized in NEMS runs
- Exercise NEMS at various PHEV penetration levels and analyze results

Products and expected outcome

- Report
- Consult with EIA for incorporating enhanced NEMS model into AEO production runs

Pacific Northwest NATIONAL LABORATORY

Preliminary NEMS Results: Cumulative Capacity Additions in 2030 as a Function of Charging Profiles



Pacific Northwest
NATIONAL LABORATORY

Results and Next Steps

Results

- Developed enhanced NEMS model to study impacts of PHEV charging profiles
- Preliminary analysis performed based on AEO2007 Reference case

Next steps

- Consult with EERE on status of the PHEV penetration model and its ability to be integrated into NEMS
- Perform analyses with U of Michigan's penetration results

Additional Slides

National Survey on Consumer Adoption of Plug-in Hybrid Electric Vehicles

PI: Richard Curtin, University of Michigan

Project Objectives:

- Estimate the overall rate of consumer adoption of PHEV vehicles under different vehicle cost and fuel saving scenarios
- Determine the impact of economic factors (household and vehicle characteristics) and non-economic factors (environmental and technology) on PHEV purchases
- Assess impact of battery charging preferences on demand for off-peak electricity as well as availability of outlets where the vehicle is regularly parked

Project Methodology:

- Representative national sample of 2,500 consumers
- Survey conducted July to December 2008

Links to Other Projects:

- Data will be used as inputs to demand estimates by Sullivan and McManus
- Data used in estimates of consumer demands on national grid on off-peak hours

Expected Project Outcomes:

- Provide estimates of sensitivity of PHEV demand to various tax incentives
- Assess rate of expected growth in demand for electricity due to PHEVs

Market Models for Predicting PHEV Adoption and Diffusion

PI: Walter McManus, Head, Automotive Analysis Division of UMTRI, University of Michigan

- Goals and Objectives
  - An economic market model of the diffusion of PHEVs that is grounded in historical demographics, economics, and vehicle ownership by households
  - Grounded through the use of revealed preference information (UM Survey 1980-2003) on the value of fuel economy and the interest in technology
  - Built on current stated preference information (national survey, R. Curtain)
  - The model is designed to predict the adoption of PHEVs by U.S. households based on vehicle ownership (by type), demographics (age of household head, type of household, number of adults, number of children), economics (household income, employment of household members), and indicators of attitudes towards the environment and advanced technologies
  - Close collaboration with developers of the survey and agent based models
- Outcome and value
  - Disaggregated dynamic predictions for households by type, age of head, income to aid in understanding the diffusion process (including influences of across demographic groups and inertia in choices within a group as it ages)
  - A flexible aggregate U.S. predictive model that can also provide predictions by region

Pacific Northwest NATIONAL LABORATORY

Complex System Modeling of Consumer Adoption of PHEVs

PIs: John Sullivan & Carl Simon, University of Michigan

- Objective
  - Develop agent based modeling (ABM) that represents a virtual marketplace for following the penetration of new technologies (e.g. PHEVs) into the U. S. auto marketplace
  - ABM provides an alternative assessment to economic analyses
- Expected modeling outcomes
  - PHEV penetration curves
    - robustness of a market penetration
    - rate of penetration
  - Assessment framework to elucidate the influence of :
    - policy instruments (carbon taxes, CAFE, etc.)
    - competing technologies
    - fuel prices
    - circumstances and market conditions that reveal potential tipping points

Technological Barriers for Acceptable PHEV Performance and Cost

PI:Zoran Filipi, Mechanical Engineering Dept., University of Michigan

- Objective
  - Optimize the Plug-in Hybrid Electric Vehicle design and control using the
    - Advanced vehicle system simulation tool
    - Naturalistic driving data
    - Design targets derived from the survey of consumer attitudes
  - Establish representative PHEV configurations for given All Electric Range and Energy Consumption targets and estimate cost implications
- Methodology
  - Extract vehicle *driving and resting patterns* from databases of Field Operational Tests generated by University of Michigan Transportation Research Institute
  - Use the results of *consumer attitude* surveys from national survey (R. Curtain) to derive PHEV design targets
  - Provide representative PHEV configurations and usage patterns for analyses of *PHEV adoption, diffusion, grid reliability, transmission and distribution system in* Tasks 2c, 3 and 4
- Outcome and value
  - Characterization of PHEV design and performance-cost tradeoffs
  - Stochastic model of driving cycles suitable for optimization of complex PHEV systems
  - Analysis of vehicle trips and resting patterns for assessing the impact of PHEV charging on the power grid and the local distribution network

Pacific Northwest NATIONAL LABORATORY