Modeling for Light and Heavy Vehicle Market Analysis

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Project ID: VAN012

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Overview

TIMELINE		
	FY14	FY15
Start Date	Oct. 2013	Oct. 2014
End Date	Sept. 2014	Sept. 2015
% Complete	100%	70%

BUDGET	
Total Project Funding*	
Received for FY14	$130,000
Funding for FY15	$145,000

COLLABORATIONS & INTERACTIONS

- ANL: Tom Stephens, Joann Zhou, Aymeric Rousseau
- NREL: Aaron Brooker
- ORNL: Zhenghong Lin, Changzheng Liu
- Sandia: Dawn Manley, Rebecca Levinson
- EIA: Nicholas Chase, Patricia Hutchins
- 21st CTP and SuperTruck program managers & industry partners

BARRIERS ADDRESSED (from 2011-2015 VTP MYPP)

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

*Approximate funding received by TA Engineering, Inc. for work completed in FY14. Funding anticipated by Energetics Inc. for FY15. Funding to and work completed by TA Engineering, Inc. in FY15 is not reported in this presentation.

Overview: HD Analysis Tools

Heavy Truck Energy Balance (HTEB)

Estimates HD vehicle fuel consumption based on vehicle characteristics and duty cycle.

TRUCK Market Penetration Model

Projects market adoption of advanced technology vehicles based on fuel economy, fuel price, annual mileage, incremental vehicle cost, and mileage dependent costs.

HTEB Summary Worksheet

Compares results of multiple HTEB runs to a base run; attributes improvement by VTO program area.

(not reviewed)

Stock Accounting (VISION)

Projects in-use fleet fuel economy, fuel consumption, and emissions.

See VAN006

Benefits Calculation Worksheet

Compares a base and scenario case; attributes to VTO program area.

(not reviewed)

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Overview: LD Analysis Tools

Autonomie

Based on technology assumptions: estimates vehicle attributes, manufacturing cost, and fuel consumption for various test cycles.

See VSS164

RunLVCFlex

Extracts data from vehicle attribute flat file; calculates required LVCFlex inputs, and writes attributes to LVCFlex worksheets.

LVCFlex

Projects market adoption of advanced technology vehicles based, vehicle attributes, fuel prices, and consumer preferences (utility-theory, nested multinomial logit).

Stock Accounting (VISION)

Projects in-use fleet fuel economy, fuel consumption, and emissions.

See VAN006

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.
    - Supplements other analytical tools, e.g. Autonomie.
  - Task objectives (FY14):
    - Provide capability for quick analysis.
    - Allocate technology fuel consumption benefits to DOE program areas.

Objectives and Relevance, Cont.

- TRUCK; LVChoice/LVCFlex relevance:
  - Estimate market acceptance of advanced vehicle platforms based on performance (fuel economy) and cost;
  - Translate vehicle performance into sales fleet fuel and emissions savings.
- TRUCK task objectives:
  - No development task in FY14-15
  - Apply to GPRA (FY14) and updated SuperTruck (FY15) benefits analyses.
- LVChoice/LVCFlex task objectives:
  - Estimate market acceptance of advanced vehicle technologies using approach and methodology consistent with NEMS;
  - Improve flexibility of scenario specification, e.g. technologies, size classes, and technology group;
  - Improve user interface to automate input specification;
  - Perform analysis to support comparison of results to other models;
  - Analyze sensitivity of results to model structure and parameter specification.
  - Scope integration of manufacturer choice model.

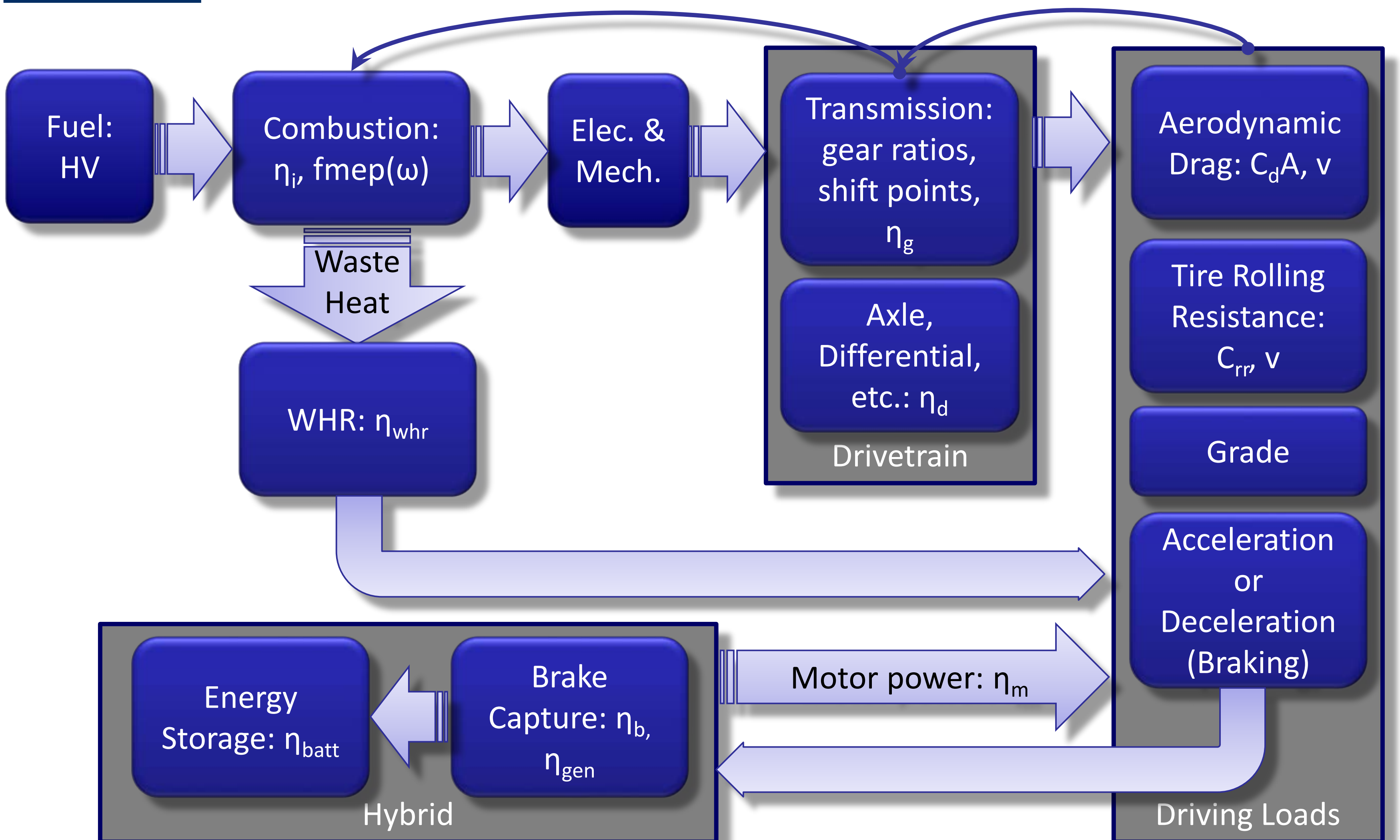
HD Milestones FY14-15

Date	Milestone / Go-No Go	Description	Status as of 4/10/15
HTEBdyn			
4/30/14	Milestone	Develop user guide and version for review distribution.	100%
5/30/14	Milestone	Model documentation.	100%
7/25/14	Milestone	Model validation against simulation and test data – reprioritized.	50%
7/25/14	Milestone	Journal article submission – reprioritized.	reprioritized
9/30/14	Milestone	Update class 4-6 characterizations – reprioritized.	reprioritized
Applied Analysis – Application of TRUCK and HTEBdyn			
1/6/14	Milestone	Complete analysis and documentation for GPRA 2015	100%
6/30/15	Milestone	Complete SuperTruck Benefits Analysis; publish draft report.	10%

LD Milestones FY14-15, Cont.

Date	Milestone / Go-No Go	Description	Status as of 4/10/15
LVChoice / LVCFlex			
5/30/14	Milestone	Update to AEO 2014 – reprioritized to coincide with BaSce 2015 (GPRA 2016) analysis; see below.	reprioritized
6/13/14	Milestone	Final analysis of common inputs with sensitivity.	100%
9/30/14	Milestone	Analysis of FA, MMA, and calibration factors – reprioritized; see below.	reprioritized
2/27/15	Milestone	Develop new architecture with flexible technology definitions and group assignments; benchmark to AEO 2014.	100%
3/20/15	Milestone	Analysis of BaSce 2015 common inputs.	100%
8/1/15	Milestone	Draft paper (co-author) on choice model comparisons.	0%
10/30/15	Milestone	Sensitivity analysis and validation against historical data.	10%
10/30/15	Go – No Go	Scope integration of manufacturer decision model.	50%

HTEB Approach



HTEBdyn Accomplishments FY14

- Work completed under FY14 funding to TA Engineering, Inc. through August 2014.
- 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.
- Improved allocation of fuel consumption benefits (case comparison) to DOE program elements.
- Partial validation against Autonomie simulation results.
- Completed model documentation and user guide.

Applied Analysis Approach: SuperTruck Benefits

- Characterize SuperTruck base and demonstration vehicle configurations and drive cycles used for analysis and testing
  - Quarterly Technology Reports
  - Industry team data requests and interviews
- Calibrate HTEBdyn models and determine fuel consumption benefits of component technologies.
- Develop baseline scenario and base Class 8 combination unit HTEBdyn inputs (AEO reference case).
- Develop advanced vehicle platforms (Class 8 CU only)
  - Not direct representations of any particular team’s vehicle.
  - Representative of the range of technological approaches, technology costs, and fuel savings benefits included within the research program.
  - Representative of possible technology deployment scenario.
- Develop cost estimates relative to base vehicle.
- Analyze baseline and advanced platforms in HTEBdyn on a single drive cycle (e.g. HHDDT65).
  - Provide fuel economy projection for up to four platforms including a representative base vehicle
- Project platform market adoption and new fleet fuel economy in TRUCK.
- Project future on-road fuel and CO_2 emissions savings using a stock accounting model.
- NOTE: this project will not estimate the market adoption of the demonstration vehicle configurations nor provide a relative ranking of the industry teams’ approaches.

Accomplishments: SuperTruck Benefits

- Project start in March 2015.
- Approach, data needs, and data sources identified.
- Contact with industry teams initiated.
- Review of existing documentation in April 2015.
- Project scheduled for completion by June 30, 2015.

Required Data	Units	Notes
Operational		
Fuel economy	mpg	Over specified duty cycle; used for model validation
Operating weight (vehicle + payload)	lb or kg	65,000 lb
Drive cycle		Characterized by time, speed, and grade.
Annual operation	mi/yr	Only required if reported mpg includes non-cycle idling
Idling	hrs/yr	If reported mpg includes idling in addition to drive cycle
Idle fuel rate (non-cycle idle)	gal/hr	If idle reduction device is used (e.g., APU)
Engine		
Displacement	L or in^3	
Maximum power	kW or hp	
Gross indicated efficiency	%	Estimated theoretical frictionless efficiency.
Friction losses		Includes losses due to rubbing and reciprocating friction in the crankshaft and other reciprocating parts and the valve train; losses due to engine auxiliaries (e.g. oil, water, and fuel pump); and pumping losses due to gas exchange and fluid flows.
Average loss over duty cycle and/or idle, or	kW	
Friction mep coefficients for variation w/ engine speed	kPa kPa/rps kPa/rps^2	
Auxiliaries and Parasitics		
Fan	kW	Assumed to apply only at idle and low vehicle speed
Other Mechanical	kW	Assumed to apply at all times
Electrical	kW	Assumed to apply at all times
Waste Heat Recovery		
Turbocompound		Can additionally / alternatively report net recovery over drive cycle
Recovery at max torque	%	
Recovery at 0 torque (asymptotic)	%	
ORC		Can additionally / alternatively report net recovery over drive cycle
Max recovery from exhaust	%	
Max recovery from coolant	%	
Drivetrain		
Transmission make and model	NA	If off the shelf; or specify gear ratios and shift points (rpm)
Efficiency improvement	%	Reduction in losses relative to specified make/model
Driveline efficiency	%	Clutch, torque converter, axle, etc.; net
Drive axle gear ratio	NA	
Tire diameter	In.	
Aerodynamics		
Frontal area	ft^2 or m^2	
Coefficient of drag (Cd)	NA	
Rolling Friction		
Coefficient of rolling friction (Crr)	NA	Net for all wheels
Coefficient, velocity dependent (Crr_v)	/(m/s)	
Hybrid System (if applicable)		
Motor peak power	kW	Continuous; total power if more than one motor
Motor efficiency	%	
Generator peak power	kW	
Generator efficiency	%	
Regenerative braking max capture	%	Limited to 0.3 g and generator peak power
Battery capacity (usable)	kWh	
Battery voltage	V	
Off-cycle idle engine off?	Y/N	

LVChoice/LVCFlex Approach & Strategy

- LVChoice developed for NPC and adapted to suit VTO analysis needs:
  - Nested multi-nomial logit structure and coefficients from NEMS;
  - Subset of NEMS size classes and technologies according to interest of VTO.
- Develop an interface Excel file using VBA code to translate flat vehicle attribute file (Autonomie outputs) – FY14.
  - Maximize flexibility in interface file:
    - Allow user to map model technologies and size classes to any input values in the flat file.
    - Specify all calculation parameters in the interface file (not hardwired in code).
    - Column mapping in in interface file to accommodate changes in data organization.
  - Include specification of all possible inputs, including those unique to LVChoice.
  - Include data checks, debug output, and run log.
- LVCFlex enhancements - FY15:
  - Include as many technology platforms as in NEMS;
  - Complete flexibility in technology definition (powertrain type, fuel, etc.).
  - Allow user to easily assign platforms to technology groups and size classes; accommodates scenarios that depart from the NEMS technology suite.
  - Include switches to easily apply user inputs, AEO defaults, or endogenous algorithms (calibration, FA, and MAA).

LVCFlex Accomplishments: User Interface, Technology Definitions

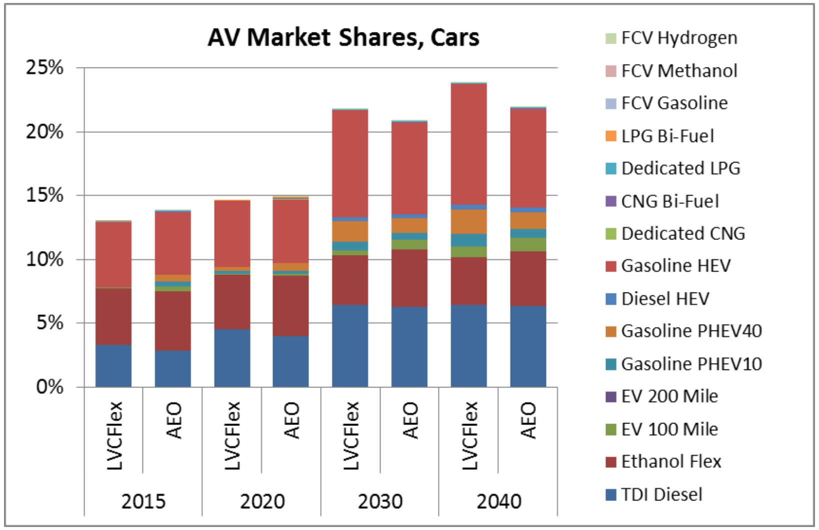
LVC Tech Index	Description	Fuel 1	Fuel 2	Calculate Fuel Shares in Nest 3?	Apply UF to input MPGs?	Capable of Home Refueling	Tech Group	Group ID	Max Sales Share Within Group	AEO Tech for Default Attributes	AEO Tech Index	Include in Class? Small Car	Large Car	Pickup	Small SUV	Large SUV
1	Gasoline Conventional	Gasoline	NA			FALSE	Gasoline/Diesel Capable, incl Bi- or Flex-fuel	1	100.0%	Gasoline	1	TRUE	TRUE	TRUE	TRUE	TRUE
2	CI_Conventional	Diesel	NA			FALSE	Gasoline/Diesel Capable, incl Bi- or Flex-fuel	1	100.0%	Turbo DI Diesel	2	TRUE	TRUE	TRUE	TRUE	TRUE
3	E85_Conventional	Gasoline	E85	TRUE		FALSE	Gasoline/Diesel Capable, incl Bi- or Flex-fuel	1	100.0%	Flex-Fuel Ethanol	3	FALSE	FALSE	FALSE	FALSE	FALSE
4	BEV100 DM	Electricity	NA			TRUE	Electric Plug-in	5	100.0%	Electric Vehicle - 100 miles	4	TRUE	TRUE	TRUE	TRUE	TRUE
5	BEV300 DM	Electricity	NA			TRUE	Electric Plug-in	5	100.0%	Electric Vehicle - 200 mile	7	TRUE	TRUE	TRUE	TRUE	TRUE
6	SI_Split PHEV10	Gasoline	Electricity	FALSE	FALSE	TRUE	Hybrid	2	50.0%	PHEV10	5	TRUE	TRUE	TRUE	TRUE	TRUE
7	SI_EREV PHEV40	Gasoline	Electricity	FALSE	FALSE	TRUE	Hybrid	2	50.0%	PHEV40	6	TRUE	TRUE	TRUE	TRUE	TRUE
8	CI_Split HEV	Diesel	NA			FALSE	Hybrid	2	100.0%	Diesel/Electric Hybrid	8	FALSE	FALSE	FALSE	FALSE	FALSE
9	SI_Split HEV	Gasoline	NA			FALSE	Hybrid	2	100.0%	Gasoline/Electric Hybrid	16	TRUE	TRUE	TRUE	TRUE	TRUE
10	CNG_Conventional	CNG	NA			FALSE	Dedicated AF ICE	3	100.0%	Dedicated CNG	11	FALSE	FALSE	FALSE	FALSE	FALSE
11	CNG_Split HEV	CNG	NA			FALSE	Hybrid	2	100.0%	Diesel/Electric Hybrid	8	FALSE	FALSE	FALSE	FALSE	FALSE
12	CI_EREV PHEV40	Diesel	Electricity	FALSE	FALSE	FALSE	Hybrid	2	50.0%	PHEV40	6	FALSE	FALSE	FALSE	FALSE	FALSE
13	BEV 200 DM	Electricity	NA			FALSE	Electric Plug-in	5	100.0%	Electric Vehicle - 200 mile	7	FALSE	FALSE	FALSE	FALSE	FALSE
14	SI_EREV PHEV30	Gasoline	Electricity	FALSE	FALSE	FALSE	Hybrid	2	50.0%	PHEV40	6	FALSE	FALSE	FALSE	FALSE	FALSE
15	FC Series PHEV40	Hydrogen	Electricity	FALSE	FALSE	FALSE	Fuel Cell	4	50.0%	Hydrogen Fuel Cell	14	FALSE	FALSE	FALSE	FALSE	FALSE
16	FC Series HEV	Hydrogen	NA			FALSE	Fuel Cell	4	100.0%	Hydrogen Fuel Cell	14	TRUE	TRUE	TRUE	TRUE	TRUE
				NOTE: if both flags are TRUE, Nest 3 takes precedent.												
				If Fuel 2 is defined and both flags are FALSE, fuels will be consumed simultaneously using mpg1 and mpg2												

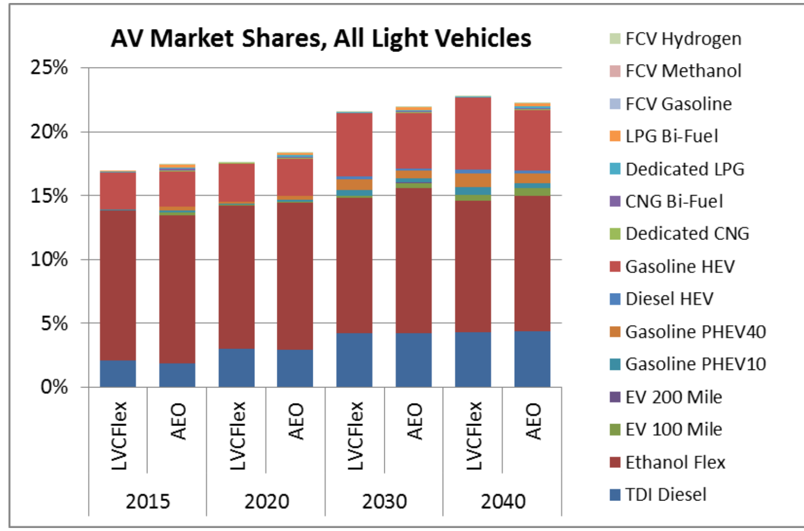
- Technology definition worksheet allows complete flexibility in technology definition.
  - Fuel type(s), fuel shares determination, technology group, within group share limits, and size class inclusion.
  - Up to 15 alternative technologies of any type, in any group.
  - Quick analysis of alternative assumptions.
- Prior version:
  - Hardwired technology group map;
  - Preset number of technologies in each group;
  - Preset calculation methodologies for each technology;
  - Adding new technology required model restructuring;
  - Removing a technology from a size class required overwriting vehicle attributes to preclude adoption.

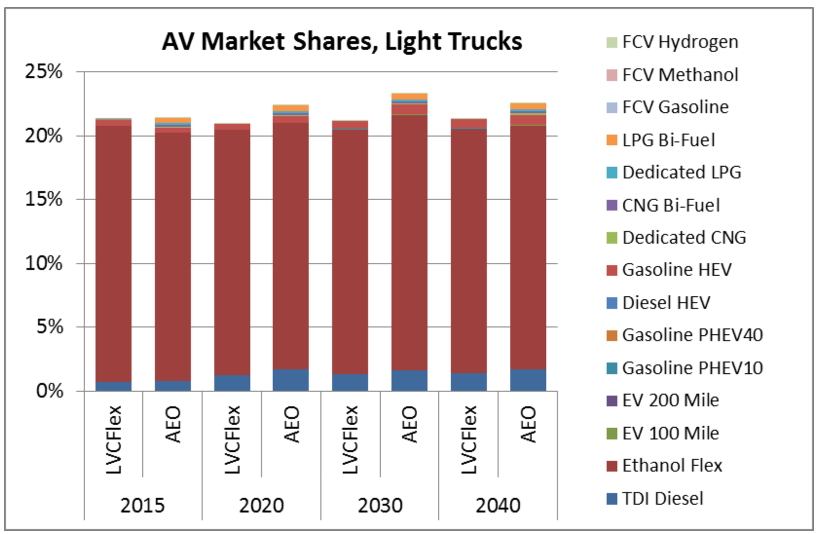
LVCFlex Accomplishments: Calibration and Validation

- LVCFlex was developed to specifically allow exploration of scenarios using the NEMs consumer choice approach.
- Calibration coefficients were taken directly from the NEMS input file for AEO 2014.
  - Coefficient is a utility value intended to account for omitted variables; EIA determines values that produce historical shares.
  - LVCFlex allows the user to map the EIA values to scenario technologies or adjust the coefficients when required (e.g., use of different technology suite).
- For validation, vehicle and fuel attributes were extracted from the AEO 2014 reference case and market share results were compared.
- Note that the AEO output tables do not report:
  - Acceleration times at the level of technology type within size class.
  - Annual calculation of make-model availability.
  - Annual calculation of fuel availability.

LVCFlex Accomplishments: Benchmark Comparison to AEO 2014



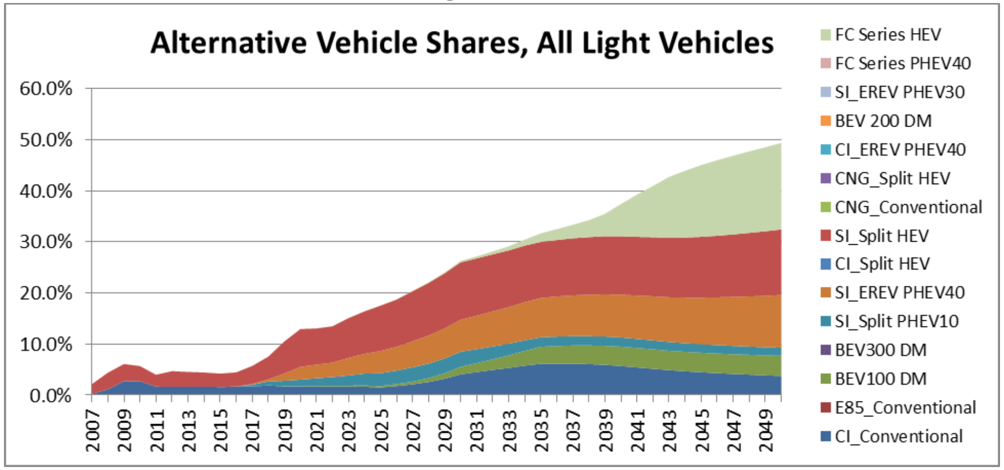




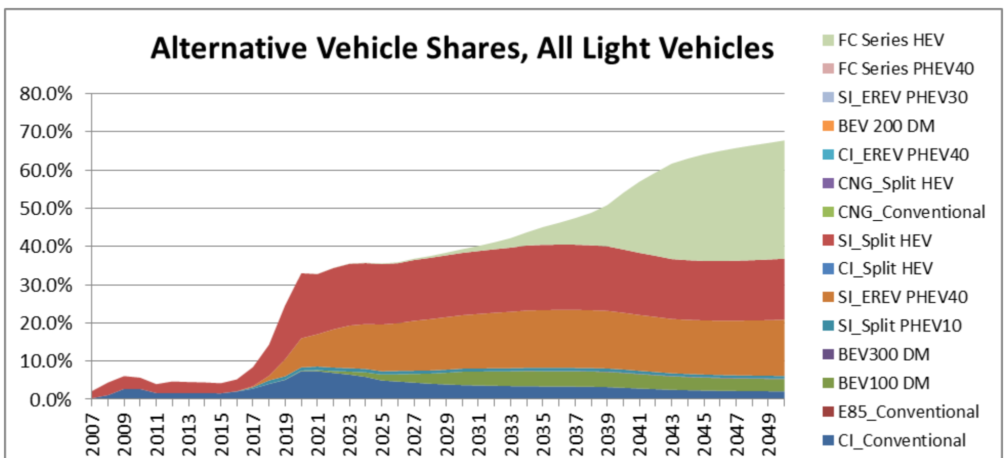
- LVCFlex can analyze full technology suite from NEMS / latest AEO.
- LVCFlex projects a slighter higher sales fleet fuel economy:
  - Higher share for HEVs in cars in 2030-2040 timeframe.
  - Generally lower shares of alternatives in trucks.
- Some reasons for differences:
  - Size class aggregation (attributes and coefficients).
  - Estimated acceleration times.
  - No fleet or commercial vehicle calculations.
  - National versus regional.
  - Possible differences in MMA and FA.

LVFlex Accomplishments: BaSce Analysis (GPRA 2016)

"No Program" Case:



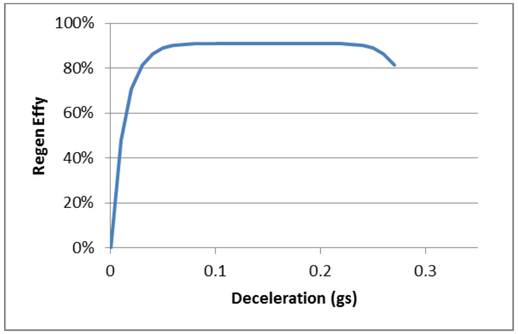
"Program Success" Case:



- Technologies included:
  - Gasoline Conv.
  - CI_Conventional
  - SI_Split HEV
  - SI_Split PHEV10
  - SI_EREV PHEV40
  - FC Series HEV
  - BEV100 DM
  - BEV300 DM
- "No Program" case
  - Gradual market expansion of HEVs, reaching saturation around 2030.
  - Modest share of PHEV10 that phases out.
  - Gradual uptake of PHEV40 and BEV100.
  - Significant share of CI after 2027.
  - Gradual uptake of H2 FCV 2030-2040 with significant expansion after 2040.
- "Program Success" case
  - Overall much higher share for AVs.
  - Rapid market uptake of HEV and PHEV40 vehicles between 2017 and 2020.
  - Saturation of HEV and PHEV 2020-2030.
  - More rapid expansion in H2 FCV after 2040.
- AV adoption in light trucks is hindered by calibration coefficient (EIA).
- H2 FCV success due to favorable attributes, fuel price, and availability (exogenous) and positive feedback (MMA).

Response to Previous Year's Comments

1. **Inclusion of maintenance costs and other total costs of ownership in all models.** The HTEBdyn model is strictly a power demand accounting model. TRUCK has the capability to add any mileage-dependent costs. LVChoice structure is based on the NEMS CVCM which includes maintenance and battery replacement costs in the vehicle attributes.
2. **The HTEBdyn assumption that any available braking energy is used seems over-simplified; regenerative efficiency should be a function of initial braking speed, braking rate, etc.** Available braking energy is modeled as a function of user-specified maximum efficiency and required deceleration as illustrated below. This function reaches maximum efficiency below 0.1 g then declines above 0.2 g. Above 0.3 g, all braking is assumed to be mechanical. Available braking energy is then reduced by drivetrain and generator efficiencies to obtain captured brake energy, all of which is assumed to be usable by the hybrid drive system.



3. **HTEBdyn might not be using state of the art assumptions; the presenter could not discuss the baseline vehicle; the model should be validated against a base engine, a 2014-2018-compliant engine, and incremental engine efficiency.** The "base" vehicle for HTEBdyn scenarios can be defined however the user desires: any engine indicated thermal efficiency, engine friction losses, transmission, driveline efficiency, aerodynamic profile, etc. Default engine MEP curves are provided and are representative of MY2012-2013 engines, but the user can enter custom inputs. We agree that the model would benefit from validation against a variety of engine and vehicle test data and have included this as proposed future work in this year's AMR.
4. **The TRUCK model should include class 2b-3 and incorporate updated adoption rate and population survey data.** We agree with these suggestions for future improvement. We are actively pursuing sources of updated data from new and existing sources, including trade groups, our industry partners in the 21st CTP, private industry, and government agencies.

Response to Previous Year’s Comments

5. **a.) LVChoice is duplicative of AEO and its purpose is unclear; the model is very sensitive to input assumptions; the results of one simulation could give a distorted view of the future.** LVChoice replicates the consumer choice methodology used in EIA’s NEMS but is simplified and easy to run. This allows VTO to independently analyze scenarios *counter* to the AEO without expending the significant resources required to run NEMS. It also allows VTO to explore the sensitivity of scenario results to EIA’s parameter assumptions and to compare the results of the NEMS formulation to alternative structures and assumptions in other consumer choice models included in the VTO portfolio.

   b.) Why does DOE not use the Autonomie model instead of HTEBdyn? We see the models as complimentary. HTEBdyn was developed to provide quick analysis of multiple platforms for GPRA reporting and is specifically structured to allocate fuel consumption benefits between scenarios to DOE program areas. Autonomie is extensively vetted and peer reviewed and does provide for high fidelity analysis. However, this analysis is more time-intensive than HTEBdyn. In addition, because HTEBdyn is a MS Excel spreadsheet, it is easily accessible and transparent.

   c.) Fleet modeling with TRUCK and LVChoice overlap with other DOE fleet models (e.g., VISION) and therefore seem duplicative. The TRUCK and LVChoice models estimate market shares for new technologies and are not fleet models. LVChoice does apply VISION scrappage rates to estimate vehicle stock in order to project fuel and model availability. However, these rough stock estimates are not a model output. Neither TRUCK nor LVChoice calculates fleet VMT, energy consumption, or emissions, which are the primary output of the VISION stock accounting model. In the future, it might be possible to link LVChoice to VISION to provide more accurate stock estimates for the LVChoice algorithms and allow for a more integrated analysis.

6. **This project’s reports, models, and data should be made widely available and to the fullest extent possible.** The models and associated documentation have been made available though the ANL website. The heavy vehicle models were used for the SuperTruck Benefits Analysis (2012) and the VTO GPRA 2015 analysis; the final reports for these are also available on the ANL website. Future analysis results will also be made available. See http://www.anl.gov/energy-systems/group/energy-systems-analysis

Collaboration and Coordination

- All FY14 projects performed by TA Engineering, Inc. under contract to Argonne National Laboratory, project manager Tom Stephens.
- Applied market analysis of heavy vehicles for GPRA 2015 (FY14):
  - 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).
- SuperTruck Benefits Analysis update performed using inputs gathered through extensive communication and collaboration with industry partners with review and coordination by VTO program managers. Results / final report to be reviewed by both industry and DOE stakeholders.
- LVChoice/LVCFlex development and applied analysis, coordinating with:
  - ANL - Tom Stephens, Joann Zhou, Aymeric Rousseau, Deena Patel
  - EIA - Patricia Hutchins, Nicholas Chase
  - NREL – Aaron Brooker
  - ORNL – Zhenhong Lin, Changzheng Liu
  - Sandia – Dawn Manley, Rebecca Levinson

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.
- LVCFlex
  - Availability of data for calibration / validation
    - Historical vehicle attributes and sales
    - AEO vehicle attributes by technology platform within size classes
  - Calculates only technology shares and not sales, which are significantly affected by vehicle cost / price; sales would vary between scenarios but must be specified exogenously; cannot analyze economic impacts:
    - Compliance with emissions and CO_2 standards
    - DOE R&D success
  - As a stand-alone choice model, LVCFlex cannot evaluate policies that influence manufacturers' decision-making regarding technology deployment or pricing strategies.

Proposed Future Work

- HTEB development:
  - Continue model validation;
  - Improve engine characterizations
    - Advanced (current and near term) engines;
    - Gasoline engines for class 4-6;
    - Long term: Consider look-up table approach to characterization / engine map.
  - Conversion of calculations to VBA or migration of model to another platform to allow solution for vehicle speed when system is under powered;
  - Electrical coupling of TuCo and ORC systems; and
  - Add class 3 characterizations.
- TRUCK development:
  - Update vehicle sales distributions by class and fuel type with new data (Polk).
  - Update vehicle use distributions with new data (21st CTP partners and NREL).
  - Update and improve technology adoption decision parameters.
    - In collaboration with industry / trade groups.
    - Additional information to quantify factors other than payback period.
  - Detailed treatment of Class 3 body types (pickup, vocational, van?), as data permits.

Proposed Future Work, cont.

- LVChoice development:
  - Analysis of fuel availability and make model availability algorithms.
  - Analysis of EIA calibration coefficients.
  - Model validation against AEO; validation using historical data.
  - Consider adding integrated model of producer decision-making to allow consideration of CAFE, ZEV mandates, and other policies.
    - Endogenous calculation of new vehicle fuel economy and price.
  - Add additional capabilities as requested.
- Applied analysis:
  - Apply models to analyses as requested.

Summary

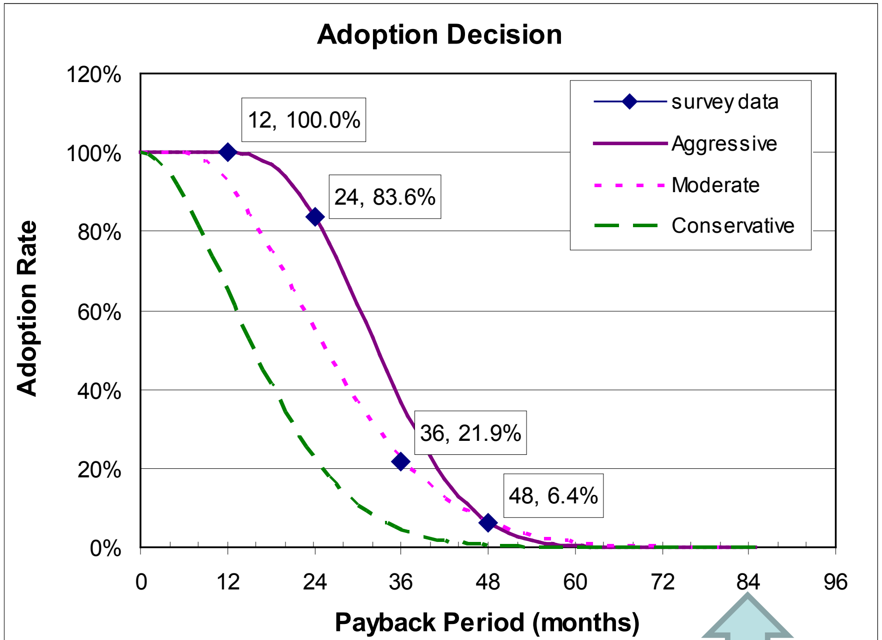
RELEVANCE	❑ HTEBdyn, TRUCK, and LVChoice provide a toolset to support VTO program planning, management, evaluation, and reporting. ❑ Models translate program technical targets into future fuel consumption and greenhouse gas reduction benefits.
APPROACH	❑ Build on legacy models/tools; ❑ Use methodologies based on engineering fundamentals, market data, and consumer behavior theory; and ❑ Maximize flexibility and ease of use.
ACCOMPLISHMENTS FY14-15	❑ Tools refined to increase ease of use, add flexibility, add features, and enhance quality of analysis results. ❑ Models utilized for GPRA and SuperTruck Benefits Analyses. ❑ 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 and beyond. ❑ Enhance model and analysis credibility through rigorous validation. ❑ Improve policy analysis capabilities through additional development.

Technical Backup

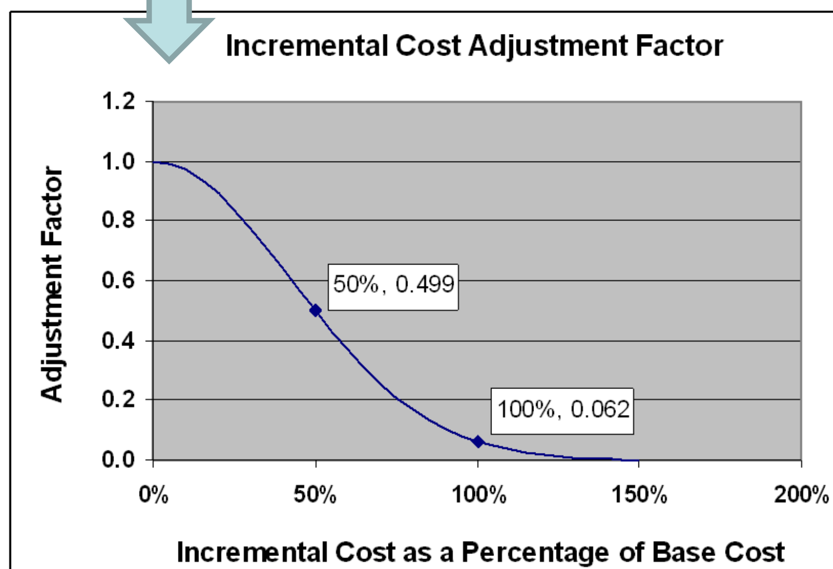
TRUCK Approach

- 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 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.

ENERGETICS
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HTEB Approach

- At each time step of 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 organic Rankine cycle).
- Use simplified relationships that capture the performance characteristics of component systems; “black box” approach rather than detailed component modeling / simulation.

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).

LVCFlex 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 user input

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