

# *Accelerating the Evaluation and Market Introduction of Advanced Technologies Through Model Based System Engineering*

**2014 DOE Hydrogen Program and Vehicle Technologies  
Annual Merit Review**

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Sponsored by David Anderson

**Project ID # VSS139**



**U.S. Department of Energy**

**Energy Efficiency and Renewable Energy**

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# Project Overview

## Timeline

- Start – October 2014
- End – September 2014 (Maintenance)  
– September 2015 (MBSE)
- 50% Complete

## Barriers

- Bring technologies to market faster
- Accelerate technology evaluation
- Support requirements definition

## Budget

- Total Project Funding (DOE)
- Autonomie Maintenance: \$300k
  - MBSE Enhancements: \$200k

## Partners

- General Motors
- LMS/Siemens (AMESim)
- MathWorks
- Expert Tool Companies (Gamma Technology, Mechanical Simulation ChiasTek, Esse)
- National Labs (NREL, ORNL)
- Argonne (MCS & CSE divisions)



# Relevance

## VTO Benefits

Autonomie 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...

- Examples of projects related to Autonomie
  - Projects using Autonomie to perform studies include VSS048, VSS127, VSS128, VSS133, VSS139, VSS140, VSS141, VAN008, ACE011...
  - Projects using Autonomie results include VAN001, VAN002, VAN005, VAN006, VAN012, VAN014...
  - Projects feeding Autonomie include VSS001, VSS020, VSS030, VSS031, VSS097, ST001, ST100, APE006, ES189, FC017, FC018...
  - Autonomie is also used by Gate Programs (TI020, TI023, TI024)

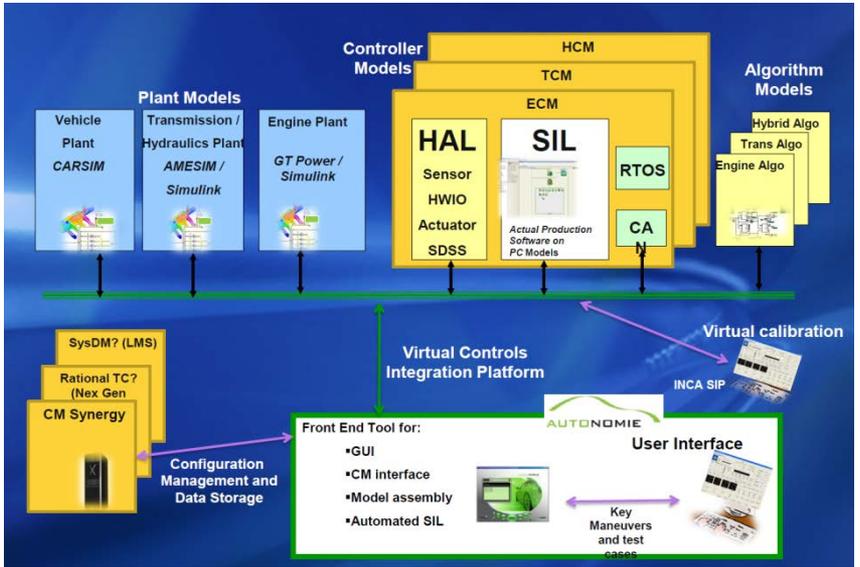
# Relevance

## Users Benefits

Due to its large user base (>160 companies worldwide), Autonomie contributes to accelerate the market introduction of new technologies

Example: Production control development at GM

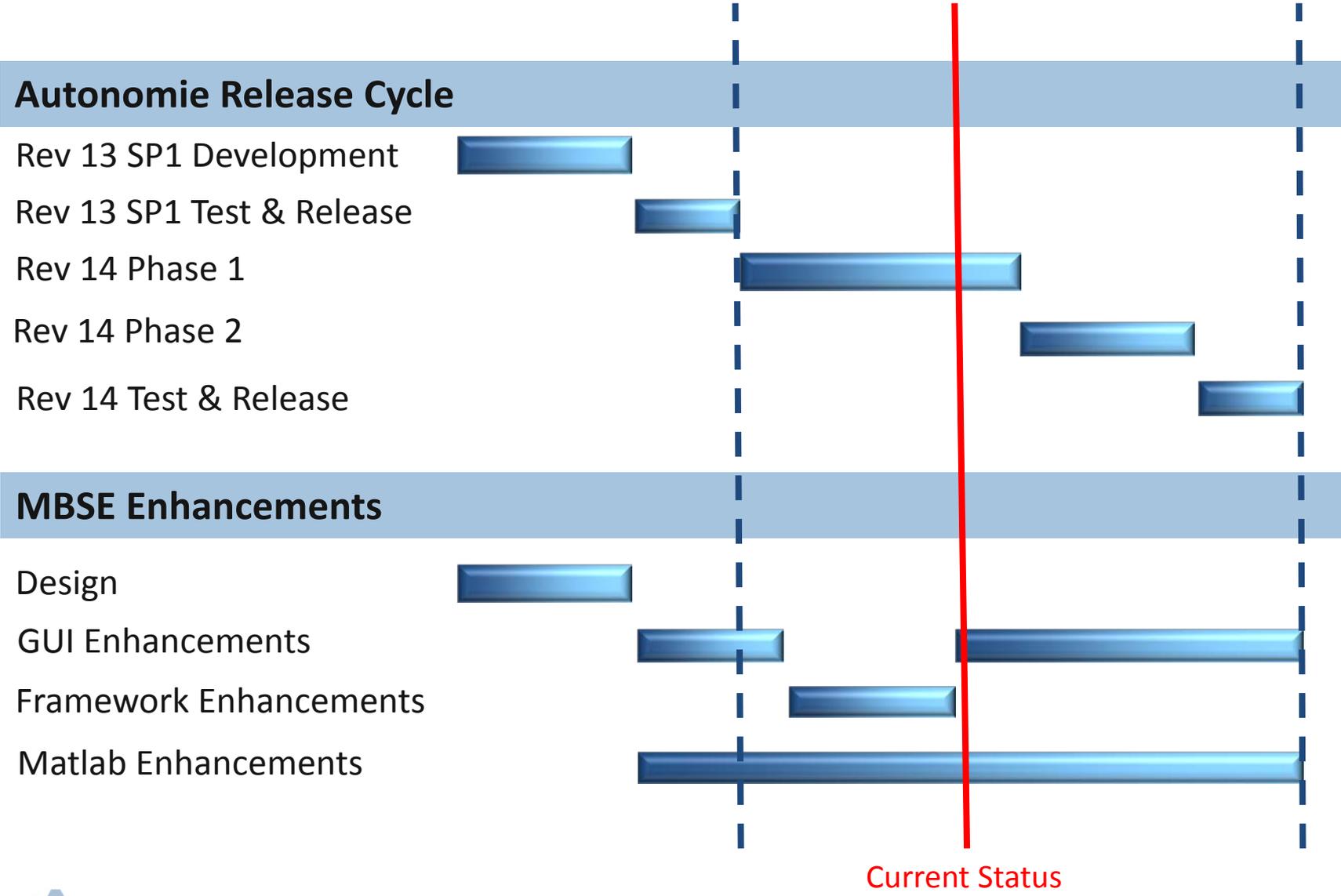
“Autonomie is a fundamental game changer for math-based design, development and engineering of automotive systems and controls”, Mike Steele, Manager, Controls Modeling and Architecture at GM



(1) Source – GM – LMS Vehicle Conference 2012



# Milestones



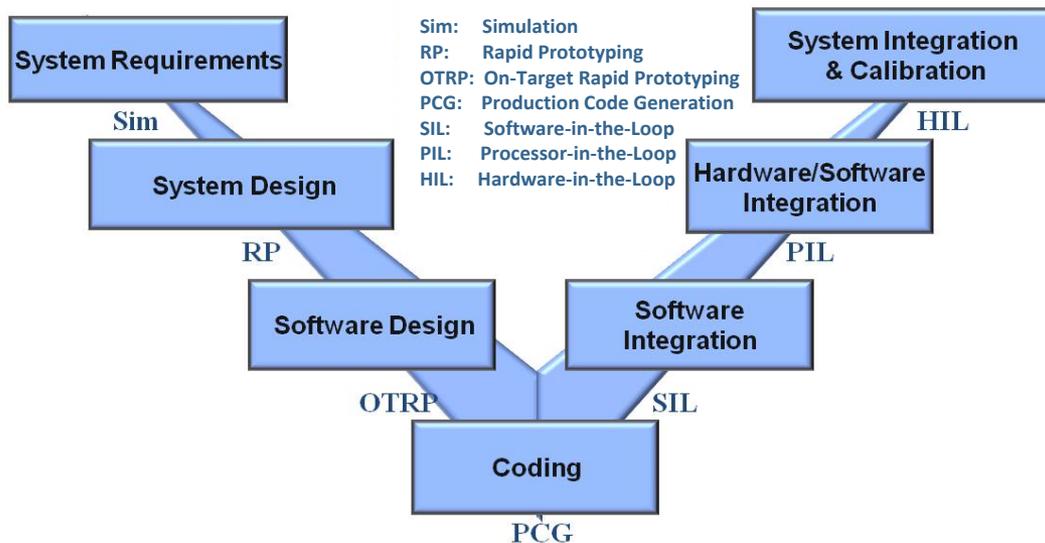
Current Status



# Approach

## Use Virtual Engineering Approach to Accelerate the Vehicle Development Process

### Virtual Engineering Process



### Solution:

OEMs are moving towards an increasing reliance on modeling to accelerate the introduction of advanced technologies

### Problem:

- Heavy reliance on hardware leads to high cost and longer development time
- Integration of new technologies in a system lowers its expected benefit

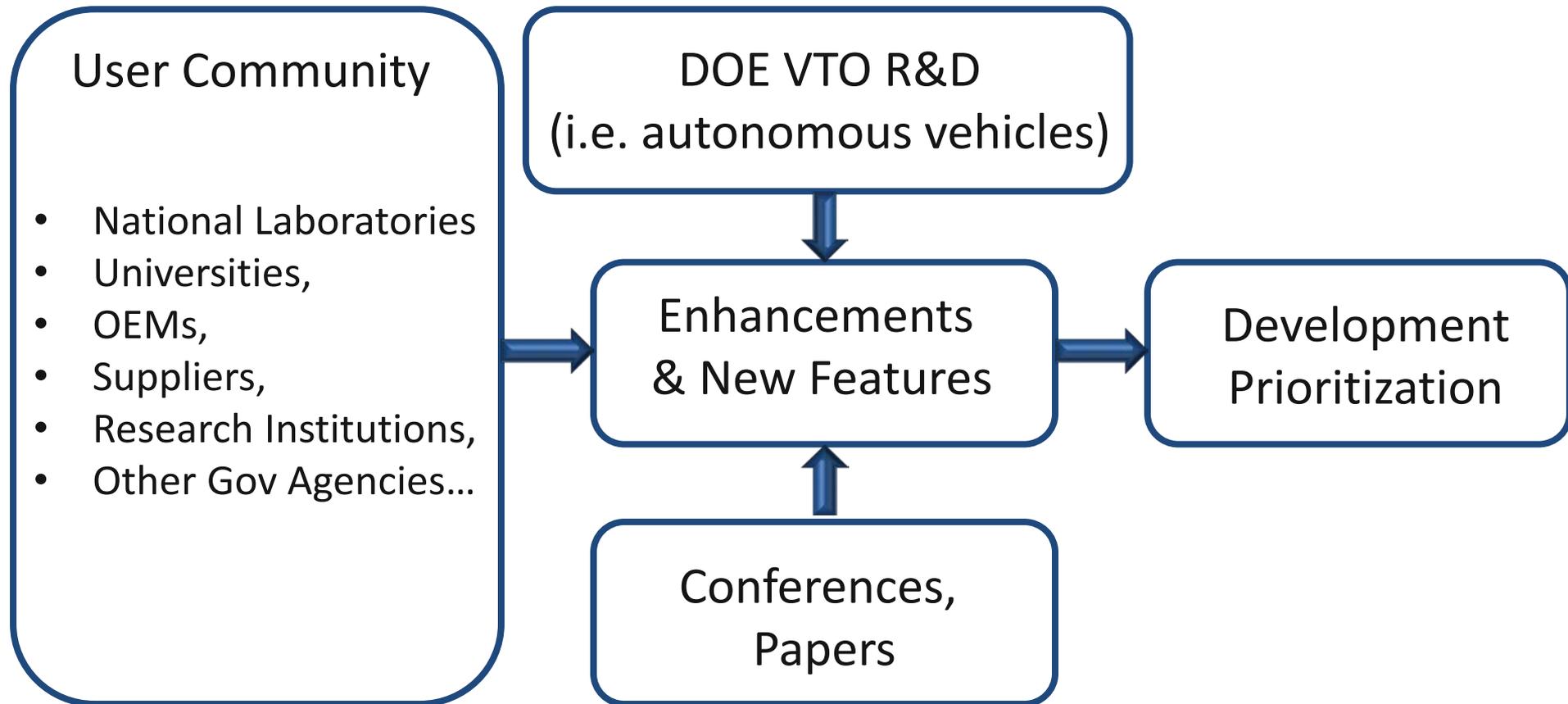
### Result:

Wasted Opportunities, Time, and Resources (People & \$)

DOE is leading the way with the development of Autonomie

# Approach

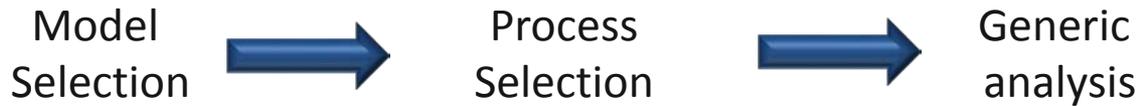
## Gather Requirements from Autonomous User Community to Prioritize Development



# Approach

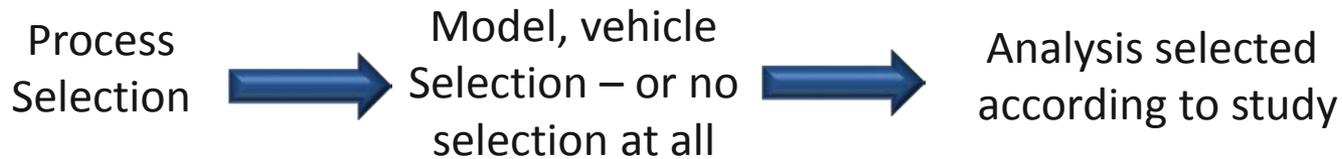
## Autonomie Workflow Enhancement to Enable Larger MBSE Use

### Current Flow



Issues: not all processes require models, some processes require multiple models, not all processes require the same analysis...

### Future Flow



Benefit: we can now integrate processes with multiple vehicles (i.e. BaSce VTO benefits), analyze large databases (i.e. USDrive Requirement study), additional DOE VTO tools (i.e. BatPac, GREET, MA3T...)



# Technical Accomplishments

## Main New Features

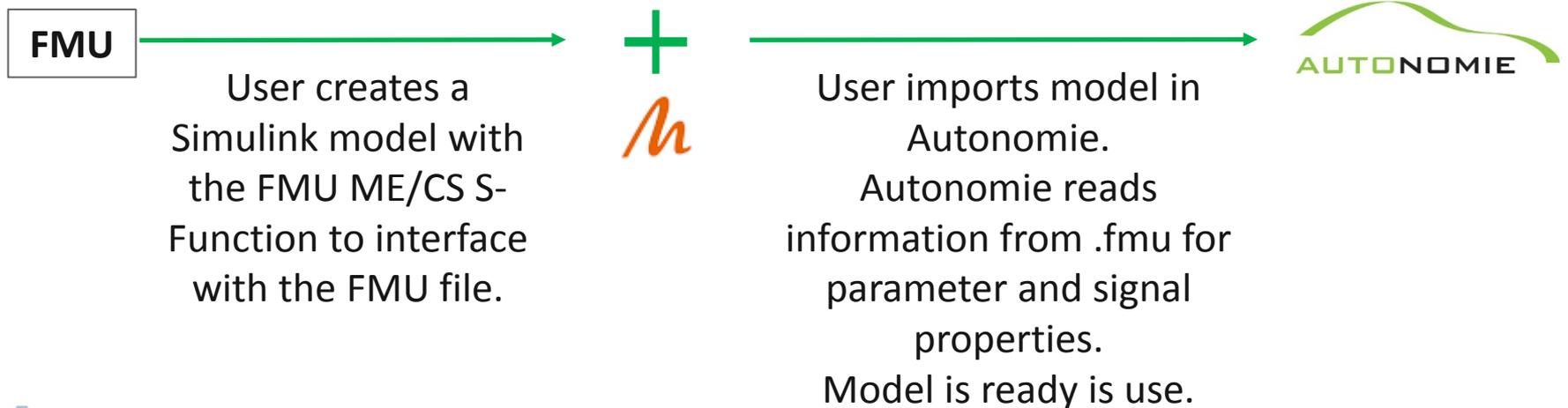
- Models
  - New powertrain configurations (i.e., Honda 2 Motor, hydraulic hybrids)
  - New component models (i.e., dual clutch transmission)
  - New controllers (i.e., shifting algorithm for advanced transmissions)
  - Support for Matlab .slx files (R2012a and up)
- Tool Integration
  - Link to Functional Mock-up Interface (FMI) standard
  - Link with ANL battery cost model (BatPac)
  - New multi-objective optimization algorithm (POUNDER)
  - Improved CosiMate support
- Software
  - Improved import process based on OEMs feedback
  - In-GUI display and edit of HTML reports
  - New Autonomie help using Microsoft-style format



# Technical Accomplishments

## Functional Mock-up Interface (FMI) Standard Integration

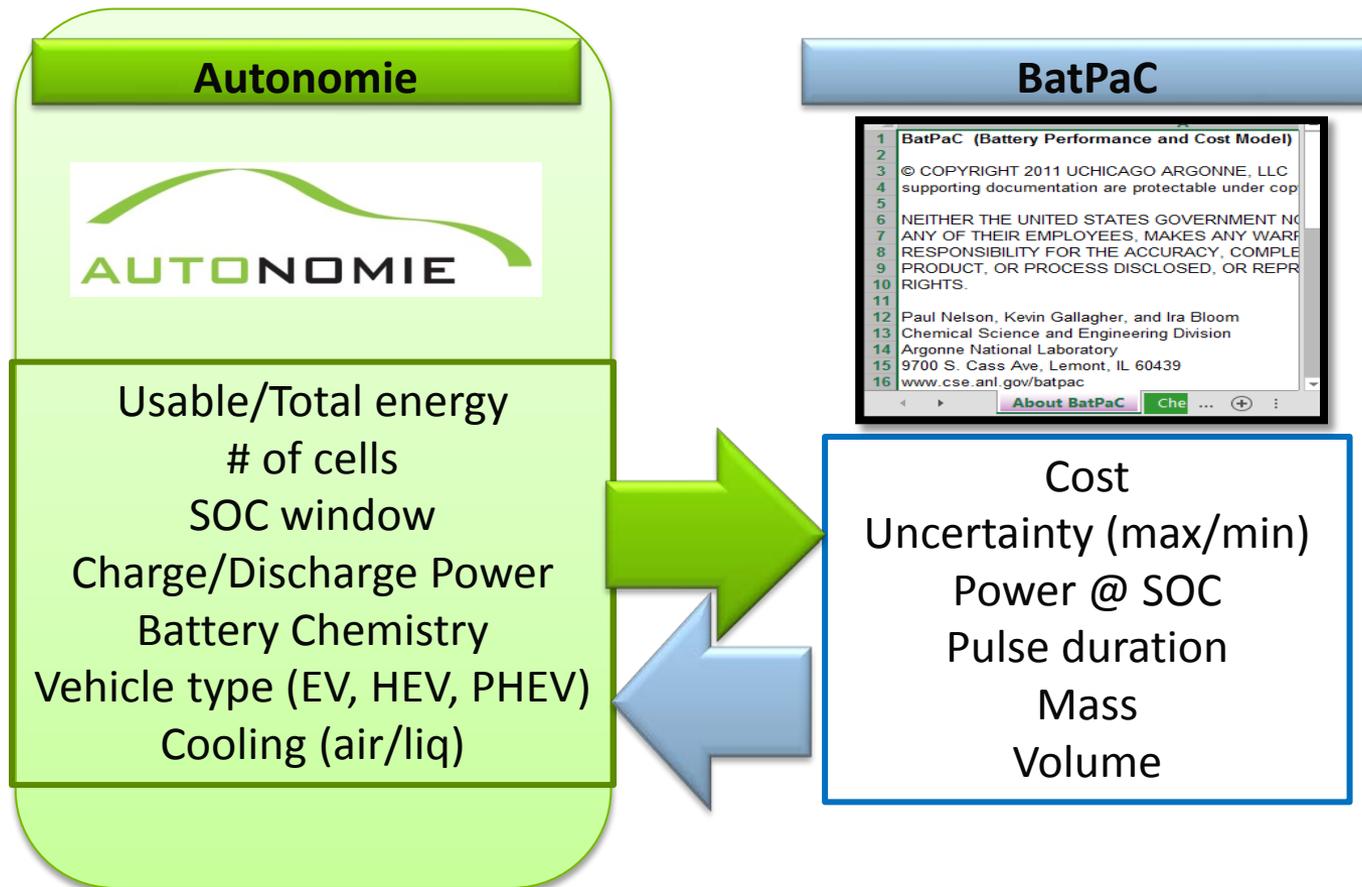
- Allow medium and high fidelity component models developed within VTO to be shared amongst researchers while protecting IP
- “Functional Mock-up Interface (FMI) is a tool independent standard to support both model exchange and co-simulation of dynamic models using a combination of xml-files and compiled C-code” (<https://www.fmi-standard.org/>)
- Integrate FMI into Autonomie via Modelon toolbox for Matlab



# Technical Accomplishments

## Link with BatPac Provides Detailed Battery Costs

BatPac used to estimate the cost of advanced battery technologies to guide DOE VTO R&D



# Technical Accomplishments

## Multi-Objective Optimization

- New algorithms used to support VTO studies relying on multi-objectives (i.e. increase performance while decreasing fuel consumption and minimizing cost)
- Two optimization algorithms, “Pounder” and “Random Search” were developed for Autonomie by the Argonne Mathematical and Computing Sciences (MCS) division
- The generic optimization process also allows users to substitute their own optimization algorithm.

The screenshot displays the Autonomie optimization interface, divided into several sections:

- Define Input Variables:**
  - 1 – Select Parameters:** A tree view on the left shows the hierarchy: Split SingleMode HEV 2wd Midsize > Driver > Environment > Vehicle Propulsion Controller > Vehicle Propulsion Architecture.
  - Variable Name: (Drag and Drop Here)** A table lists selected variables with their bounds and values:

Variable Name	Lower Bound	Upper Bound	Value
eng.plant.scale.pwr_max_des	80000	200000	110269.902141002
mot2.plant.scale.pwr_max_des	20000	60000	40000.5640812811
mot.plant.scale.pwr_max_des			
ess.plant.scale.pwr_max_des			
ess.plant.scale.cap_max_des			
fd.plant.init.ratio			
- Define Constraints and Goals:**
  - Variable Name:** Same tree view as above.
  - 1 – Select Non-Linear Constraints:** A table lists constraints:

Variable Name	Lower Bo	Upper Bo
vpa.results.percent_time_trace_misse	0	0.1
  - 2 – Select Objective:** A table lists objectives:

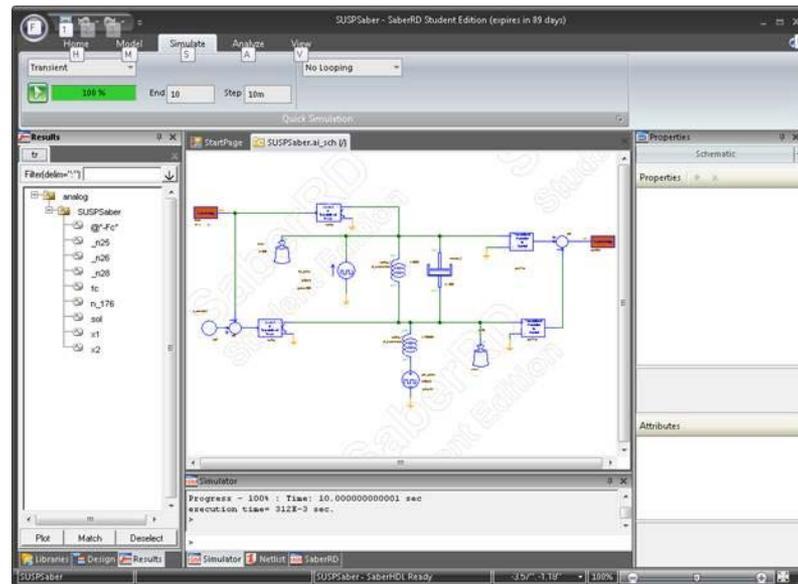
Variable Name
vpa.results.fuel_consumption.eng.this_fuel.total

# Technical Accomplishments

## Accelerate Simulation Time of High Fidelity Models Through Co-Simulation

- Simulation time is critical when using multiple high fidelity models (i.e. production control development).
- To leverage MBSE benefits and accelerate the introduction of new technologies, co-simulation algorithms are critical.
- Argonne worked with several OEMs to provide a generic solution that could be used throughout the industry.

Added support for integrating Sabre models with CosiMate



# Technical Accomplishments

## Large Scale Simulations

- The objective is to be able to launch and analyze >100,000 individual vehicle simulations automatically through the GUI

### Tasks Performed

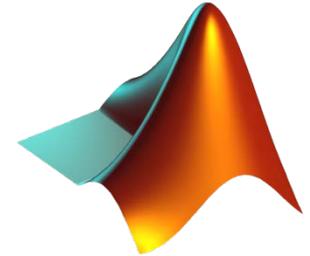
- Decoupled framework kernel from application
- Entire user interface “use case” driven
  - No mandatory vehicle selection
  - Flexibility on type of data analysis (i.e. analyzing many simulations is different than analyzing a single simulation)
- Separated “developer” use cases from “user” use cases
  - Varying levels of complexity depending on selections, not “one size fits all”
- Better tools for editing processes



# Collaboration and Coordination with Other Institutions



- Model Providers
  - National Labs (i.e., NREL, ORNL...)
  - Argonne (i.e., Battery group...)
  - Expert Tool Companies (i.e., LMS, Gamma Technology, Mechanical Simulation...)
- Process Definition & Direction
  - OEMs (i.e., General Motors, Ford...)
  - MathWorks
  - Expert Tool Companies (i.e., LMS, ChiasTek, Esse...)
  - Argonne (i.e., Math. group, HPC...)



# 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 (i.e., link with traffic flow tool to evaluate benefits of autonomous vehicles...)
  - 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.
- Expand Autonomie usage throughout DOE to promote Virtual Engineering approach.



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

- Support DOE VTO R&D activities
- Support usage of Autonomie for OEMs...
- Support virtual engineering processes throughout OEMs and DOE

