Outline

- NREL real-world mobility pattern data
- V2X communication connection application example
  - V2X-enabled fuel savings via green routing and adaptive control for the Chevy Volt
- V2X electrical connection application examples
  - WPT-enabled roadway electrification
    - Static (stationary)
    - Quasi in-motion
    - Fully in-motion

V2X = vehicle connected to “X”
WPT = wireless power transfer
Transportation Data Centers at NREL

Real-World Data and Analysis to Support Decision Making

- **Alternative Fuels Data Center (AFDC)**
  - Public clearinghouse of information on the full range of advanced vehicles and fuels

- **National Fuel Cell Technology Evaluation Center (NFCTEC)**
  - Industry data and reports on hydrogen fuel cell technology status, progress, and challenges

- **Transportation Secure Data Center (TSDC):**
  - Detailed individual travel data, including GPS profiles
  - Fleet DNA Data Collection
  - Medium- and heavy-duty drive-cycle and powertrain data from advanced commercial fleets

- **FleetDASH:**
  - Business intelligence to manage Federal fleet petroleum/alternative fuel consumption

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### Features

<table>
<thead>
<tr>
<th>Features</th>
<th>AFDC</th>
<th>NFCTEC</th>
<th>TSDC</th>
<th>Fleet DNA</th>
<th>Fleet DASH</th>
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<tbody>
<tr>
<td>Securely Archived Sensitive Data</td>
<td></td>
<td>Y</td>
<td>Y</td>
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<td>Publicly Available Cleansed Composite Data</td>
<td>Y</td>
<td>Y</td>
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<td>Quality Control Processing</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
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<tr>
<td>Spatial Mapping/GIS Analysis</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
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<tr>
<td>Custom Reports</td>
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<td>Controlled Access via Application Process</td>
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<td></td>
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<td>Y</td>
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<tr>
<td>Detailed GPS Drive-Cycle Analysis</td>
<td></td>
<td></td>
<td></td>
<td>Y</td>
<td>Y</td>
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</table>
Integration with Other Large Data Sets

- GPS Travel/Drive Cycles
- Digital Street Maps
- Traffic Speeds
- Elevation / Grade
- Ambient Temperature
- Freight Volumes
- Vehicle Registrations
- Solar Intensity
- Overall Road Volumes
Merging Data and Models to Support Real-World Analyses

Vehicle use conditions from disparate datasets can be merged in a common environment to investigate the interplay of conditions (thermal, drive cycle/routing, grade, etc.)

<table>
<thead>
<tr>
<th>Data Element</th>
<th>Source</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive Cycles/</td>
<td>NREL Transportation Secure Data Center</td>
<td>The TSDC houses hundreds of thousands of real-world drive cycles from vehicles across the country.</td>
</tr>
<tr>
<td>Trip Distributions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climate Data</td>
<td>NREL National Solar Radiation Database</td>
<td>Home to TMYs from hundreds of U.S. locations, each containing hourly climate data.</td>
</tr>
<tr>
<td>Elevation/</td>
<td>USGS National Elevation Dataset</td>
<td>Raw USGS elevations are filtered to remove anomalous data and produce smooth road grade curves.</td>
</tr>
<tr>
<td>Road Grade</td>
<td></td>
<td></td>
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</table>
Example TSDC-Enabled Studies

- Extensive NREL analyses working with large GPS datasets
  - Multi-powertrain real-world fuel economy distributions/sensitivities
  - Comparing real-world driving and standardized test profile results
  - Enabling road grade simulation and quantifying impacts
  - Synthesis with national climate data for thermal technology evaluation
  - Investigating PEV charging and alternative fuel station locations
  - Developing green routing and adaptive control algorithms
  - Assessing fuel saving opportunities from driver feedback...
Excerpt from study of V2X-enabled green routing and adaptive control applied to the Chevy Volt
Route-Connected Energy Prediction

• Drive Cycle Prediction

• Powertrain Modeling

• Application to Green Routing

• Control Mode Scheduling
Base Maps + Routing API

Routing results and TSDC GPS data are map-matched to road network to determine roads used during each leg of a trip

Functional Class 1
Functional Class 2
Functional Class 3
Functional Class 4
Functional Class 5

Road layers from HERE (TomTom also available)
Routing Analysis

• **One Option**
  o Directions API only provided one route for 21% of O/D pairs

• **Fast = Green**
  o The route with the estimated shortest travel time also required the least amount of estimated energy to complete for 42% of O/D pairs

• **Potential**
  o The remaining 37% of O/D pairs offer the potential for a green routing algorithm to inform an energy saving route selection

*Consider the route with the shortest estimated travel time to be the default.*

O / D = origin / destination
## Green Routing Example

<table>
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<tr>
<th>Route</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance, mi</td>
<td>81.6</td>
<td>76.2</td>
<td>67.6</td>
</tr>
<tr>
<td>Duration, min</td>
<td>107</td>
<td>107</td>
<td>113</td>
</tr>
<tr>
<td>Avg Elec Rate, Wh/mi*</td>
<td>0.83</td>
<td>0.89</td>
<td>1.0</td>
</tr>
<tr>
<td>Avg MPG*</td>
<td>0.45</td>
<td>0.50</td>
<td>1.0</td>
</tr>
<tr>
<td>Cost, $*</td>
<td>1.0</td>
<td>0.89</td>
<td>0.59</td>
</tr>
</tbody>
</table>

*Normalized Values
Will people select the green route?

- On aggregate, the benefits of green routing appear to be significant.
- However, in order for green routes to be selected in practice, the incentive of energy savings must be weighed against the disincentive of longer travel times.
Value of Time Considerations

- Energy savings plotted against increase in travel time (selecting green route over shortest duration)
- This 2D space is swept versus value of passenger time ($/hr) to show cumulative effects of green routing given a return on investment threshold
  - **Ex1:** If passenger has no value of time, cost/energy could be decreased by 12.3% and travel time increased by 14.4%
  - **Ex2:** If passenger values time at $35/hr, cost/energy could be decreased by 1.0% and travel time increased by 0.0%

*The data only consider the 37% of O/D pairs previously identified as having green routing potential.*
Summary

- Demonstrated ability to model vehicle speed/accel profiles relative to road type
- Constructed high-level powertrain model employing cycle metrics and vehicle state as inputs
- Applied model using real-world distribution of O/D pairs, demonstrating:
  - Aggregate energy savings of up to 4.6% for green routing (relative to passenger value of time)
  - Average energy savings of 3.3% for mode scheduling

Modest aggregate savings, but may be cost effective
Highlights from studies on potential fuel savings and relative cost effectiveness from roadway electrification
Wireless Power Transfer (WPT) Technology Advancements

- Potential to maximize electrified miles and resulting fuel savings
  - Static charging when parked; quasi in-motion at brief stops
  - Farther out: fully in-motion

Source: Momentum Dynamics
Source: ORNL
Source: Qualcomm
Source: NREL
Source: Utah State University
Source: KAIST
Source: Siemens
Source: WiTricity WT-3300 Data Sheet
Source: Volvo Group
Analyses of Static and Quasi In-Motion Applications

- Increasing convenience avoids missed charging
  - People do not always plug in PHEVs
    (avt.inel.gov/pdf/phev/HymPriusPersonal-useChAndDrSept08-Mar10.pdf)

- Charging at stops could provide even further fuel savings
  - Chart reflects outer bound assumption of charging at every stop

PHEV = plug-in hybrid electric vehicle
Analyses of Static and Quasi In-Motion Applications

- **Transit bus application using fleet data**
  - Co-optimize number of charging stations and PHEBs, charging power and battery energy
Analyses of In-Motion Applications for Heavy Trucks

- **Aggressive deployment on entire interstate/highway system**
  - Saves a lot of fuel with margin for higher cost assumptions ($3M/mile, 100 kW, used by all)

- **Initially deploy where road grade >1.5%**
  - Still attractive for fuel and cost savings
  - Potential hybridization (and engine downsizing) enabler
Analyses of In-Motion Applications for Light-Duty Vehicles

- Identified potential for small fraction of in-motion WPT infrastructure to cover significant amount of travel
  - Opportunity to maximize benefit/cost ratio
  - 1% of infrastructure would cover 15%–20% of travel
  - 10% of infrastructure would cover ≈60% of travel
Analyses of In-Motion Applications for Light-Duty Vehicles

• Analyzed incremental roll out within urban areas
  – Electrifying 1% of urban freeways consistently displaces ~25% of urban fuel use

• Estimated consumer preference impacts for advanced vehicles
  – Reduced range limitation for PEVs
  – Improved cost effectiveness for HEVs with in-motion WPT

PEV = plug-in electrified vehicle (includes battery electric and PHEVs)
Analyses of Resulting Load on the Grid

- Assuming different fractions of traveling vehicles draw power from the electrified roadway
Relative to Typical Grid Loads

- Evaluated for each season (colored text indicates percent load growth over the baseline for each new seasonal average load peak)
- Historic U.S. load growth is ≈2% annually (twice load impact from 5% vehicle penetration, which would take a long time to realize)

Electrified Roadway Scenarios added to Typical Fall Grid Load
Overall Summary

• NREL uses real-world data on mobility patterns as a key input into numerous advanced vehicle analyses

• Examples include green routing for Chevy Volt
  – Modest fuel savings from V2X connectivity that could be cost effective and substantially beneficial in aggregate

• Examples for WPT-enabled roadway electrification
  – Increase electrified miles for static and quasi in-motion
  – Also displace instantaneous fuel use with fully in-motion
    • High leverage opportunity for travel on interstates/highways
    • Improve value proposition for WPT-connected PEVs and HEVs
    • Grid growth should be able to accommodate, though at high penetrations would need to manage peak alignment and impacts to load shape
The DOE Vehicle Technologies Office funded this work. We wish to thank our sponsors David Anderson and Lee Slezak in the Vehicle Technologies Office Vehicle Systems Program.
Class 8 Line Haul Truck Functional Class Distribution

- **FC0**: 6%
- **FC1**: 4%
- **FC2**: 2%
- **FC3**: 1%
- **FC4**: 13%
- **FC5**: 74%

**FC1**: Functional Class 1 corresponds to high-speed interstates.

**FC5**: Functional Class 5 links to neighborhood streets.