



# Electric Vehicle Grid Integration Research

## *Analyzing PHEV Impacts on Distribution Transformers in Hawaii*



**Tony Markel**  
**Mike Kuss**  
**Mike Simpson**

**[Tony.Markel@nrel.gov](mailto:Tony.Markel@nrel.gov)**

**Electric Vehicle Grid Integration**  
**National Renewable Energy**  
**Laboratory**

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# NREL Role in Grid Integration of Vehicles

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- *Understanding usage profiles, benefits, and battery life*
- *Integration with renewable resources*
- *Interoperability with grid – standards development and testing*
- *Exploring grid services technology*

# PEV Grid Integration Research Spectrum

Days to  
Years

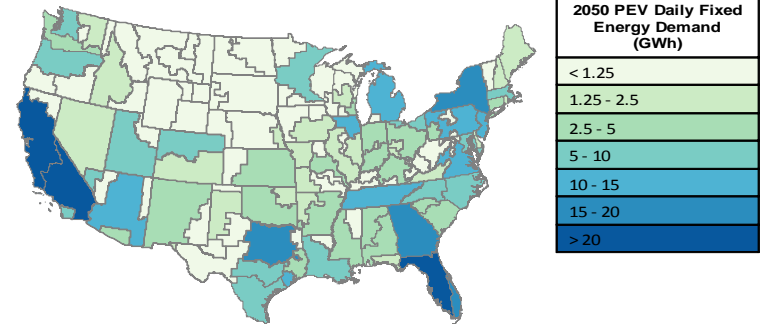
- **Renewable Electricity Futures Study**
  - Future forecast and energy dispatch

Minutes to  
Days

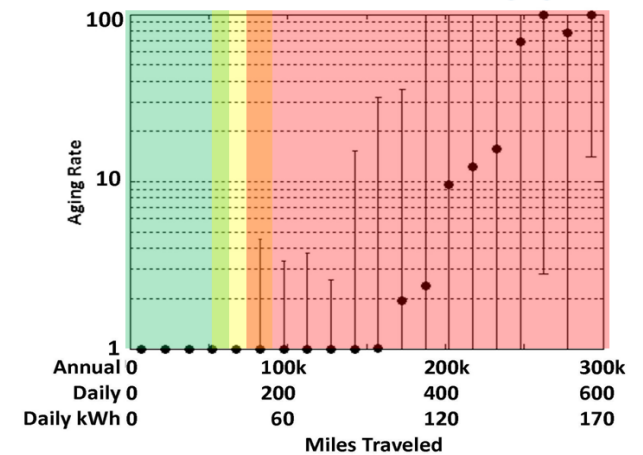
- **Transformer Distribution System Impacts**
  - Loads and temperatures of distribution components

Subsecond  
to Minutes

- **Component Interoperability Testing**
  - Operational response and communications for management



Transformer Aging vs. Total Mileage  
25kVA, 3.3 kW Charging



# EV Distribution System Impacts

- Customer:
  - U.S. Department of Energy's Hawaii Clean Energy Initiative (HCEI)
  - Also working directly with the Hawaii Electric Company (HECO) and HCEI Transportation Working Group
- Status:
  - Completed forecasting of impacts on distribution grid residential transformers due to various EV charging scenarios
- Remaining work:
  - Currently under discussion but could include deployment of managed charging system

# Key Questions

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**Under what PHEV penetration scenarios will distribution transformer impacts occur?**

**How might TOU rates affect the distribution system impacts?**

**How does public charging availability affect residential charging loads?**

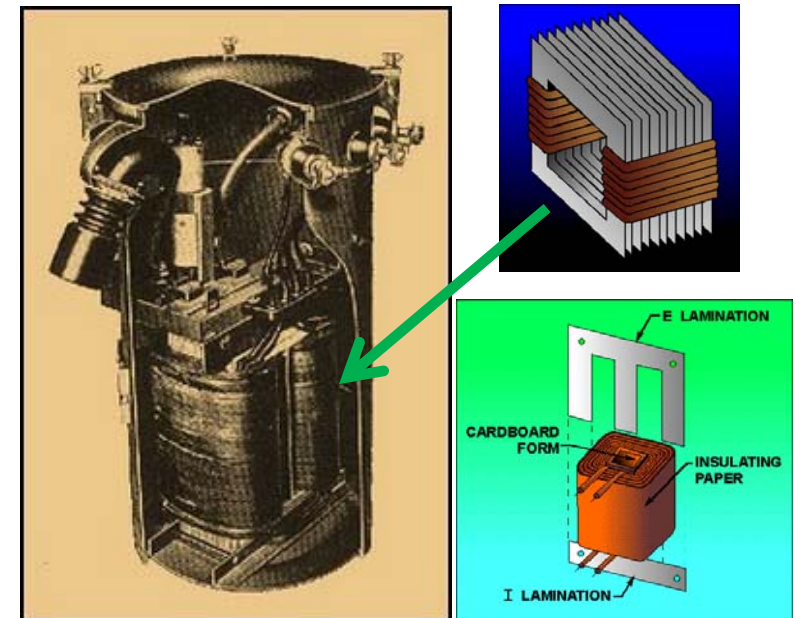
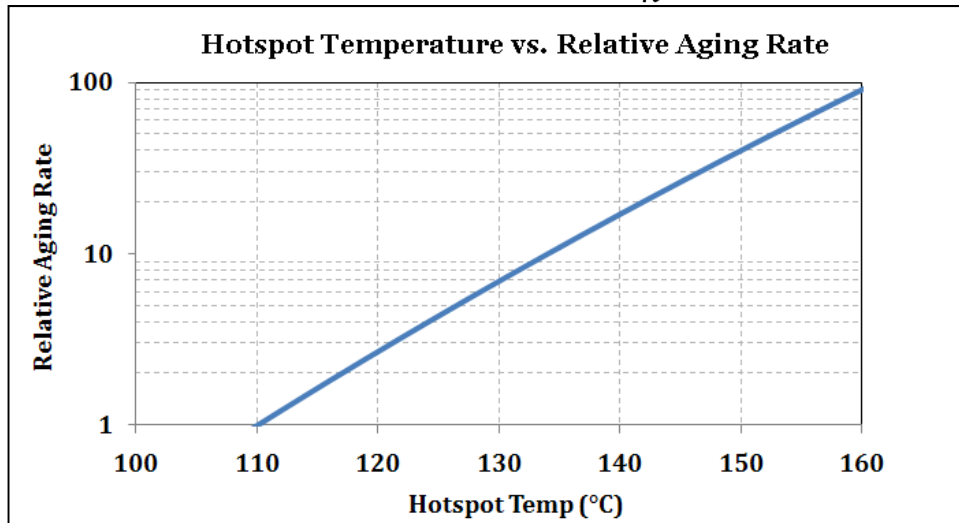
# How Transformers Degrade

- Chemical bonds within voltage-insulating paper & oil breaks down above 110°C
- The reaction depends upon time (linear) and temperature (exponential)
- Hotspot temperature  $\theta_h$  determines reaction rate:
- The aging rate for a transformer has been empirically determined and published in IEC 60076 and IEEE C57.91:

$$V = \exp\left(39.16 - \frac{15000}{\theta_h + 273}\right)$$

$$\theta_h = \underbrace{\theta_o}_{\text{Top-oil T}} + \underbrace{\Delta\theta_h}_{\text{Hotspot T rise}}$$

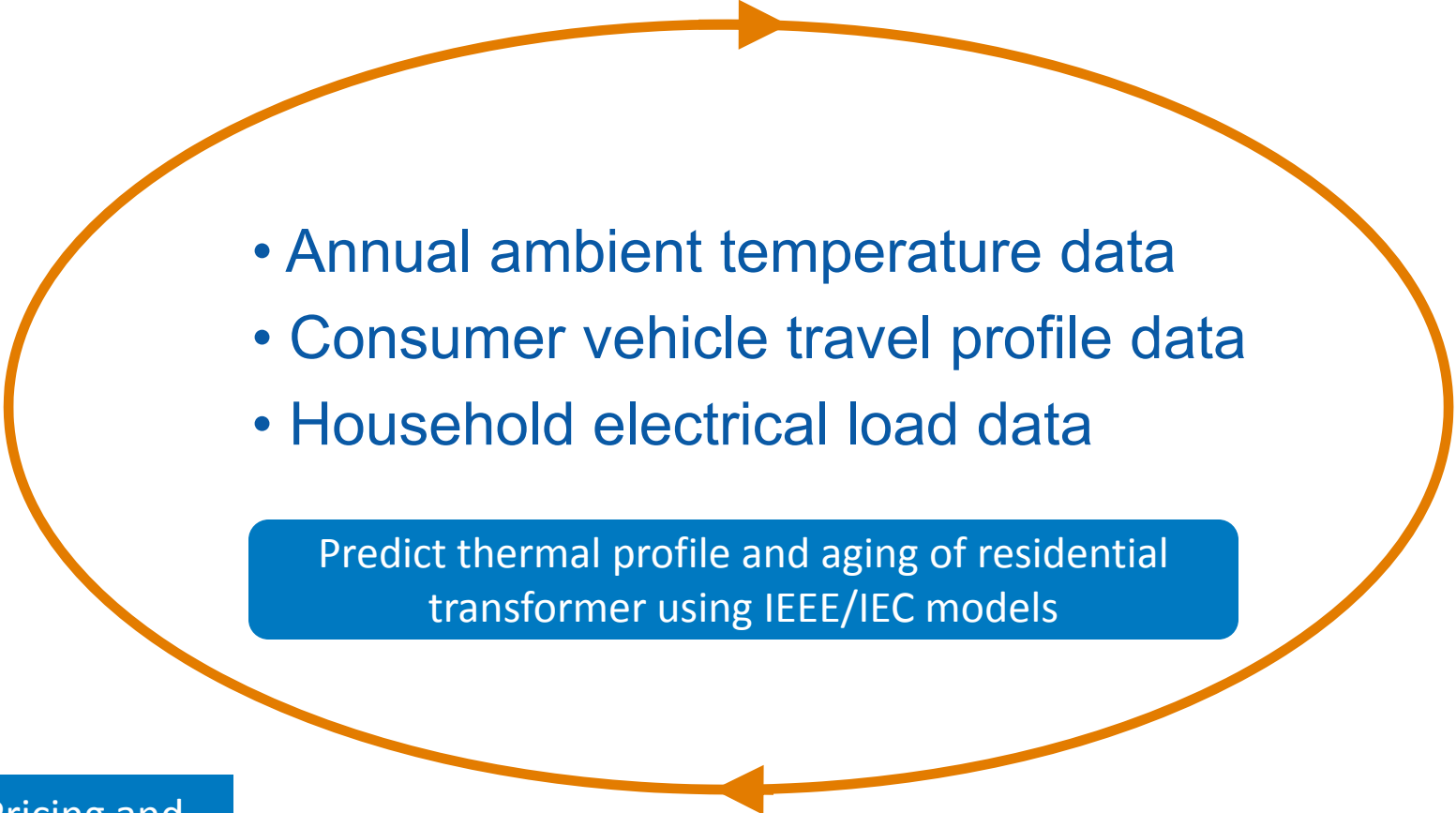
Function of load & ambient temp      Function of load



[http://www.sayedasad.com/fundamental/index\\_transformer.htm](http://www.sayedasad.com/fundamental/index_transformer.htm)  
<http://cenvironment.blogspot.com/2009/12/electrical-transformers-utility-poles.html>

# Approach

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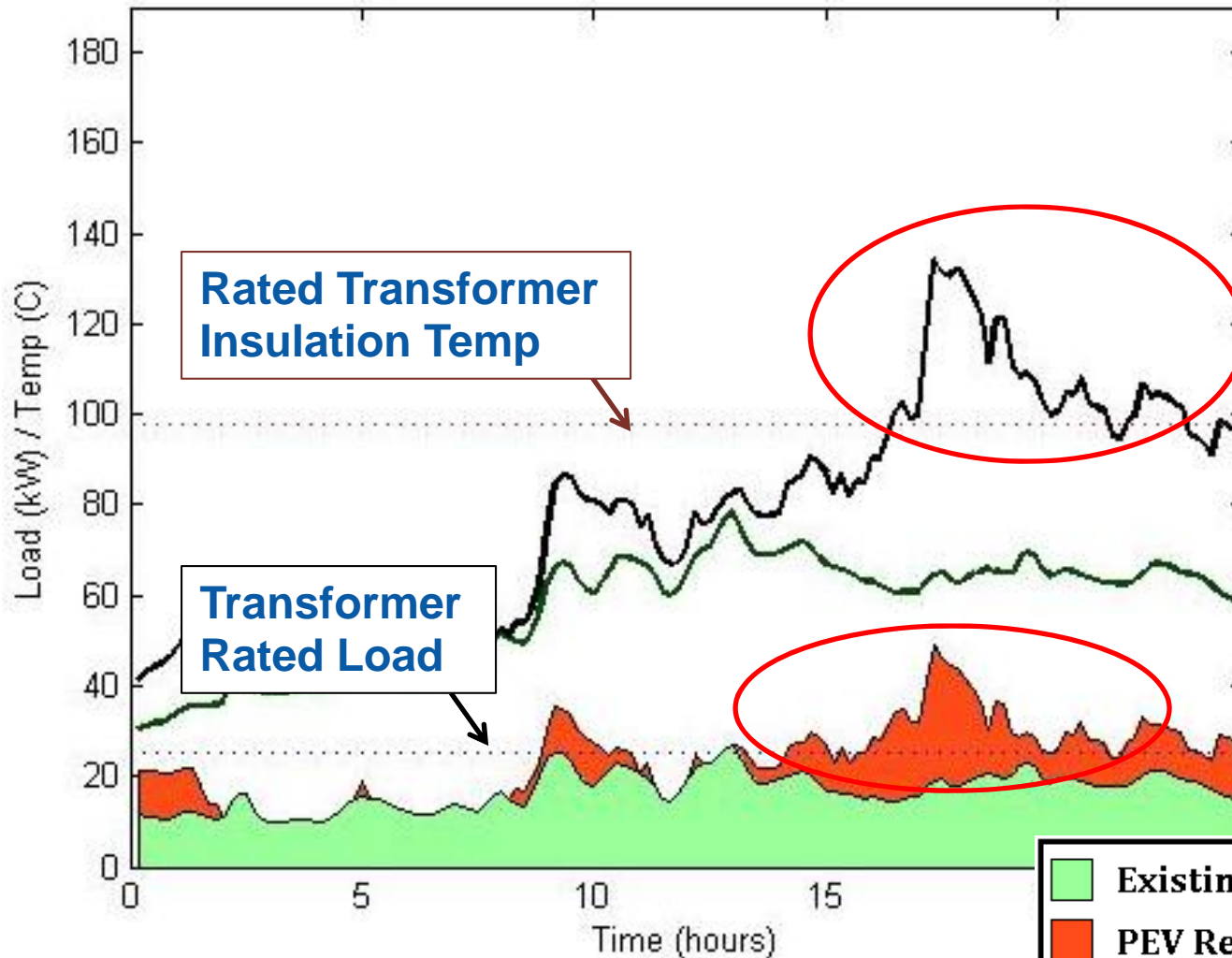
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- Annual ambient temperature data
  - Consumer vehicle travel profile data
  - Household electrical load data


Predict thermal profile and aging of residential transformer using IEEE/IEC models

TOU Pricing and Opportunity Charging included as external factors

**Remix travel and load inputs to create a spectrum of results**

# With high penetration of PEVs and many houses per transformer, some overloading can occur.








**20**   
**houses / 25kVA transformer**  
 \*Home Charging Only

← Light load 3-5      8-12      Heavy load 15-20 →

**100%** 

penetration of EVs  
 with 2.6 kWh of  
 charge required per  
 PEV (36 vehicles) @  
 3.3 kW charge rate.

-  Existing House Loads
-  PEV Residential Loads
-  PEV non-Residential Loads
-  Transformer Temperature
-  Transformer Temperature (+PEVs)

Preliminary results from 1/17/2011  
 Thermal model and transformer aging rates  
 from IEC 60076 and IEEE C57.91

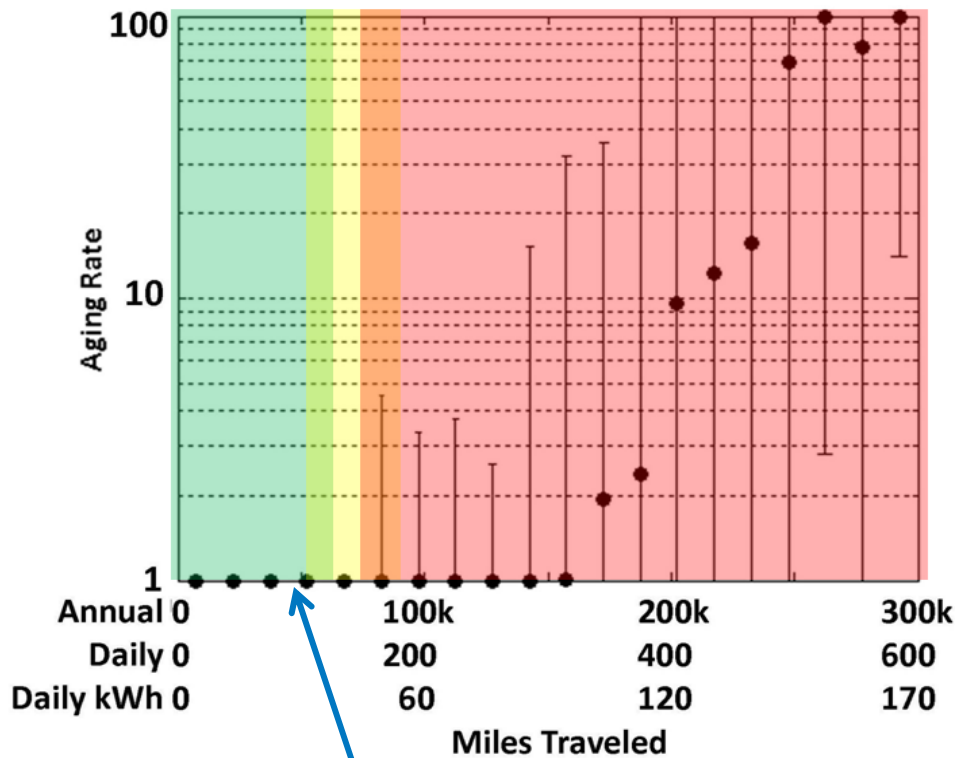
# Aging Rate as a function of Transformer Mileage

Green - "transformer upgrade likely unnecessary"

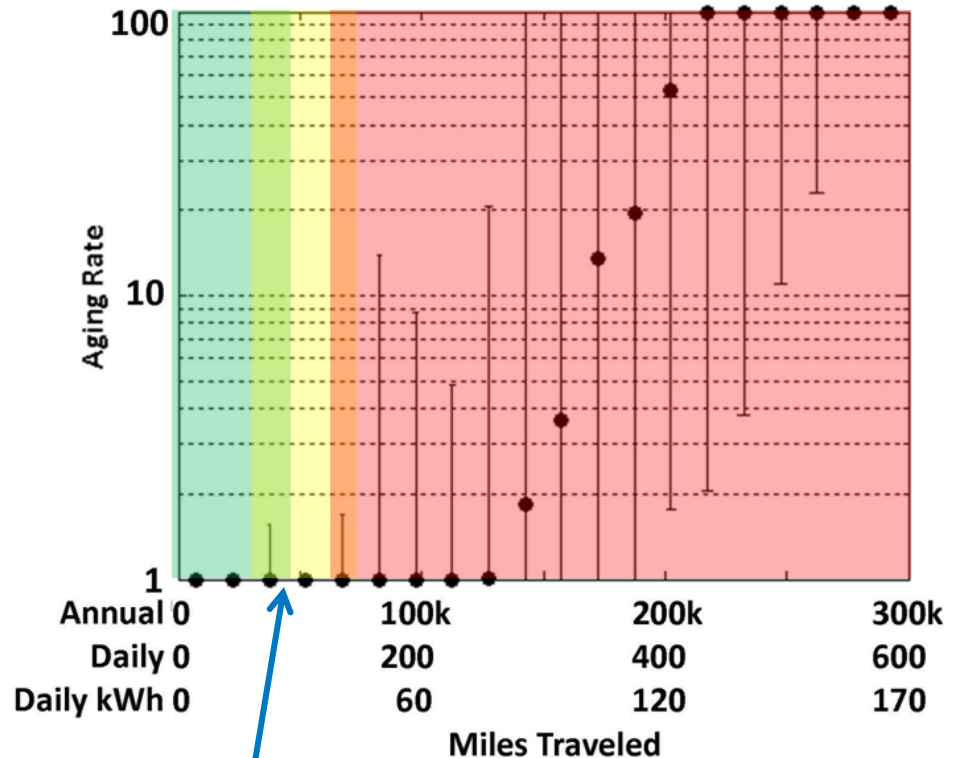
Yellow - "transformer upgrade likely necessary"

Red - "transformer upgrades definitely necessary"

Transformer Aging vs. Total Mileage  
25kVA, 3.3 kW Charging



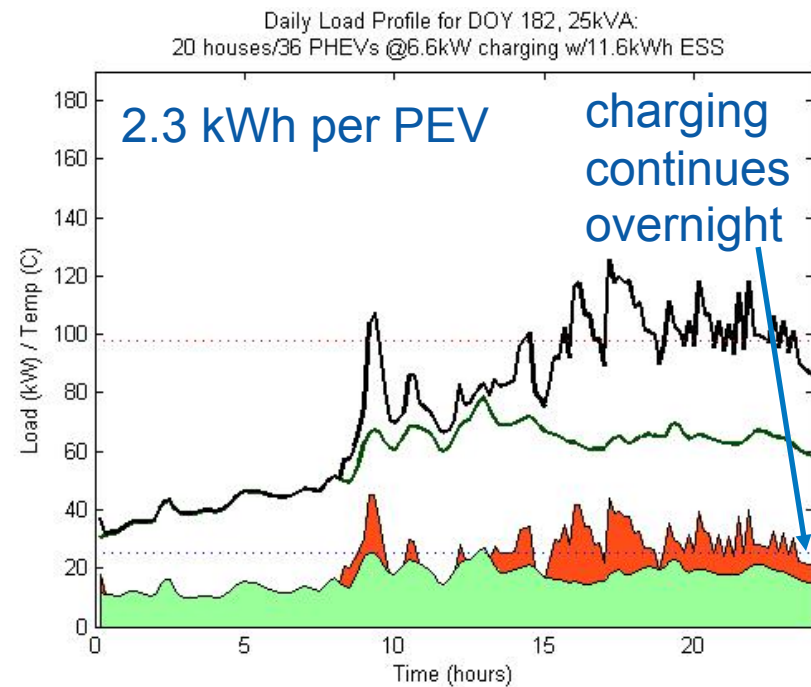
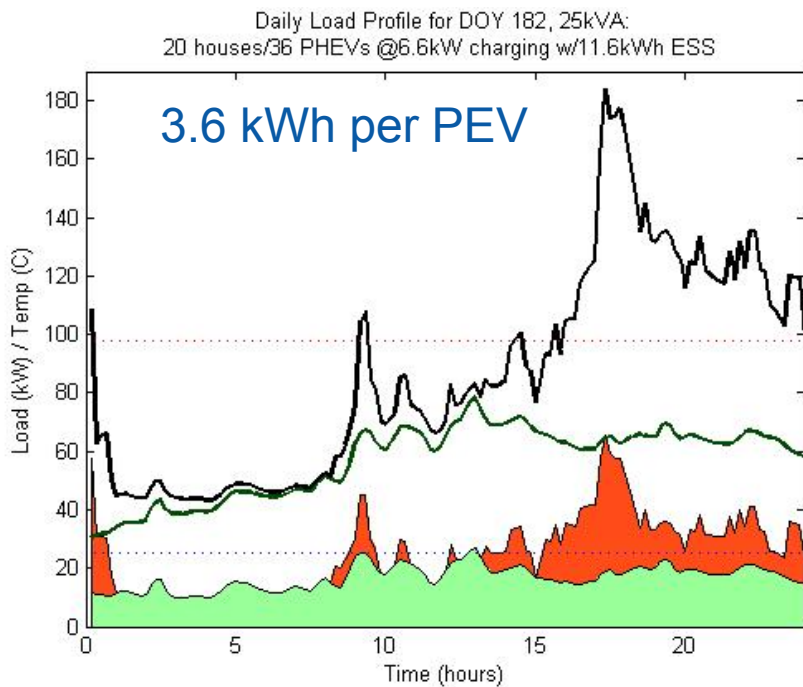
Transformer Aging vs. Total Mileage  
25kVA, 6.6 kW Charging



40-50% penetration assuming ~12 homes per transformer

# Smart Communications Reduces Transformer Time-at-Temperature

- Simple 1-way communication tells vehicles to delay charging when transformer temperature rises above 98°C threshold
- Temperature input could be measurement- or model-based
- Smart Grid extends capacity of 25kVA transformer



# Key Findings

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**The impact of PHEVs on distribution transformers is linked to several factors.**

The strongest seem to be,

- Number of households per transformer
- PHEV penetration rate
  - Vehicle mileage per transformer
- Charging rate

**Several moderating steps can be taken,**

- Daytime public charging reduces the amount of energy needed to be delivered through residential transformers
- Low to moderate levels of TOU pricing adoption shifts load to reduce coincident load peaks
  - High levels of TOU adoption may create new peaks
- Limited demand management control based on transformer thermal state offers significant transformer capacity expansion
- Distributed renewables located near PEV loads?

# A tool to track PEV roll-out and grid impacts

NREL: Science and Technology - Working with Us

http://www.nrel.gov/science\_technology/working\_with.html#avf

**NREL**  
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NREL HOME

### Load It:

Please enter your account information or upload a previously created database. For a template, [click here.](#)

User Name

Password

[Forgot your Password?](#)

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**Transformer Database**

**Base Load Database**

Enter vehicle adoption rate to randomly distribute PEVs across the distribution system.

Vehicle Adoption Rate  %

### Build It:

Scenario Name

Base Load

Tx #	Tx Desc	Age (yrs)	# PEVs	Type (s)
1	50 kVA	10	1	Volt
2	25 kVA	23	1	Leaf
3	...	19	2	Prius, Leaf
4	...	8	0	-
5	...	14	2	Th!nk, Volt

Transformer Type

Transformer Age  Number PEVs

	Vehicle Type	Charge Profile
1	<input type="text" value="Nissan Leaf"/>	<input type="text" value="Opportunity"/>
2	<input type="text" value="Toyota Prius"/>	<input type="text" value="EV-R Off-Peak"/>
3	<input type="text" value="Toyota Prius"/>	<input type="text" value="EV-R Off-Peak"/>

### Analyze It:

**Distribution Network:**

**Results:**

TX #	Desc.	Age	# PEVs	d(Age)
...	...	...	...	...
...	...	...	...	...
...	...	...	...	...

# Renewable Fuels for Plug-in Hybrid Electric Vehicles

*Provides Integrated Low CO<sub>2</sub> Solution*



## Communication

Solar



Wind



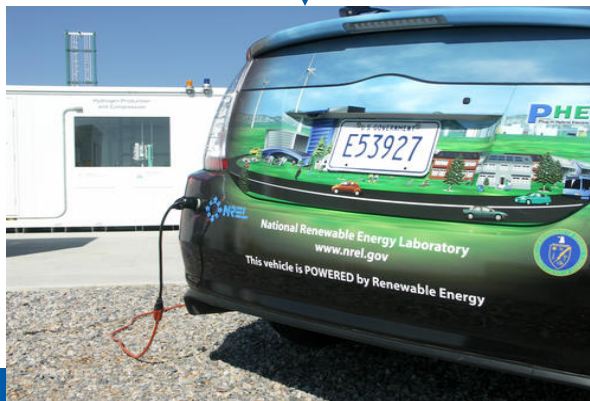
## Utility Interface



Energy Storage



Plug-in Electric Vehicles



Biofuels



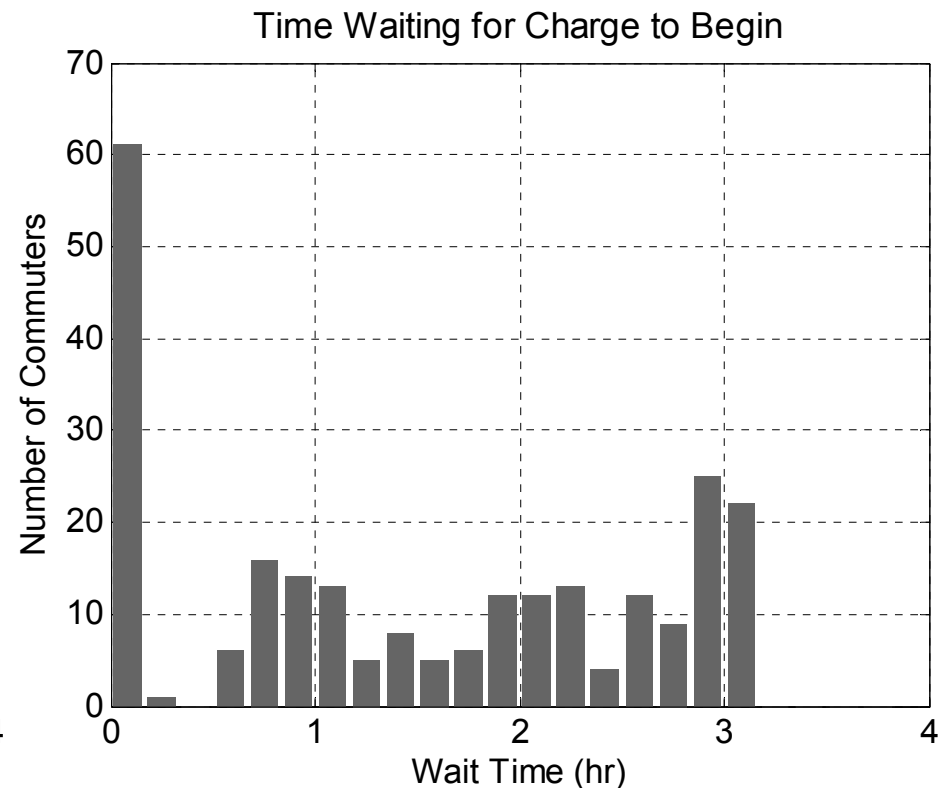
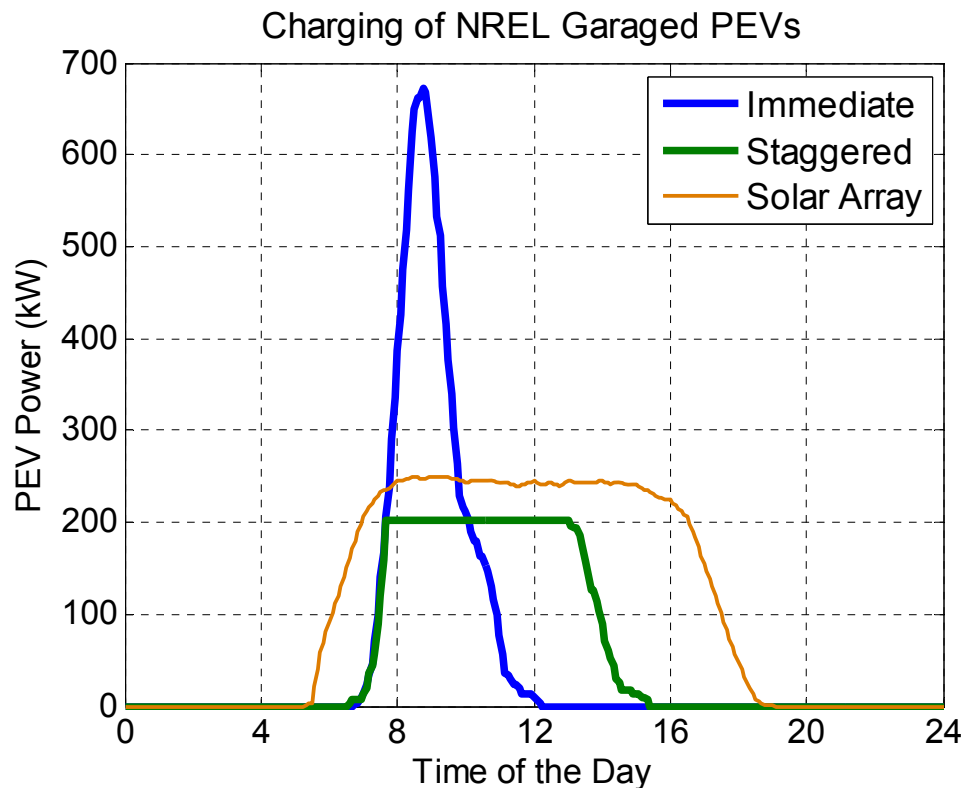
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National Renewable Energy Laboratory

Innovation for Our Energy Future

# Charge Management Simulations Connect NREL Commuting to Renewables

- 20% penetration of PEVs => 24% miles electrified
- All charging completed within work day hours
- Grid capacity requirements minimized and matched to solar



# Questions?

Tony Markel  
National Renewable Energy Laboratory  
[tony.markel@nrel.gov](mailto:tony.markel@nrel.gov)