VTO Program Benefits Analysis

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2017 Vehicle Technologies Annual Merit Review

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Washington, DC

Project VAN018

Overview

Timeline

Ongoing project prior to FY 2017

Project start: 1 Oct 2015

Project end: 30 Sep 2019

Barriers

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

Budget

FY 2017: $407k

(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
- Energy security
- Emissions
- Economics benefits, consumers, transportation users and society

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
- Integrating analysis of benefits from VTO programs and Fuel Cell Technology Office (FCTO) programs
- 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
Nov 2016	Report preliminary benefits estimates	complete
Apr 2016	Final benefits analysis report for budget year 2018	complete
Jul 2017	Report on external costs of advanced vehicles	In progress
Jul 2017	Report documenting side cases and sensitivities of program benefits	In progress
Sep 2017	Preliminary version of fully enhanced AVCEM	In progress
Sep 2017	Link BEAM and PLEXOS to estimate benefits and costs of VGI	In progress

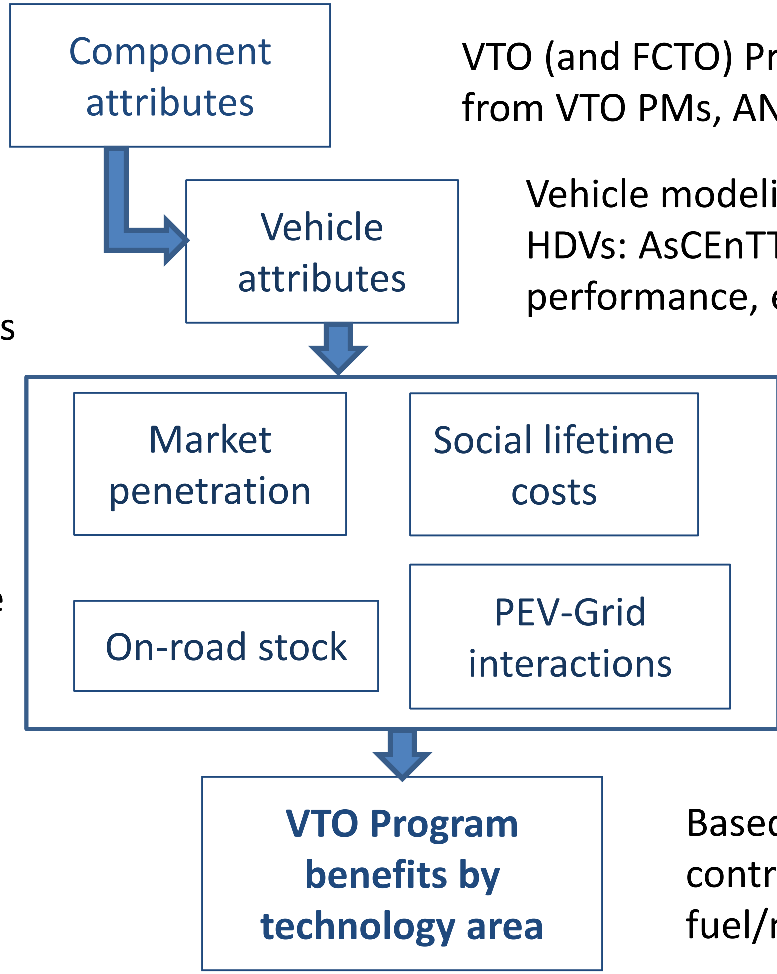
Components -> Vehicles & Charging Infrastructure -> System-wide

VTO (and FCTO) Program targets, and inputs from VTO PMs, ANL and industry experts

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

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

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



Social costs: (AVCEM)

PEV Benefits (BEAM, 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
AsCEnTT: Assessment of Cycle Energy of Truck Technologies (Energetics, Inc.)
AVCEM: Advanced Vehicle Cost and Energy Use Model UC Berkeley
GREET: Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model, Argonne
BEAM: Behavior, Energy, Autonomy, Mobility 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 and lubricants R&D
- Materials 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 #VAN017)
Heavy trucks analyzed by TA Engineering using AsCEnTT and TRUCK models

Capture Significant System Benefits of PEVs

- 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

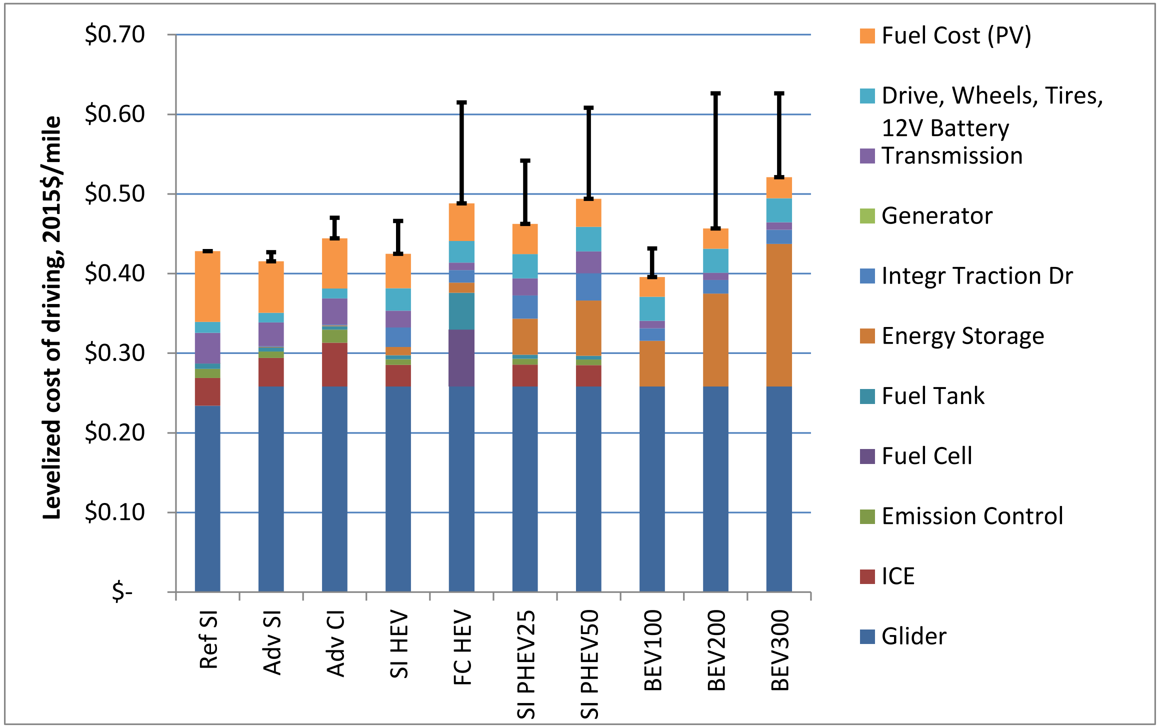
Addressing technical barrier:

Providing indicators and methodology for evaluating environmental sustainability and cost impacts

FY17 Progress – Ownership costs

- Levelized cost of driving, Midsize car, 2025:

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



Fuel prices (2010$/gge):
- Gasoline: $3.32
- Diesel: $3.55
- Elec: $0.12/kWh
- Hydrogen: $3.03 - $7.05

14,000 mi/yr

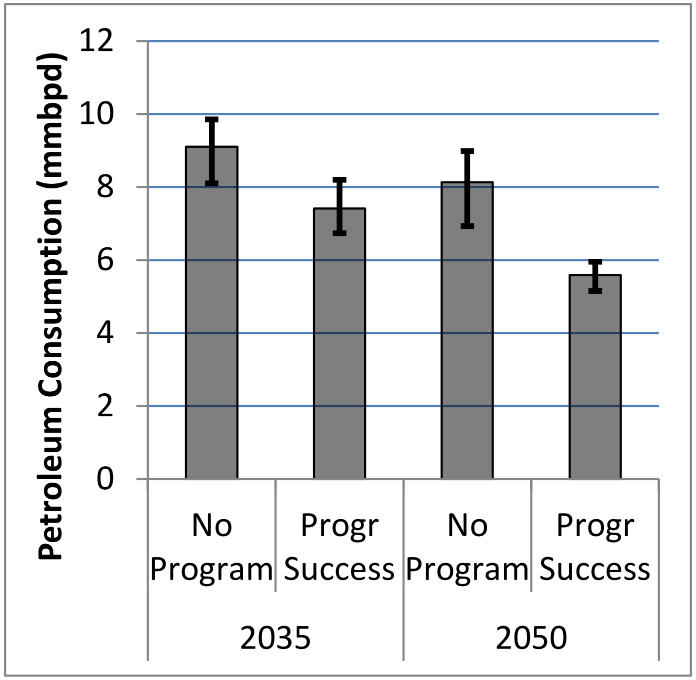
5 year ownership period

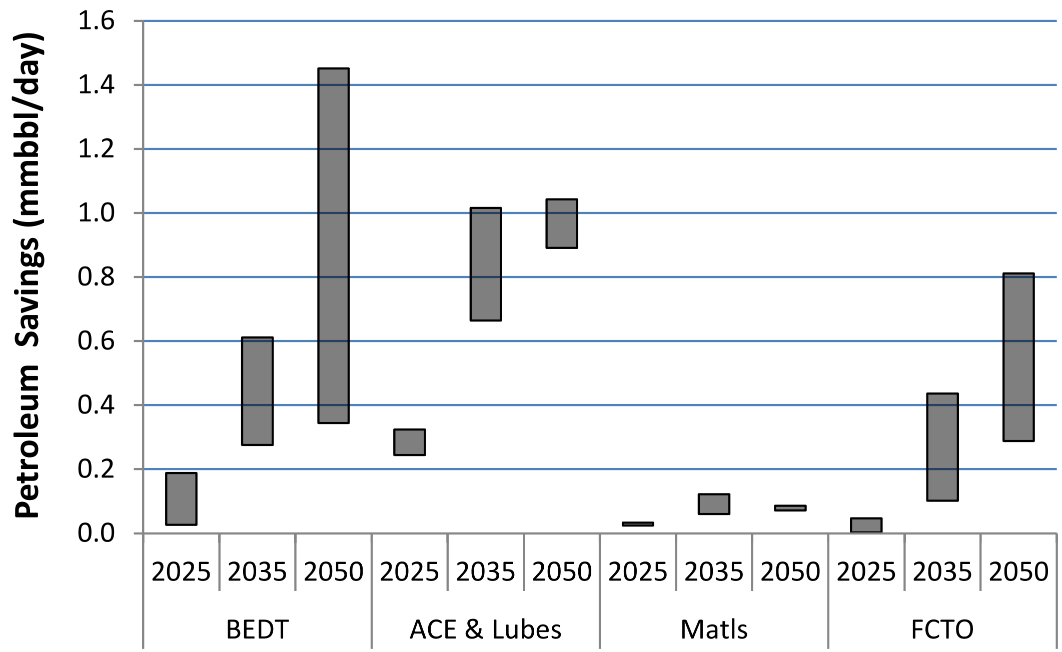
7% discount rate

- Colored bars show LCD for Program Success
- Tops of error bars show LCD for No Program

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

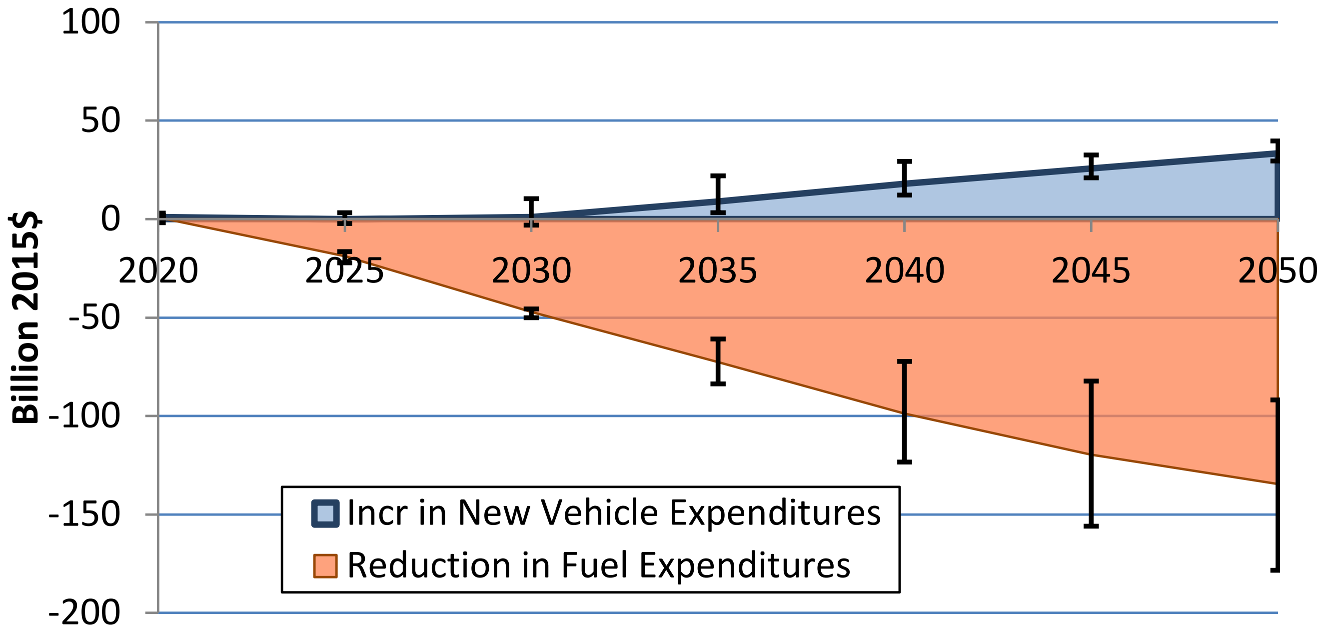
FY17 Progress: Projected petroleum savings and GHG reductions *by VTO technology subprogram*





- Projections based on LDV sales shares developed using four consumer choice models:
  - LVCFlex (Energetics, Inc.)
  - LAVE-Trans (Oak Ridge National Laboratory)
  - MA^3T (Oak Ridge National Laboratory)
  - ParaChoice (Sandia National Laboratories)
- And one medium-heavy-duty vehicle market penetration model: TRUCK model (Energetics, Inc.)
- **Although future consumer behavior is uncertain, VTO petroleum and GHG reductions are significant**

Changes in national expenditures for new vehicles and fuel

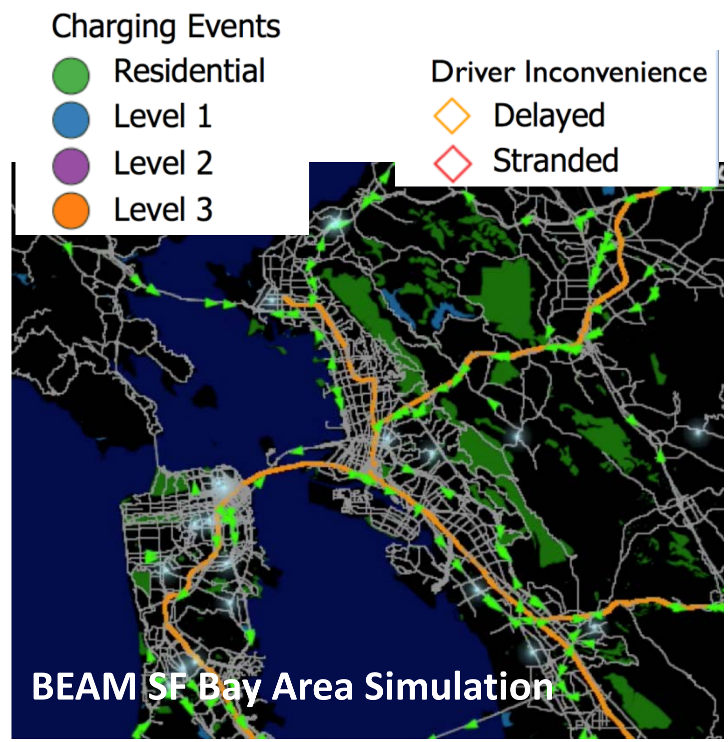


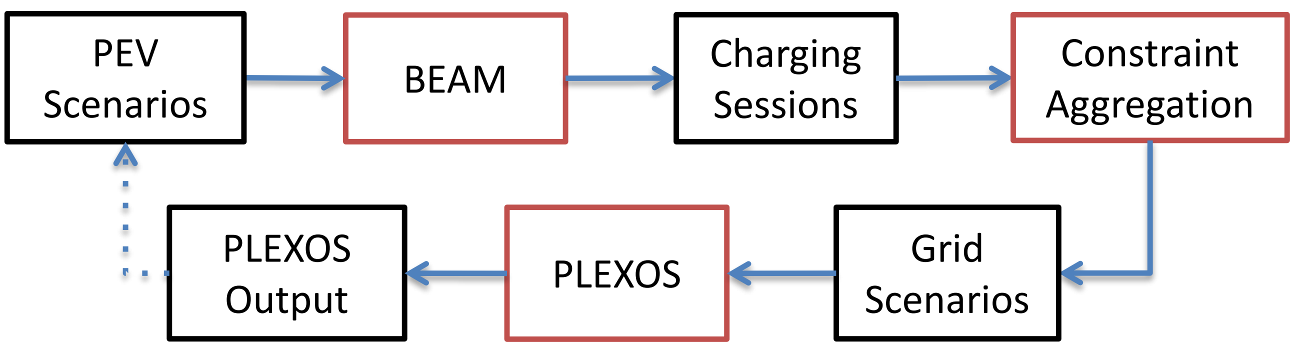
- Changes due to both FCTO and VTO Programs
- Error bars show ranges for each scenario due to different market projections

Advanced vehicle technology increases vehicle expenditures somewhat, but decreases fuel expenditures more

Plug-in Electric Vehicle – Infrastructure – Grid Interactions Analysis

- BEAM (Behavior, Energy, Autonomy, Mobility) model: Agent-based PEV mobility and charging behavior model featuring:
  - Explicit representation of chargers in a network
  - Competition between drivers for access to chargers
  - Driver adaptation to lack of adequate charging infrastructure
- Integrated with PLEXOS electricity grid production, distribution and cost model
- Application: SF Bay Area & California
  - Using travel demand estimated from cellphone data
- Beginning model calibration and validation of spatio-temporal charging demand
  - Charging behavior data from ChargePoint data





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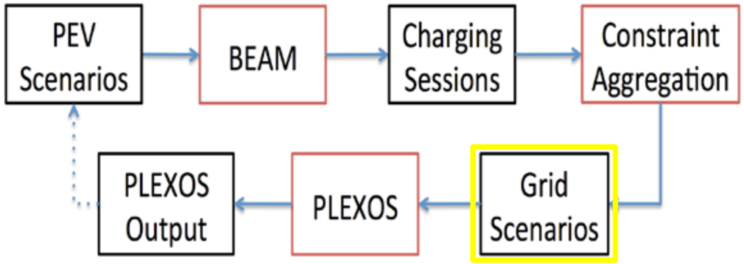
Grid Scenarios



- Case 0: No PEVs in CA
- Case 1: 2024 forecast of inflexible or unmanaged CA PEV load added
- Case 2: 2024 forecast of flexible or managed CA PEV load added (shifting charging within session only)

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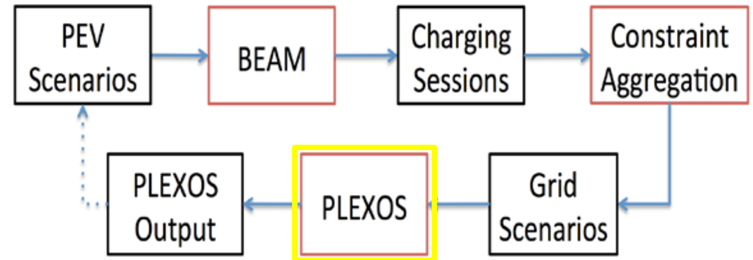
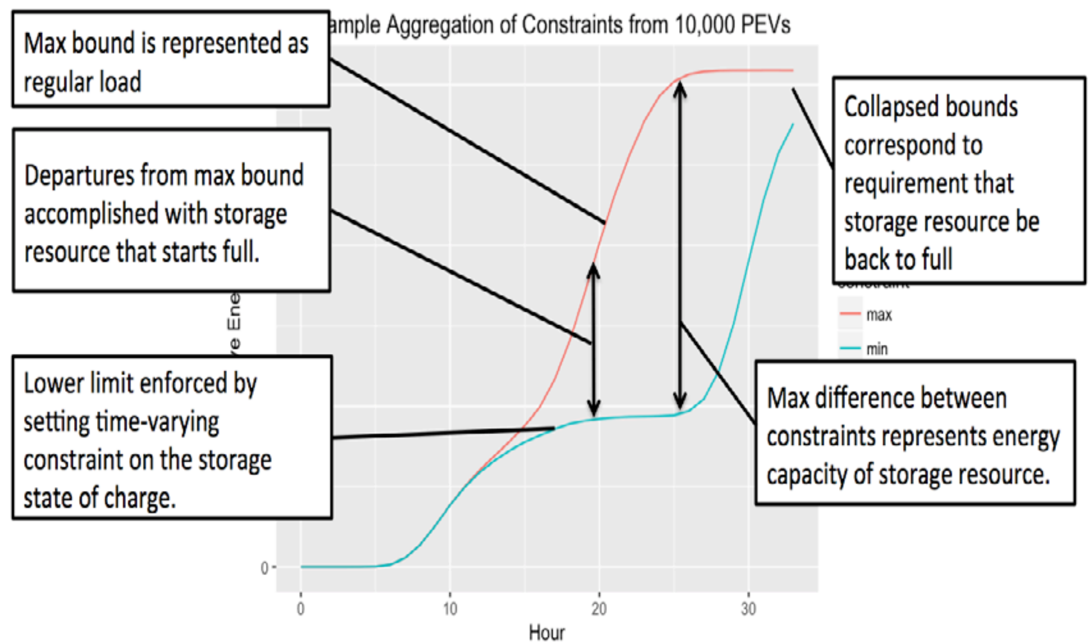
PLEXOS



- Smart Charging PEVs are represented in PLEXOS as a combination of inflexible load and a pumped storage hydro facility designed to operate within the contraints of the aggregated fleet of PEVs
- Currently, Outputs of PLEXOS are analyzed to give key metrics:
  - Total system cost (key to BaSce)
  - Renewable energy production & curtailment
  - System-wide emissions
  - Marginal hourly prices
- Planned:
  - Feed marginal prices back into BEAM to influence charging behavior



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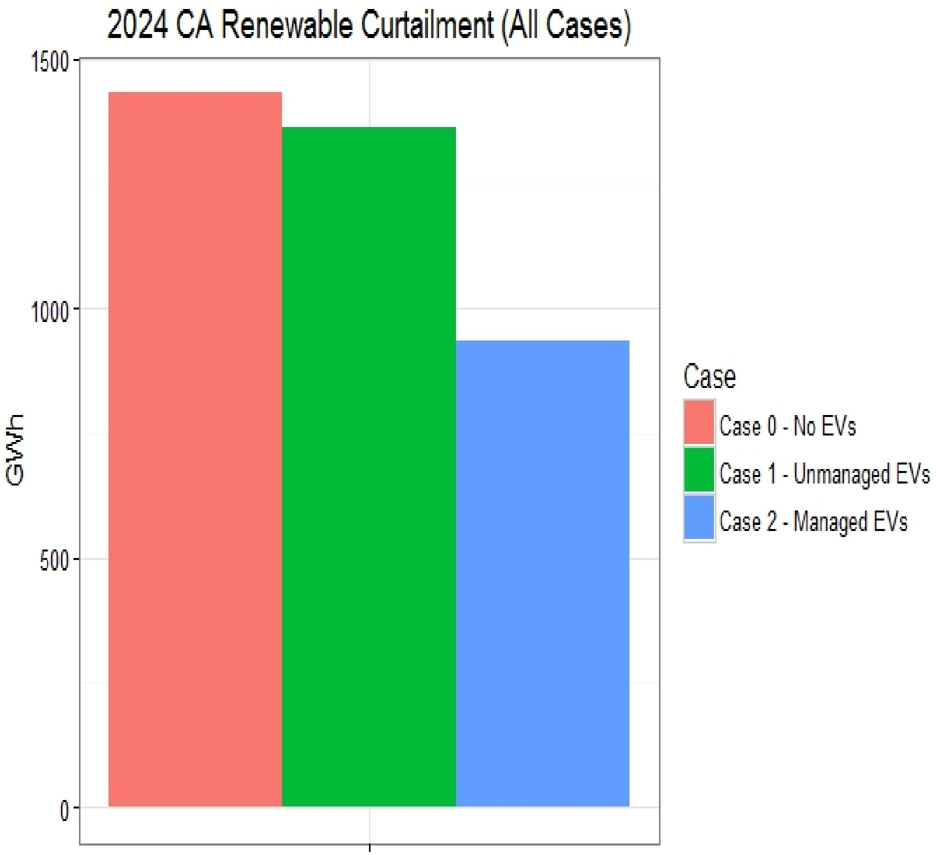
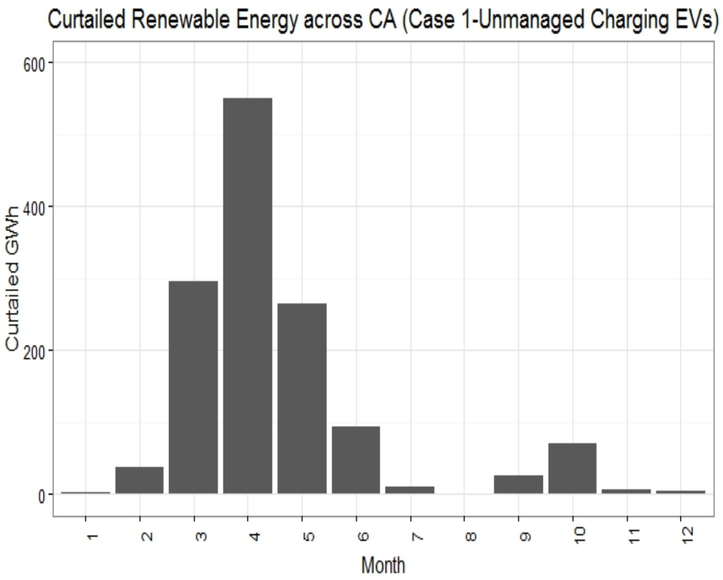
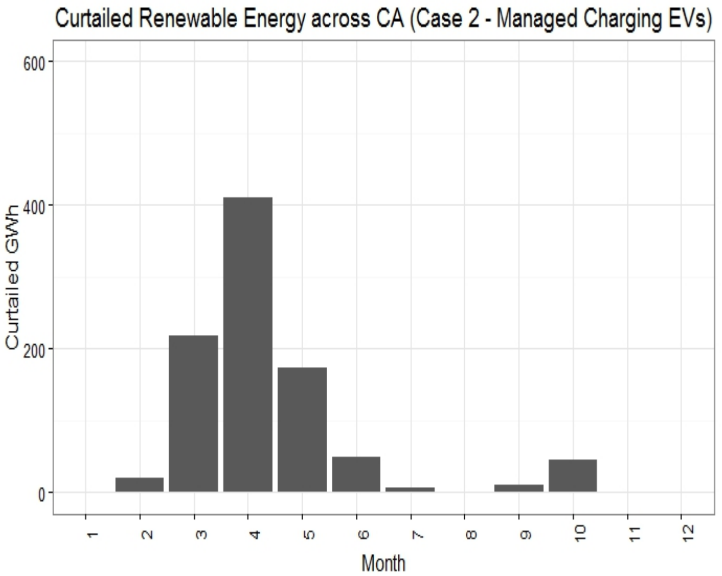
Preliminary Results

- Managed charging substantially lowers renewable curtailment







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
  - Extension of NREL battery lifetime model
- 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

Responses to Previous Reviewers' Comments (2016 AMR)

Comments	Response
" ... the current analysis approach ... Ignores corporate average fuel economy (CAFE)/GHG standards through 2025." " ... the non-VTO case did not comply with CAFE standards."	The analysis is designed to give vehicle attributes d sales shares resulting from component-level technology progress. DOE technology managers do not assume that future vehicles will meet CAFE/GHG standards without DOE R&D when defining component-level inputs. The resulting fleet average fuel economy and GHG emissions are outputs, not inputs. However, the projections do not differ widely from the standards (some exceed the standard somewhat, while some are lower). Importantly, since the bulk of the projected petroleum savings and GHG reduction occur after 2025, once advanced technology vehicle penetrate the on-road stock significantly, Therefore the estimated benefits are not sensitive to assumptions about meeting CAFE/GHG standards..
"... Grid interaction analysis is also a significant addition to the project... More information on the model, assumptions, and insight that the project team expects to learn should be mad more explicit ..."	Progress reports describing the BEAM model have provided DOE with relevant details of model approach, assumptions, and planned applications. An information flow diagram provided in this presentation is intended to show how grid interaction results will be integrated into the benefits analysis.
" ... information on the AVCEM model and expected insight should be more explicit"	Progress reports on AVCEM models have been submitted describing AVCEM model components and their outputs. The information flow diagram shows these will be used in an integrated benefits analysis

Collaborating with other laboratories

- Teaming with multiple labs to develop market share projections
  - LVCFlex (Energetics, Inc.)
  - LAVE-Trans, MA^3T (Oak Ridge National Laboratory)
  - ParaChoice (Sandia National Laboratories)
  - TRUCK (Energetics, Inc. for medium- and heavy-duty vehicles)
- Oil security costs estimated by ORNL Oil security metrics model

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

Sandia National Laboratories

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
  - Possible changes to vehicle use due to ride-hailing, connectivity and automation
- 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

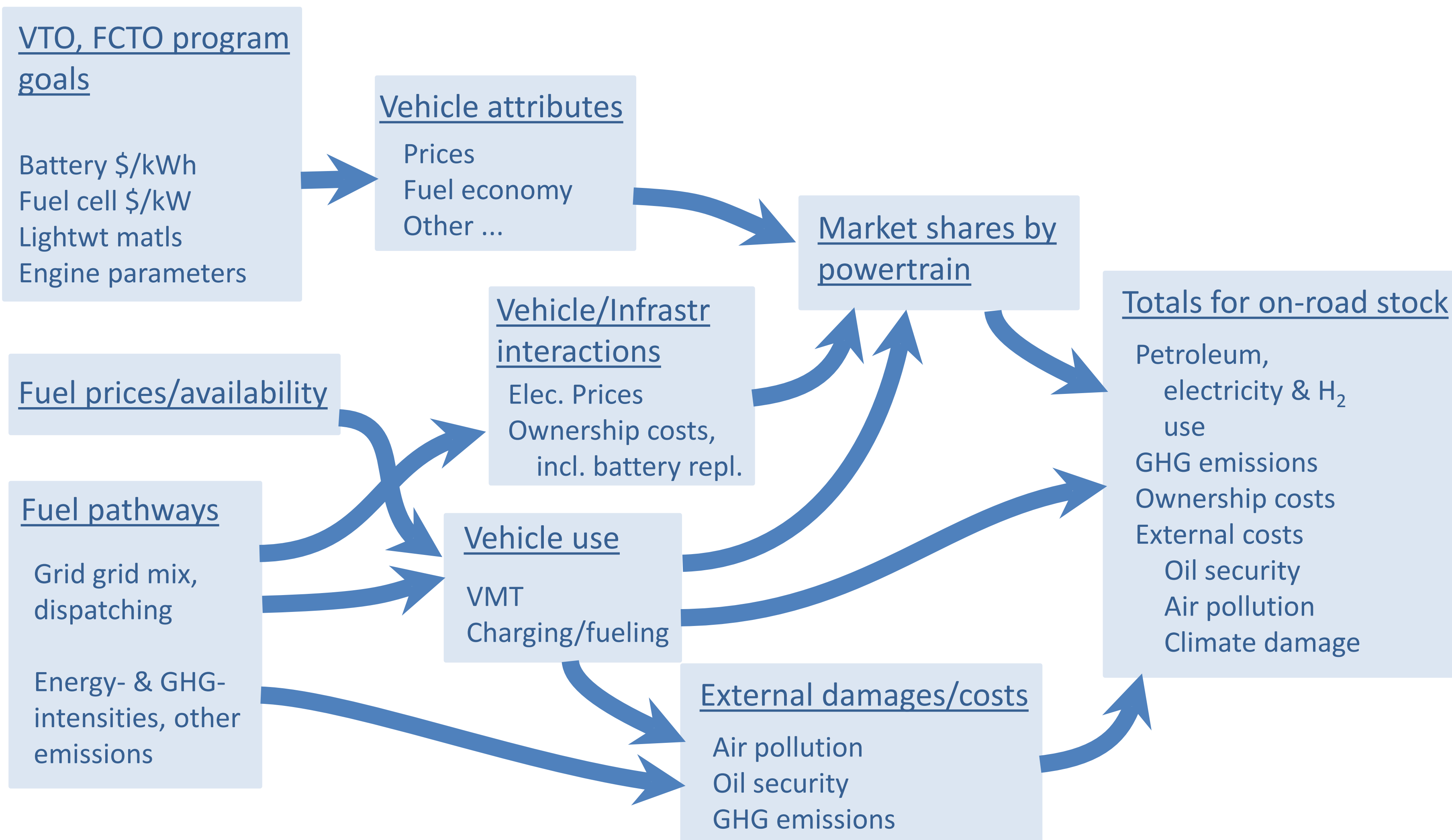
- Examine selected side cases and assess sensitivities
  - Fuel prices, other market uncertainties
  - Improve realism of vehicle attributes: include low-volume manufacturing costs, timing and availability of new models
- Analyze important components of social costs of advanced vehicles
  - More comprehensive 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
  - Consider changes to vehicle use due to ride-hailing, connectivity and automation

- Integrate these costs to allow consistent comparison by powertrain

Any proposed future work is subject to change based on funding levels.

Integration

- Integrated analysis will provide a more comprehensive benefits assessment



Any proposed future work is subject to change based on funding levels.

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 VTO 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

		2035	2050
On-road fuel economy improvement (%)	LDVs	**24-30%**	**38-67%**
	HTs	**13%**	**23%**
Oil savings (million bpd)		**0.9-1.5**	**1.7-3.4**
Reduction in annual fuel expenditures (billion 2015$/yr)		**85-108**	**153-240**
Increase in annual new vehicle expenditures (billion 2015$/yr)		**6-25**	**33-43**
GHG emission reduction (million mt CO_2eq/yr)		**338–374**	**608-744**

- **Proposed future work:**
  - Analysis additional cases and assess sensitivities
  - Estimate social cost impacts comprehensively
  - Account for EV/infrastructure interactions
  - Integrate social costs and PEV-grid interactions into the benefits assessment

Any proposed future work is subject to change based on funding levels.

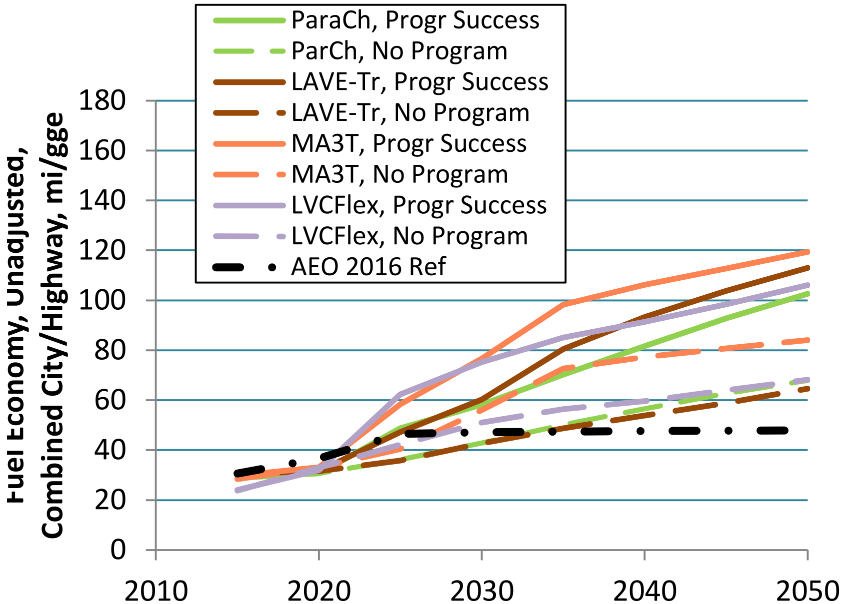
Technical Back-up Slides

Modeling the On-Road Stock

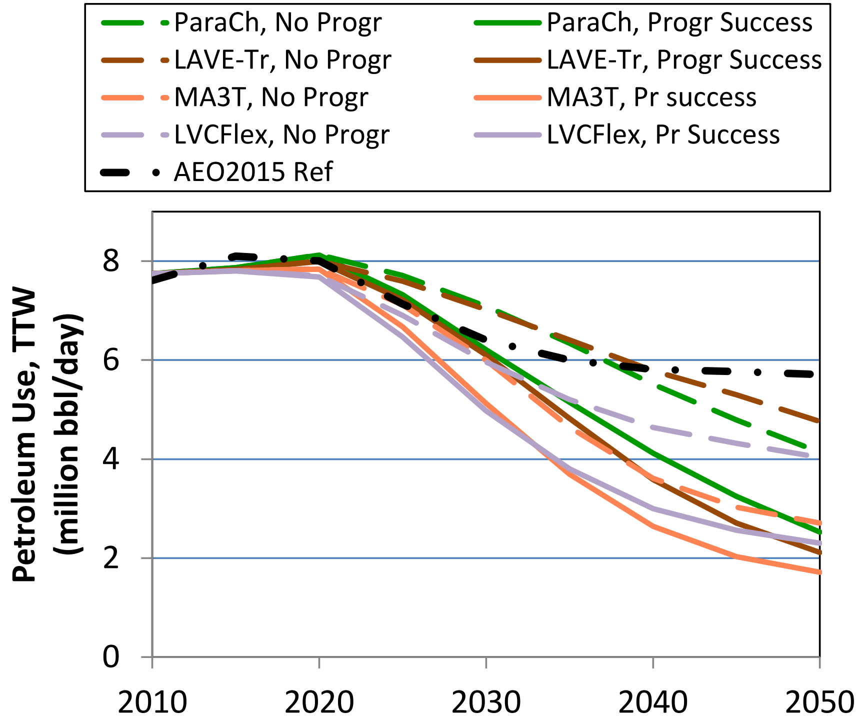
- Energy used by the on-road stock of vehicles of each powertrain type was calculated using the Argonne VISION model
- Given the following, VISION provides the consumption of all fuel types in on-road vehicles of each powertrain type
  - Fuel economy (from vehicle simulations),
  - Sales shares by powertrain 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 Fuel Economy and Fuel Consumption

- It is not assumed that the new light-duty vehicle fleet meets the CAFE/GHG standards through 2025
- Some projections of fuel economy exceed the standard, and some are below the standard
- The majority of petroleum reductions attributed to VTO occur after 2025 and are not sensitive to fuel economy between 2020 and 2025



Comparison of fuel economy projections and AEO 2016 Ref case (standard-compliant



Comparison of petroleum use projections and AEO 2016 Ref case (standard-compliant