Argonne NATIONAL LABORATORY

... for a brighter future

ANL Vehicle Modeling & Simulation Activities Overview

FreedomCAR Directors

November 2008

Aymeric Rousseau

U.S. Department of Energy

UChicago Argonne LLC

A U.S. Department of Energy laboratory managed by UChicago Argonne, LLC

FreedomCAR & Vehicle Technologies Program

FreedomCAR & Fuel Partnership

PSAT Simulations Support R&D and Management Decisions

- Primary vehicle model for all FreedomCAR and 21 CTP activities by the U.S.DOE, stating that "*All future code development and enhancements for OFCVT shall focus on PSAT and PSAT-PRO*"

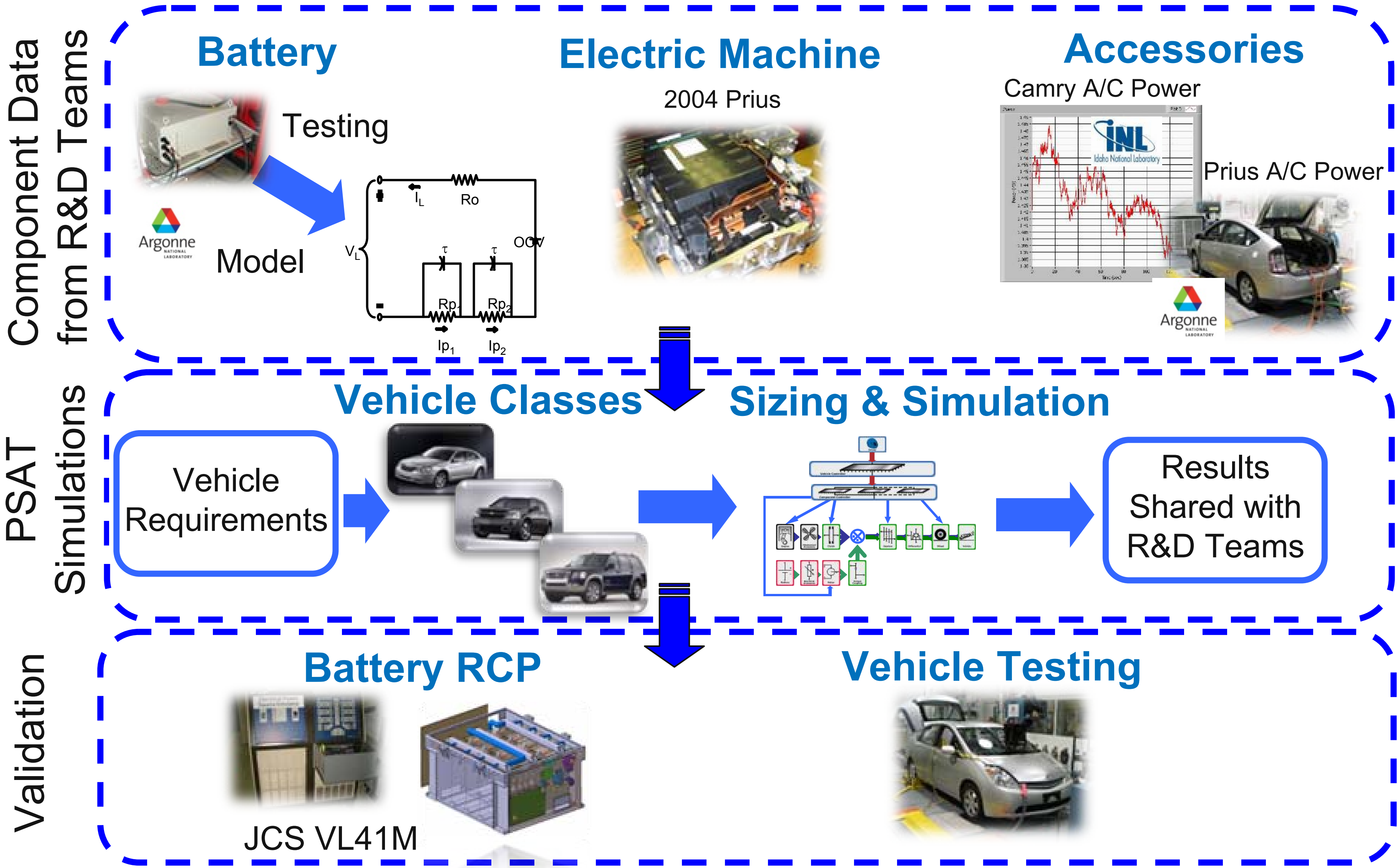
- PSAT has been awarded a R&D100 Award in 2004.

- Support numerous FreedomCAR activities:
  - Component requirements
  - Component technology evaluation
  - Powertrain configuration evaluation
  - Control strategy

- Used by more than 110 companies worldwide (>350 users)

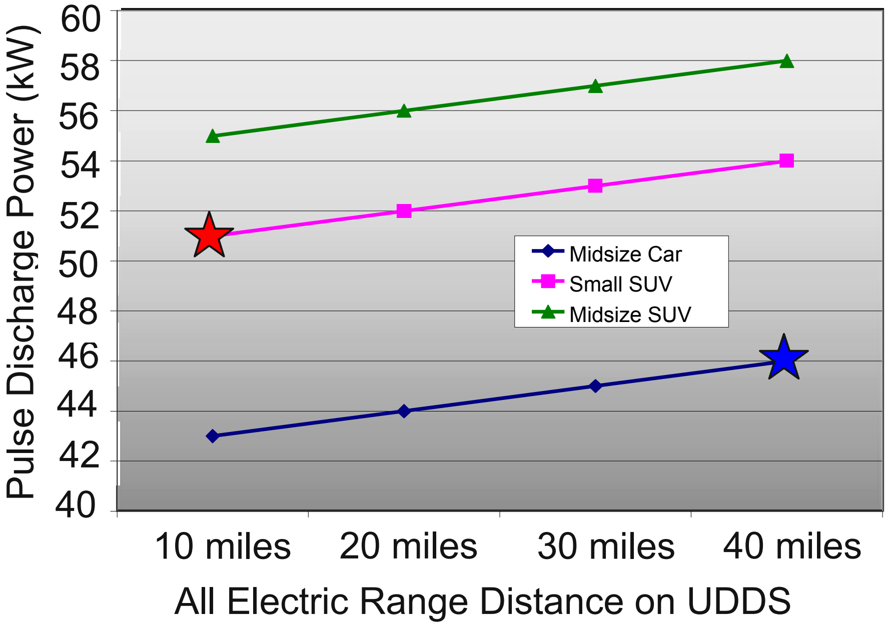
- *"… We need a model that's intuitive, easy to use, and provides accurate results. PSAT gives us that."* Randy Yost - GM Engineering Specialist

PHEVs Component Requirements Process

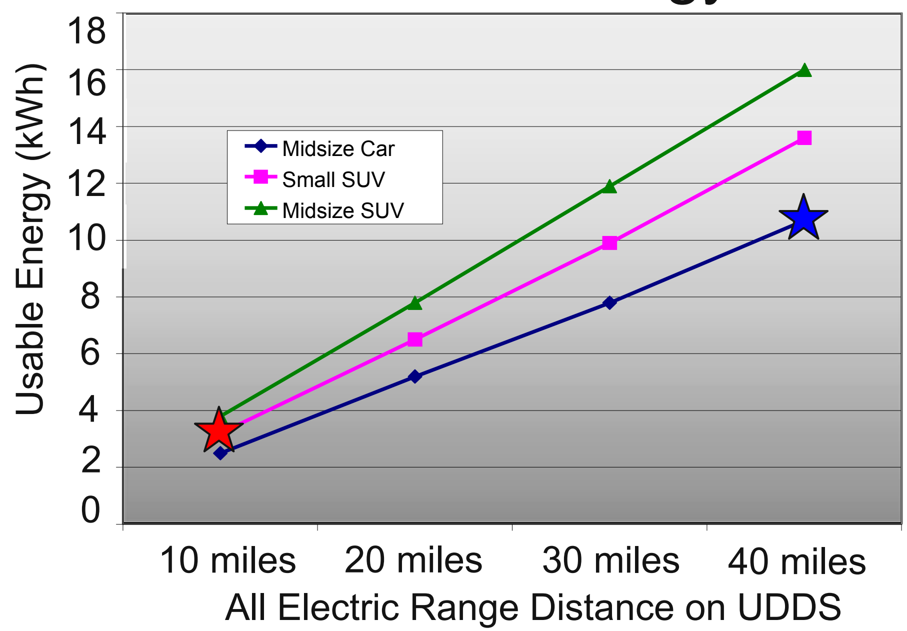


Optimum Battery Power and Energy Defined for Several Vehicle Platforms and AER

Power



Usable Energy



Final values selected by the ESS Tech Team

- Short term 10 miles AER (3.4 kWh, 50 kW) ★
- Long term 40 miles AER (11.6 kWh, 46 kW) ★

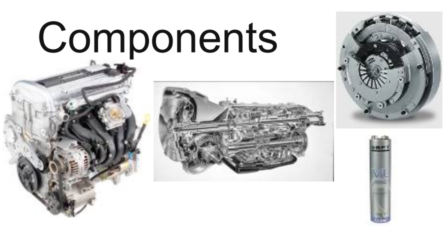
Component Requirements Uncertainties Currently Evaluated

Vehicle Technology

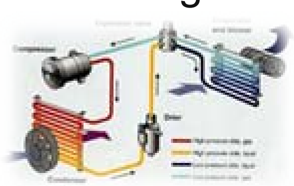
Glider Mass

Drag Coefficient

Components

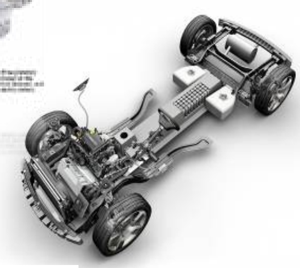


Air Conditioning

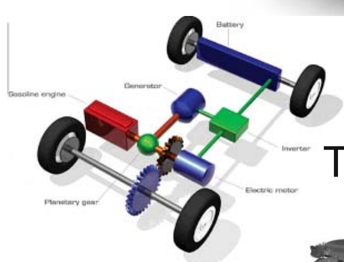


Powertrain Configuration

2Mode



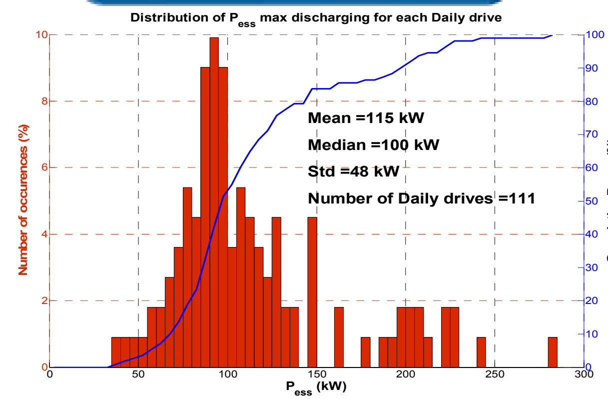
Series

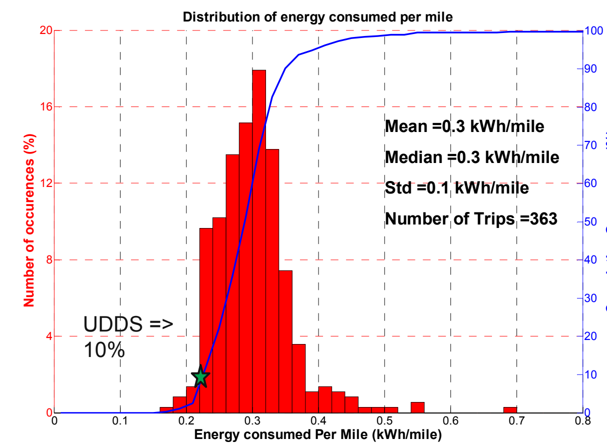


THS II

Parallel

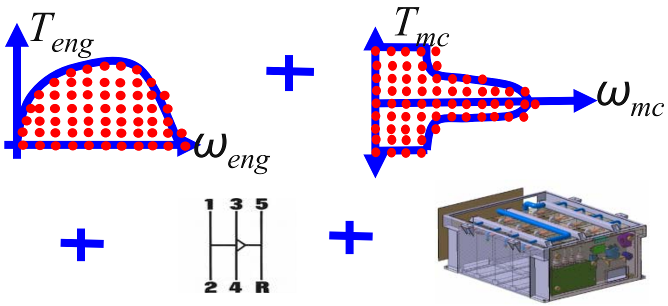
Real World Drive Cycles



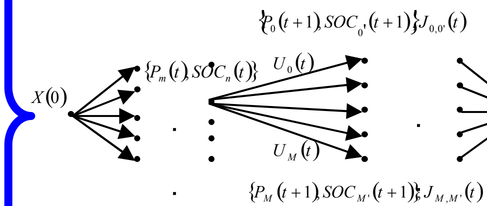


3-Way Approach to Control Optimization

Global Optimization



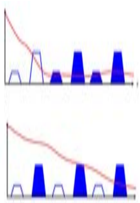
Backward model (not PSAT)



Bellman Principle

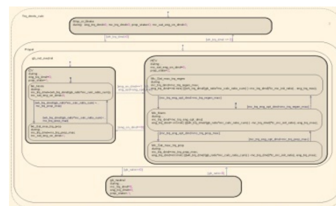
Optimal Control, Minimal Fuel Cons.

Control Design



Various Control Principles

PSAT +

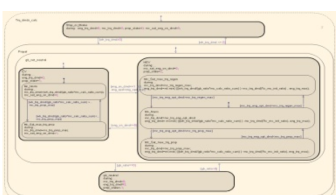


Rule-Based Control Design

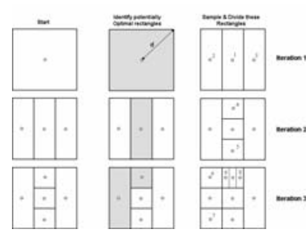
Various PSAT Control Strategies

Heuristic Optimization

PSAT +



Existing Control Logic

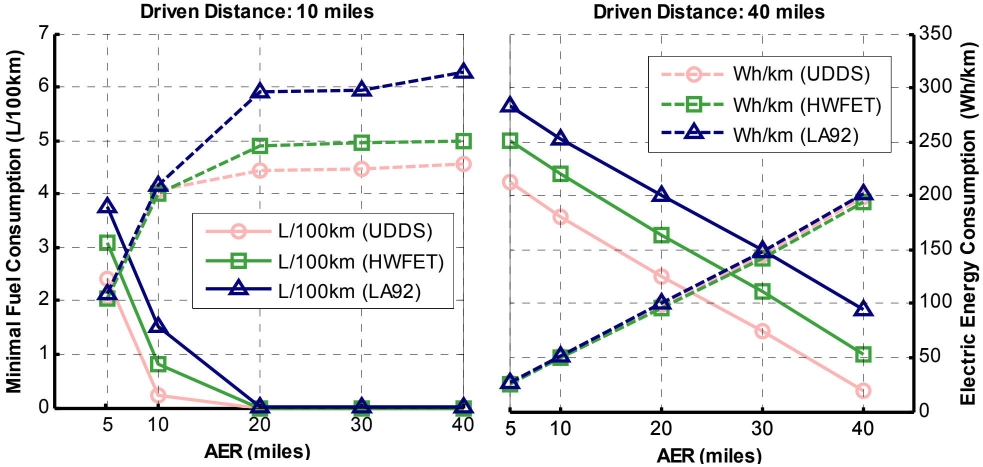


DIRECT Algorithm

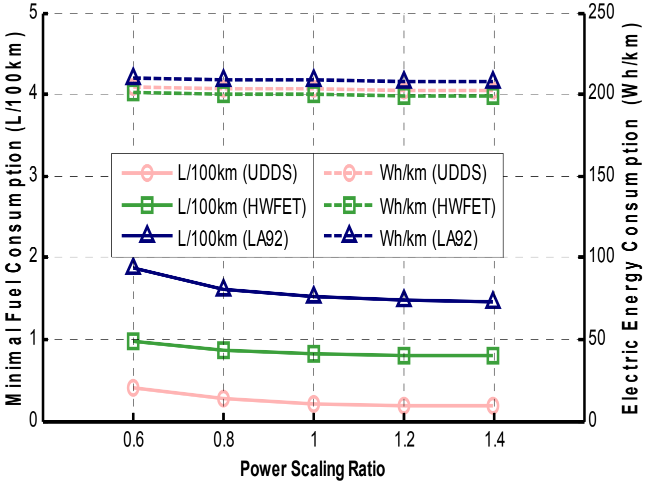
Optimally tuned Parameters

Influence of Component Characteristics Impact

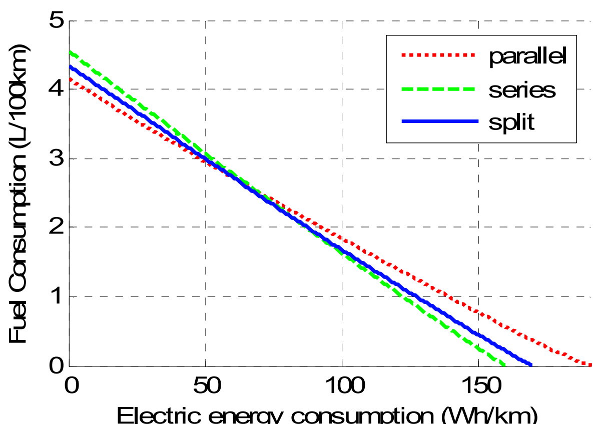
Battery Energy



Battery Power

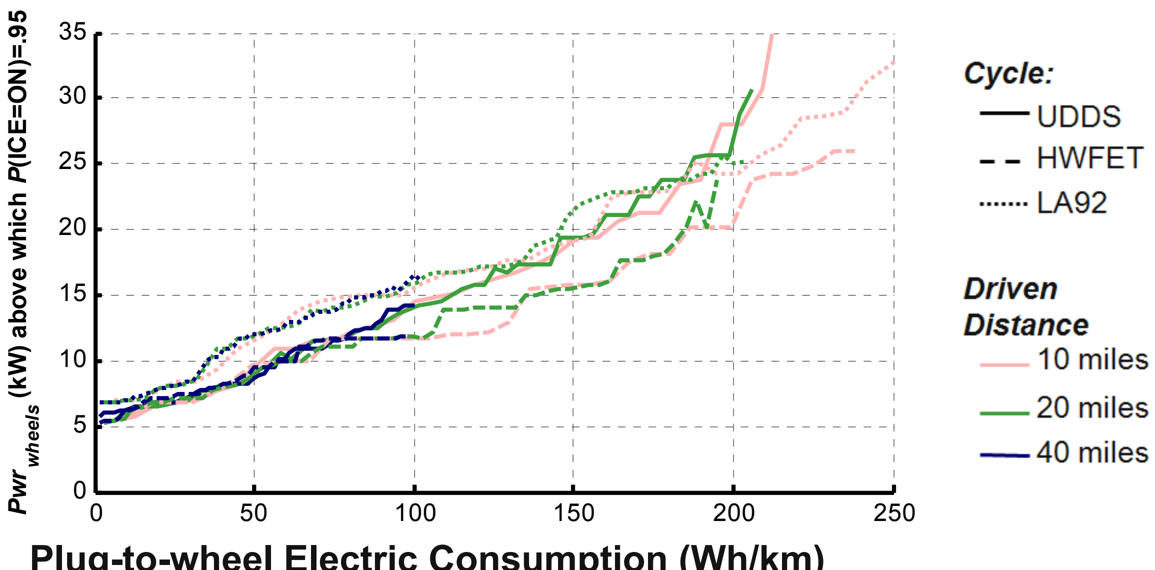


Powertrain Configuration



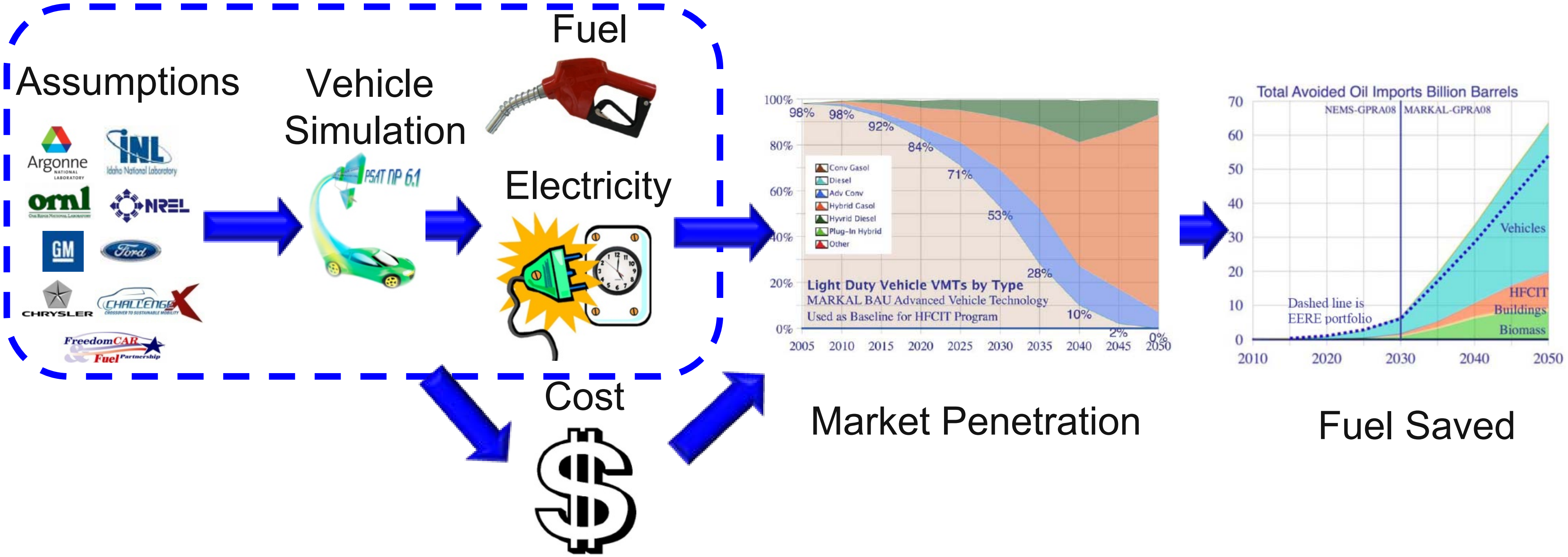
Definition of Rules for Real Time Control

- When the trip distance is greater than the All Electric Range, using the engine throughout the trip (blended control) is preferable to depleting the battery as fast as possible
- Optimum control depends on the distance
- Engine On/Off is linked to wheel power demand and available electrical energy
- When used, engine should be operated at high efficiency



Evaluate Vehicle Fuel Economy of Advanced Technologies

- Developed as an input to the Government Performance and Results Act (GPRA) evaluates the amount of fuel saved due to the introduction of new technologies.
- Used to evaluate cost/benefit of DOE sponsored projects



Large Number of Vehicles

Vehicle Classes ⊗ **Timeframes** ⊗ **Powertrain Configurations** ⊗ **Fuels** ⊗ **Risk Analysis**

Current

2010

2015

2030

2045

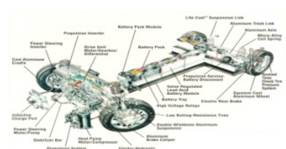
Conventional

ICE HEV

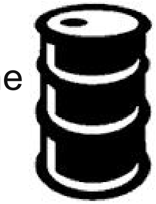
PHEV

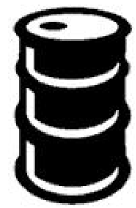
Fuel Cell

Electric



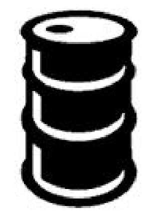
Gasoline





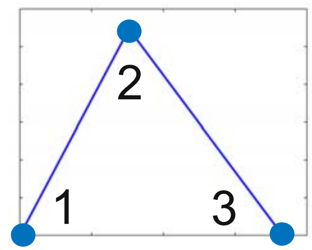
Diesel

Ethanol



H_2

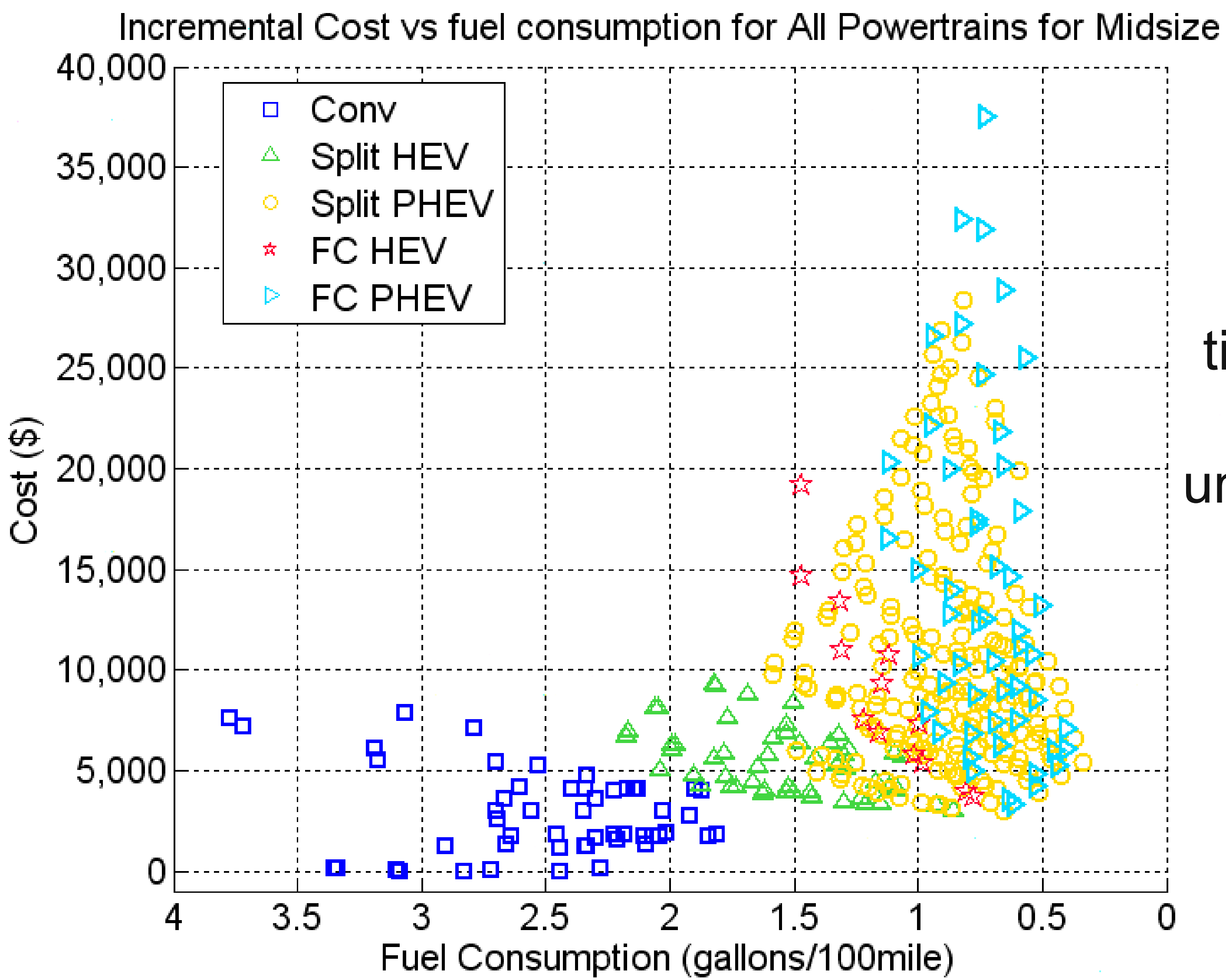
Triangular Uncertainty



1 = 10%
2 = 50%
3 = 90%

> 600 Vehicles

Example of Cost Benefit Analysis



All timeframes and uncertainties included

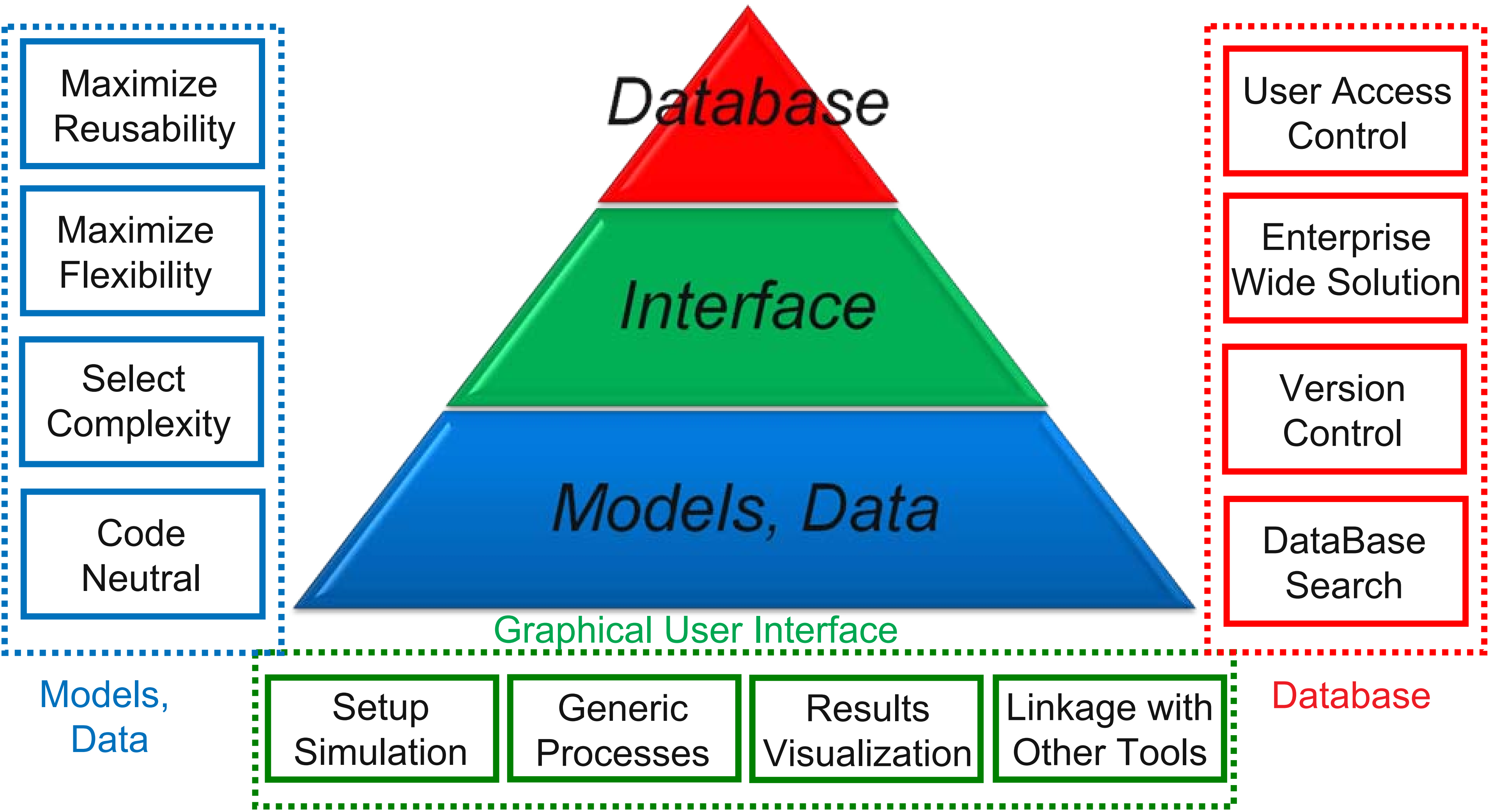
Designing the Next Generation of Vehicle Simulation Tools

- **<u>Problem:</u>**
  - **Evaluation of Fuel Economy (FE) Technologies**
    - *Propose, Analyze & Predict – Theoretical Analysis*
    - *Build, Test & Confirm – Several Years*
    - *Real FE < Predicted FE => Why?*
      - Steady-State / Quasi-Steady-State Theoretical Analysis
      - Transient Dynamics => Emissions & Drivability (ED) Gap
      - Need to Balance FE & ED (FEED) in the Analysis
    - *Result: Wasted Opportunities, Time, and Resources (People & $)*
- **<u>Solution:</u>**
- **Include Control System Design in the Up-Front Math-Based Design & Analysis**
  - Move Control System Design in Parallel with Hardware Design
  - Evaluate FEED Under Transient Conditions
  - Perform Technology Sort in the Math-Based Virtual Environment
  - Focus Developmental Builds on Most Promising Technologies

Plug&Play Model Architecture Required to Achieve Goals

- **Develop Software Architecture & Environment to Plug-and-Play Hardware & Software Models**
  - *Enable Efficient, Seamless Math-Based Control Sys. Design Process*
  - *Enables Efficient Re-Use of Models*
  - *Share Modeling Expertise Across the Organization(s)*
    - Leverages Modeling Expertise From System/Subsystem Experts
- **Establish Industry Standard for Architecture & Model Interfaces**
  - *Enables Suppliers, Universities, National Labs., Etcetera To Provide Subsys. & Component Models*
  - *Enables Mixing & Matching of the 'Best' Models*
  - *More Efficient Use of Resources – Industry-Wide*
  - *Faster Design of Optimal System Solutions*
  - *Accelerates Sorting & Roll Out of Fuel Efficient Technologies*

Develop Software Architecture & Environment to Plug-and-Play Hardware & Software Models to Include Control System Design in the Up-Front Math-Based Design & Analysis



Current & Future Activities

- Assess influence of component and vehicle assumptions on PHEV requirements and fuel efficiency
- Evaluate benefits of PHEVs using real world drive cycles based on component, powertrain configuration, control strategies…
- Assess different high level vehicle control strategy benefits for PHEVs
- Design the next generation of vehicle simulation tool and establish the industry standard