

Assessing Energy and Cost Impact of Advanced Technologies through Model Based Design



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2016 DOE Hydrogen Program and Vehicle Technologies
Annual Merit Review

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Project ID # VAN023

Project Overview

Timeline	Barriers
■ Start – October 2016 ■ End – September 2019	■ Bring technologies to market faster ■ Accelerate technology evaluation ■ Support requirements definition
Budget	Partners
■ Total Project Funding (\$4.5M over 3 years) ■ FY16 Funding : \$1.5M	■ LMS/Siemens ■ MathWorks ■ Third Party Tool Companies (Gamma Technology, ChiasTek, Esse) ■ OEM users (GM, Ford, Chrysler, Cummins...) ■ National Labs users (NREL, ORNL...) ■ Multiple other Argonne groups including engine, battery, mathematics ...

Relevance

VTO Benefits

Autonomie⁽¹⁾ is used by a very large number of VTO projects to define R&D targets, evaluate the benefits of advanced technologies at a vehicle system level, provide R&D guidance...

- During the 2015 AMR, more than 35 projects were related to Autonomie:
 - More than 10 projects provided inputs to Autonomie⁽²⁾
 - More than 15 projects used Autonomie to perform studies⁽³⁾
 - More than 10 projects used results from Autonomie to perform further studies / analysis⁽⁴⁾
- Autonomie is also used to support education (Gate), DOT and DOD

(1) Autonomie is a vehicle system simulation tool designed to assess the energy and performance of advanced vehicles technologies. www.autonomie.net

(2) EDT006, VSS021, VSS030, VSS134, VSS154, VSS160, VSS164, VSS166, VAN002...

(3) FC017, SA044, SA050, ACE011, ACE022, FT008, VSS097, VSS133, VSS140, VSS141, VSS153, VSS154, VSS161, VSS164, VSS166, VAN001...

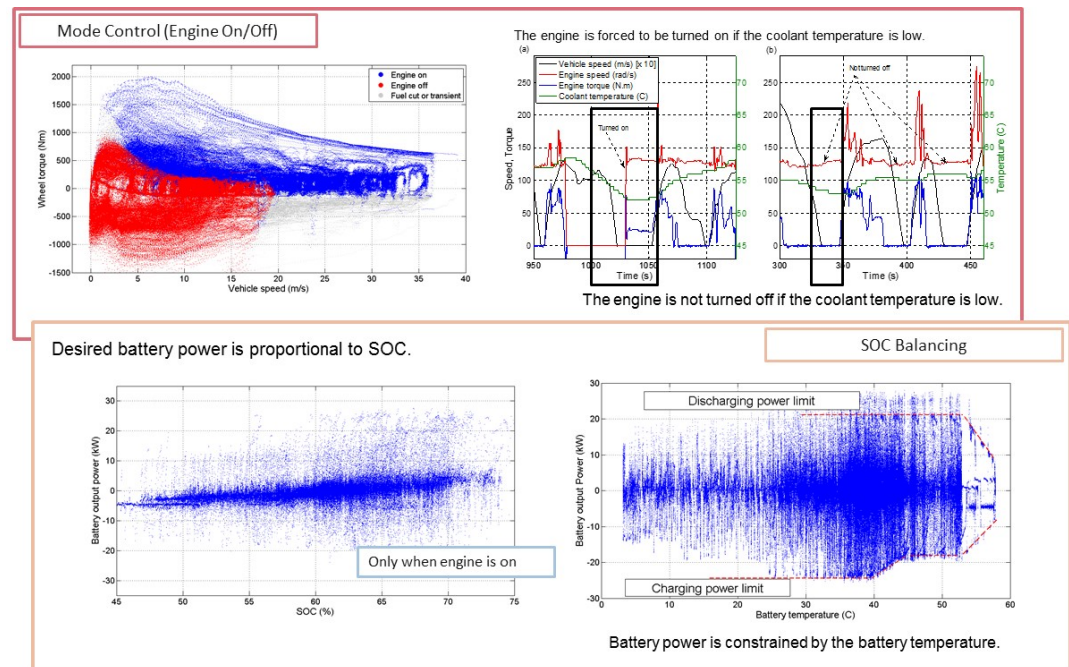
(4) FC017, SA050, SA055, VSS164, VAN001, VAN005, VAN012, VAN013, VAN014...

Relevance

Users Benefits

Autonomie is the only commercially available software the includes full vehicle models with state-of-the-art vehicle level controllers for a wide range of powertrains

Example: Prius HEV
Vehicle Level Control
Algorithm developed from
ANL's APRF⁽¹⁾ test data



(1) Advanced Powertrain Research Facility

Milestones

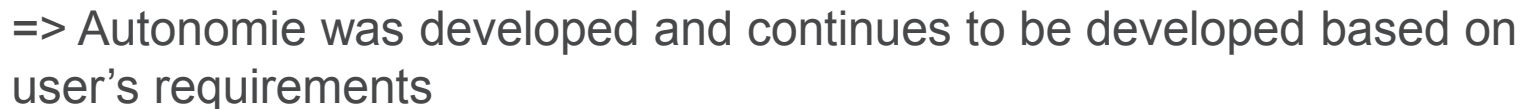
	FY16	FY17	FY18
<u>Task 1</u> Autonomie Model Based System Engineering⁽¹⁾	- Release R15 & R15SP1 - Demonstrate Process Centric Architecture (Autonomie 2.0)	Release R16 & R16SP1 (Autonomie 2.0 with current capabilities)	Release R17 & R17SP1 (Autonomie 2.0 with new large scale simulation capabilities)
<u>Task 2</u> Vehicle Validation⁽²⁾	Develop and validate a full thermal vehicle model of the BMW i3-EREV	- Develop and validate a full thermal vehicle model (vehicle TBD) - Develop automated validation process	Develop and validate a full thermal vehicle model (vehicle TBD)
<u>Task 3</u> Quantify and Maximize VTO Energy Impact⁽³⁾	- Provide report assessing the impact of VTO technology packages on standard cycles - Quantify the energy and cost impact of individual VTO technologies on standard cycles	Quantify the energy and cost impact of VTO technology packages under real world driving conditions	- Provide report assessing the impact of VTO technology packages on standard cycles - Quantify the impact of advanced control to maximize VTO technology benefits

(1) New releases of Autonomie developed to support US Government projects across the National Laboratories & outside users

(2) ANL vehicle testing funded through separate projects

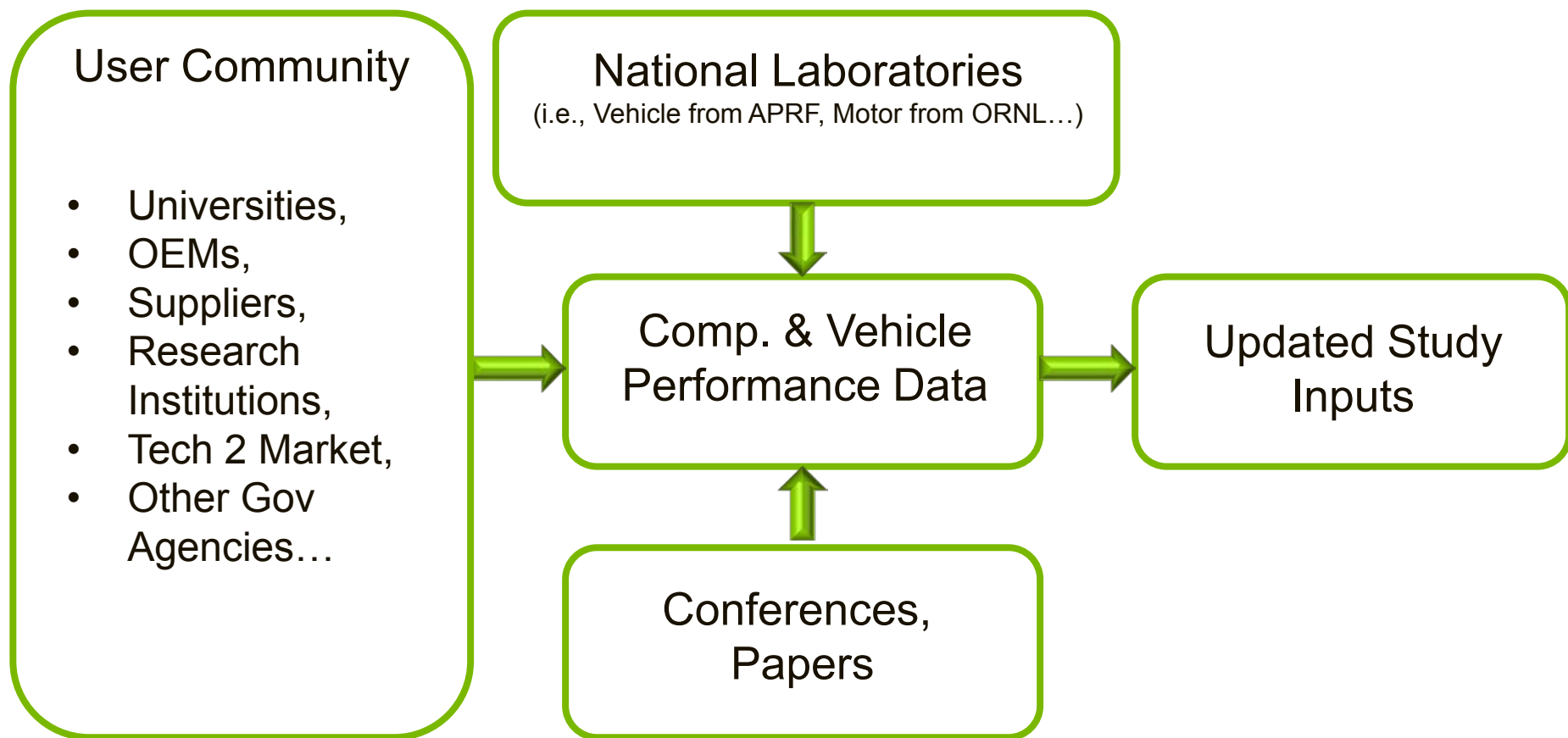
(3) Studies designed to provide guidance to VTO managers and inputs to other researchers (i.e., GHG with GREET, market penetration with MA3T...)

Gather Requirements from Autonomie User Community to Prioritize Development



Approach – Performance Data

Gather Component and Vehicle Level Data from Nat. Lab, OEMs, Suppliers, Autonomie User Community and Literature



Technical Accomplishments

Autonomie – Model Based System Engineering

Main New Features Summary

The features described below have been developed based on requests and feedback from Autonomie users

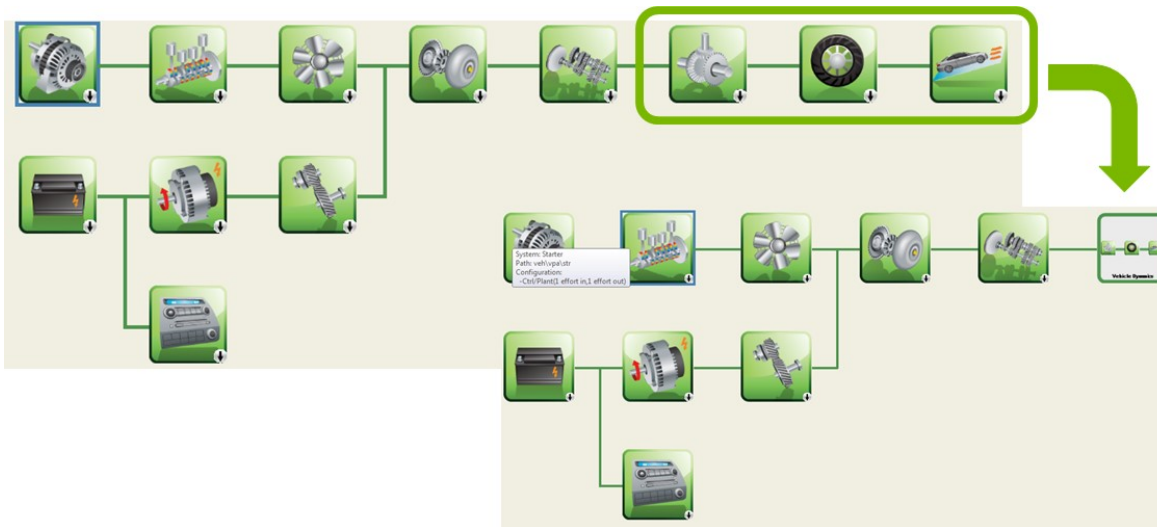
- **Plug&Play:**
 - Documented existing APIs and added new ones to facilitate the import of new models and files as well as usage of the tool for large scale simulations
 - Improved memory management to support the simultaneous analysis of much larger number of results
 - Developed new functionalities to allow users to further customize the tool (i.e., settings, import, process...)
 - Integrated source control tools into the GUI to manage file versions
- **Vehicle Energy Consumption Application:**
 - Released more than 100 new turn-key vehicles including
 - Updated light duty vehicles across a wide range of powertrain configurations
 - New light duty vehicles across multiple vehicle classes from compact car to pick up truck
 - New medium and heavy duty vehicles
 - Adopted new powertrain configuration organization to facilitate model reuse (i.e., quickly go from a conventional 2WD to a 4WD or from a conventional to a start-stop system)

Technical Accomplishments

Autonomie – Model Based System Engineering

New Model Organization to Facilitate Model Reuse (SAE J3049⁽¹⁾)

- Best recommended practice developed over multiple years under an SAE committee led by Argonne⁽²⁾
- Configurations developed to reduce the number of architecture choices while increasing the number of vehicle powertrain and maximizing model reuse across options.



Example: Grouping final drive, tires and chassis into a single vehicle dynamics block facilitates switching from 2WD to 4WD powertrains

(1) http://standards.sae.org/j3049_201508/

(2) National Laboratory support funded by DOE/VTO⁹

Technical Accomplishments

Autonomie – Model Based System Engineering

Released New List of Turn-key Vehicles

- Light duty conventional vehicles across multiple vehicle classes (compact car to pickup truck) representative of 2015 technologies⁽¹⁾
- Vehicles provided to perform comparison of powertrain configurations including micro-HEV, Start-stop, xEVs (pre-transmission, powersplit, series, multi-mode...)
- Vehicles provided to perform comparison of individual component technologies (e.g., 5 vs 6 vs 8 speed automatic transmissions or Automatic vs DCT vs CVT)
- Medium and heavy duty vehicles for multiple classes (e.g., Class 3 school bus/van, Class 4 StepVan, Class 5 Construction, Class 7 School bus, Class 8 line-haul/refuse truck...)⁽²⁾
- Special use cases: full vehicle thermal model, FMI⁽³⁾, Hardware-in-the-Loop, linkage with third party tools (GTPower...), two energy-storage vehicles...

(1) Developed under Task 3 of VAN023

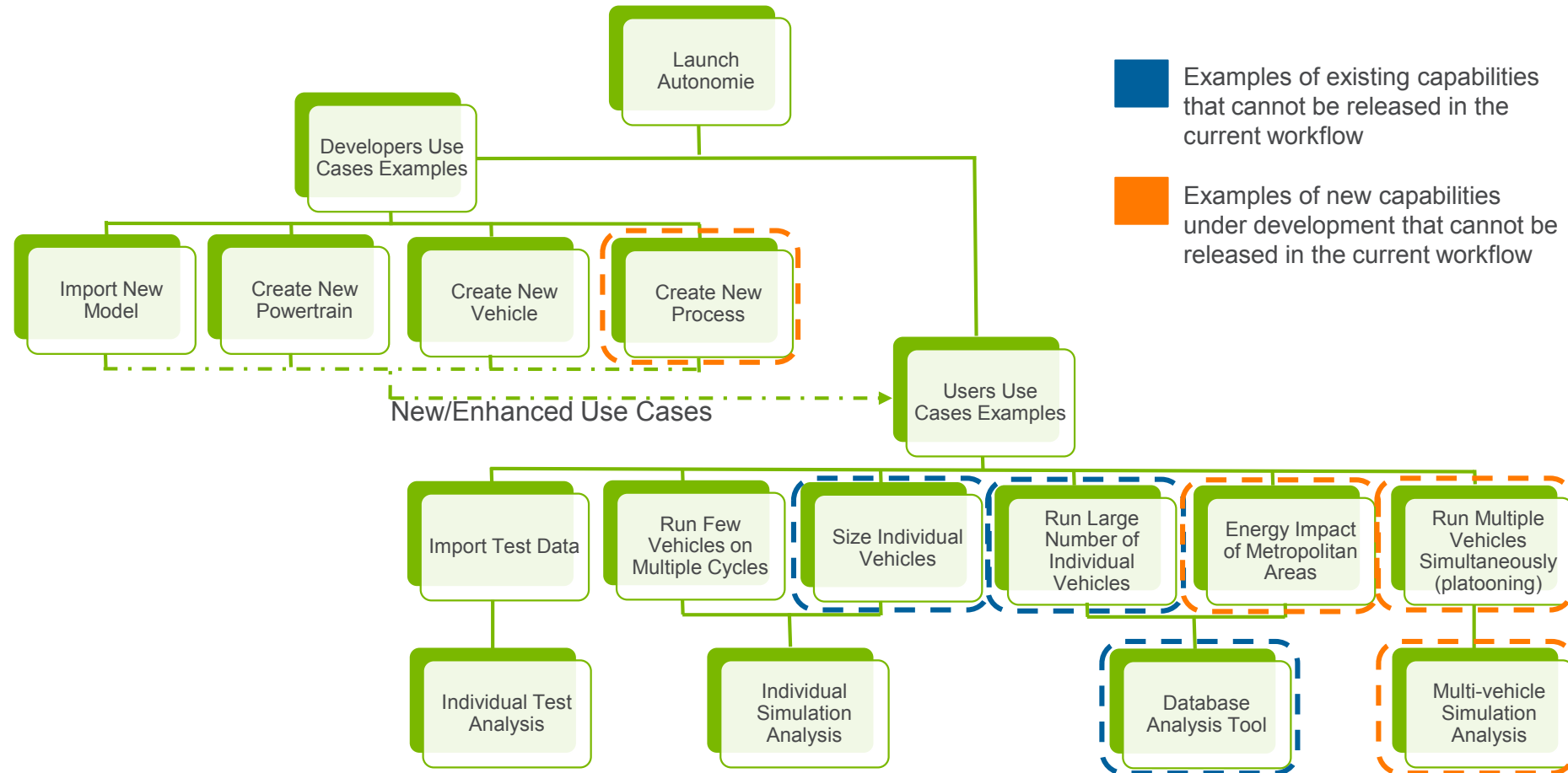
(2) Developed under TV032

(3) Functional Mockup Interface - <https://www.fmi-standard.org/>

Technical Accomplishments

Autonomie – Model Based System Engineering

Autonomie Process Centric (2.0)



=> New platform will enable dissemination of existing and new capabilities to the entire user community as well as streamline Argonne internal processes

Technical Accomplishments

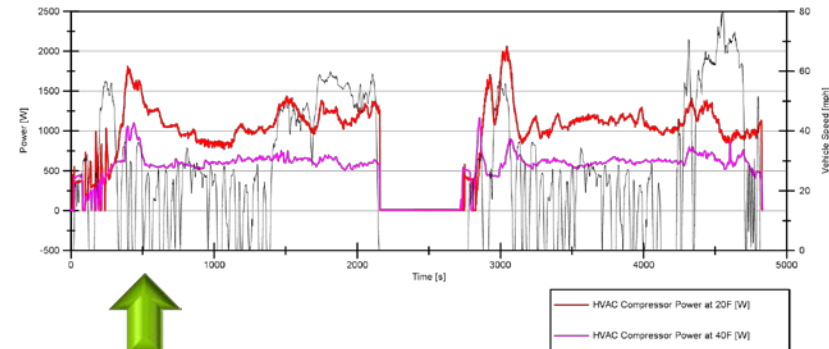
Vehicle Thermal Validation

BMW I3-EREV

- Validated vehicle thermal models necessary to assess the impact of temperature for multiple advanced technologies
- Current project expands on the list of powertrains previously validated across multiple temperatures (Conventional, HEV, PHEV, E-REV, BEV)
- Leverage test data from Argonne's APRF (VSS030)

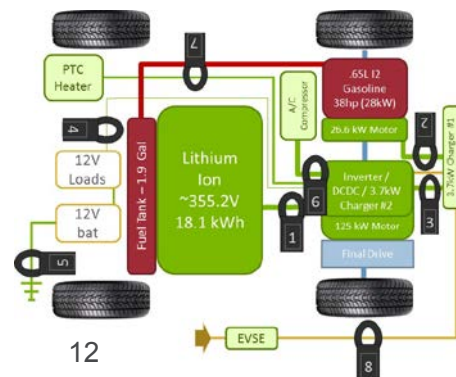


List of Tests
Developed to
Reverse Engineer
Controls



Test Data Analyzed to
Develop Vehicle Level
Control & Validate Model

Extensive Instrumentation
Developed in Collaboration with
APRF Experts for Model
Development and Validation
(High Voltage Example)



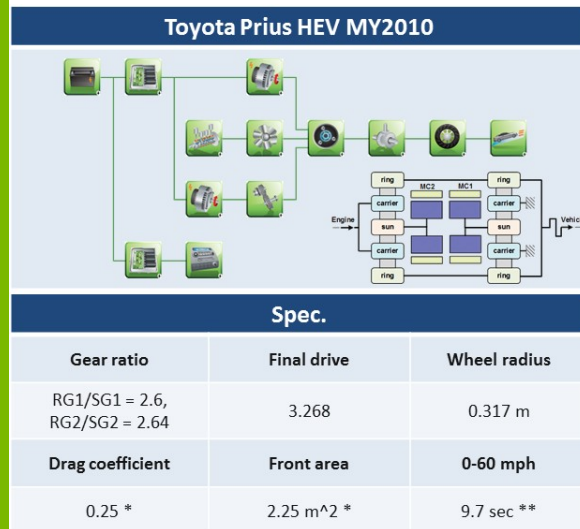
Technical Accomplishments

Vehicle Energy Impact

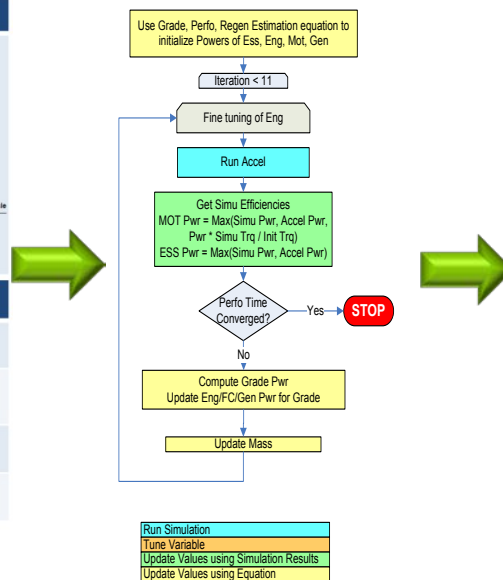
Automated Sizing Algorithm Validation

- Vehicle powertrain sizing algorithm have been developed over the years for multiple configurations to size the components to match a specific set of performances.
- The latest algorithms have been validated using specific vehicles

Making Assumptions



Sizing Algorithm



Sizing Validation

	OEM Source : Toyota Prius HEV MY2010	Sizing results form Autonomie
Vehicle weight	1530 kg	1463 kg
Engine Power	73 kW	75 kW
Motor1 Power	60 kW	66 kW
Motor2 Power	40 kW	43 kW
Battery Power	27 kW	36 kW
Acceleration Performance: 0-60 mph	9.7 sec	9.74 sec
- Baseline vehicle specification : Toyota Prius HEV MY2010 - Specific power for electric motor and battery is from DOE assumptions - Individual component performance data not available (estimated)		

* http://ecomodder.com/wiki/index.php/Vehicle_Coefficient_of_Drag_List

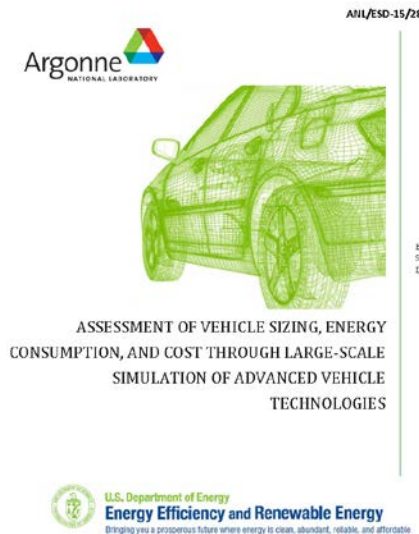
** <http://www.zeroto60times.com/vehicle-make/toyota-0-60-mph-times/>

Technical Accomplishments

VTO Energy Impact

VTO Packages Energy Impact Report Released

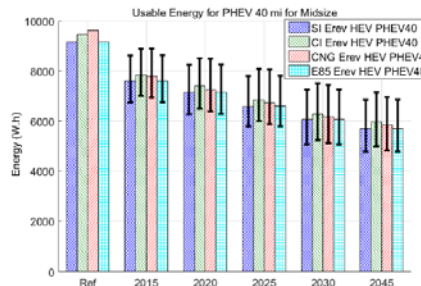
Report⁽¹⁾



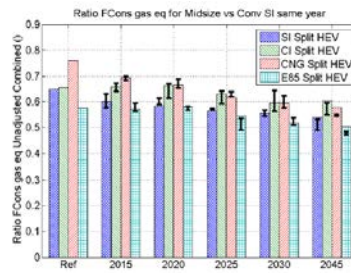
includes



Component Sizing



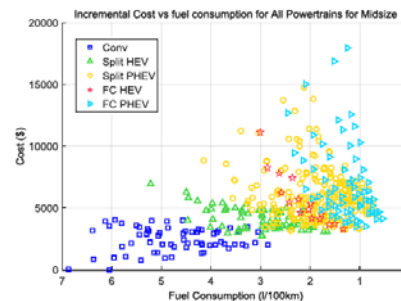
Vehicle Energy Consumption



usage



Component & Vehicle Cost



- VTO Benefits
- EV Everywhere analysis
- USDrive C2G (Cradle to Grave) Working group
- GHG (GREET)
- Market penetration tools (MA3T, LAVE-Trans, LVCFlex, ParaChoice, ADOPT)
- BLAST-V (NREL)
- DOE Advanced Tech Modeling runs with NEMS
- Multiple research organizations (IEA, AVERE, NorthWestern Univ...)
- ...

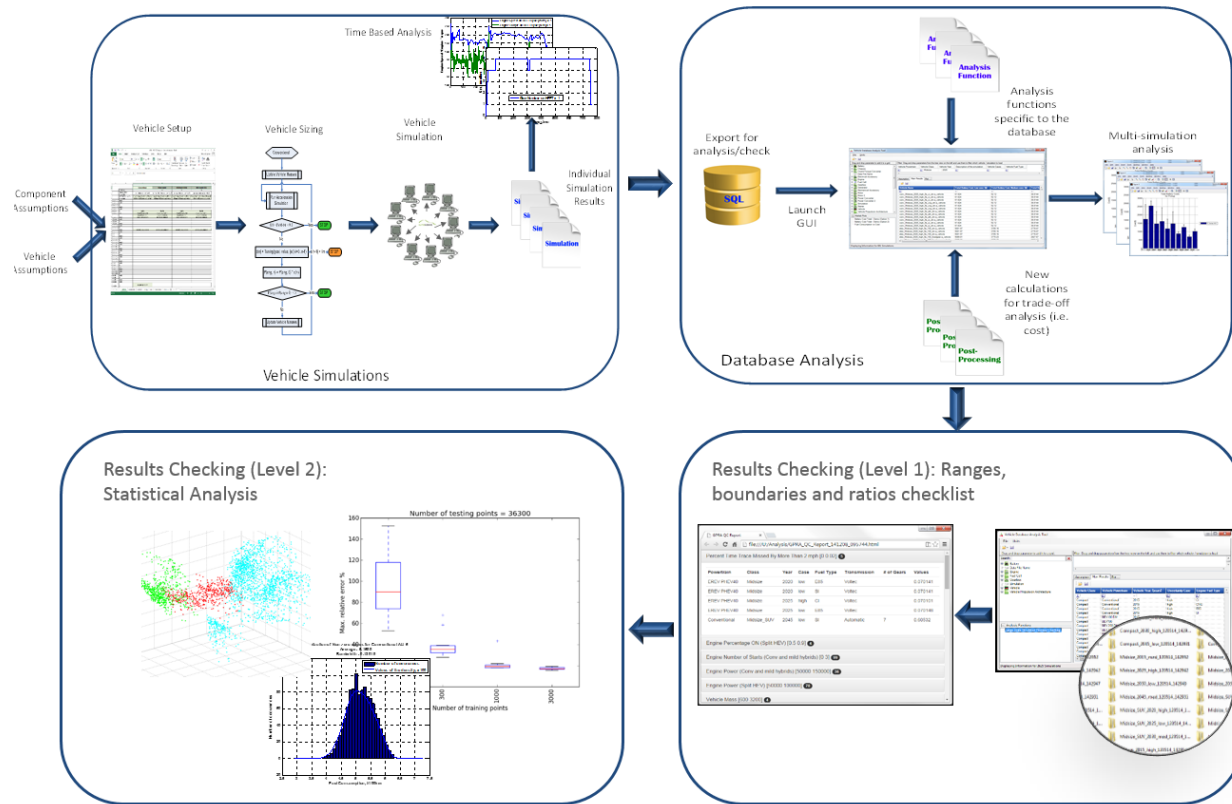
(1) Full report, assumptions and detailed results are available at http://www.autonomie.net/publications/fuel_economy_report.html

Technical Accomplishments

VTO Energy Impact

VTO Individual Energy Impact Study (In Progress)

- The objective is to quantify the contribution of each individual VTO technology (engine, energy storage, battery, fuel cell, H2 storage, light weighting) for each VTO package.
- Large scale simulation process initially developed for DOE to perform package simulations and recently expanded to support DOT/NHTSA CAFE leveraged
- Individual simulations including a permutation of the order of introduction of each technologies have been performed.



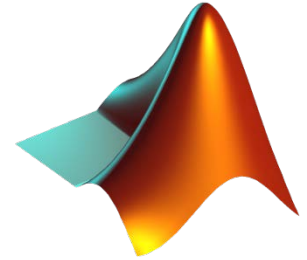
Collaboration and Coordination with Other Institutions



Gamma
Technologies



- Data & Model Providers
 - National Labs (e.g., ORNL)
 - Argonne (e.g., APRF, Battery...)
 - Expert Tool Companies (e.g., Siemens, Gamma Technology, Mechanical Simulation...)
- Process Definition & Direction
 - OEMs (e.g., GM, Ford...)
 - MathWorks
 - Expert Tool Companies (e.g., Siemens, ChiasTek, Esse...)
 - Argonne (e.g., Math. group, HPC...)



SIEMENS



Responses to Previous Review Comments

- ***Reviewer #5 - The reviewer indicated that the program still looks hard to use with so many technical features even though progress has been made for a large-scale simulation run. This may become more or less of an issue when it is integrated with so many other commercial codes.***

=> The new process centric approach (Autonomie 2.0) has been developed with that specific focus in mind

- ***Reviewer #3 - The reviewer stated that future plans to enhance the tools are a logical approach; however, finding ways to facilitate industry and user acceptance is important for the future of this project.***

=> Argonne has been closely working with several OEMs to review requirements, implementation (i.e., GUI mockup) to ensure final acceptance

- ***Reviewer #5 - The reviewer stated it seems good, but felt it was unclear from the presentation what Gamma Technologies or Mathworks brought to the project***

=> Argonne has been a Preferred MathWorks Partner for many years, allowing us to access advanced releases for internal testing as well as acquire discounted licenses for demonstrations. Companies such as GT provide no-cost licenses of their tool as well as technical support to test the integration of the latest version of their tools in Autonomie.

Responses to Previous Review Comments

- ***Reviewer #5 - The reviewer stated that all future work plans are good, but questioned whether this can be done without using DOE funding or taxpayer dollars, because large commercial license fees may be able to support the model development.***

=> Autonomie is the ONLY commercially available tool that includes full vehicle level models including control. All controllers have been developed with vehicle test data from the APRF. Due to the cost of vehicle testing, it is commercially not viable for any company to fund testing and modeling of so many vehicles for software licensing.

- ***Reviewer #5 - The reviewer stated that no explanation was provided about the relevance of this project to petroleum displacement***

⇒ Answer was provided by Reviewer #4 -> “The reviewer stated that systems modeling, as opposed to actual hardware integration/testing, is increasingly used and essential to accelerate the design and implementation of advanced vehicular technologies. Systems modelling lowers costs and improves time-to-market which leads to significant competitive advantages”

Proposed Future Work

- Continue to enhance Autonomie to support DOE VTO R&D activities by gathering requirements from all users (i.e., Nat Labs, Univ., OEMs, Gov. agencies...), including:
 - Expand Autonomie EcoSystem with linkages to additional expert tools
 - Link with transportation system simulation tools (i.e. POLARIS) to evaluate benefits of connected & autonomous vehicles...
 - Link with market penetration tools (i.e. MA3T) for fleet analysis
 - Focus on large scale simulation leveraging High Performance Computing (i.e., >100,000 individual vehicle packages) and co-simulation
- Continue to provide guidance for DOE R&D activities by assessing the energy and cost impact of advanced vehicle technologies

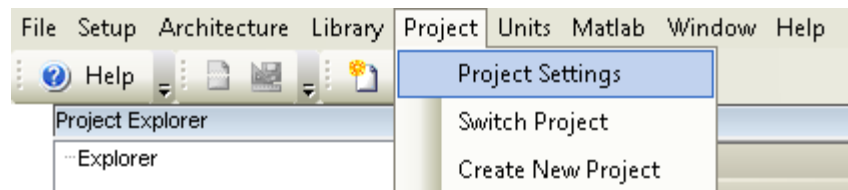
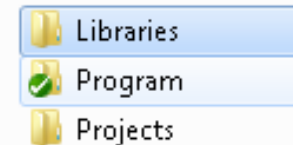
Summary - ANL Will Continue to Accelerate Technology Development and Market Introduction

- Widespread usage of Autonomie across the automotive community contributes to accelerating the introduction of advanced technologies and the evaluation of their benefits.
- New features included in semi-annual releases prioritized in collaboration with users (including Argonne) to maximize the tool impact.
- Extensive collaboration with other institutions to implement state-of-the-art component performance data and use vehicle test data for model development and validation.
- Vehicle level system simulation is critical to evaluate the impact of new technologies at the component, powertrain, vehicle and fleet level.
- Large number of studies performed to assess the impact of the VTO technologies at the individual and overall program level.
- Most of the current and future developments focused on supporting new VTO initiatives such as Smart Mobility.

TECHNICAL BACKUP SLIDES

Plug-in Linkages to Source Control Tools

- Both internal & external users requested an easier way to manage separate set of files & Autonomie settings for multiple projects:
 - Autonomie separated in 3 separate folders:
 - Program, containing the base Autonomie program
 - Libraries, containing Autonomie vehicle application library as well as any other defined by the user
 - Projects, containing the user projects
 - New a_project file defines setting for each projects, including which folders to include and the Matlab version to use.



New Settings Organization and UIs for Customizations

- Some settings used to be editable only in the associated xml file
- Now all settings have a user interface

default

Global User Project

Project Informations

Name: **default**

Location: C:\Autonomie\Rev15_tmp\Projects\default

Description: Default Autonomie Project

Default Matlab Release to Launch

R2010a (32-bit) c:\program files (x86)\matlab\r2010a\bin\win32\matlab.exe

☒ Single Window Mode (Default, Preferred) Launch a limited command window only. Will launch a separate Matlab session for each Autonomie Runs

☐ Desktop Mode Launch the full Matlab environment. Slower, but better for development. Caveat: the same Matlab session would be shared by parallel runs of Autonomie

Libraries

[Create New Library Folder](#) [Add Folder as Library](#) [Remove Selected Library](#)

Library Name	Library Path	Source Control	Branch	Version	URL
Public	C:\Autonomie\Rev15_tmp\Librarie	Subversion	trunk	17	vms-fs/VMS/

Cancel Save

Faster Start and Lower Memory Usage

- No more Flash Start screen
- Autonomie automatically starts with the settings of the last project used or double clicked
- The speed of loading multiple simulation results has been increased several folds.
- No more out of memory issues when loading a dozens+ of simulation results

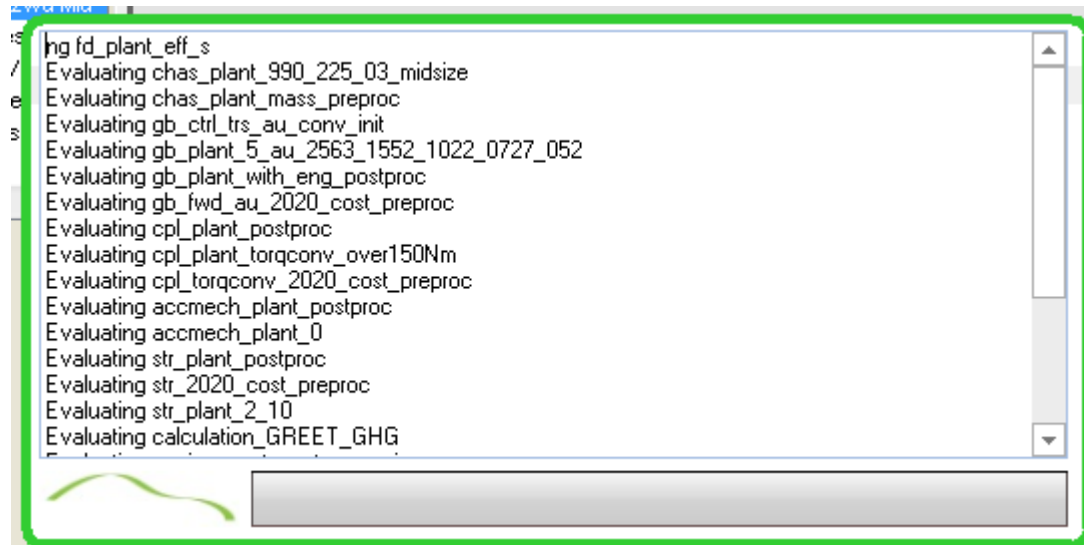
Enable Overwrite of String Parameters

- String parameters can now be overwritten directly in the GUI

System Properties	
Initialization Files	eng_plant_si_2200_110_SIDI_AHL
0	eng_plant_si_2200_110_SIDI_AHL
DataFileType	Init
Parameters	(Collection)
eng.plant.init.cyl_config	radial
eng.plant.init.mass.eng	147.1093 kg
eng.plant.init.mass.fuel	47.749 kg
eng.plant.init.mass.tank	20 kg
eng.plant.init.spd_idle	80 rad/s
eng.plant.init.throttle_position_fuel_off	5 %

Improved Waitbar with more Feedback Information to the User

- New Waitbar with improved feedback to user



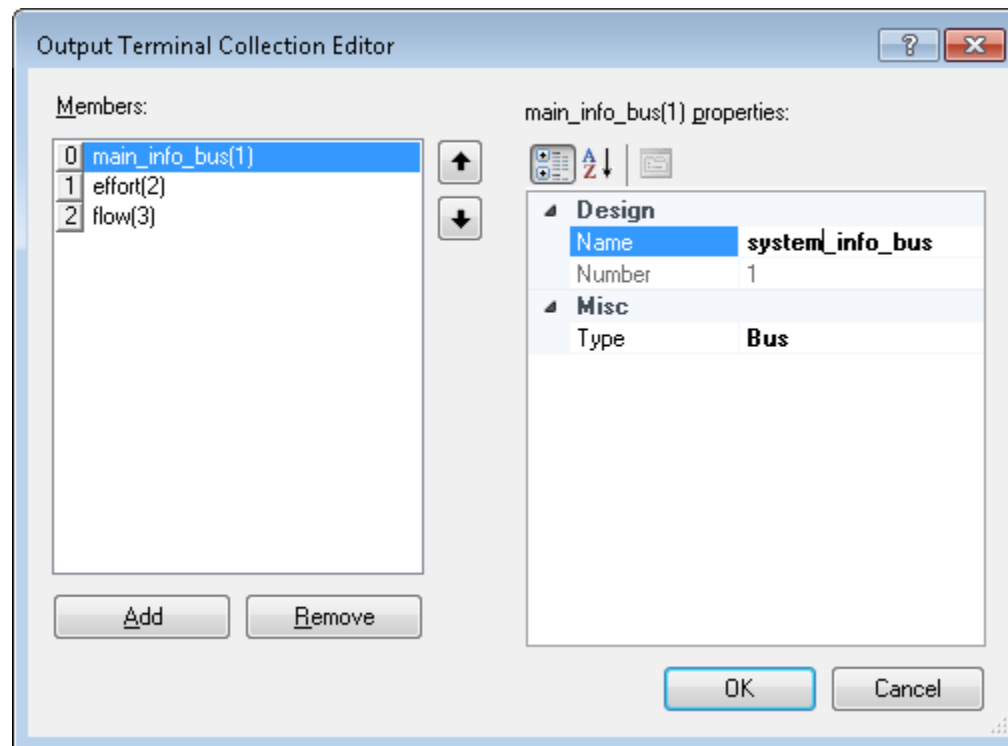
Improved Function for Batch Import of Matlab Scripts

- MToXml script can take model list & parent system list as input argument for batch import without going through the GUI, e.g.:

```
MToXml('env_plant_common.m','env_plant_common.a_init',{'env_plant_earth'},{'env','true'})
```

Editable Bus Names in the Configuration Builder GUI

- Autonomie used to automatically setup the bus name in the configuration builder.
- However, some customer wanted to use their own convention.
- They can now overwrite those name in the editor



Can Use any Time-based Cycles with Distance-based Models

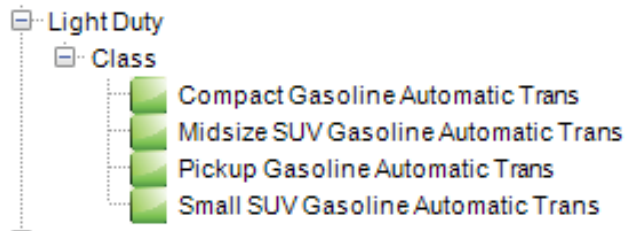
- Autonomie has hundreds of time based cycles. These include many real world driving cycles.
- All of these time based cycles can now be used with the distance based driver without the user having to spend time converting them into distanced based cycles
- That is, the vast library of time based cycles in Autonomie can now be easily leveraged by users running heavy duty vehicle simulations.

Automated testing for all vehicles

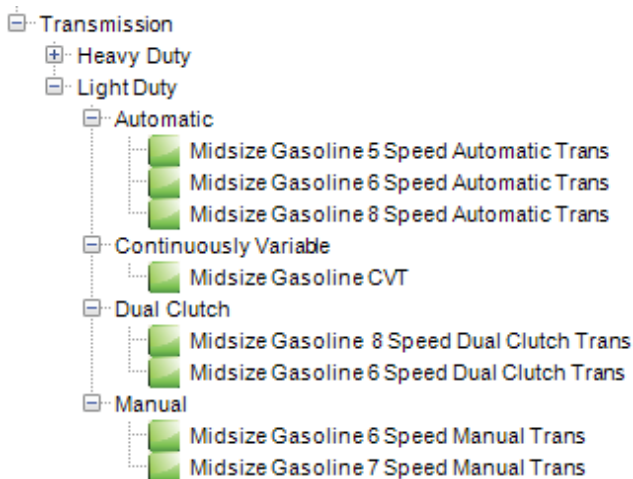
- Every time a vehicle, model or initialization file is modified in our Source Control system, it automatically launches a set of tests to ensure:
 - All vehicles are loading, building and running without any errors
 - All simulation results stay consistent from previous runs
- Dozens of additional unit & release tests are run on the User Interface and whole release as well.

Sample of New Reference Vehicles

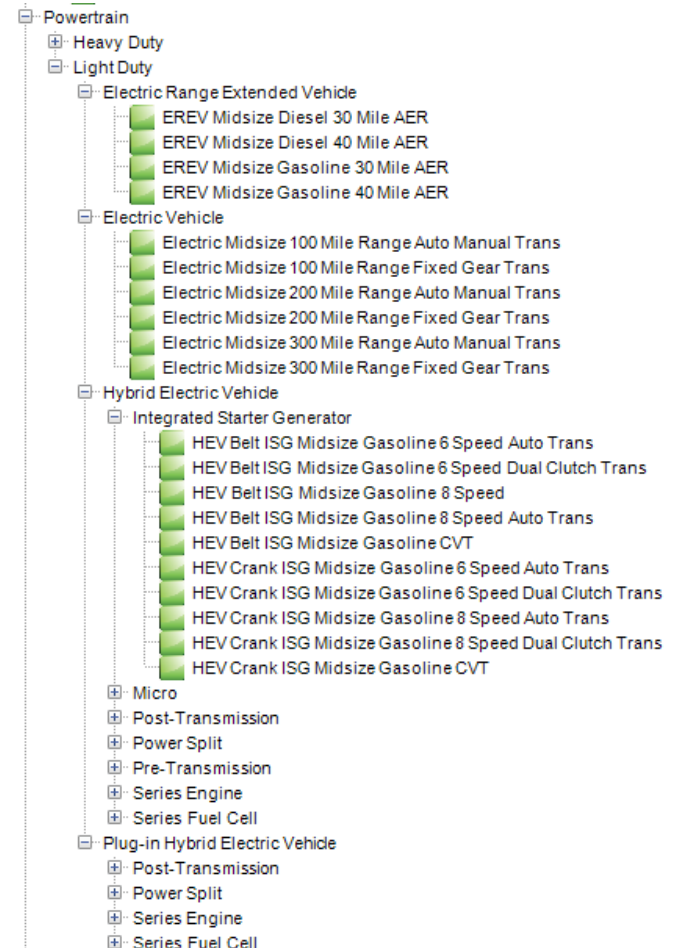
Multiple LDVs Classes



Transmission Comparison

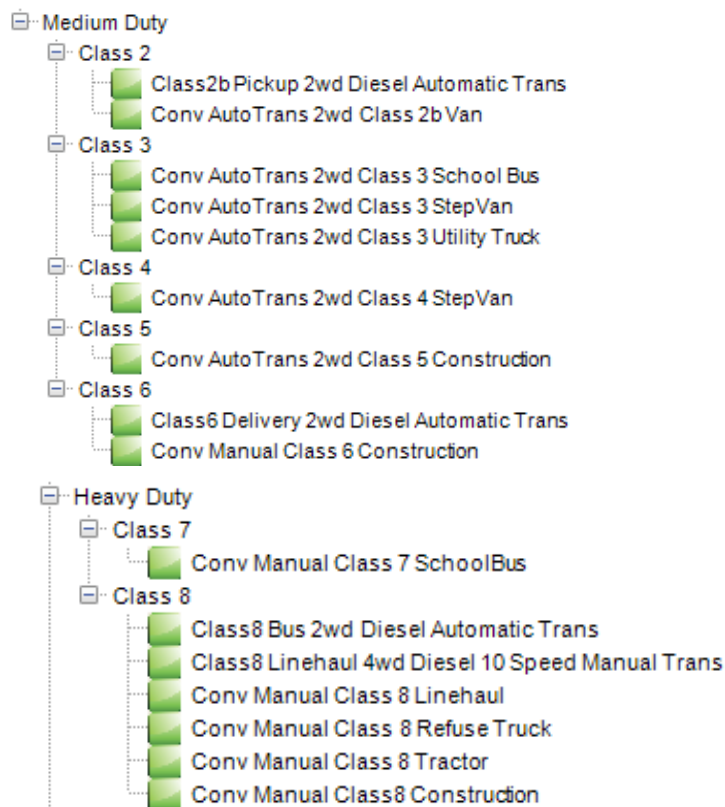


Powertrain Comparison



Sample of New Reference Vehicles (Cont'd)

MD & HD Classes



Specific Applications

