Modeling for Market Analysis: HTEB, TRUCK, and LVChoice

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Annual Merit Review

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Project ID: VAN012

TA Engineering, Inc.
Technical Analysis and Engineering

Overview

TIMELINE		
	FY13	FY14
Start Date	Oct. 2012	Oct. 2013
End Date	Sept. 2013	Sept. 2014
% Complete	100%	70%

BUDGET	
Total Project Funding	
Received for FY13	$141,306
Funding for FY14	$130,000

COLLABORATIONS

- Contract to ANL, Tom Stephens
- Collaborations & Interactions:
  - ANL: Aymeric Rousseau, Anant Vyas, Joann Zhou
  - NREL: Aaron Brooker
  - ORNL: Zhenghong Lin
  - EIA: Nicholas Chase, Patricia Hutchins
  - 21st CTP and SuperTruck program managers & industry partners

BARRIERS ADDRESSED*

- Program evaluation of: progress against stated goals; program rationale; process; impact; and cost-benefit.

*from 2011-2015 VTP MYPP

Objectives and Relevance

- Overall objective - develop, improve, and apply analysis tools to support program planning, management, evaluation, and reporting, relative to VTO goals to:
  - Reduce energy use and greenhouse gas emissions by enabling development of efficient and clean highway vehicles that are cost and performance competitive.
- HTEBdyn relevance:
  - Estimates benefits of heavy vehicle advanced technologies in terms of fuel consumption reduction;
  - Translates technical targets into vehicle performance benefits.
- HTEB task objectives:
  - Perform analysis in support of VTO GPRA reporting.
  - Maintain quick analysis capability.
  - Improve estimation of:
    - Interactive effects of grade, aerodynamics, and braking;
    - Waste energy availability for recovery technologies; and
    - Impact of duty / drive cycle on benefits.

Objectives and Relevance, Cont.

- TRUCK; LVChoice relevance:
  - Estimate market acceptance of advanced vehicle platforms based on performance (fuel economy) and cost;
  - Translate vehicle performance into fleet fuel and emissions savings.
- TRUCK task objectives:
  - Perform analysis in support of VTO GPRA reporting;
  - Maintain flexibility of technology specification;
  - Adjust data on truck population to better characterize vehicles targeted by DOE R&D.
- LVChoice task objectives:
  - Allow analysis consistent with NEMS methodologies;
  - Improve flexibility of scenario specification, e.g. technologies and size classes;
  - Improve user interface to automate input specification;
  - Perform analysis to support comparison to other models;
  - Analyze sensitivity of results to model structure and parameter specification.

Milestones FY13-14

Date	Milestone / Go-No Go	Description	Status
HTEBdyn			
5/16/13	Milestone	Conduct workshop (AMR side meeting); incorporate industry comments	Complete
4/30/14	Milestone	Develop user guide and version for review distribution, class 8.	90%
5/30/14	Milestone	Model documentation	75%
7/25/14	Milestone	Model validation against simulation and test data.	50%
7/25/14	Milestone	Journal article submission	0%
9/30/14	Milestone	Update class 4-6 characterizations.	0%
TRUCK			
	Milestone	Update to AEO 2013; subdivide class 4-6.	Complete
Integrated Analysis – Application of TRUCK and HTEBdyn			
12/21/12	Milestone	SuperTruck benefits analysis final report publication.	Complete
1/6/14	Milestone	Complete analysis and documentation for GPRA 2015	Complete

Milestones FY13-14, Cont.

Date	Milestone / Go-No Go	Description	Status
LVChoice			
6/14/13	Milestone	Alter model to suit VTO analysis needs.	Complete
7/16/13	Milestone	Develop interface file.	Complete
9/3/13	Milestone	Add fuel availability and make/model availability algorithms	Complete
9/9/13	Milestone	Update to AEO 2013 and perform validation.	Complete
9/9/13	Milestone	Perform preliminary analysis of common inputs with sensitivity.	Complete
5/30/14	Milestone	Update to AEO 2014.	0%
6/13/14	Milestone	Final analysis of common inputs with sensitivity.	0%
9/30/14	Milestone	Analysis and refinement of FA and MMA algorithms; analysis of calibration factors.	10%

HTEB Approach

- Apply approach from legacy model that estimated power demand based on average drive cycle statistics.
- For a specified drive cycle, calculate required engine brake power P_b at each time step as a function of system losses/demands:

$$P_b = P_{drive} + P_{mech} + P_{elec} + P_{tran}$$
$$P_{drive} = P_{aero} + P_{rr} + P_{accel} + P_{grade}$$

- Calculate fuel consumption rate as a function of brake power, engine friction loss, and engine indicated efficiency:

$$\dot{F} = \frac{P_b + P_f}{\eta_i}$$

- Reduce engine power demand for:
  - Hybrid system contribution (regenerative braking)
  - Mechanically coupled waste heat recovery (turbo-compounding and ogranic Rankine cycle).
- Use simplified relationships that capture the performance characteristics of component systems; “black box” approach rather than detailed component modeling / simulation.

HTEBdyn Accomplishments FY13-14

- Initial development of "dynamic" formulation completed in FY13.
- Presented at 2013 workshop (AMR side meeting); incorporated industry feedback:
  - Added time lag to heat available to ORC recovery.
  - Adjusted regenerative brake recovery algorithm.
  - Hybrid system simplified and parameterized to maximize energy recovery and use; avoids attempt to design power management system.
- Improved estimation when vehicle is unable to meet the drive schedule:
  - Estimated loads are recalculated through one iteration.
  - Added schedule smoothing options to minimize harsh acceleration demand, vehicle under-speed results, and associated power imbalance.
- Improved engine friction definition and estimation.
- Added transmission options, characterized by gear ratios and shift points (rpm).
- Improved user interface:
  - Basic operation from one input worksheet using default engine parameters and default transmission.
  - User options for custom input.
- Validation in progress (Autonomie simulations, NREL fleet tests).

HTEB Accomplishments: Validation against Autonomie Simulation

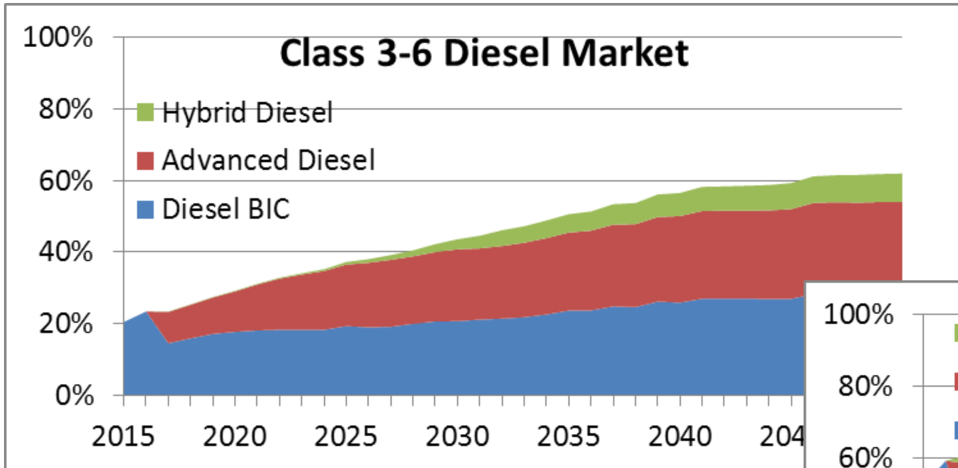
	UDDS Cycle			HHDDT65 Cycle		
	ANL	HTEB	% diff	ANL	HTEB	% diff
Conventional						
Engine Avg Efficiency	36.4%	36.7%	0.94%	40.5%	39.7%	-2.11%
Consumption (gal/100 mi)	22.7	22.9	0.97%	16.1	16.2	0.64%
Hybrid						
Engine Avg Efficiency	38.0%	37.8%	-0.64%	40.9%	40.0%	-2.26%
Brake Recovery @ wheel	74.6%	74.1%	-0.69%	57.8%	57.6%	-0.29%
Consumption (gal/100 mi)	16.2	15.8	-2.68%	15.3	15.3	0.10%
Hybrid Fuel Savings						
gal/100 mi	6.5	7.2	10.1%	0.80	0.89	11.0%
%	29%	31%	9.03%	5.0%	5.5%	10.3%

- Comparison to simulation results documented in ANL 2009 report for NAS.
- Difference between runs is strictly drive cycle or hybridization.
- Estimates of fuel consumption are within 1% for conventional truck and 3% for hybrid truck.
- HTEBdyn estimates higher benefits for hybrid; model is parameterized to maximize use of energy recovered.

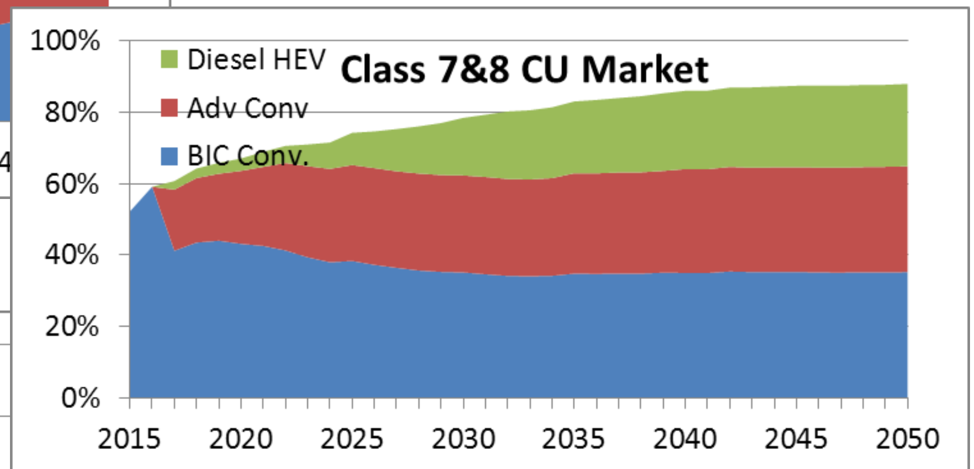
TRUCK Approach

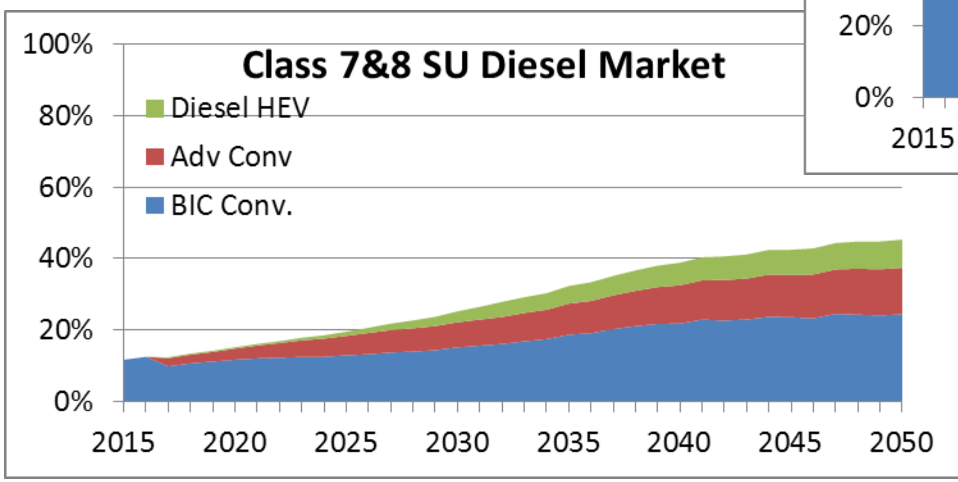
- Estimate market penetration of fuel saving or alternative fuel heavy trucks based on technology cost and value of fuel savings.
  - Fuel price projection from latest AEO.
  - Determine estimated payback period within each of eleven mileage cohorts based on VIUS data for new trucks (≤ 2 yrs).
  - Estimate adoption rate of based on distribution of required payback period (ATA Return on Investment Survey, 1997).
  - Separate calculations for four classes (3-6 gasoline, 3-6 diesel, 7&8 Single Unit, 7&8 Combination) and two refueling strategies (central, non-central).
- Compete up to 3 platforms against a baseline
  - All four vehicles may use any transportation fuel included in AEO.
  - Baseline must have the lowest vehicle purchase price.
- Include capability to consider technology preferences that are not reflected in costs (e.g., fuel availability, risk aversion, imperfect information, technical features, etc.).
- Separate model for class 4-6 trucks (vs. 3-6) for GPRA 2015.

TRUCK Accomplishments FY13-14: GPRA 2015 Sales Shares



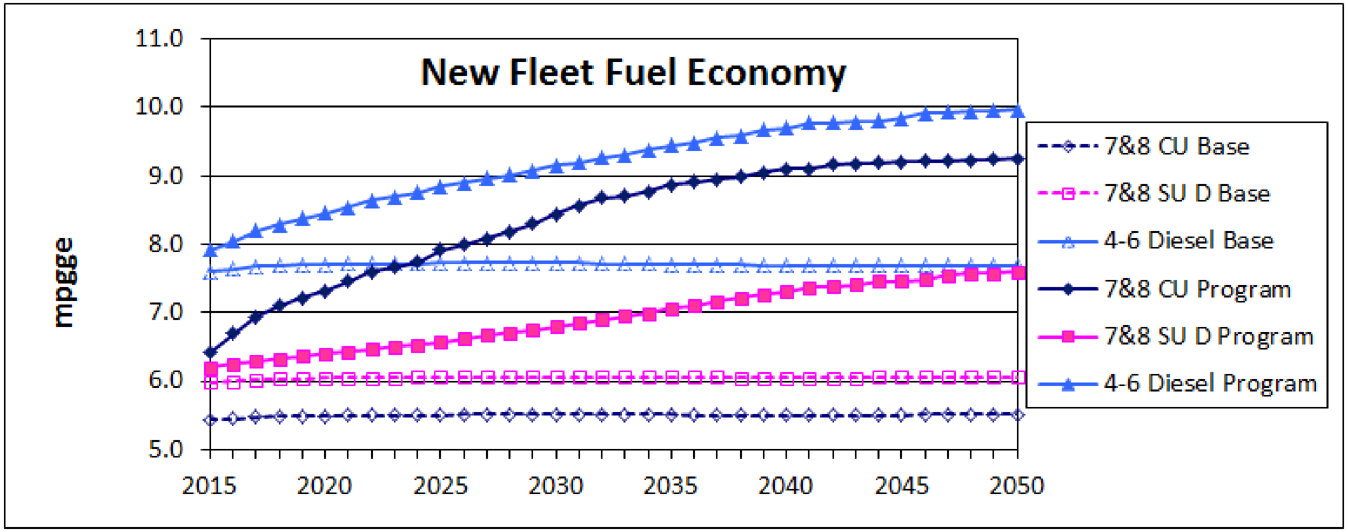
The high annual mileage driven by Class 7&8 CU trucks (tractor trailers) results in higher annual fuel savings and shorter payback periods.

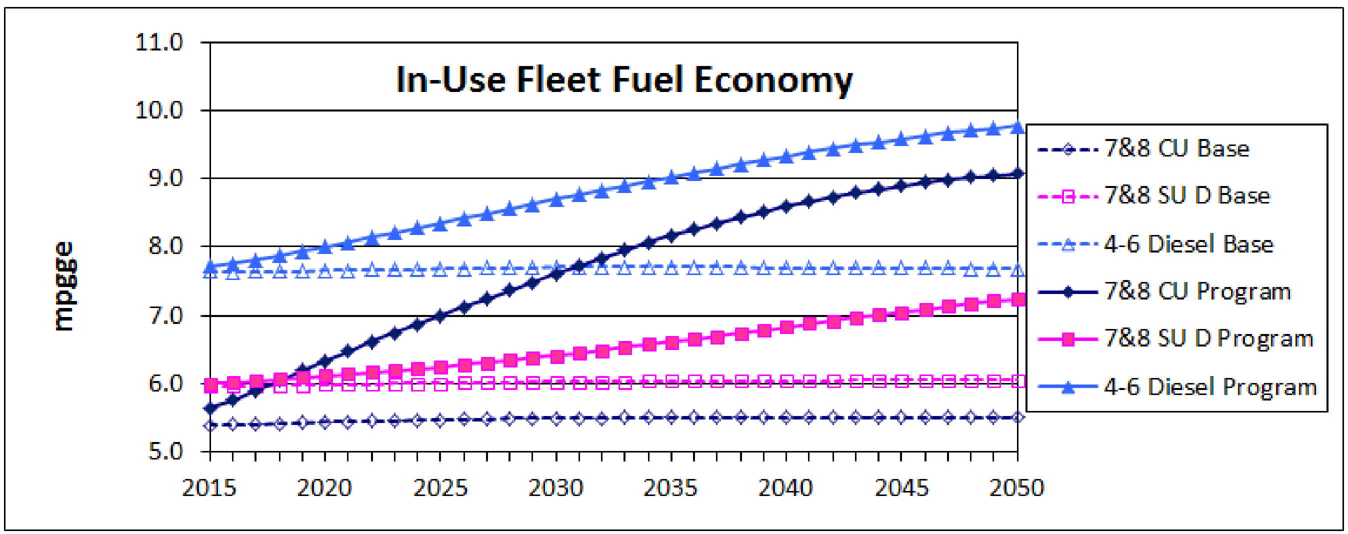




Market shares are % of annual class VMT. Shares as % of trucks will be lower since higher mileage trucks are more likely to adopt.

TRUCK Accomplishments FY13-14: GPRA 2015 Fleet Fuel Economy



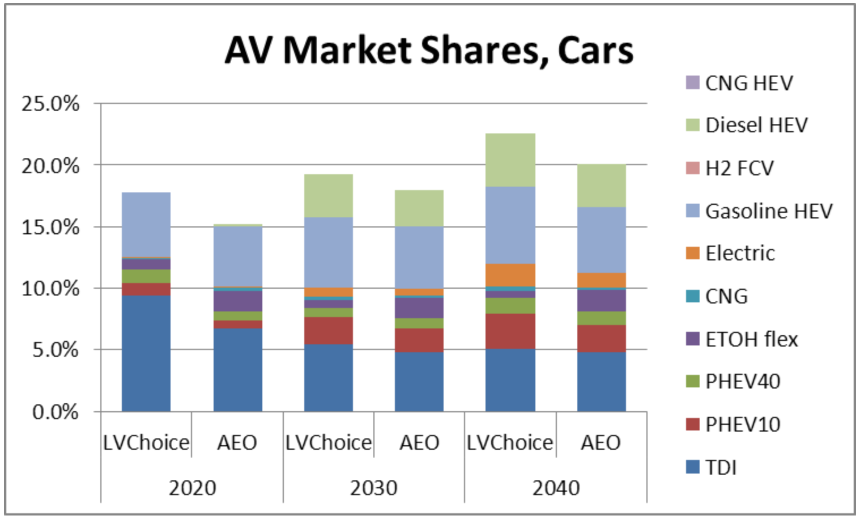


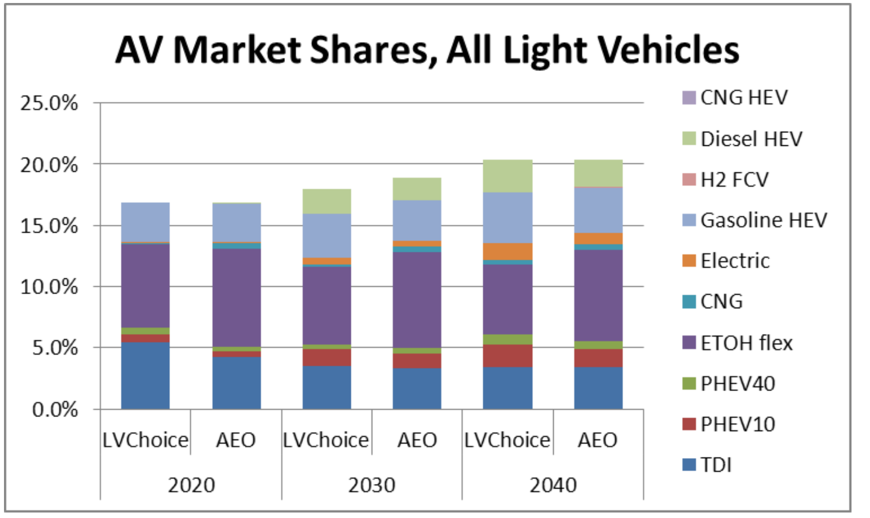
Due to lower mileage of single unit (SU) class 7 & 8 trucks and long payback periods, market shares for advanced technologies are limited. As a result, combination unit (CU) truck fuel economy is projected to far exceed SU fuel economy.

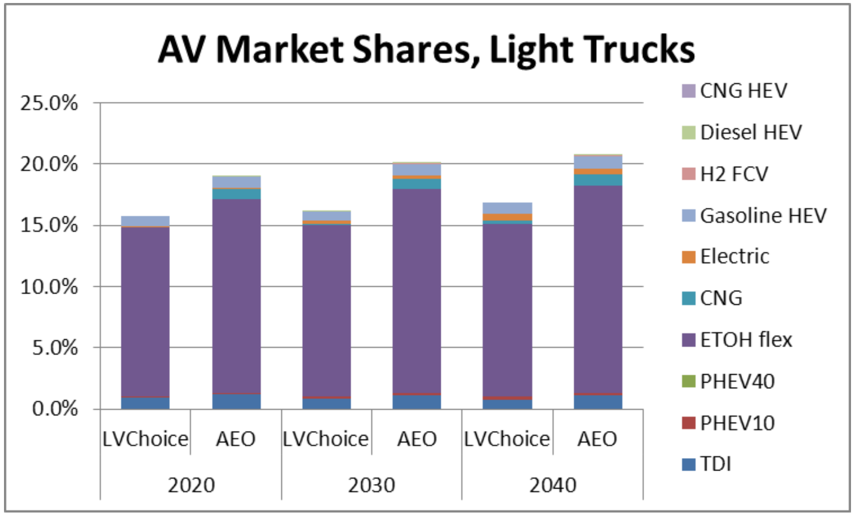
LVChoice Approach / Strategy

- LVChoice model developed for NPC and adapted to suit VTO analysis needs:
  - Nested multi-nomial logit structure and coefficients from NEMS, including calibration coefficients;
  - Include subset of NEMS size classes and technologies according to interest of VTO.
- To facilitate comparison to other VC tools: develop an interface Excel file using VBA code to translate “flat” input file.
  - Compatible with original model; model can still be run independently;
  - Accessible and transparent.
- Maximize flexibility in interface file: allow user to map model technologies and size classes to any input values in the flat file.
  - Accommodates any future changes to source program (Autonomie) and availability of new source program data;
  - User may include all or a subset of both technologies and classes;
  - Not all specified inputs need to be applied in a given run.
- Maximize flexibility in interface file: specify all utility factor and fuel economy calculation parameters in the interface file.
- Include specification of all possible inputs, including those unique to LVChoice.

LVChoice Accomplishments: Benchmark Comparison to AEO

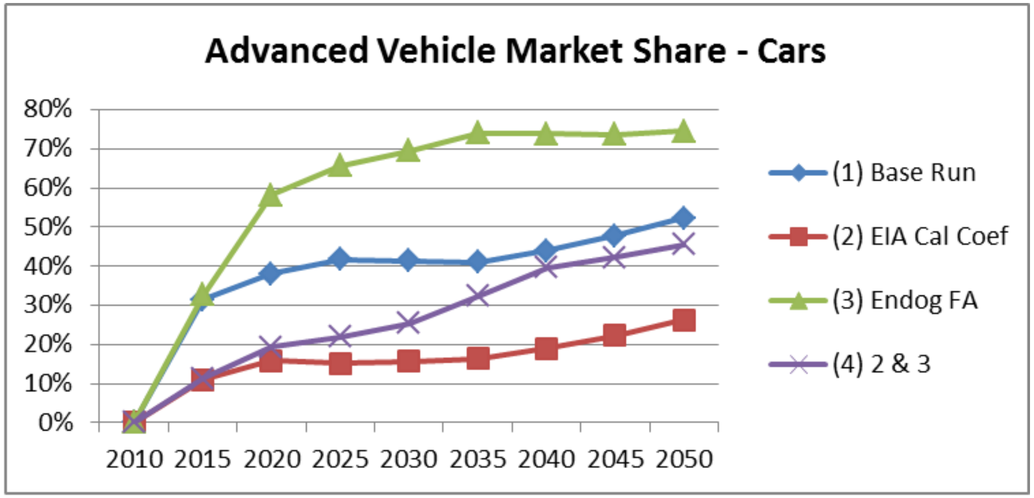


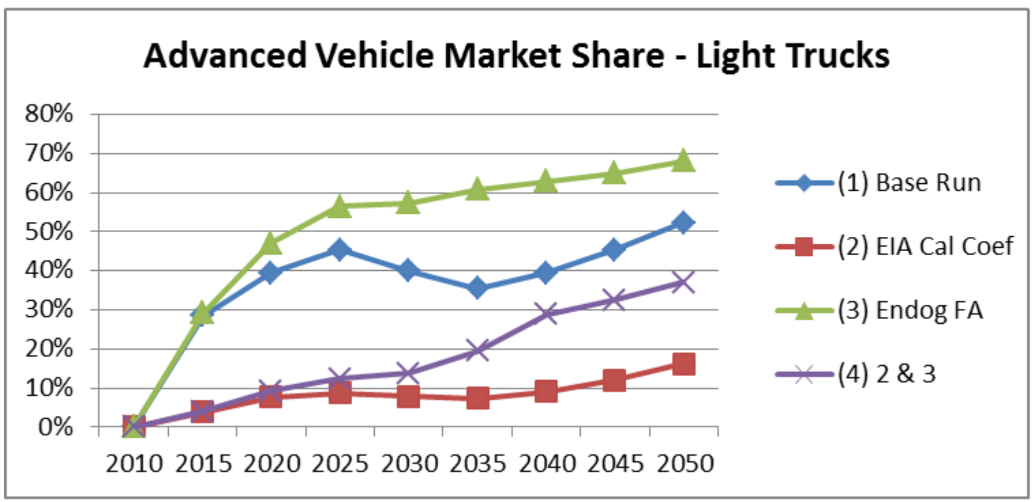




- LVChoice projects a higher overall fleet fuel economy due to differences in the car market
  - Initially due to higher TDI sales
  - In 2030-2040 timeframe, LVChoice projects higher market share for HEVs, PHEVs, and EVs.
- Some reasons for differences:
  - LVChoice does not include manufacturer decision-making to meet CAFE regulations.
  - LVChoice has different size classes and does not have the full NEMS technology suite.
  - “True” comparison would require a NEMS run matching these iinputs.

LVChoice Accomplishments: Sensitivity Analysis





- Base run with zero calibration coefficients and exogenous fuel availability (FA).
- All runs with endogenous make / model availability (MMA) and no early year market limits.
- Sales share of advanced vehicles is highly sensitive to calibration coefficient and FA.

Response to Previous Year's Comments

- This project was not reviewed in previous years.

Collaboration and Coordination

- All projects performed under contract to Argonne National Laboratory, project manager Tom Stephens.
- Integrated analysis of heavy vehicles for GPRA:
  - Performed in collaboration with Tom Stephens (ANL);
  - Assistance with AEO inputs provided by EIA (Patricia Hutchins, Nicholas Chase).
  - Coordination of inputs with VTO program managers (Roland Gravel, Ken Howden, Gurpreet Singh).
- HTEBdyn reviews and comments provided by Aymeric Rousseau (ANL) and SuperTruck industry partners (Daimler, Cummins, Navistar, Volvo, Detroit Diesel).
- LVChoice development and analysis, coordinating with:
  - ANL - Tom Stephens, Joann Zhou, Aymeric Rousseau, Anant Vyas, Deena Patel
  - EIA - Patricia Hutchins, Nicholas Chase
  - NREL – Aaron Brooker
  - ORNL – Zhenhong Lin

Remaining Challenges

- HTEBdyn
  - Model validation – lack of published test data that includes all necessary model inputs.
    - Coordinating with national labs and with SuperTruck and 21st Century Truck partners.
  - Many possible component and system configurations.
    - Configuration of hybrid and waste heat recovery systems impacts benefits.
    - Model needs to include pre-defined options with flexibility for customization.
  - Requirement to maintain quick run-time limits ability to solve power imbalance when vehicle does not meet schedule speed.
- LVChoice
  - Model comparisons complicated by sensitivity to variables that are treated differently among models, particularly fuel availability, make model availability, and calibration coefficients.

Proposed Future Work

- Update all models to latest AEO and perform analysis for GPRA 2016.
  - Analysis complete 2/28/2015
  - Documentation complete 4/30/2015.
- HTEB development:
  - Continue model validation;
  - Improve characterization of engines;
  - Characterization of gasoline engines for class 4-6;
  - Conversion of calculations to VBA or other platform to solve for vehicle speed when system is under powered;
  - Electrical coupling of TuCo and ORC systems; and
  - Add class 3 characterization.

Proposed Future Work, cont.

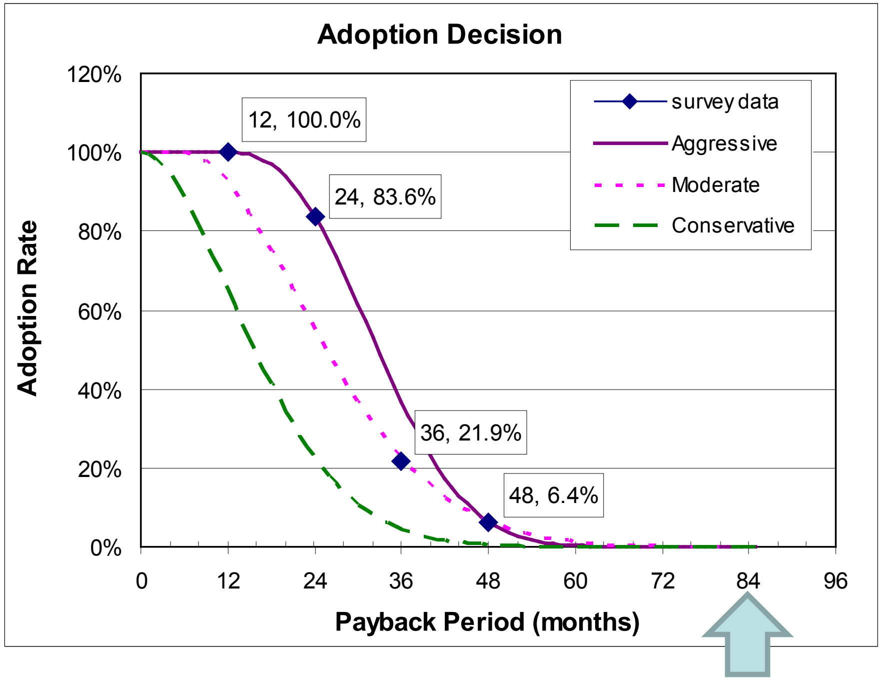
- TRUCK development:
  - Research and analyze data (population distribution by annual mileage) for class 3 commercial trucks.
- LVChoice development:
  - Analysis of fuel availability and make model availability algorithms and validation of results.
  - Model restructuring to increase flexibility; i.e. easily accommodate changes to technology suite.
    - Generic technologies with automated mapping to logit nests.
    - Fuel specification flexibility.
  - Add integrated model of producer decision-making to allow consideration of CAFE and ZEV mandates.
    - Endogenous calculation of new vehicle fuel economy and price.

Summary

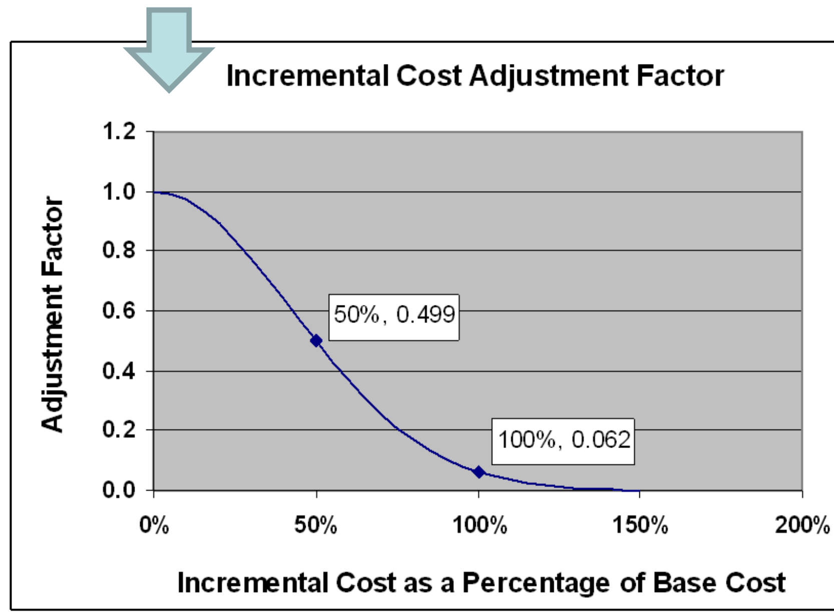
RELEVANCE	❑ HTEBdyn, TRUCK, and LVChoice provide a toolset to support VTO program planning, management, evaluation, and reporting. ❑ Models translate program technical targets into future fuel consumption and greenhouse gas reduction benefits.
APPROACH	❑ Build on legacy models/tools; ❑ Use methodologies based on engineering fundamentals, market data, and consumer behavior theory; and ❑ Maximize flexibility and ease of use.
ACCOMPLISHMENTS FY13-14	❑ Tools refined to increase ease of use, add flexibility, add features, and enhance quality of analysis results. ❑ Model validation / calibration / comparison is in progress.
COLLABORATIONS	❑ Work conducted in collaboration / consultation with experts at DOE, EIA, national labs, and industry partners
FUTURE WORK	❑ Expand the scope of the models to enhance coverage of the technologies and applications in the VTO R&D portfolio as well as spillover benefits in other applications.

Technical Backup

TRUCK Methodology



- AR curve is neutral to magnitude of incremental cost.
- Willingness to adopt is limited by availability of capital and perception of risk.
- AR is reduced with increasing cost



- Adoption rate (AR) determined from one of three curves (user selected).
- Most "aggressive" represents stated preferences
- Two remaining curves represent levels of risk aversion.

HTEBdyn Methodology: Engine Friction

- Engine friction includes all losses that vary with engine speed and is calculated from the friction mean effective pressure (fmep):

$$fmep = k_0 + k_1 \cdot \omega + k_2 \cdot \omega^2$$

$$P_f = \frac{1}{2} \cdot fmep \cdot D \cdot \omega$$

  - k_0: boundary friction; power varies with ω
  - k_1: viscous (hydrodynamic) losses; power varies with ω2
  - k_2: losses due to turbulence; power varies with ω3
- Includes losses due to:
  - Rubbing and reciprocating friction (crankshaft, valve train, etc.);
  - Engine auxiliaries (oil, water, fuel pump); and
  - Pumping losses due to gas exchange and fluid flows.
- Method is from PERE and consistent with Heywood (1988).

LVChoice Methodology: Nested Multi-nomial Logit Formulation

- Market share of advanced vehicle i (AV_i) within a size class is the probability of purchase based on relative utility:

$$P_i = \frac{e^{\sum_j \beta_j \cdot x_{i,j}}}{\sum_i^N e^{\sum_j \beta_j \cdot x_{i,j}}}$$

  - Where

    $x_{i,j}$ = value of attribute j for AV_i
    $\beta_{i,j}$ = coefficient on attribute j
    Utility from selecting vehicle i is: $U_i = \sum_j \beta_j \cdot x_{i,j}$
    N = total number of vehicle technologies

  - Note that the coefficients differ among size classes.

LVChoice Methodology: Vehicle Attributes

Attribute	Notes
Vehicle Price	Specified or calculated from production cost
Fuel Cost	Per GGE
Range	
Battery Replacement Cost	Cost currently = 0
Acceleration, 0-60 mph	
Home Refueling for EVs	Dummy (1,0)
Maintenance Cost	
Luggage Space	
Fuel Availability Coefficient 1	% of stations; exogenous or endogenous = f(est. stock)
Fuel Availability Coefficient 2	Utility due to FA is an exponential function
Make/Model Availability	Index to conv.; Exogenous or endogenous = f(3-yr avg share)
Technology Set Gen. Cost	Calculated per NEMS
Multi-Fuel Gen. Cost	Calculated per NEMS
Calibration coefficient	Specified annually per NEMS or static value

- LVChoice uses the same attributes as NEMS; coefficients are based on NEMS.
- Endogenous FA and MMA calculations based on NEMS algorithms.