VTO Program Benefits Analysis

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Project VAN018

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Overview

Timeline

Ongoing project prior to FY 2016

Project start: 1 Oct 2015

Project end: 30 Sep 2018

Barriers

- Relating component-level technologies to national-level benefits
- Indicators and methodology for evaluating environmental sustainability and cost impacts

Budget

FY 2015: $455k

FY 2016: $550k

(100% DOE)

Partners

- Interactions / Collaborations
  - Lawrence Berkeley National Lab
  - Univ of California at Berkeley
  - Oak Ridge National Laboratory
  - National Renewable Energy Laboratory
  - Sandia National Laboratories
  - Energetics, Inc.

Objective

Estimate potential future benefits attributable to the VTO Program, including reductions in

- Petroleum use
- GHG emissions
- Reductions in impacts from GHGs and air pollutant emissions
- Benefits, net of costs to consumers and society

taking PEV/infrastructure interactions into account

Challenges

- Establishing a transparent, well-founded link between VTO program goals (performance and manufacturing cost, at the component level) and:
  - Oil use, emissions, and private and external costs at a national level
  - Relationship between driving and charging patterns, possible benefits to the grid, battery costs, battery performance, and battery lifetime

- Creating a user-friendly, publicly available modeling framework to consistently assess consumer and social costs over the lifetimes of vehicles, explicitly accounting for differences in these costs for different powertrain types

VTO uses results of this analysis to communicate the benefits of the program to DOE management, other agencies, Congress and others.

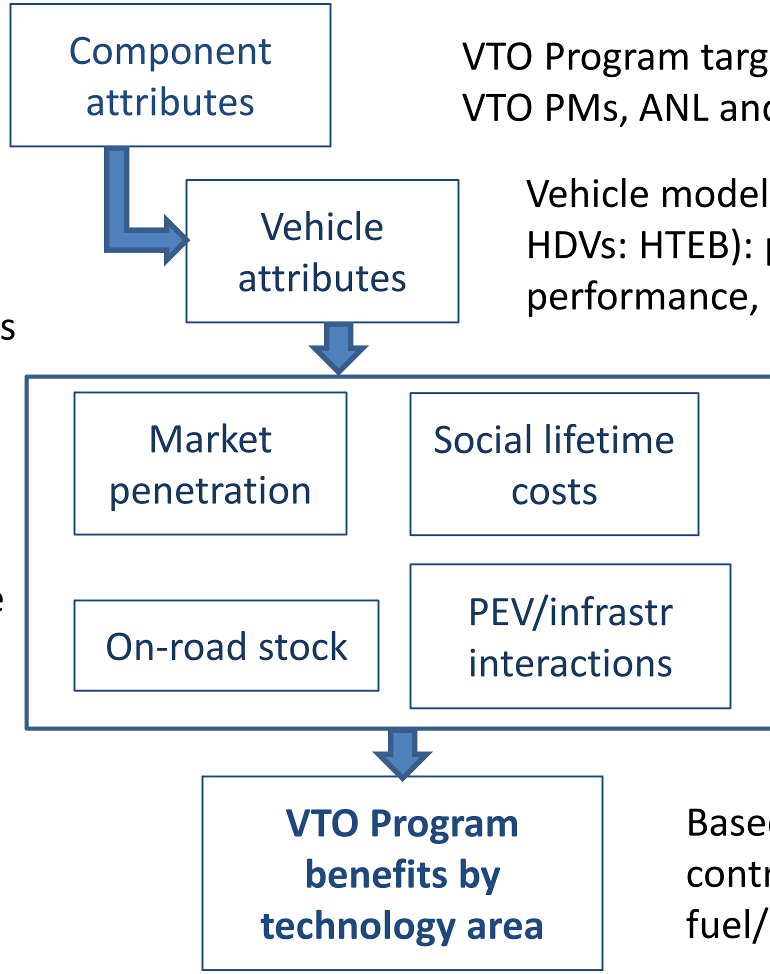
Reducing ownership costs and external costs is important for achieving market success and benefitting society

- Benefits depend on future vehicle attributes and market penetration
- Current “levelized cost of driving” metric includes vehicle purchase price and fuel costs
- Since consumers consider other costs, a more comprehensive metric is needed
- All important costs & benefits, private and external, should be considered, including costs and benefits from PEV/infrastructure/grid interactions

Milestones

Month / Year	Description	Status
Apr 2015	Issue final benefits report	complete
Apr 2016	Establish component-level inputs for heavy vehicle simulation and assumptions for scenarios	In progress
Jul 2016	Input for market penetration modeling complete	In progress
Sep 2016	Review initial scenario results with VTO	
Jun 2016	Complete battery cost and lifetime models, with documentation	In progress
Sep 2016	Preliminary estimates of PEV use implications and charging behavior under selected scenarios of PEV infrastructure	In progress

Components -> Vehicles & Charging Infrastructure -> Fleet



VTO Program targets, and inputs from VTO PMs, ANL and industry experts

Vehicle modeling (LDVs: Autonomie, HDVs: HTEB): price, fuel economy, performance, etc.

Sales shares by vehicle class and drivetrain type (LDVs: MA^{3}T & others; HDVs: TRUCK model)

Social costs: (AVCEM)

Calculate fleet stock, fuel use and GHGs (VISION model, and GREET^{TM})

PEV/Infrastr (PEVI, PLEXOS Grid economics)

Based on estimated contribution to reduction in fuel/mi by technology

VISION: Energy use and GHG emissions of U.S. on-road fleet, Argonne

AVCEM: Advanced Vehicle Cost and Energy Use Model UC Berkeley

GREET: Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model, Argonne

PEVI: Plug-in Electric Vehicle Infrastructure model, LBNL

Compare two scenarios, with and without successful deployment of VTO Technologies

- Program Success: Vehicles meet VTO performance, fuel economy and cost targets
  - Vehicle component cost and performance based on VTO program targets, projected to 2050
  - Vehicle attributes estimated from component attributes
- Baseline (No Program): Without VTO technology improvements
  - Vehicles simulated on the basis of VTO inputs for "No Program"

VTO targets for subprograms:
- Electric drive and batteries
- Adv. combustion engine R&D
- Materials R&D
- Fuels and Lubricants R&D

For light-duty and heavy-duty vehicles

Addressing technical barrier:

Relating component-level technologies to national-level benefits

Light-duty vehicle simulations performed by ANL Autonomie Team (see poster #VAN023)
Heavy trucks analyzed by TA Engineering using HTEB and TRUCK models

Provide More Comprehensive Benefits Analysis

- Include more cost components
  - Plug-in vehicle (PEV) battery costs (based on Argonne BatPaC cost model) and lifetime (based on NREL battery lifetime model)
  - Additional ownership costs: maintenance, depreciation, etc., as data become available
  - External costs: oil use, GHG impacts, air pollution impacts
- Include interactions between PEVs, charging infrastructure, and the grid
  - Assess cost implications of charging infrastructure availability to PEV owners
  - Assess cost implications of vehicle-to-grid integration ,e.g., PEVs providing ancillary grid services
  - Model how PEV use may change with charging infrastructure deployment
- Provide firmer technical basis
  - Develop relationships between vehicle retail cost and manufacturing cost
  - Develop consistent framework for discounting of costs

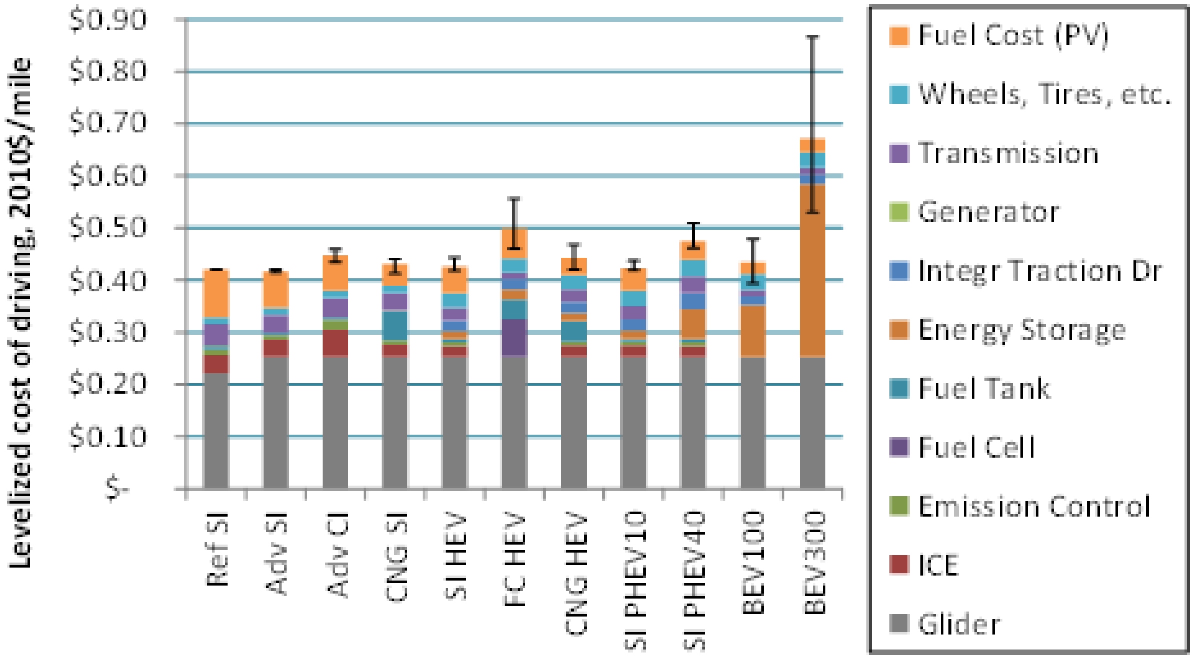
Addressing technical barrier:

Providing indicators and methodology for evaluating environmental sustainability and cost impacts

FY15 Progress – Ownership costs

- Levelized cost of driving, Midsize car, 2025:

$$LCD = \frac{P_{Veh} + PV(C_{Fueli})}{\sum_i^N VMT/yr_i}$$



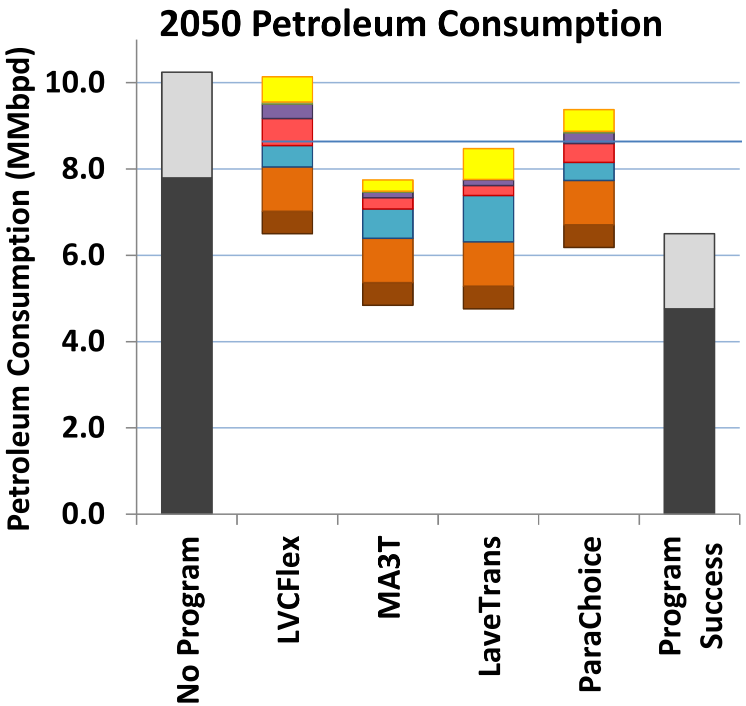
Fuel prices (2010$/gge):
- Gasoline: $3.38
- Diesel: $3.62
- Elec: $0.107/kWh
- Hydrogen: $2.54 - $4.73

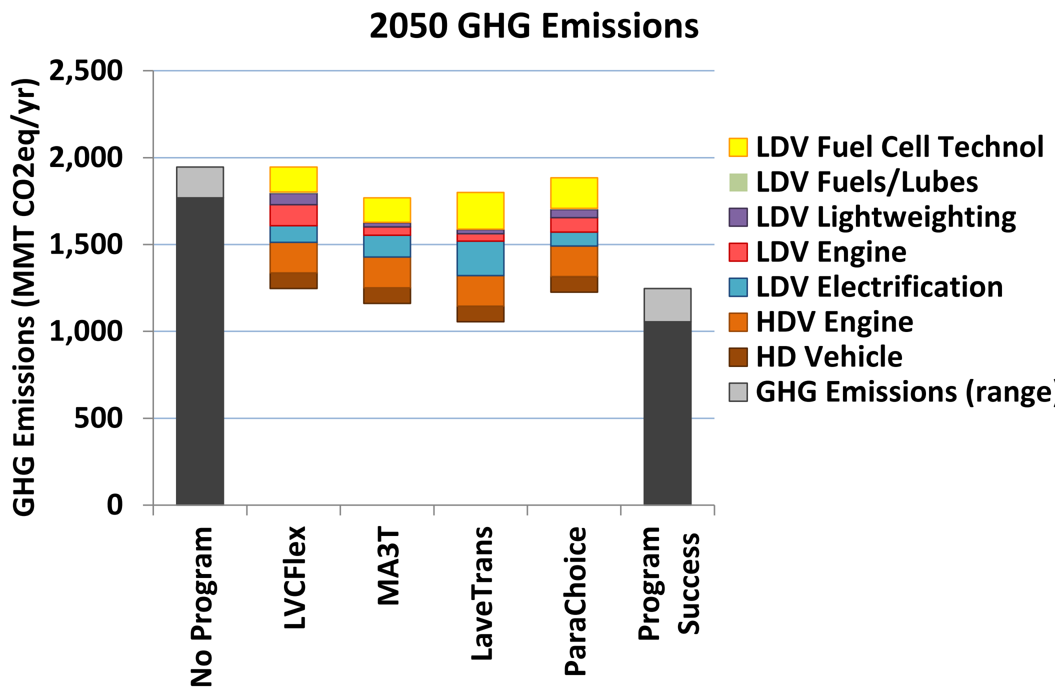
5 year ownership period

7% discount rate

Need more comprehensive cost metrics, e.g.,
- Social costs of GHG and air pollution impacts, and oil use
- For PEVs: infrastructure/PEV interactions and possible grid ancillary benefits

FY15 Progress: Projected petroleum savings and GHG reductions *by VTO technology subprogram*

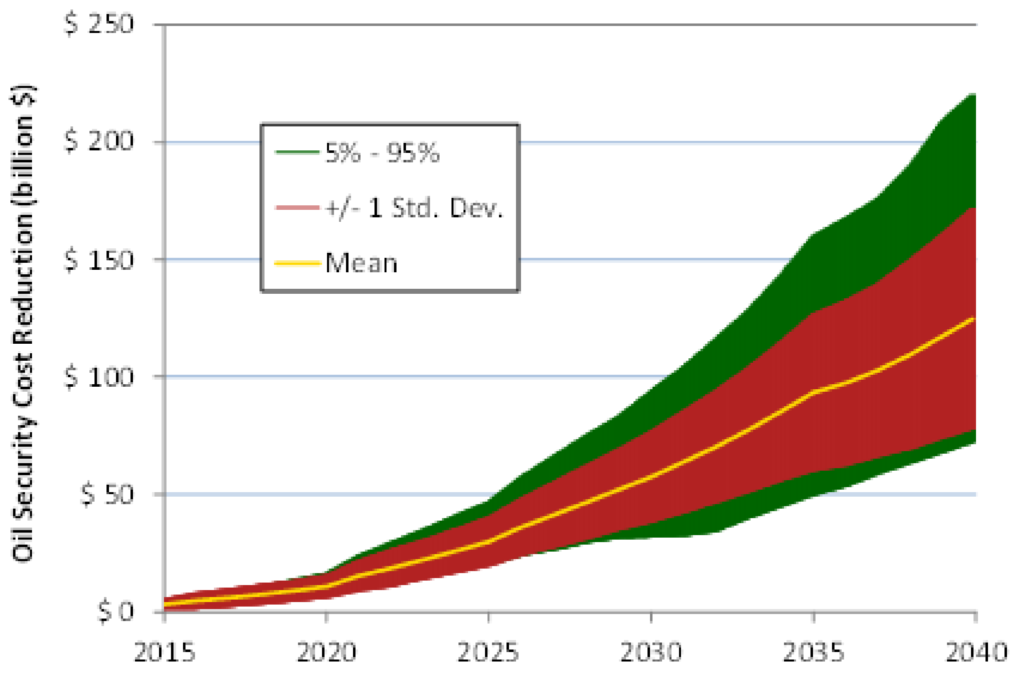




- Projections based on LDV sales shares developed using four consumer choice models:
  - LVCFlex (Energetics, Inc.)
  - MA3T (Oak Ridge National Laboratory)
  - LAVE-Trans (Oak Ridge National Laboratory)
  - ParaChoice (Sandia National Laboratories)
- And one medium-heavy-duty vehicle market penetration model: TRUCK model (TA Engineering, Inc.)
- **Although future consumer behavior is uncertain, VTO petroleum and GHG reductions are significant**

Savings in Oil Security Costs estimated

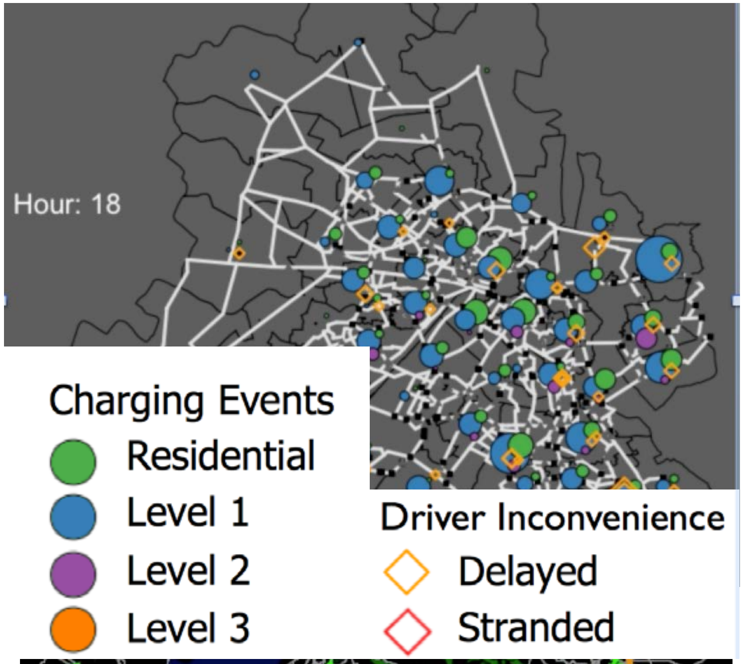
- Oil security costs include
  - Wealth transfer
  - Economic surplus losses
  - Macroeconomic disruption costs
- Estimated electricity used, fuel displaced by PEVs and electric VMT



Calculated using the Oil Security Metrics Model from petroleum use projections based on LDV shares projected using the LAVE-Trans model and HDV shares projected using TRUCK model, by Changzheng Liu, ORNL

Plug-in Electric Vehicle – Infrastructure – Grid Interactions Analysis

- PEVI model: Agent-based PEV mobility and charging behavior model featuring:
  - Explicit representation of chargers in a network,
  - Competition between drivers for access to chargers, and
  - Driver adaptation to lack of adequate charging infrastructure
- PEVI methods paper published in IEEE Transactions on Transportation Electrification, March, 2016
- Embedding PEVI into the MATSim framework to better characterize and forecast PEV mobility while including all other transportation network activity and constraints (e.g. congestion and modal alternatives
- Application: SF Bay Area
  - Using state-of-the-art travel demand estimated from cellphone data
- Beginning model calibration and validation of spatio-temporal charging demand



Smart Bay – MATSim Applied to SF Bay Area

Advanced-Vehicle Cost and Energy-Use Model (AVCEM)

- Reduced forms of battery cost and lifetime models for integration into comprehensive social cost model
  - Reduced-form version of ANL BatPaC cost model
    - Preliminary version complete; reproduces BatPaC results closely (see next slide)
    - *Next steps: validate, incorporate into AVCEM*
  - Extension of NREL battery lifetime model
    - Original NREL model fully incorporated
    - Developing extensions for aging beyond 10 years, extreme temperatures
    - *Next steps: continued development, collaborate with NREL*
- Discount rate analysis
  - Reviewing literature; developing conceptual/theoretical framework
  - *Next steps: continue developing framework, begin work on formal methods*
- Retail cost vs. OEM cost
  - Simple, theoretically grounded functions developed and partially validated
  - *Next steps: incorporate data and analysis from recent detailed studies*
- Electricity transmission and distribution cost model to link PEVI and AVCEM
  - *Working on literature review, data analysis, and functional forms*

Validating Reduced Form Version Of Argonne BatPaC Model

AVCEM polynomial fit vs original Argonne BatPaC estimates

Cost of materials & components for pack (no labor, overhead); 100,000 packs per year

Capacity kWh	Power kW	Argonne BatPaC Cost	AVCEM Polynomial Fit	**% Difference**
5	40	$1,328	$1,319	**0.7**
5	65	$1,590	$1,550	**2.5**
10	65	$2,090	$2,078	**0.6**
10	100	$2,403	$2,410	**0.3**
20	100	$3,491	$3,464	**0.7**
20	150	$3,907	$3,923	**0.4**
40	180	$6,342	$6,344	**0.03**
60	250	$9,153	$9,127	**0.3**
80	310	$11,923	$11,921	**0.01**

Responses to Previous Reviewers' Comments (2015 AMR)

Comments	Response
" ... the process could be improved through additional sensitivity analyses addressing uncertainties in consumer behavior and/or acceptance, fuel prices, and fueling infrastructure development." " ... the reviewer would like to see some uncertainty analysis performed."	We explicitly analyzed benefits using a range of projections from different consumer choice models to assess uncertainty due to future consumer behavior. Plan to examine more side cases varying other assumptions.
"... how the supply-side is modeled: for example, how to disaggregate improvements from VTO R&D versus regulation and consumer market demands ..."	Project scope in FY15 did not include supply side constraints such as automaker investment behavior. The PI has had discussions with EPA and the USDOT Volpe Lab, but models such as those used by EPA and NHTSA for regulatory analysis focus on near-term technologies, whereas relevant VTO technologies are pre-competitive and long-term. Automaker decisions and supply-side constraints relevant to longer-term vehicle technologies can be approximately represented in market projections as constraints or limits to sales growth rates and assumptions about advanced technologies
" ... the work is assessing the impact of the VTO program on petroleum and GHG reductions and related impacts (e.g., externalities and social costs), and is an important contribution to achieving the program's goals."	Work is proceeding to analyze a broader scope of costs in order to include externalities and social costs.

Collaborating with other laboratories

- Teaming with multiple labs to develop market share projections
  - LVCFlex (TA Engineering, Energetics)
  - LAVE-Trans, MA33T (Oak Ridge National Laboratory)
  - ParaChoice (Sandia National Laboratories)
  - TRUCK (TA Engineering, Inc. for medium- and heavy-duty vehicles)
  - ADOPT (National Renewable Energy Laboratory)
- Oil security costs estimated by ORNL Oil security metrics model
- Working with NREL on battery lifetime model
- Worked with Navigant Research to develop estimated electricity consumed and fuel displaced by plug-in vehicles in the U.S. in 2011 – 2014.

ENERGETICS A Subsidiary of VSE Corporation

OAK RIDGE NATIONAL LABORATORY MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Sandia National Laboratories

TA Engineering, Inc Technical Analysis and Engineering

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Remaining Challenges and Barriers

- Expand the scope of benefits analyzed
  - Estimate potential reductions in social costs and changes in externalities:
  - GHG and pollution impacts
  - External costs of oil use
- Make results more robust
  - Examine uncertainty to other variables (fuel prices, vehicle manufacturing energy/GHGs, etc.)
  - Improved relationship between vehicle manufacturing costs and retail prices
  - Improved approach to discounting, based on consistent theoretical framework
- Assess competitiveness of vehicles with VTO technologies
  - More comprehensive assessment of ownership costs, e.g., include all relevant ownership cost, by powertrain type
  - Maintenance, repair (including battery packs), depreciation, taxes & fees, etc.
  - For plug-in vehicles, assess the cost implications of interactions with electricity supply infrastructure
  - Optimization of charging infrastructure to minimize costs
  - Influence of driving needs and charger availability on charging behavior
  - Economic benefits of grid ancillary services/smart charging benefits
  - PEV energy use

Proposed Future Work

- Complete scenario development and initial program benefits estimation
- Examine selected side cases and assess sensitivities
  - Fuel prices, other market uncertainties
  - Improve realism of vehicle attributes: include low-volume manufacturing costs, timing and availability of new models, fuel economy under realistic driving cycles
- Analyze important components of social costs of advanced vehicles
  - More comprehensive assessment of ownership costs, e.g., include all relevant ownership cost, by powertrain type: maintenance, depreciation, taxes & fees, etc.
  - Cost of lifecycle GHG emissions and lifecycle air-pollution emissions
  - External costs of petroleum use
  - Firmer technical basis for retail prices and discount rates
  - For plug-in vehicles,
    - Include models of battery lifetime and cost
    - Assess the cost implications of interactions with electricity supply infrastructure
  - Optimization of charging infrastructure to minimize costs
  - Influence of driving needs and charger availability on charging behavior
  - Economic benefits of grid ancillary services/smart charging benefits
  - PEV energy use
- Integrate these costs to allow consistent comparison by powertrain

Summary: Successful development and deployment of VTO technologies can reduce petroleum use & GHG emissions

- Relevance: Estimating VTO's potential reductions petroleum use, GHG emissions, and other metrics
- Approach: Scenarios link specific program targets and on-road future benefits
  - Integrated with other TO analysis efforts to address key technical barrier
- Accomplishments: Significant benefits from VTO programs
  - Elucidates the contribution of VTO (by technology) to EERE mission
  - Provide quantitative projections to communicate the impacts of VTO technologies

		2030	2050
On-road fuel economy improvement (%)	LDVs	**38-52%**	**61-98%**
	HTs	**30%**	**47%**
Oil savings (million bpd)		**1.9-2.3**	**2.9-3.7**
Annual primary energy savings (quad/yr)		**3.1-3.8**	**7.3-9.3**
GHG emission reduction (million mt CO_2eq/yr)		**338–374**	**608-744**

- Proposed future work:
  – Complete ongoing analysis, in collaboration with other labs
  – Estimate social cost impacts comprehensively
  – Account for EV/infrastructure interactions

Technical Back-up Slides

Modeling the On-Road Stock

- Energy used by the on-road stock of vehicles of each powertrain type was calculated using the Argonne VISION model
- Given the following, VISION provides the consumption of all fuel types in on-road vehicles of each powertrain type
  - Fuel economy (from vehicle simulations),
  - Sales shares by powertrain type (from vehicle choice models)
  - Annual vehicle-miles-traveled and survival functions (based on FHWA & NHTS data, taken from the AEO input file, modified for LDVs using a elasticity of travel demand)
- Additional analysis is done to disaggregate heavy vehicles by fuel and size class and to disaggregate fuel savings by vehicle technology
- Use of GREET coefficients gives fuel-fuel cycle energy and GHG emissions
- Reductions in fuel use attributable to each VTO subprogram and to Fuel Cell Technologies Office program are then disaggregated for each powertrain type

Light-duty Vehicle Choice Models Used for Benefits Analysis
(developed under separately-funded projects)

Multinomial logit models Inputs: Vehicle attributes, fuel prices/availability, consumer driving patterns
(Model diversity, on-road fuel econ adjustment, size classes and powertrains represented were not identical for all models)
Outputs: Sales or sale share by powertrain (or model)

	LAVE-Trans	LVCFlex	MA^3T	ParaChoice
POC, institution	**Changzheng Liu, ORNL**	**Alicia Birky Energetics, Inc.**	**Zhenhong Lin, ORNL**	**Rebecca Levinson, Sandia**
Model origin	CA ZEV NRC	Simplified version of EIA's NEMS VCM	Legacy development from TAFV, HyTrans, etc.	Sandia LDRD
Significant vehicle attributes	Vehicle price (–) Fuel cost/mi (–) Acceleration (–) PEV Batt. repl. cost (–) Luggage space (+) Model diversity (+) PEV charger costs (–) Refueling time (–)	Vehicle price (–) Fuel cost/mi (–) Maint. Cost/yr (–) Range (+) Acceleration (–) PEV Batt. repl. cost (–) Luggage space (+) Model diversity (+) Alt fuel utility (+/–) Home PEV recharge (+)	Vehicle price (–) Fuel cost/mi (–) Acceleration (–) PEV Batt. repl. cost (–) Luggage space (+) Make/model diversity (+) PEV charger costs (–) Model diversity (+)	Vehicle price (–) Fuel cost/mi (–) Fuel availability (+) PEV charger costs (–) CNG compressor cost (–) Refueling time (–) Model diversity (+) Range(+)
Special features	Market penetration can be exogenously limited to represent supply-side constraints. Hydrogen prices can be endogenous (function of hydrogen demand)	Market penetration can be exogenously limited to represent supply-side constraints.	Market penetration can be exogenously limited to represent supply-side constraints.	Hydrogen production pathway and prices determined endog. as a function of cost and demand. Elec. grid evolves endog. Built in parameterization of uncertain variables

Extending NREL Battery Pack Lifetime Model

Functional forms developed that extend the NREL battery degradation and lifetime model to capture:

- Degradation beyond 10 years of "calendar" (no-cycling) life;
- Effect of extreme temperatures;
- Different battery chemistries;
- Aging effect of cycling frequency (distinguish short-term from long-term cycling);
- Accelerated cycling-aging after 30% capacity fade
- Aging effect of charging rate
- Aging effect of discharge rate (to be developed)