Electric Vehicles – Impacts & Opportunities

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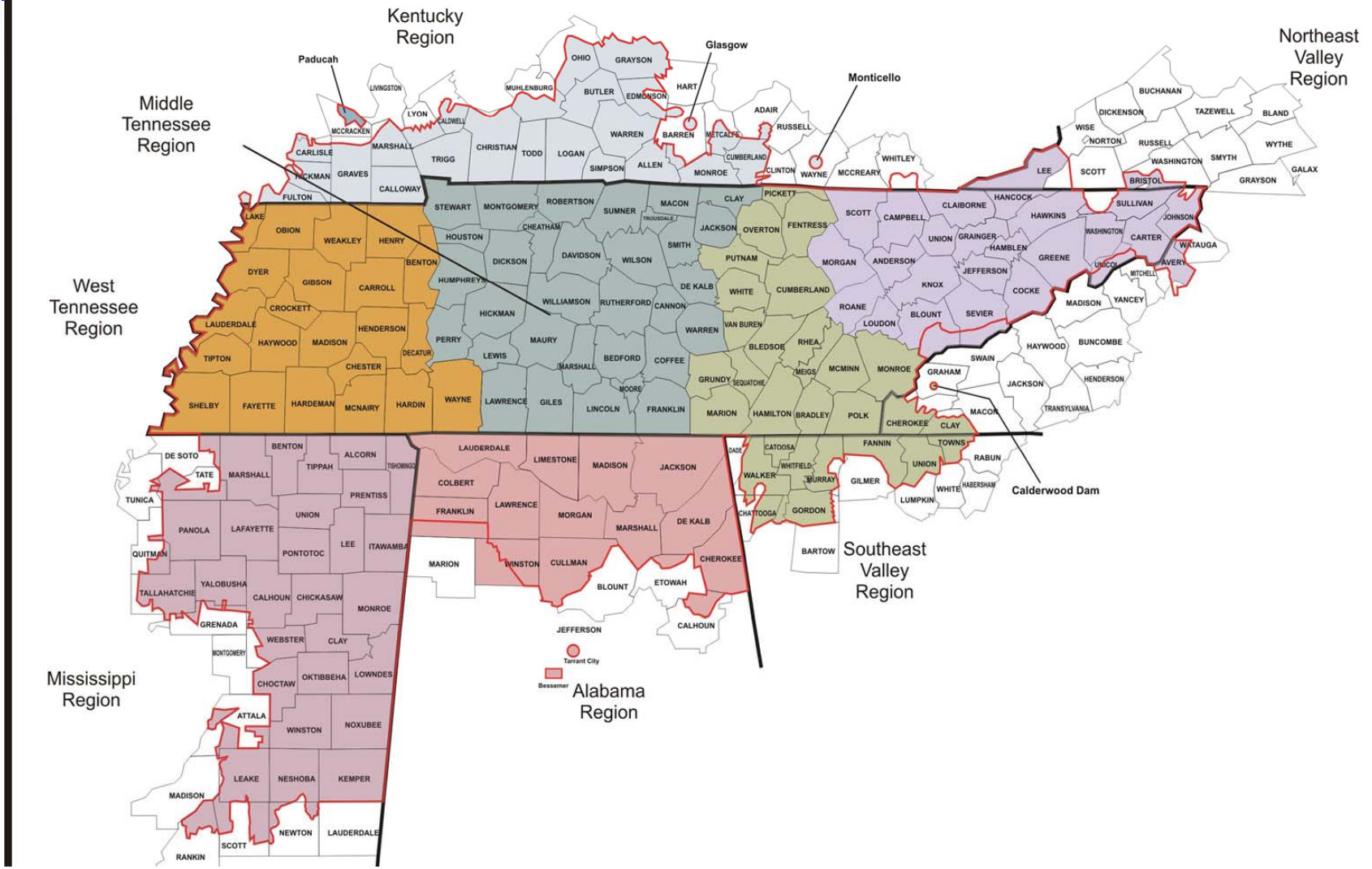
The TVA Power Service Area



Quick Facts about TVA

- Established by Congress in 1933.
- Board appointed by the President.
- Funded solely by power revenue.
- Serving Tennessee and portions of 6 other states, ~9 million people.
- Generator, wholesaler and regulator.
  - 155 Power distributors – Municipals and Cooperatives.
  - 59 Direct served accounts .
- Peak load 33,482 MW.

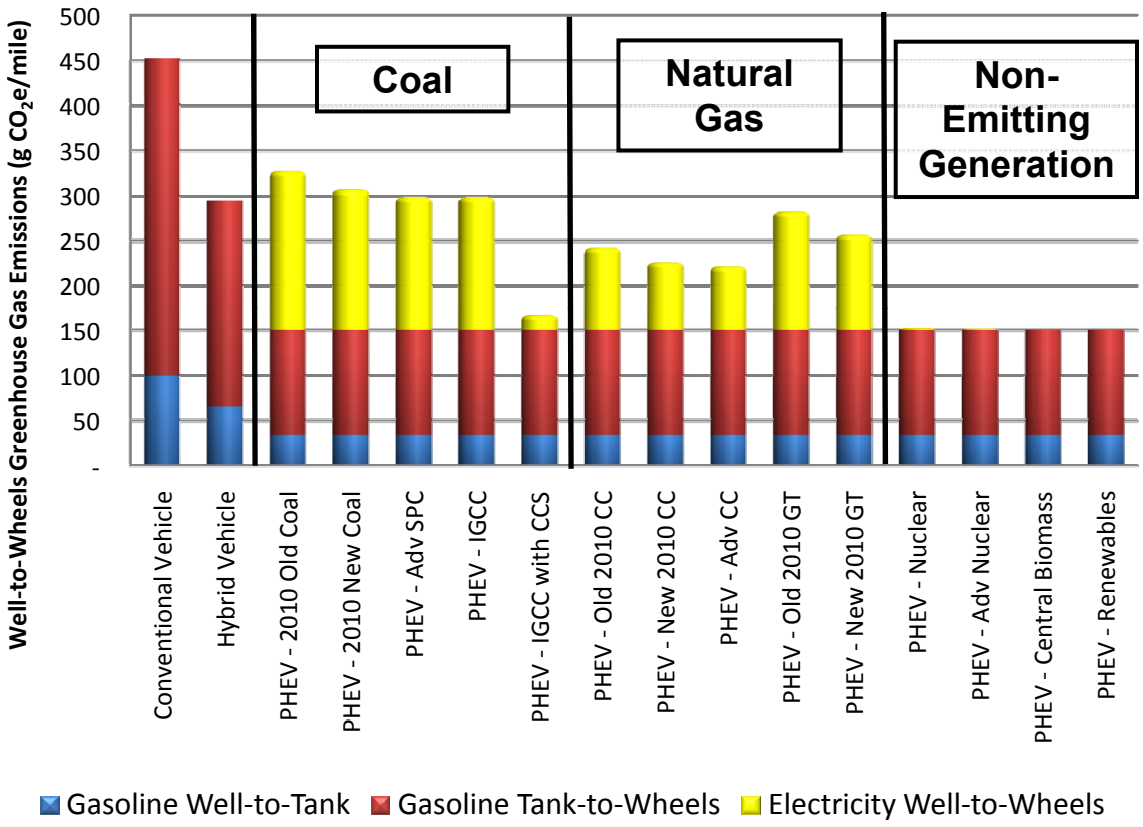
TVA Mission
- Alignment with Electric Transportation

TVA Missions

- **Economic development.** √
- **Environmental stewardship.** √
- **Affordable electricity.** √
- **Technological innovation.** √
- Integrated river system management

Environmental Assessment of Plug-in Hybrid Electric Vehicles (EPRI/NRDC Study)

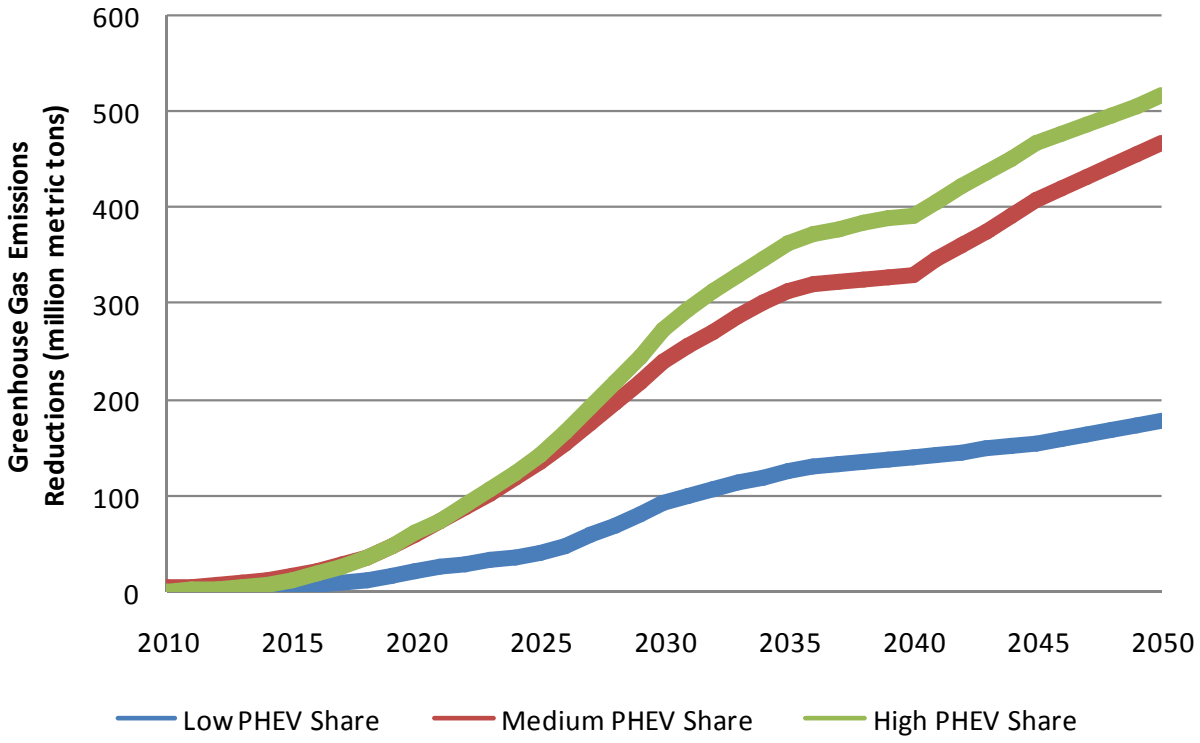
- Supported by TVA, other Utilities, and the Natural Resources Defense Council (NRDC)
- Volume 1 - PHEVs are a minimum of 30% better than conventional vehicles for Greenhouse Gas Emissions
- Volume 2 – PHEVs Improve Overall Air Quality
  - Ozone
  - Secondary $PM_{2.5}$
  - SO_x
  - NO_x



Source: EPRI report 1015325: Environmental Assessment of Plug-in Hybrid Electric Vehicles, Volume 1

Annual greenhouse gas emissions reductions from PHEV adoption

- There is the potential for a 400-500 million metric ton annual reduction in GHG emissions by 2050 nationwide (the US currently emits 6 billion metric tons annually)
- Petroleum reduction of 3-4 million barrels per day by 2050
- Reductions in TVA's territory are 4.7 MMTons by 2030 and 11.7 MMTons by 2050



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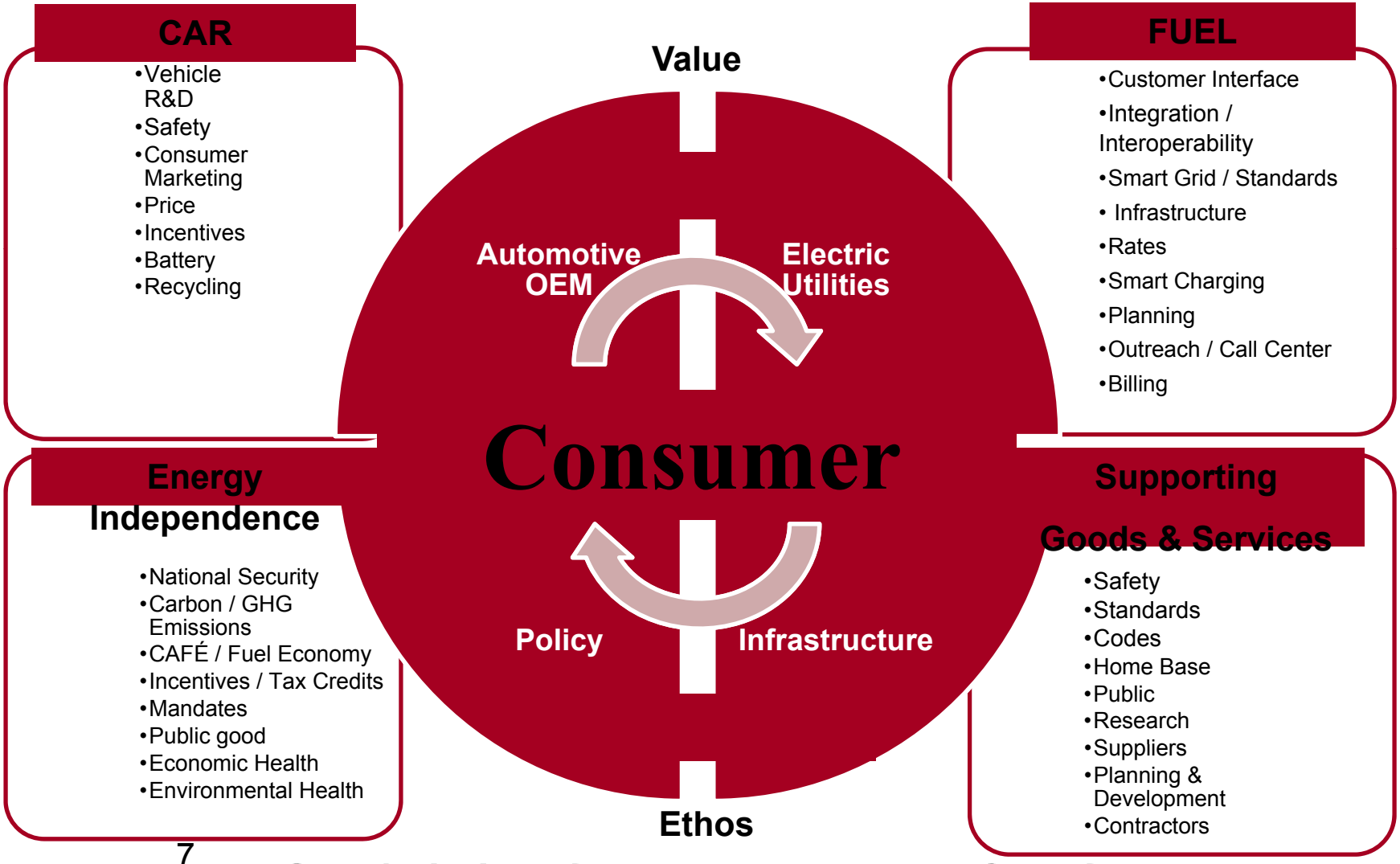
CONSUMER STAKEHOLDER MAP



Complexity in and among actors, systems & services.

Traditional Consumer Fuel Paradigm

House = Consumer's Largest Purchase Decision

Strong Consumer / Utility Dynamic Exists

Consumer billed / pays AFTER power consumption

- **Largest Consumer Purchases are traditionally mutually exclusive**
- **Power is paid for after its used**
- Fuel is prepaid prior to use
- **Traditionally NO Fueling at House**
- Many Public Fuel Choices

Vehicle = Consumer's 2nd Largest Purchase Decision

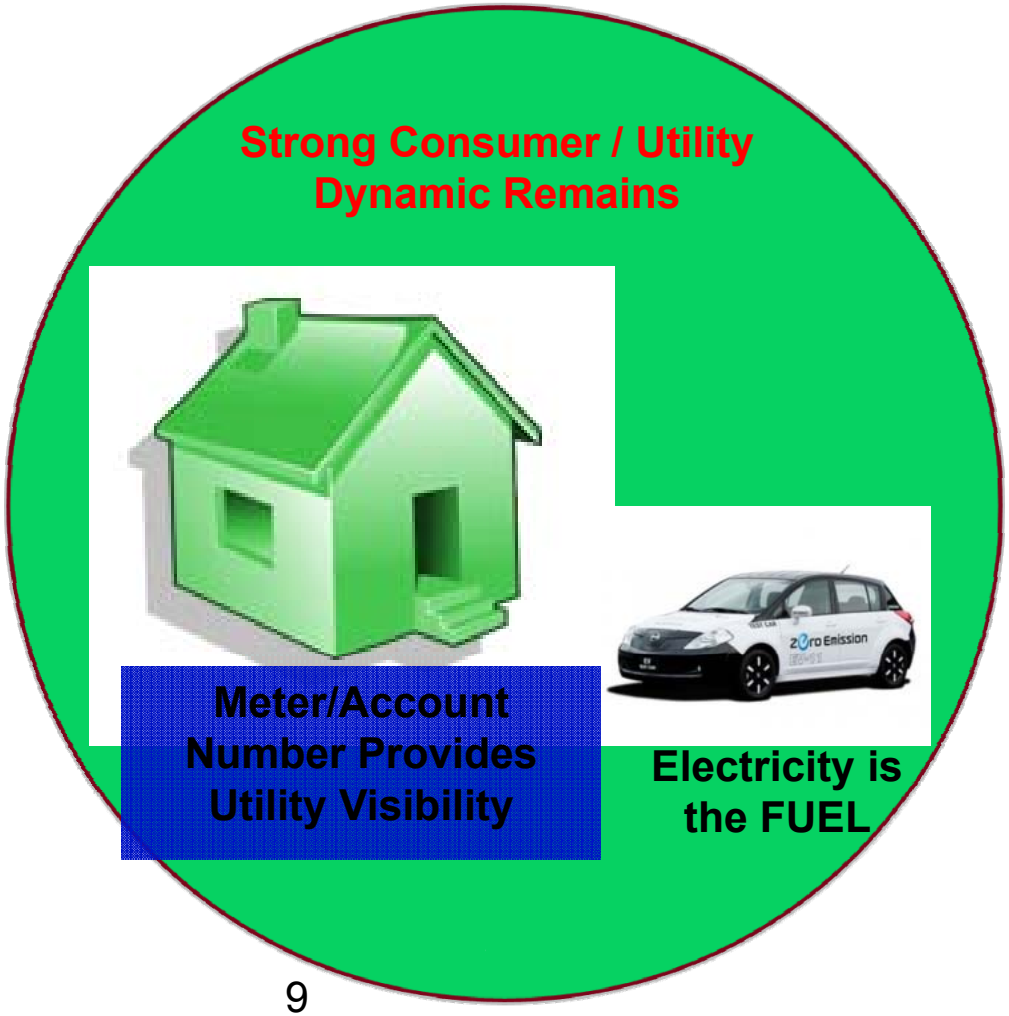
NO Utility Role

Consumer NOT brand loyal to FUEL

Utility has no role in vehicle purchase

New Consumer Fuel Paradigm

Home = Primary Re-Fueling Location



Utility Role

- ❑Existing customer dynamic with their utility will NOT be changed by vehicle using electricity as a fuel
- ❑Consumer experience will be directly affected by utility engagement
- ❑Power Bill is increased from more kWh usage; Consumer NET COSTS decrease from transportation Fuel and O&M savings
- ❑Utility will maintain PRIMARY point of contact for electrical issue resolution

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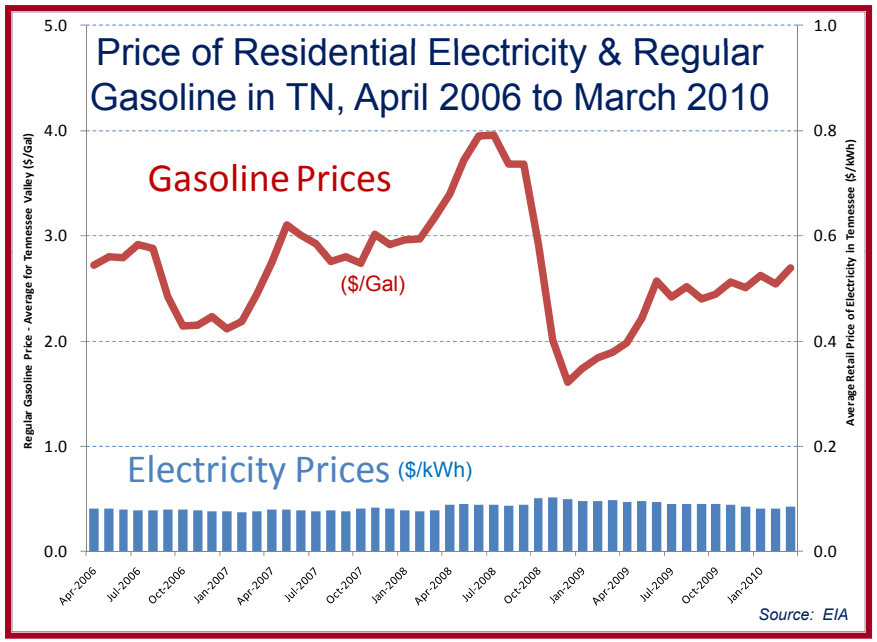
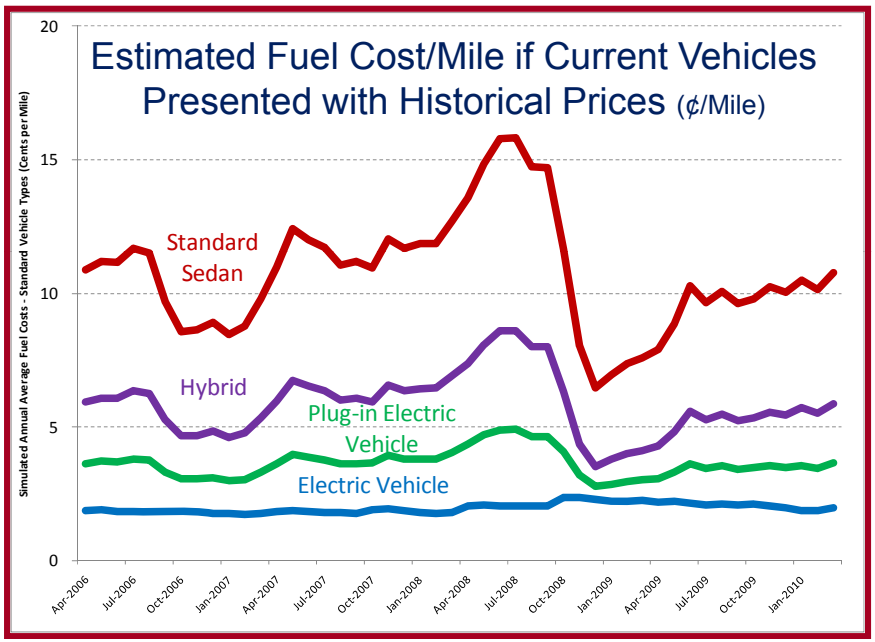
ELECTRICITY AS A TRANSPORTATION FUEL

ECONOMIC





- TVA Electricity is equivalent to $0.75 ¢ per gallon of gasoline

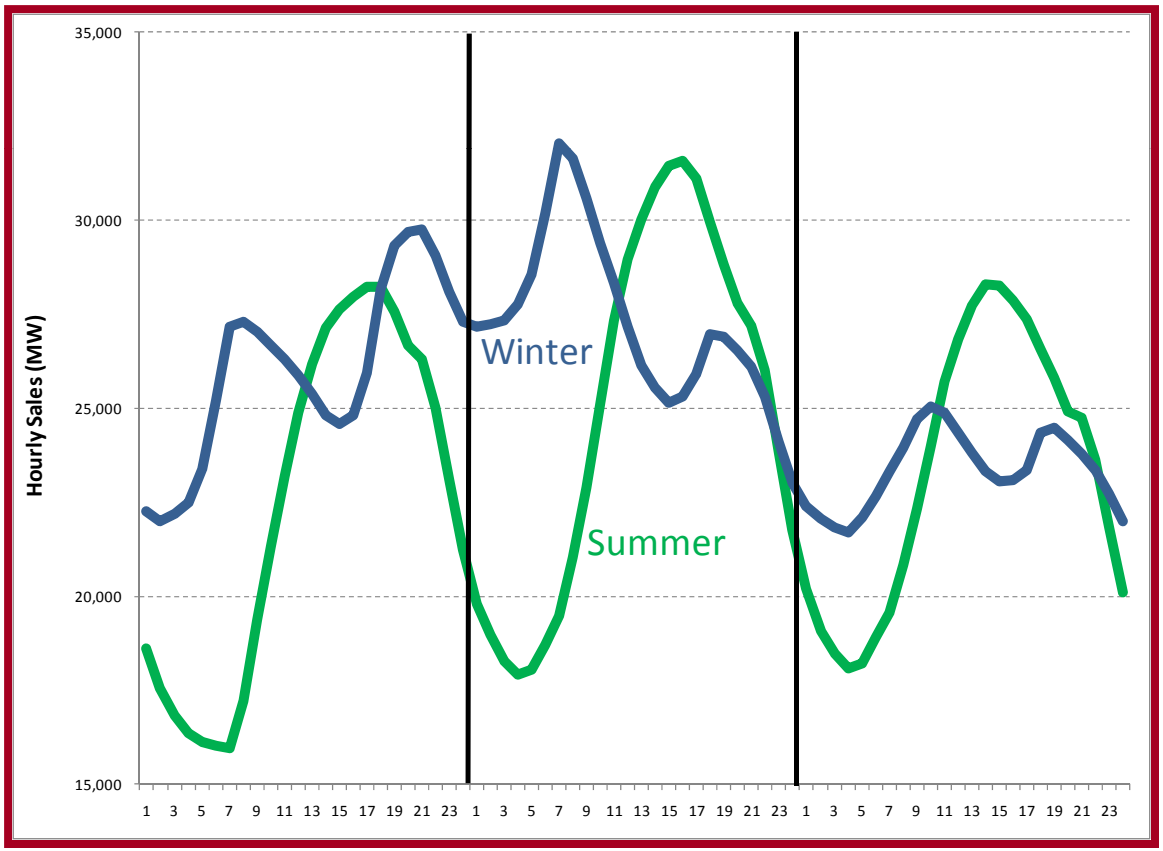
  …. ALL THE TIME!

- Electricity is consumer friendly - less volatile than gasoline and easier to estimate overall transportation fuel expense.

ELECTRICITY AS A TRANSPORTATION FUEL

ENERGY

TVA Hourly Seasonal Load Curves, Example Three-Day Periods in 2008



Dual Peaking System – Summer & Winter

Electric Transportation load will overlay an already-existing load pattern.

The Fuel Challenge:

Smooth it out

Options:

Education
Smart Charging
TOU
EV Rate

Why Utilities Should be Plug-In Ready

Central Air conditioning	3 – 20 kW
Water heater (40 gallon)	4.5 – 5.5 kW
Clothes dryer	1.8 – 5 kW
Plug-in Electric Vehicle	1.44 – 7.2 kW

Unplanned "*per capita*" load growth

We do not yet know how consumers will respond

First Plug-in Vehicles to Market
Very Different Grid Impacts!

Chevrolet Volt

- Extended Range Electric Vehicle (EREV - A plug-in hybrid with a guaranteed electric range).
- 40-mile electric range
- Charging:
  8-9 hours at 120V, 12A
  3 hours at 240V, 15A

Nissan Leaf

- Battery Electric Vehicle
- 100-mile range
- Charging:
  20 hours at 120V, 12A
  8 hours at 240V, 15A
  30 min at 400V, 150A DC

Charging Scenarios

Charger	AC Power Supply		Charger		Charge Time
Type	Volts	Continuous Current	Power	Location	
Level 1	110-120V	12 A	1.4 kW	On-board	18 h
Level 2	220-240V	15 A	3.3 kW	On-board	8 h
		32A (80A)	6.6 kW (20 kW)	On-board	4 h (1.2 h)
'Fast', or 'DC'	Input: 3 Phase Typically 480V AC		50-60 kW DC into the vehicle	Off-board – Vehicle controls the charger	<30 min

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EPRI PEV Distribution Impact Study – A Collaboration Initiative

- Detailed analysis of circuits, PEV impacts
- 45 circuits at 25 utilities, including:
  - Nashville Electric Service,
  - Middle Tennessee EMC,
  - Chattanooga EPB,
  - Knoxville Utilities Board.
  - Memphis Light Gas & Water
- Compilation and comparison across different distribution systems.

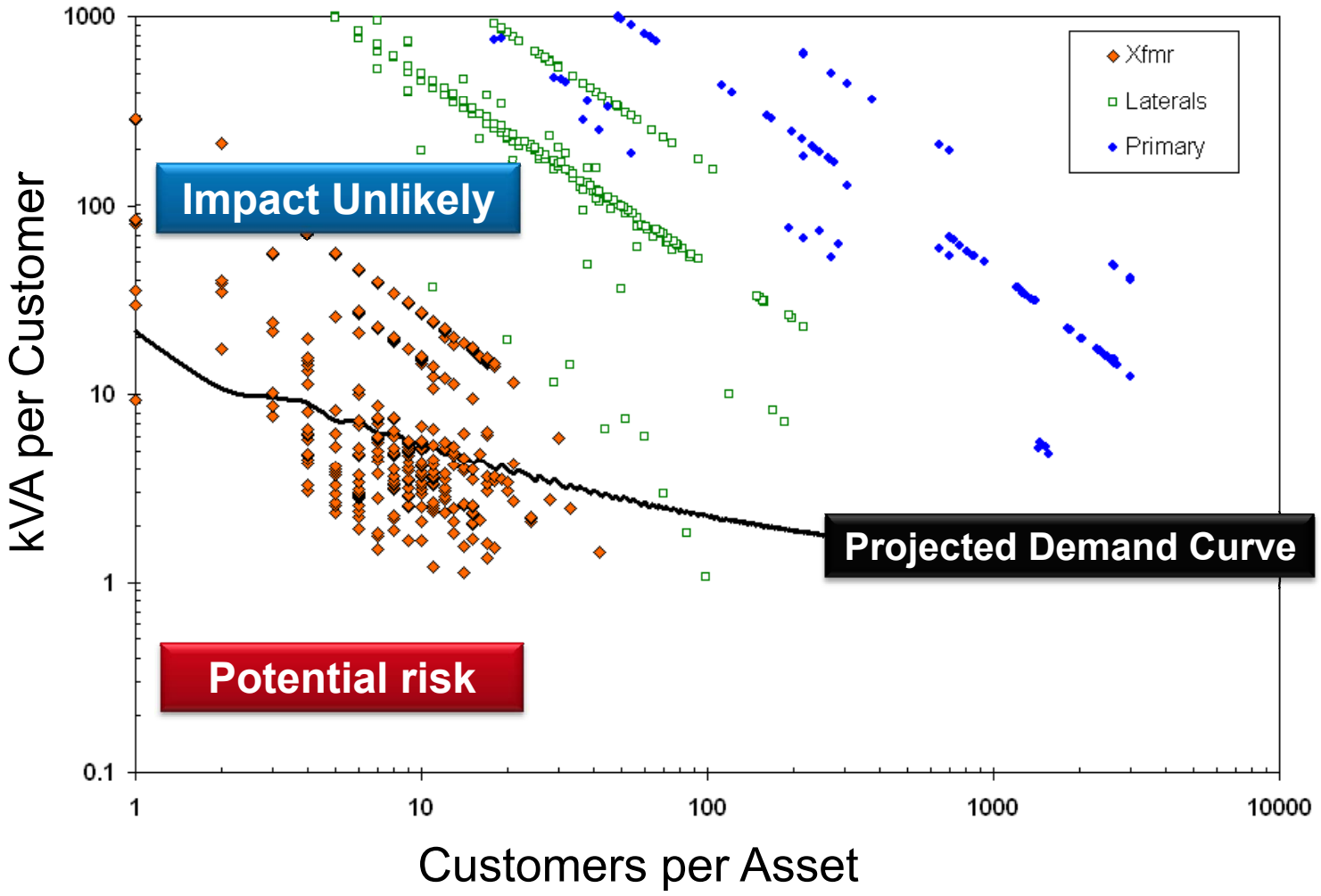
Near-term Planning Horizon

Load only operation
Customer behavior driven
Market projections
Mainly residential charging

Evaluated Impacts

Feeder demand
Thermal overloads
Steady-state voltage
Losses
Imbalance
Power quality

Typical Asset Risk Analysis



Key Findings – Asset Risk

- Greatest impact – transformer life.
  - Transformers with low kVA rating per customer.
  - At constant kVA/customer, fewer customers/ transformer reduce diversity, increase risk
- PEVs loads exacerbate pre-existing problems.
  - Undersized secondaries.
    - Long runs, smaller diameter
    - Length, diameter, often un-documented.
  - Lower voltage primaries – e.g. 4 kV

General Study Findings – Phase I

Minimal near-term impacts expected

Negligible Impacts	Local Risks - Reliability, Voltage	Planning Adjustments
• Losses • Imbalance • Power Quality • Primary Voltage	• Close to the customer • Low capacity per customer • Undersized secondaries	• Equipment sizing • Asset-to-customer allocations • Transformer ratings

Grid Impact Study – Phase II (pending)

- Area-Wide Asset Risk Planning and Evaluation Tool
- Generalize, Automate, & Apply Phase One Learnings
- Provide Utility tool for easy application
- Broader than PEV Impact
- Scope - TBD

SAE Power Quality Standards,- J2894

- PQ Standards for Chargers
  - Attainable goals
  - To protect utility, customers
  - To protect public interests (efficiency)
- Standards for AC Power Supply
  - Attainable goals
    - For utilities.
    - For alternate power supplies.
  - To protect charger electronics.

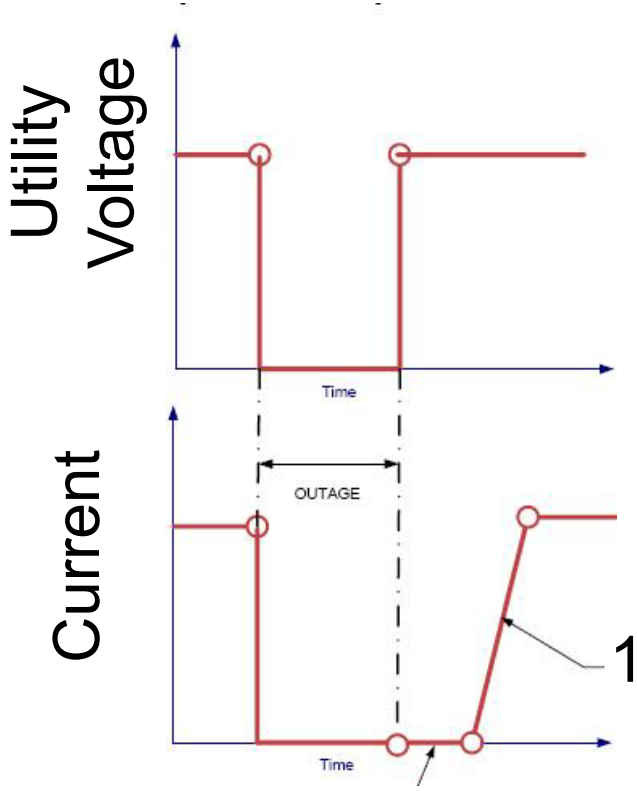
SAE Power Quality Standards,- J2894 Part 1 –Target parameters –in draft

Power Quality Standards for Chargers –

Parameter	SAE J2894	EPRI IWC (1990s)
Power Factor	95%	95%
Power Transfer Efficiency	90%	85%
%Total Harmonic Distortion (current)	10%	20%
Inrush Current	120% of nominal, max. (after 50 ms, level 1) (after 100 ms level 2)	Specified Value

SAE Power Quality Standards,- J2894 Part 1 –Target parameters

Cold Load Pickup – proposed



1 Amp/second, max.

2 Minutes (minimum)

SAE Power Quality Standards,- J2894 Part 1 –Target parameters

Power Quality Standards for AC Service

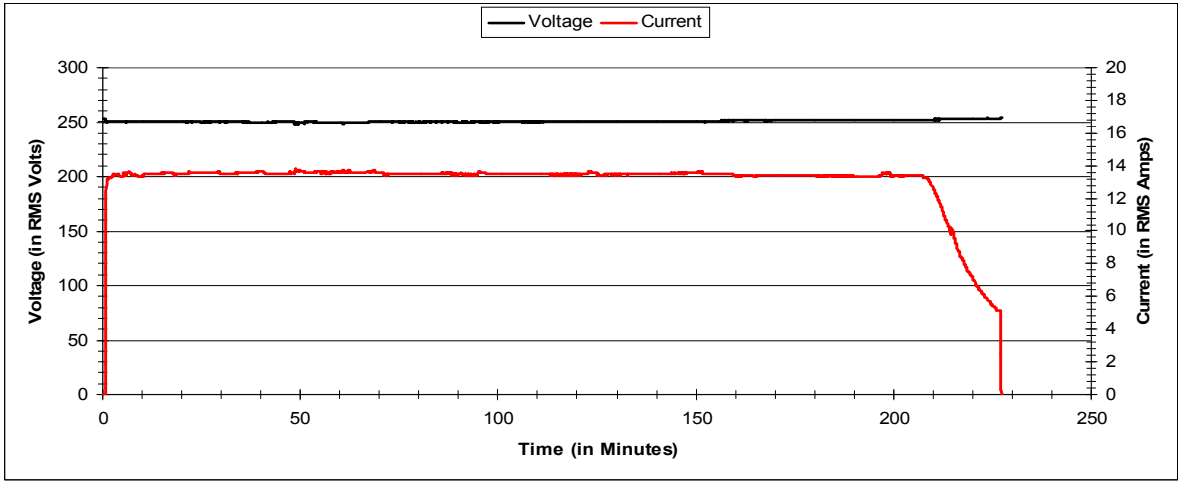
Voltage Range	SAE proposed	EPRI IWC (1990s)
Voltage Range	90-110% nominal	90-110% of nominal
Voltage Swell (1/2 cycle, minimum)	175% of nominal	180% of nominal
Voltage Surge (momentary)	6 kV	6 kV
Voltage Sag	80% for 2 s	80%
Voltage Distortion	2% max	N/A
Momentary Outage	0 V for 12 cycles	0 V for 12 cycles
Frequency Variation	+/- 2%	+/- 2%

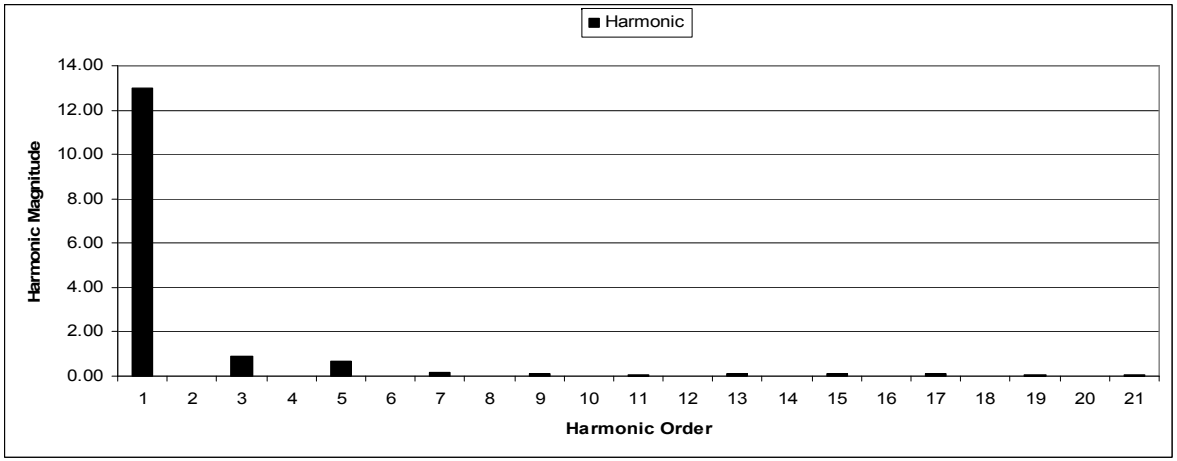
SAE Power Quality Standards,- J2894 Part 2 –Testing Procedures - pending

- Work has just begun.
- Grid and Charger interaction
  - Charger PQ during Grid Sags & Surges
  - Charger Protection during Grid sags & Surges
- Scope of tests may be controversial.
  - Limited to power conversion electronics?
  - Auxiliary loads?
  - Heating cooling loads?
- Efficiency standard driven by California's need for "Low Carbon Fuel Standard".

Chevy Volt

- A Chevy Volt was monitored during charging
  - 250 Volts, ave.,
  - 13 Amps, ave.
- Complete charge cycle, 3.8 hours.
- Sampled every 3 seconds.
- 9.37% $iTHD_{ave.}$
- 1.42% $vTHD_{ave.}$





DC Fast Charger Demonstrations

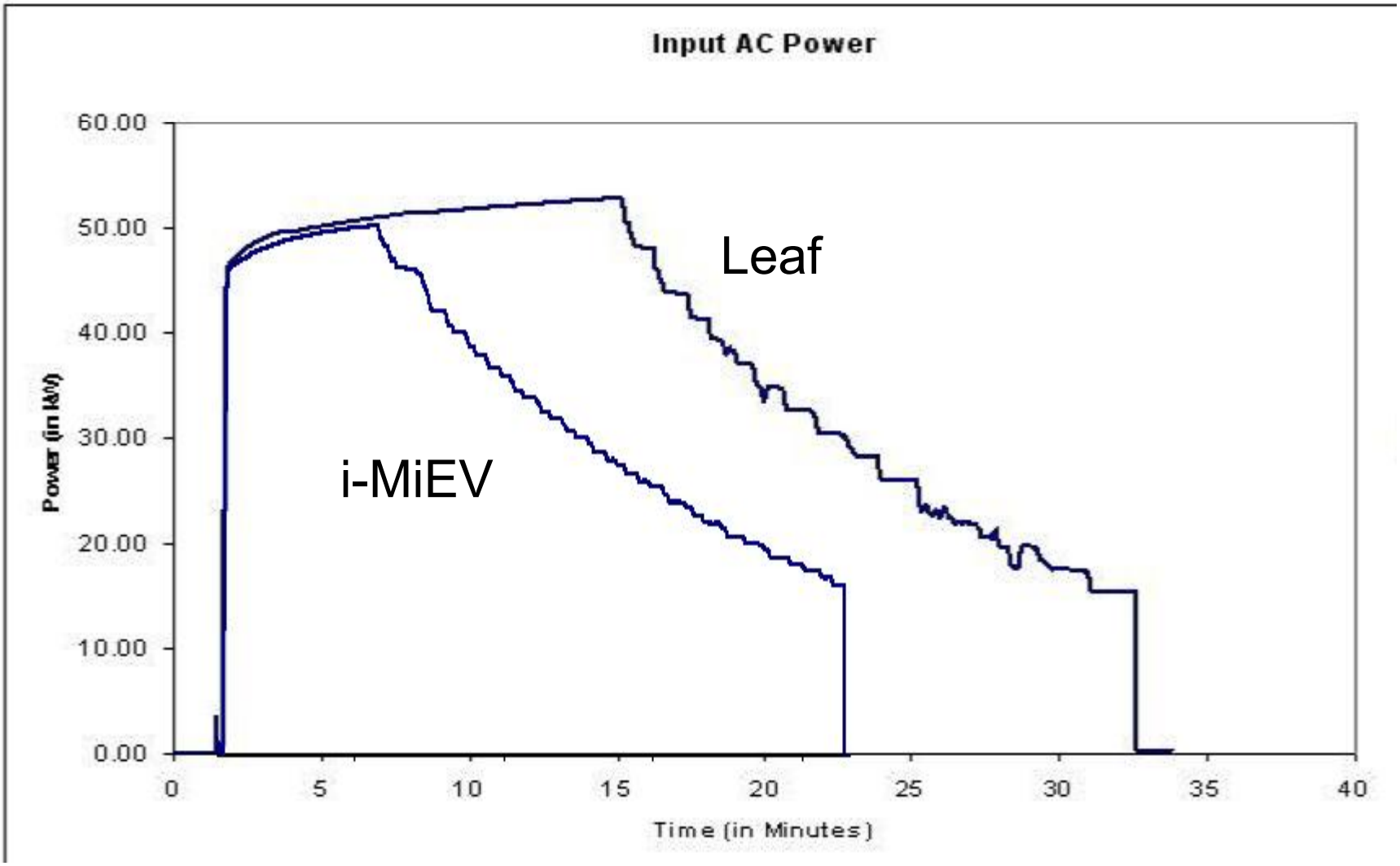
- CHAdeMO system developed by TEPCO/JARI
- Widely deployed in Japan
- Being deployed in US as part of DOE projects
- PG&E Demo underway
  - Two sites (San Francisco and Vacaville)
  - Ongoing testing of Mitsubishi i-MiEV and Nissan Leaf at PG&E
- TVA /EPRI Solar Assisted Charging Station in Knoxville.

Fast-Charge Infrastructure — ecotality

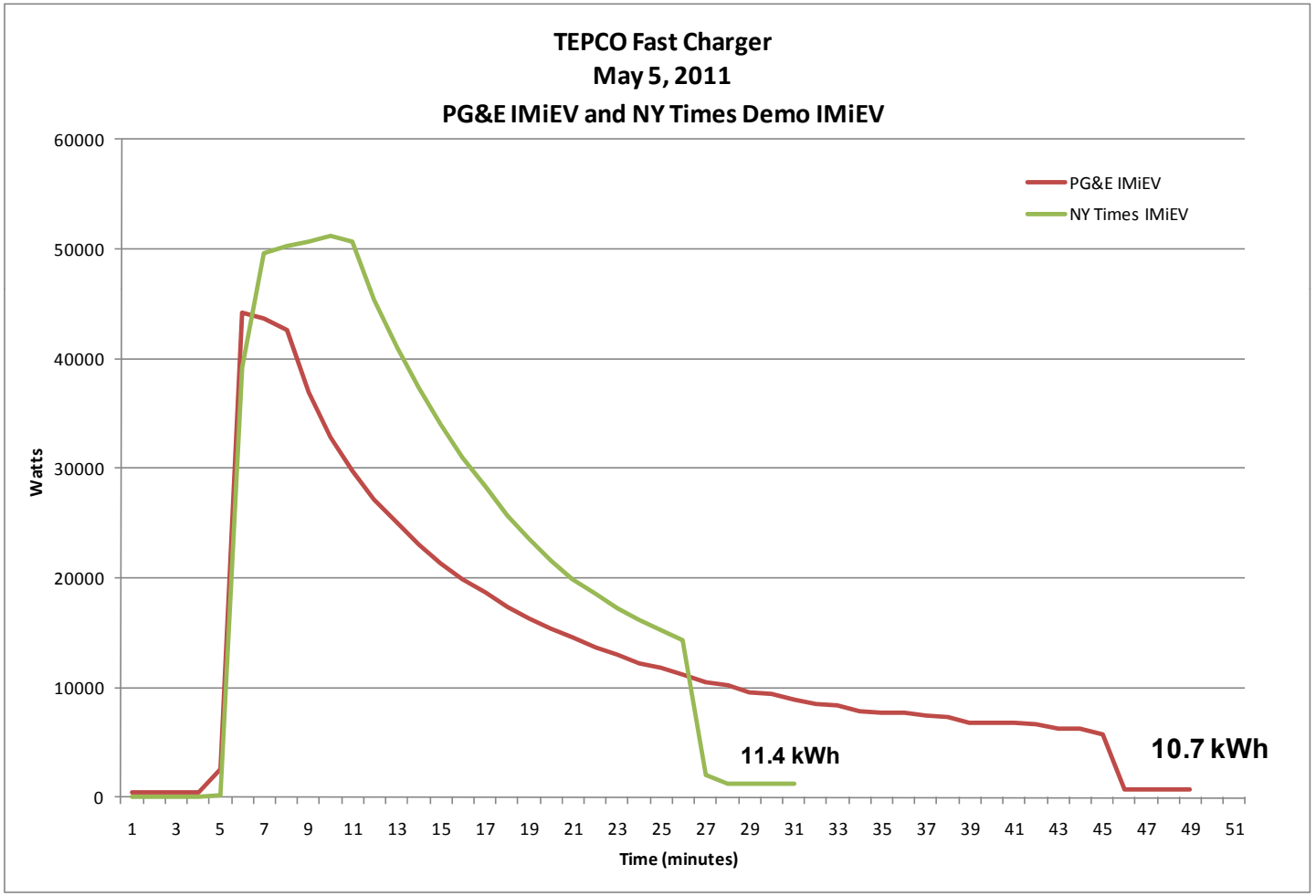
- 260 total Level 3 Chargers (~ 40kW)
- ~ 50 Level 3 chargers in each market area
- Telematics interface provides status
  - Price
  - Availability
- Project Partners:

Bovis Lend Lease, bp, CBRE CB RICHARD ELLIS, Cross Country Automotive Services, ATX

Charge Profiles for Leaf and i-MiEV - with DC Fast Charger



Other Fast Charge Data



Power Quality & Plug In Vehicles - Summary

- PEVs will impact distribution circuits
  - Impact is local, manageable.
  - Planning tools are needed

- Charging profiles are being gathered
- OEM Chargers appear to meet PQ Standards
- Prototypes – not so much
- Additional work needed:
  - Testing standards and procedures
  - Utility control for cold load pickup

Solar Charging Sites in Tennessee

TVA EPRI

- Knoxville – EPRI Site Complete
- Nashville – Site Agreement
- Memphis – Site Agreement
- Chattanooga – 2 Sites, 1 Agreement

Oak Ridge National Lab

- ORNL Site Complete,
- others pending in Knoxville, Nashville

Nissan

- Franklin HQ and Smyrna Factory

TVA- EPRI Solar Charging Station with six Chevrolet Volts

Nissan Leaf – 'Anecdotal Experience' – not a scientific test

- Mild Weather, 68-69 F (~20 C) No HVAC,
- Moderate speed, cruise control set at 38 mph.
- Level Ground, Oval Track.
- First Warning at 94.6 miles, 11 miles more predicted.
- Second Warning at 110.3 miles, 4 miles more predicted.
- Range Prediction then shows '----'
- 'Turtle Mode' warning light at 118.8 miles
- Cruise control drops out
- Max speed begins to drop steadily
- Coast to stop at 120.2 miles
- Tow to charging station, charge to 100% with 26.1 kWh