## OVERVIEW

<table>
<thead>
<tr>
<th>Timeline</th>
<th>Partners/Collaborators</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Project start date: Oct 2015</td>
<td>• Industry</td>
</tr>
<tr>
<td>• Project end date: Sep 2018</td>
<td>• Energetics, SRA, HD Systems, Ford</td>
</tr>
<tr>
<td><strong>Budget (DOE share)</strong></td>
<td>• Academia</td>
</tr>
<tr>
<td>• $1.15 m per year</td>
<td>• U. of Tennessee, UC Davis, Iowa State U., Lamar U., U. of Florida, University of Maryland, Georgia Tech, Clemson University</td>
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<tr>
<td><strong>Barriers</strong>*</td>
<td>• Government/National Lab</td>
</tr>
<tr>
<td>• Costs of advanced powertrains</td>
<td>• DOE, ANL, NREL, EIA</td>
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<tr>
<td>• Behavior of manufactures and consumers</td>
<td>• International</td>
</tr>
<tr>
<td>• Infrastructure</td>
<td>• Tsinghua University</td>
</tr>
<tr>
<td>• Incentives, regulations and other policies</td>
<td>• CATARC</td>
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<tr>
<td></td>
<td>• IIASA</td>
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*from 2011-2015 VTP MYPP
Relevance/Approach

Motivation: energy, GHG, air pollution, mobility, transition, electrification

Global satellite-derived map of fine particle pollution (PM2.5) averaged over 2001-2006. Credit: Aaron van Donkelaar, Dalhousie University.

Car dependency or true love?

Electrification barriers

If transition costs <<benefits, why aren't we seeing market players more actively seeking a slice of the pie?

(NRC, 2013)
Relevance/Approach

TEEM focus: modeling market dynamics and paradigm transitions
## FY2016 milestones

<table>
<thead>
<tr>
<th>Milestone Description</th>
<th>Month/Year</th>
<th>Status</th>
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<tbody>
<tr>
<td>Manuscripts on range, infrastructure and/or consumer choice</td>
<td>12/31/2015</td>
<td>Complete</td>
</tr>
<tr>
<td>TEEM framework, factors, and data sources</td>
<td>03/31/2016</td>
<td>Complete</td>
</tr>
<tr>
<td>Fleet vehicle market dynamics preliminary results</td>
<td>06/30/2016</td>
<td>On schedule</td>
</tr>
<tr>
<td>TEEM preliminary results on all highway vehicles</td>
<td>09/30/2016</td>
<td>On schedule</td>
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</table>
MA3T estimates endogenous scenarios of market acceptance of LDV powertrain technologies

- **Approach**
  - **Capture key dynamics among market players**
    - Consumers, OEMs, infrastructure/fuel suppliers, policy makers
  - **Proper spatial resolution, consumer segmentation and vehicle choice structure**
    - Who will buy what, where, when and by how many?
  - **Consumer-relevant attributes of technologies, infrastructure, and policy**
    - Why they buy it?
Fleet electrification opportunity—vocation segmentation, stakeholder input, vehicle simulation
In FY16, we supported several applications of MA3T

- Multi-lab (ANL, NREL, ORNL, SNL) BaSce study for VTO
- IIASA’s global energy modeling
- ORNL’s program benefit analysis for FCTO
- ORNL’s high-octane fuel study for BETO
- ORNL’s study on employment impacts of PEVs
- UTK’s study on optimal OEM pricing response to the ZEV mandate
**Accomplishment**—model application supporting the VTO-FCTO-BETO BaSce study

The 80/50 GHG goal may require all program targets, and renewable hydrogen and electricity.

- "NoProgram" is associated with "Low-Low" scenario of the most recent Autonomie vehicle simulation data on fuel economy and costs, representing no active pursue of DOE VTO or FCTO program activities.
- "ProgramSuccess" is associated with the "High-High" scenario of Autonomie, representing program targets of VTO and FCTO as if they are met on time.
Systematic validation process including formal tests and validity communications

- Formal Validation Tests
- Peer-reviewed Publications
- What-If Predictions
- Meaningful Questions
- Insightful Information
- Transparency

Modeler

Audience
MA3T Validation: Completed and Ongoing Steps

<table>
<thead>
<tr>
<th>Formal Validation Procedures*</th>
<th>Examples, specific to project</th>
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<tbody>
<tr>
<td><strong>Direct Structure Tests</strong></td>
<td>Empirical Tests: comparison with real system knowledge</td>
</tr>
<tr>
<td>(qualitative; without simulation)</td>
<td>Theoretical Tests: comparison with literature knowledge</td>
</tr>
<tr>
<td><strong>Structure Oriented Tests</strong></td>
<td>Extreme condition tests</td>
</tr>
<tr>
<td>(quantitative; with simulation)</td>
<td>Behavior sensitivity tests</td>
</tr>
<tr>
<td></td>
<td>Modified behavior prediction</td>
</tr>
<tr>
<td><strong>Behavior pattern test</strong></td>
<td>Scenarios analyses</td>
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- Compared nested logit model structure to literature models
- Confirmed MA3T parameters to be consistent with real system
- Verified dimensional consistency of the modeling equations
  - Ongoing literature review for price-elasticity validation

- Extreme conditions tests
- Behavior sensitivity verified causal relationships
- Alternate scenarios based on AEO 2014 inputs
  - Ongoing scenario analysis

- Statistical tests of MA3T vehicle sales results compared to actual sales

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MA3T Validation: Indicative Results

Extreme scenario: Range anxiety impact

- Extreme range anxiety effect on cumulative BEV sales
- EV market for modest drivers, even when range anxiety cost extremely large

Causal relationships: Rebate effects

- Rebate Effects on BEVs and PHEVs (applied from 2011-2017)
- Larger incentive drives sales up faster, smaller later

Scenario investigation: Annual Energy Outlook 2014 inputs

Q: How will CO2 fees through the energy sector affect LDV sales on a region level?

Use of EIA, 2014 projections for scenarios of $10 and $25 per ton CO2
MA3T Validation: Comparison with up-to-date sales

MA3T results compared to actual sales

Conventional SI: Actual vs MA3T sales

- Actual SI annual sales
- MA3T Results SI annual sales

Hybrids: Actual vs MA3T sales

- Actual Data HEV annual sales
- MA3T Results HEV annual sales

Plug-in Hybrids: 40 miles e-range

- Actual Data PHEV-40
- MA3T Results PHEV-40

Electric Vehicles: 100 miles e-range

- Actual Data BEV-100
- MA3T Results BEV-100

Discrepancy
Coefficient=0.08<<1
Percent error means= 0.03

Discrepancy
Coefficient=0.3
Percent error means=
0.12

Discrepancy
Coefficient=0.43
Percent error means=
0.273

Early announcement
of 2015 model

Discrepancy
Coefficient=0.012<<1
Percent error means= 0.019
MA3T MiniTool is a web-based lite version of MA3T, providing a more user-friendly interface for non-technical users to quickly use the model. Using a web browser, users of the MiniTool can easily modify input scenarios, such as battery cost or infrastructure deployment, and immediately observe the effect on market shares. Furthermore, users can save customized inputs into a set of scenarios and compare market shares and energy use across scenarios, all without the burden to learn and run the core model.
Example: Battery cost reduction and purchase subsidy could significantly increase BEV market share

Source: MA3T MiniTool
Accomplishment — MA3T CAFE analysis

PEVs can increasingly enhance OEM’s compliance ability for CAFE/GHG by 2025.
Accomplishment—CAFE Then-Now Technology Comparison

Vehicle technologies have largely progressed faster than we thought

- A meta analysis on 2015-16 vehicle technology progress comparison between
  - Then - experts’ projection made during the rulemaking period of CAFE 17-25 (around 2011)
  - Now – technology revealed today (around 2015)
- Investigated comparison criteria
  - Effectiveness or performance
  - Technology cost
  - Market penetration
Comparison of Bus Engine Mechanical Energy and battery Electric Energy Consumptions in the City of Knoxville, TN

**Drive data**
- 1-year data of 3 Knoxville Area Transit buses
- 610 days, running 4717 hours and 3287 miles
  - Avg. 9.4 mph and 52.4% idle time
  - Daily maximum range: 250 mile, 23.8 hours

**Results:**
- Battery EE vs. Engine ME: 2.17 vs. 2.89 kWh/mil
- EV braking energy recovery: 0.63 kWh/mile
- Maximum daily battery EE > ~ 500 kWh

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**Accomplishment—Fleet electrification**

**EV assumption**
- 324 kWh battery
- 2 ton mass penalty
- Charging: bus depot & garage

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**Graph:**
- Conv Vehicle Engine Mechanical Energy
- 324 kWh Battery Electric Energy
Example: Effect of Battery Size and Various Routes on SOC During Aggressive Drive Days

**Observations**
- 150 ~ 324 kWh battery requires proactive on-route charging
- Small battery causes frequently recharging over large routes
- 90kW short boost charging does not play a significant role

**90 kW charging power**

- Boost charging occurs during short stops at bus depot (typically 5~10 minute in Knoxville)

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**Accomplishment—Fleet electrification**

Short route with 13 miles and 1-hour loop time

Long route with 38 miles and 2.5-hour loop time
Public charging opportunity from parking data (1)

**Approach**

- Evaluate public charging opportunity for major U.S. cities
- Opportunity: prob. of charging facility located within walking distance from parking destination
- Evaluate opportunity under optimal charging location compared to actual charging deployment

**GIS data: public parking & charging**

**Methods**

- Assumption: Parking lots capacity is parking demand proxy
  - Data GIS analysis and descriptive stats
  - Optimal charging facility location Based on 2 frameworks:
    1) max. set coverage
    2) p-median problem
  - Charging opportunity estimation when:
    a) Chargers optimally placed
    b) Current charging deployment

- e.g., Seattle, San Francisco etc.
Public charging opportunity from parking data (2)

**Results**

Very optimistic results:

- **Optimally locating** chargers in 2% of total city parking lots covers 80% of parking demand
- Current charging deployment (5.25% of lots) covers 73% of the demand
- Decreasing marginal benefits from charging installation

**Future Work**

- Public charging opportunity analysis for Austin TX, San Francisco CA, Miami FL, New York NY, Washington DC
- Comparison of parking opportunity estimation from different approaches (parking lot data study vs. Liu and Lin 2015)
MOR-BEV model: Market-oriented Optimal Range for BEVs

Accomplishment—BEV range cost-effectiveness

- U.S. driver attributes
  - Vehicle ownership
  - Number of drivers/workers
  - Commute distance
  - Annual distance
  - A sample of 36,664 drivers
  - Source: NHTS 2009

- Backup vehicle attributes
  - Fuel economy/price
  - Refueling cost
  - Vehicle price
  - Source: Autonomie, AEO 2011

- BEV attributes
  - Battery cost/price/utilization
  - Electricity use rate/price
  - Source: Autonomie, AEO 2011

- Financial parameters
  - Discount rate
  - Perceived vehicle lifetime

Optimal range distribution
- How U.S. drivers would choose the range if given choices?

Market share or Favoring rate
- How a particular range may be liked and disliked by how many consumers and whom?

Quantified range barriers
- How serious is the issue of range anxiety? What are the cost-effective ways to solve it?
Personalized cost-effective BEV range

- Most U.S. consumers would be better off with sub-100-mile until battery cost reaches $100/kWh
- Consumer choice would shift toward longer ranges when battery cost decreases, and toward shorter ranges when range efficiency increases due to more available chargers
- The actual range distribution may result from these two conflicting dynamics
Accomplishment—BEV pricing under ZEV

TEEM activity—OEM EV pricing in response to ZEV policy

Preliminary results

Courtesy of Jinglu Song, Mingzhou Jin
Some other selected accomplishments

- A joint study with Iowa State University on the value of reducing BEV range uncertainty. The submitted manuscript is under the 2nd round of review.

- A joint study with Clemson University on mass market charging infrastructure with a focus on optimization of a micro-grid charging system. A journal paper is currently being drafted.

- A paper linking MA3T with MESSAGE, titled “Improving the behavioral realism of global integrated assessment models: an application to consumers’ vehicle choices”, was accepted for publication on Transportation Research Part D: Transport and Environment. The paper is a joint effort by researchers from International Institute for Applied Systems Analysis (IIASA) (Austria), University of East Anglia (UEA), University of California, Davis (USA), Graz University of Technology (Austria), Potsdam Institute for Climate Impact Research (Germany), PBL Netherlands Environmental Assessment Agency (The Netherlands) and Oak Ridge National Laboratory (USA)

- ORNL, SRA Inc., and Argonne National Lab are collaborating on a study of the effect of OEM incentives on the PEV market. A paper was submitted to EVS 29 for presentation and was planned to submit for journal publication.
The success of MA3T relies on collaboration with industry, universities and government agencies

- **Ford Motor Inc.**
  - Travel patterns, electric range feasibility

- **SRA International**
  - Input data processing, state incentive, result processing, historical sales data

- **Entergy Corporation**
  - Electricity demand profile, grid impact analysis

- **Argonne National Laboratory**
  - Vehicle attribute data, application, PEV sales data, coefficient estimation, cross-examination

- **National Renewable Energy Laboratory**
  - Infrastructure roll-out scenario, infrastructure costs
  - Consumer surveys

- **Energy Information Administration**
  - Energy prices, grid carbon intensity, baseline LDV sales projection

- **University of Tennessee**
  - Model structures, coefficient estimation, consumer behavior

- **University of California, Davis**
  - Consumer behavior surveys, household vehicle usage behavior, infrastructure analysis, international energy modeling

- **Iowa State University and Lamar U.**
  - Charging behavior, range uncertainty/feasibility, Infrastructure analysis, scenario file processing, policy analysis

- **University of Florida**
  - Workplace charging
Proposed Future Work

We need a better understanding of system dynamics and paradigm shifts

- Continued vehicle attribute and energy price updates
- Systematic validation
- Mobility choices
- Policy-driven vehicle pricing and infrastructure pricing
- Supply-side behavior
  - Advanced conventional vehicles competing with PEVs
  - Business models for infrastructure
- Comparison of various charging options
  - Linking charging availability and opportunity
ACKNOWLEDGEMENTS

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Vehicle Technologies Office
US Department of Energy

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