



PSAT Training Part 2: Capabilities

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Operated by The University of Chicago
for the U.S. Department of Energy***



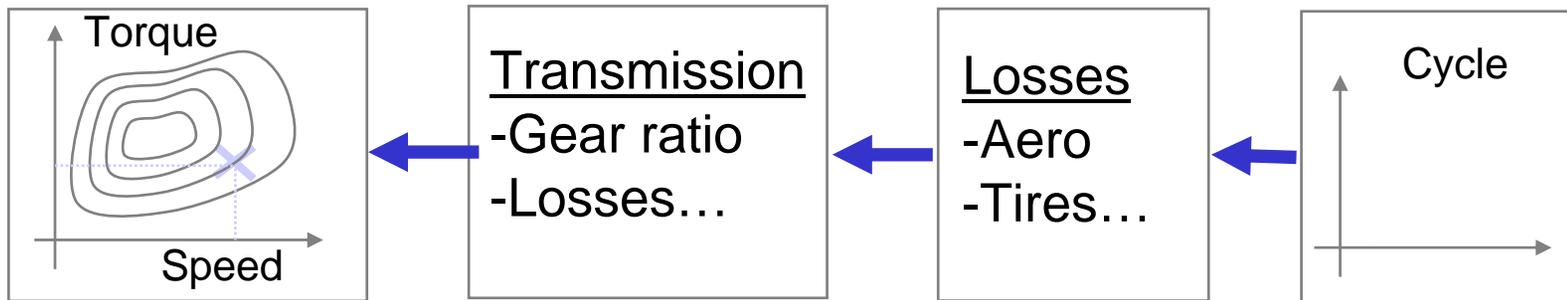
Outline

- **ANL Philosophy**
- PSAT Overview
- Validation
- Example of Work Done at ANL
- Perspectives

Backward Models

Backward-looking models (SIMPLEV, ADVISOR) are static system models that infer drivetrain operation from a speed vs time trace.

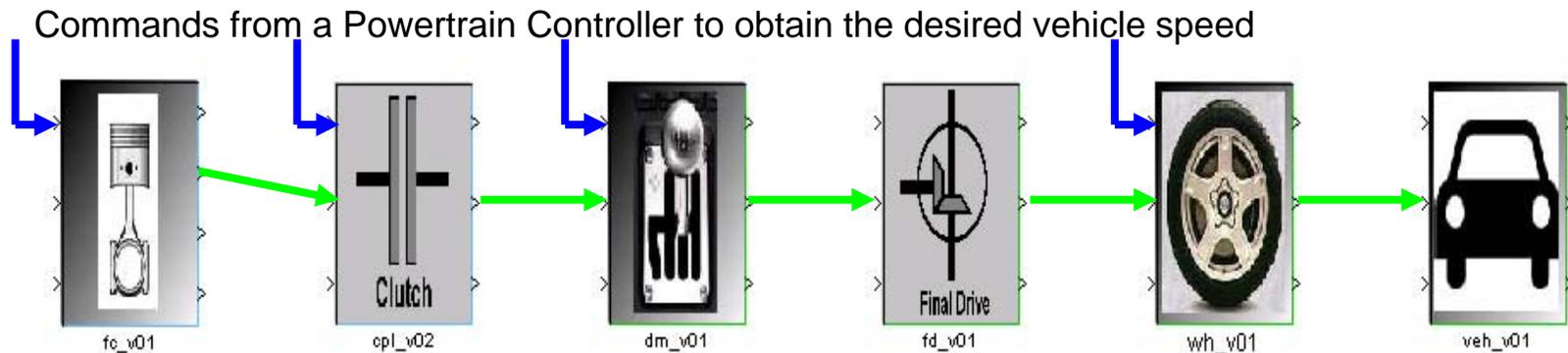
No commands: The desired speed is used to go back from one component to the next.



- **Quasi-steady models**
- **Transient effects on fuel economy and emissions not accounted for realistically**
- **Not suited for hybrid control strategy development**
- **Fast run-time (1 calculation per second in ADVISOR)**

PSAT Looks Forward

Forward modeling (driver-to-wheels) more realistically predicts system dynamics, transient component behavior and vehicle response.



- **Consistent with industry design practice**
- **More accurately represents component dynamics (e.g., engine starting and warm-up, shifting, clutch engagement ...)**
- **Allows for advanced (e.g., physiological) component models**
- **Allows for the development of control strategies that can be utilized in hardware-in-the-loop or vehicle testing**
- **Small time steps enhance accuracy**



To Satisfy Goals and Objectives: Two Different Models for Two Different Uses

ADVISOR

1. Backward-looking (static model)
2. Advantages
 - Run fast
 - Simple models
3. Capabilities
 - Components sizing
 - Sensitivity analysis
 - Efficiency vs hybridization
 - Generic cost



Provide Trends

PSAT

1. Forward-looking (dynamic model)
2. Advantages
 - Representative of dynamic systems
 - Highly advanced component models
 - Take transients into account
3. Capabilities
 - Component technology evaluation
 - Control strategy development
 - Optimization routines
 - Sensitivity analysis
 - Specific cost



Provide Decisions

Transients Are Accurately Represented



What Can Be Done with PSAT?

Yes

1. Study fuel economy & emission
2. Simulate Performance
3. Size Components
4. Simulate Gradeability
5. Perform parametric study
6. Compare drivetrain configurations
7. Compare drive cycles
8. Build drive cycles
9. Develop & integrate
 - Data
 - Component models
 - Control strategy
10. Optimization

No

1. Component calibration
2. Study driveability
3. Run with a too large sample time

Model Needed for FE & Performance

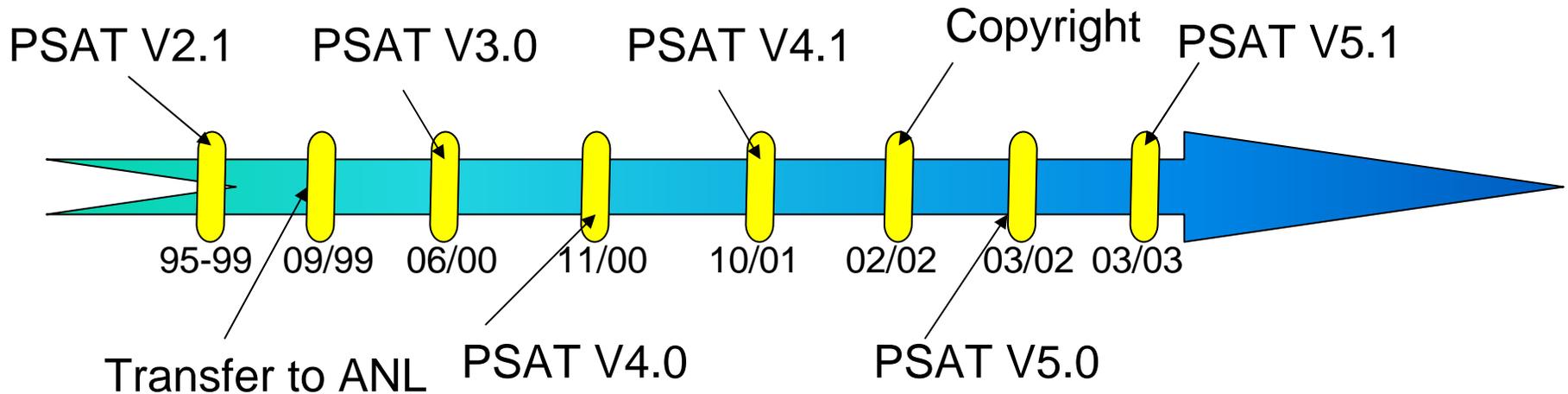
- **Map based (for efficiency & max/min characteristics)**
- **Take into account vehicle transient effects**
- **Take into account component response time (transfer function)**
- **Inertia effect is only taken into account in vehicle (not to slow simulation too much)**
- **No stiffness taken into account**
- **Physiological/NN models needed for emission & further vehicle/component transient effects**

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PSAT Has a Long History

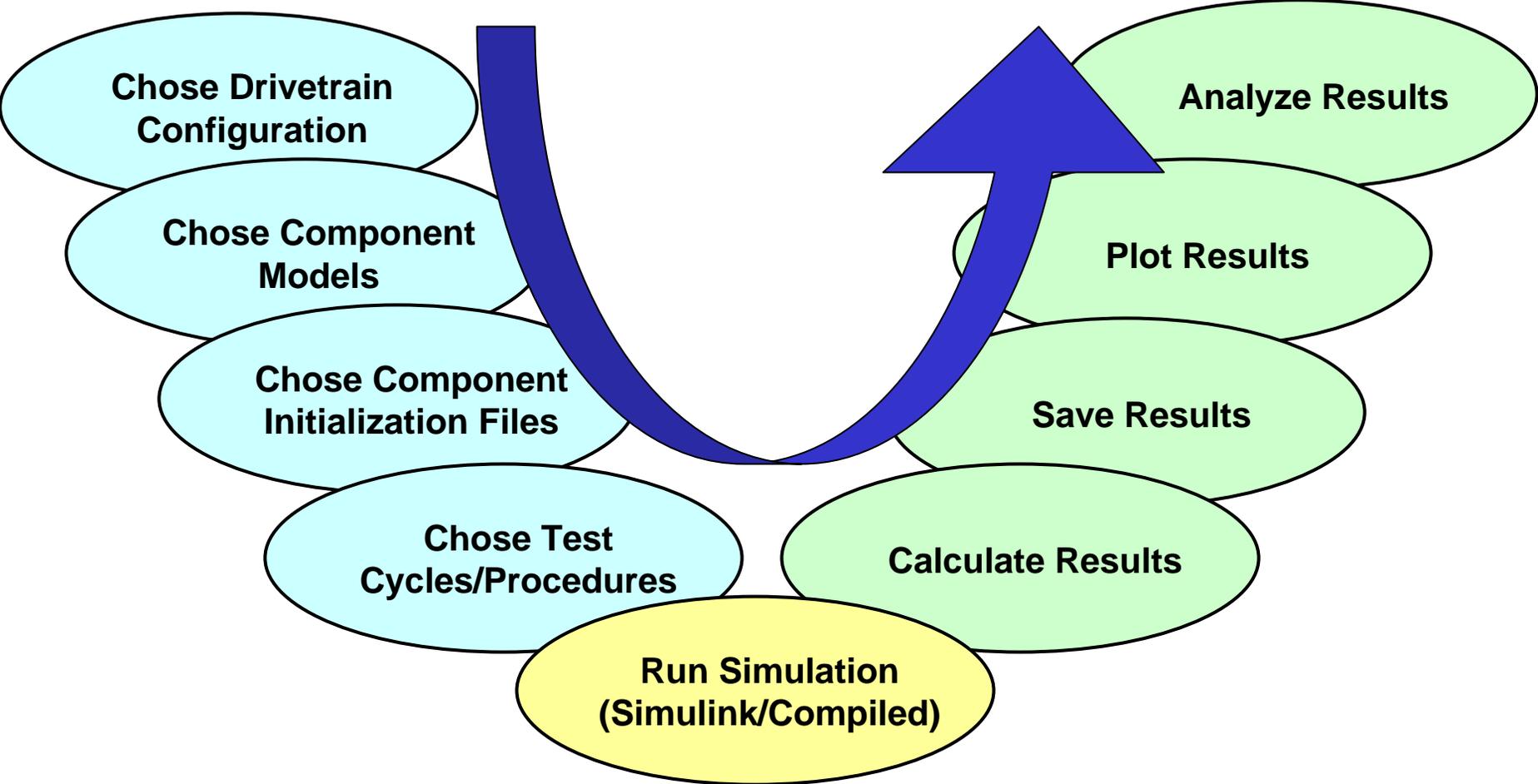
- PSAT was initiated in 1995 by USCAR (contract to TASC and SwRI).
- Redesigned by ANL since 1999 to meet the needs of DOE's integrated analysis, hardware-in-the-loop and validation activities.



PSAT Needs

- **PIII 750 MHz – 256 Ram min (The more the better)**
- **Matlab R12 or R13**
- **Optional:**
 - RTW Toolbox to compile code
 - Fuzzy Logic Toolbox to use fuzzy control strategy
 - Neural Network Toolbox for engine model

PSAT Simulation Process



Hybrids: A Wide Variety of Configurations

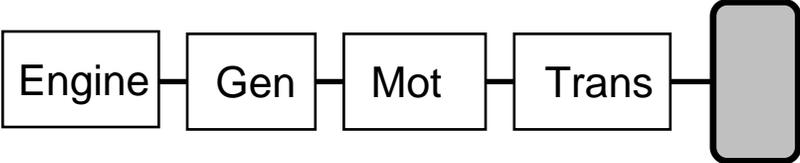


Figure 1: Series

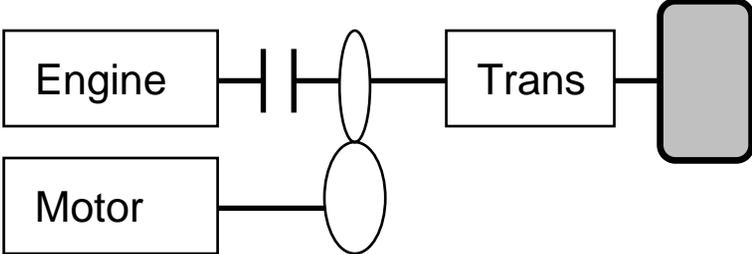


Figure 2: Single shaft parallel

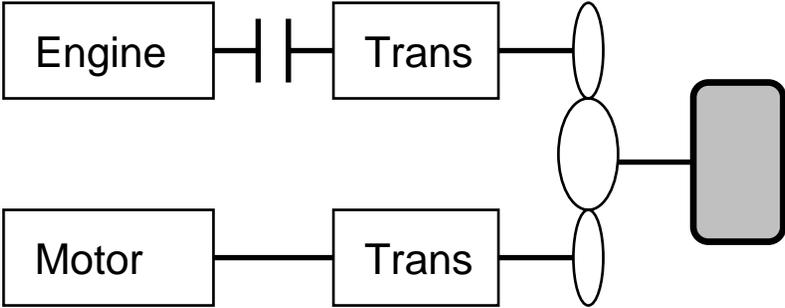


Figure 3: Double shaft parallel

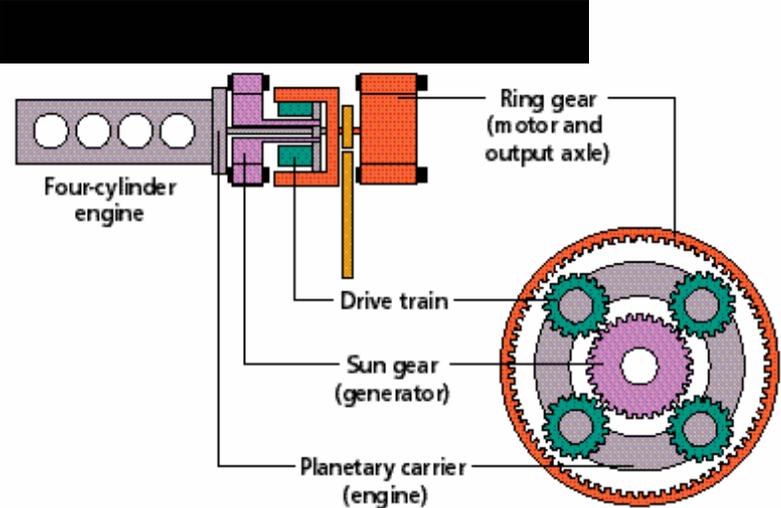


Figure 4: Power split hybrid

PSAT GUI

Vehicle Configuration

Simulation Setup

Post-processing

The screenshot displays the PSAT GUI interface, which is divided into several sections. At the top, there is a 'Vehicle Configuration' section with various icons representing different vehicle components. Below this is the 'Simulation Setup' section, which includes a 'Simulation choice' dropdown and a 'Cycle' section with a table of performance metrics. The 'Post-processing' section features three line graphs showing simulation results over time, with axes labeled 'Component' and 'Variable'. The 'Cycle' section contains the following data:

Component	Metric	Value	Unit
Engine	Fuel Economy	5.49	L/100 km
	Fuel Economy Gasoline	6.05	L/100 km
	HC Emission	0	g/km
	CO Emission	0	g/km
Standards	NOx Emission	0.065	g/km
	PM Emission	0	g/km
	Distance	0.645	km
Motor	Electrical Consumption	59.46	Wh
	SOC Init	55	%
	SOC Final	54.03	%
Combined	Hybrid Gasoline Equivalent	0.49	L/100 km
	Future Truck Gasoline Equivalent	8.23	L/100 km
	SAE Fuel Economy	n/a	L/100 km
Statistics	WSPC (SI)	2.56	L/1/100km

The 'Perfo' section includes a table with the following data:

Metric	Value	Unit
Acceleration	n/a	m/s ²
Max. Accel.	n/a	m/s ²
Distance traveled	n/a	meters
Time to reach	n/a	seconds
Max grade	0.245	m/s



Initialization Windows

The image displays a software interface for engine initialization, featuring several windows:

- Edit List --Engine:** A window for managing engine versions and types. It includes a list of engine models (e.g., eng_si_10000_224_HOT), buttons for adding/deleting files and versions, and a 'Change Picture' button. A red arrow points to the 'Help' button.
- Plotting Figure:** A graph titled 'Motor Efficiency' showing Motor Torque (Nm) vs. Motor Speed (rad/sec). The graph displays efficiency curves for a 'Motor' and a 'Generator' across various operating points.
- Parameters:** A table listing component parameters. The 'Engine' row is highlighted, showing parameters like 'eng_eff_max_des' and 'eng_eff_min_des'. The 'Engine COLD (fuel use)' parameter is also highlighted with a red circle.
- Workspace:** A window showing a list of variables and their values, including 'eng_eff_max_des' and 'eng_eff_min_des'.

Post-Processing Windows

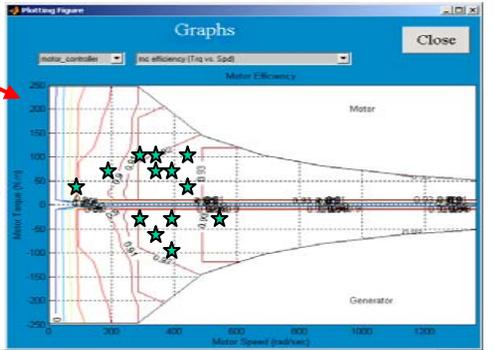
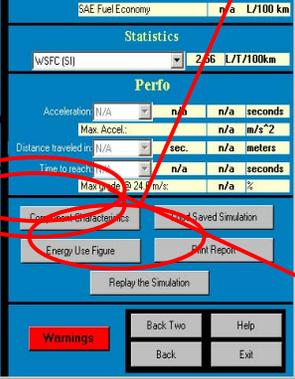
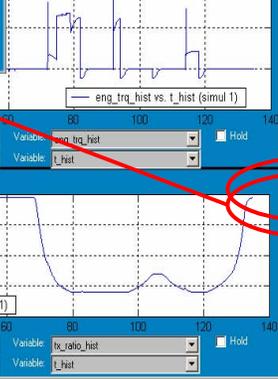
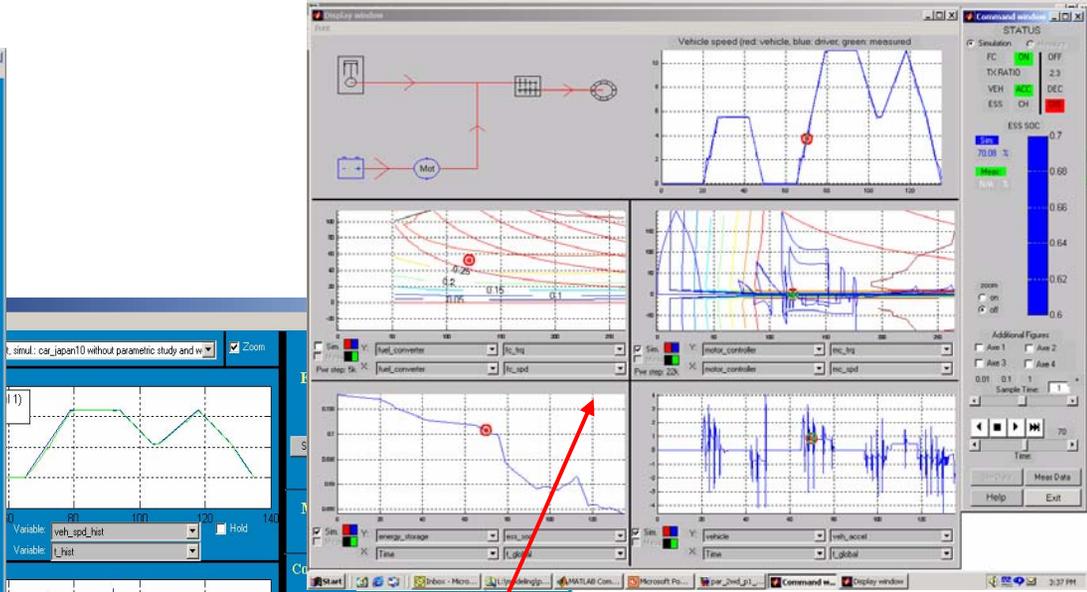
ENERGY Figure

Energy Usable Table (W.hr)

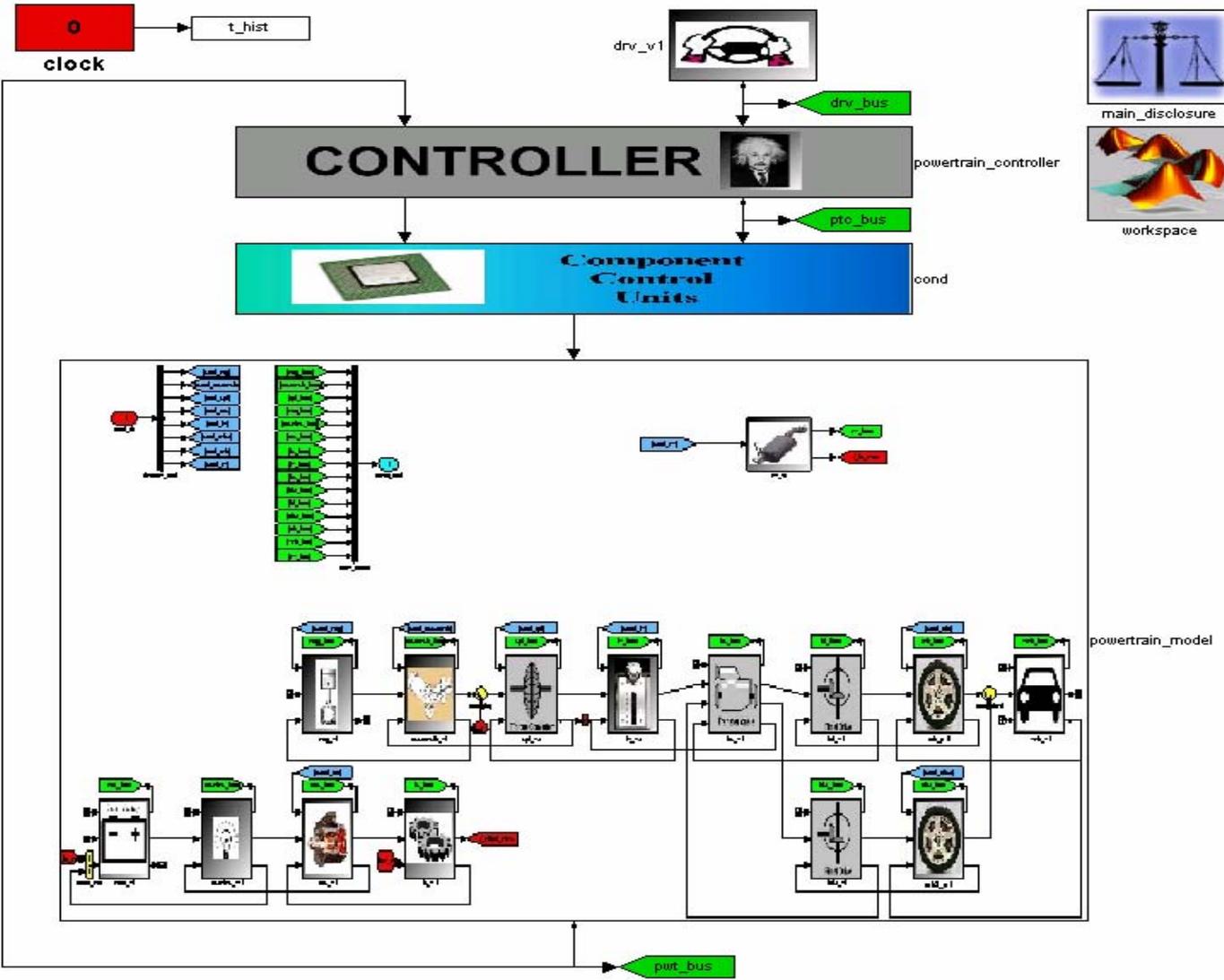
	Acceleration Mode				Deceleration Mode			
	In	Out	Loss	ER	In	Out	Loss	ER
Engine	342	90	252	0.26	65	-8	73	0.12
Fuel Cell								
Mechanical Accessory	50	01	9		-8	-15	7	
Clutch/Torg. conv.	63	54	15		-15	-17	2	
Generator	-12	-7	-5	0.6	0	0	0	0.6
Torque Coupling								
Energy Storage								
Electrical Accessory	2	-7	5		7	0	7	
Motor/Controller								
Transmission	54	53	1	0.98	-17	-18	0	0.98
Transfer Case								
Final Drive	53	48	5	0.9	-18	-19	2	0.91
Final Drive 2								
Wheel/Hole	48	48	0	1	-19	-35	16	1
Braking								
Wheel Axle 2								
Braking 2								
Stator	0	0	0	0	0	0	0	0

Overall System Efficiency: 10.000 %

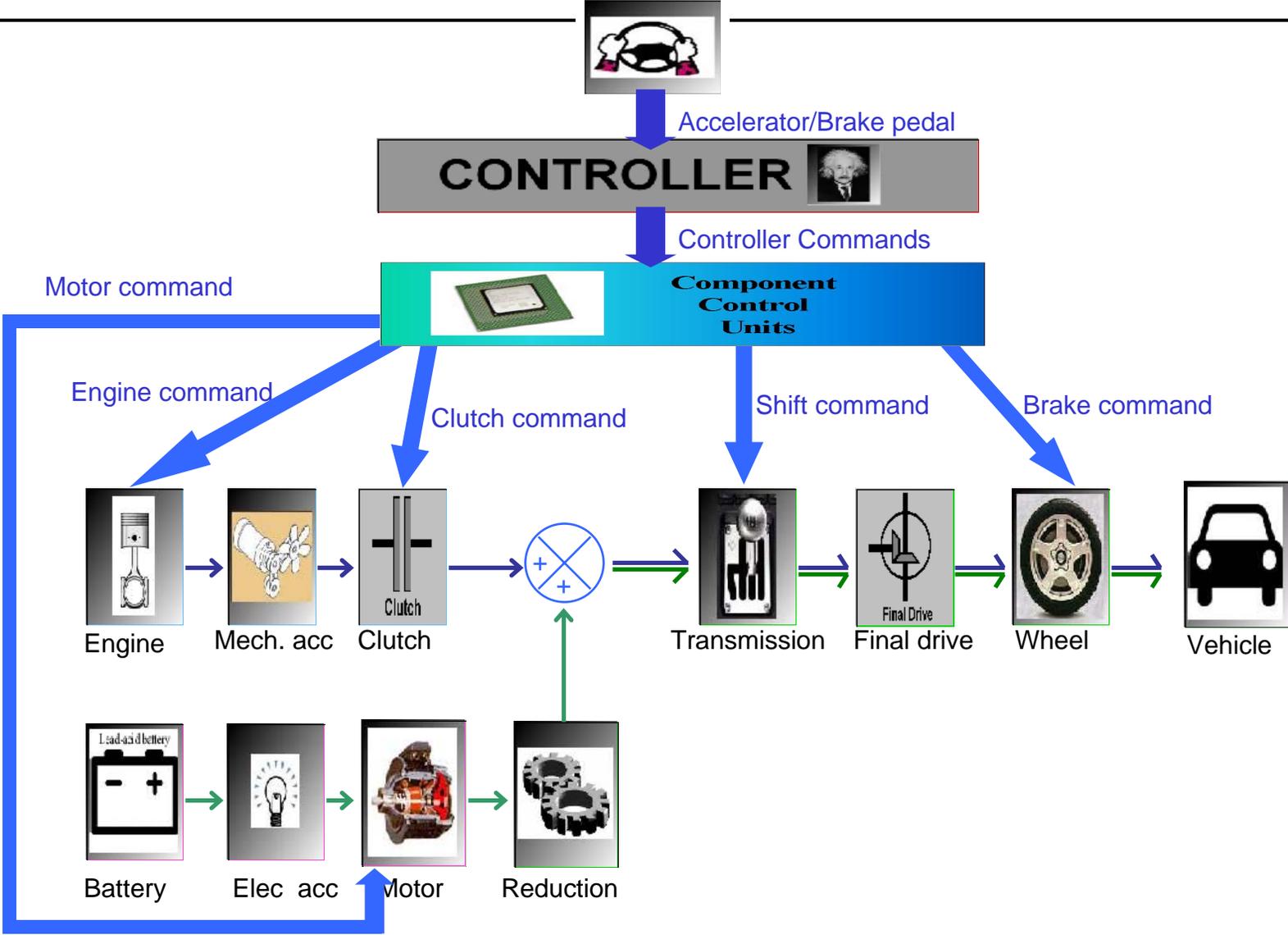
Buttons: HELP, DONE, Acceleration Table (D/A / D), Deceleration Table (D/A / D), Loss Plot (Acceleration Mode), Loss Plot (Deceleration Mode)



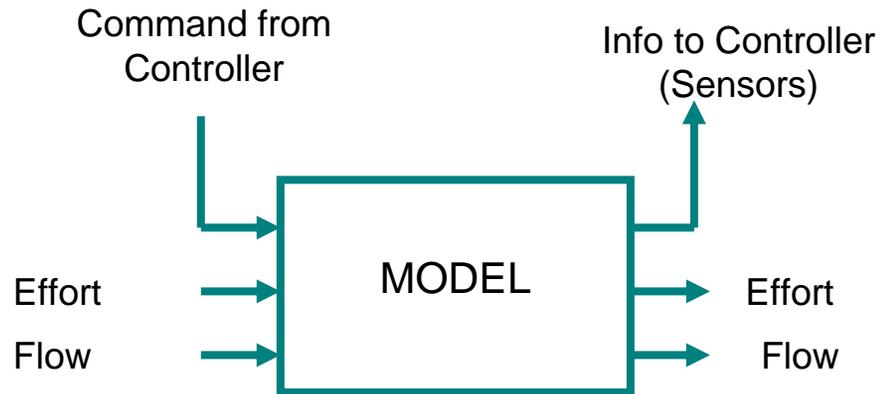
Example of PSAT Simulink Model



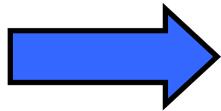
PSAT Structure Flows Intuitively



PSAT Component Model Format Is Generic



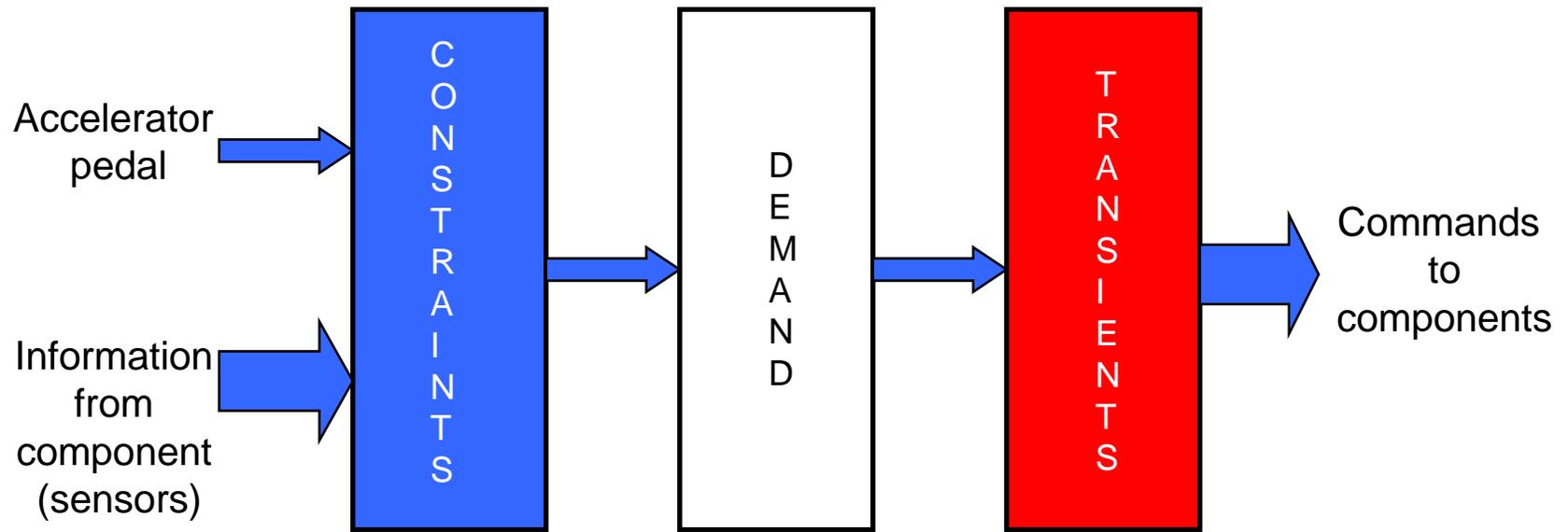
	Effort	Flow
Engine	Torque	Speed
Motor	Voltage	Current



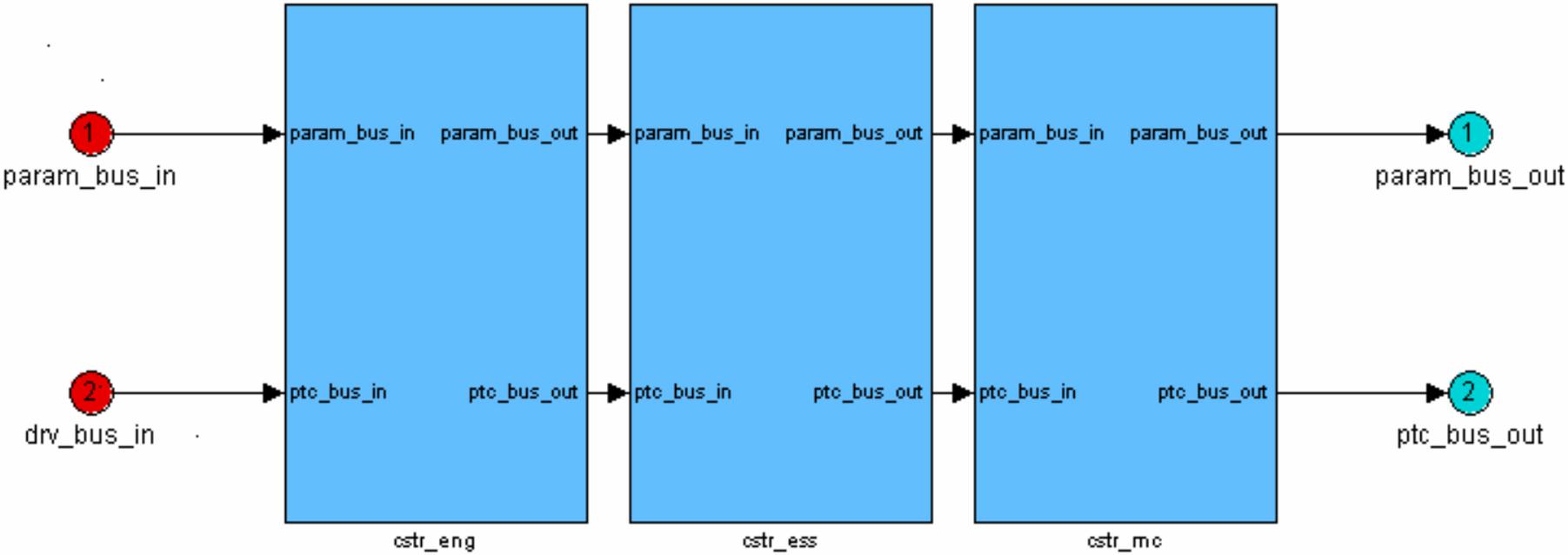
All the component models have the same number of inputs (3) and outputs (3)

Generic Power Controller Organization

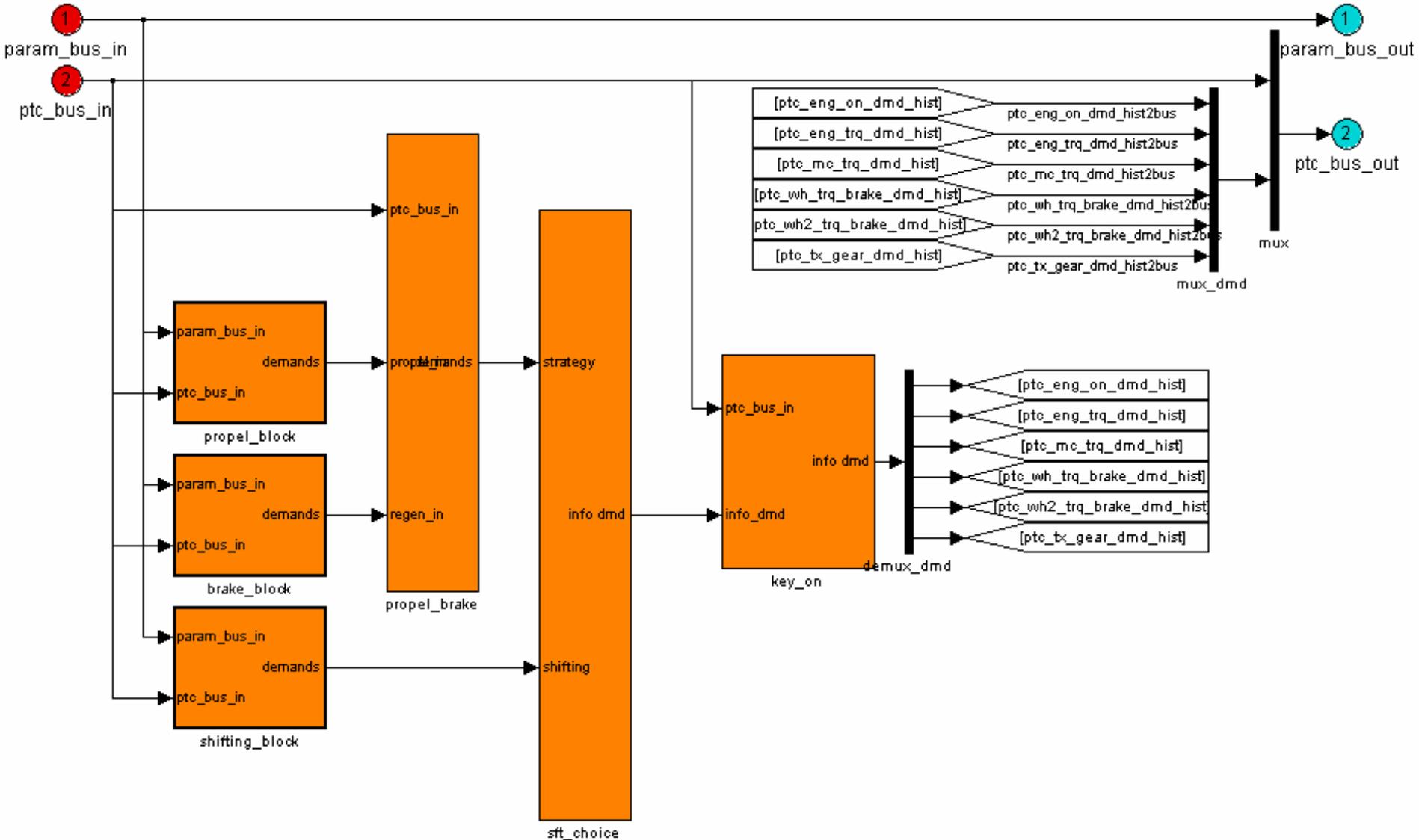
A generic organization common to all powertrains



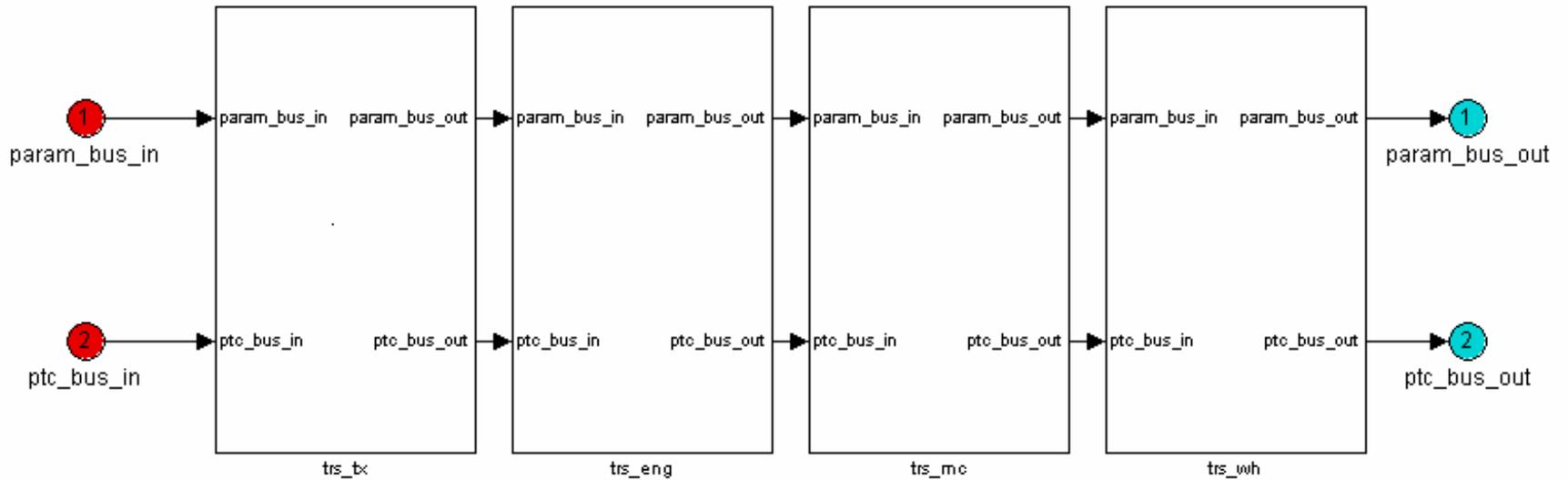
Constraint Block in Simulink



Demand Block in Simulink



Transient Block in Simulink



Control and Shifting Selections Are Easy

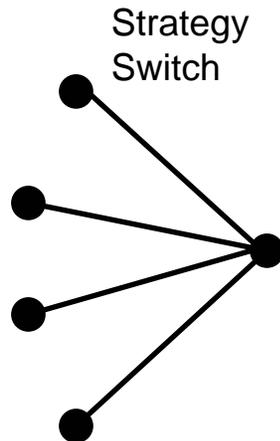
Within the same drivetrain model, we can switch between different control strategies and different shifting algorithms.

S1: vehicle speed

S2: power demand

S3: torque demand

S4: level of SOC

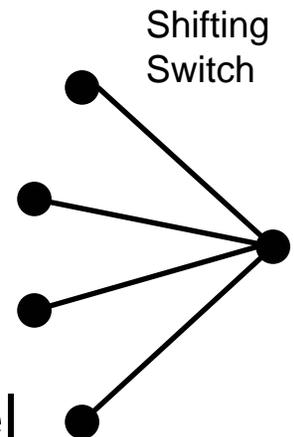


S1: vehicle speed

S2: vehicle accel.

S3: engine speed

S4: veh spd & accel



We ONLY compare separate strategies and shifting
We can EASILY implement new ones

PSAT Is Flexible and Reusable

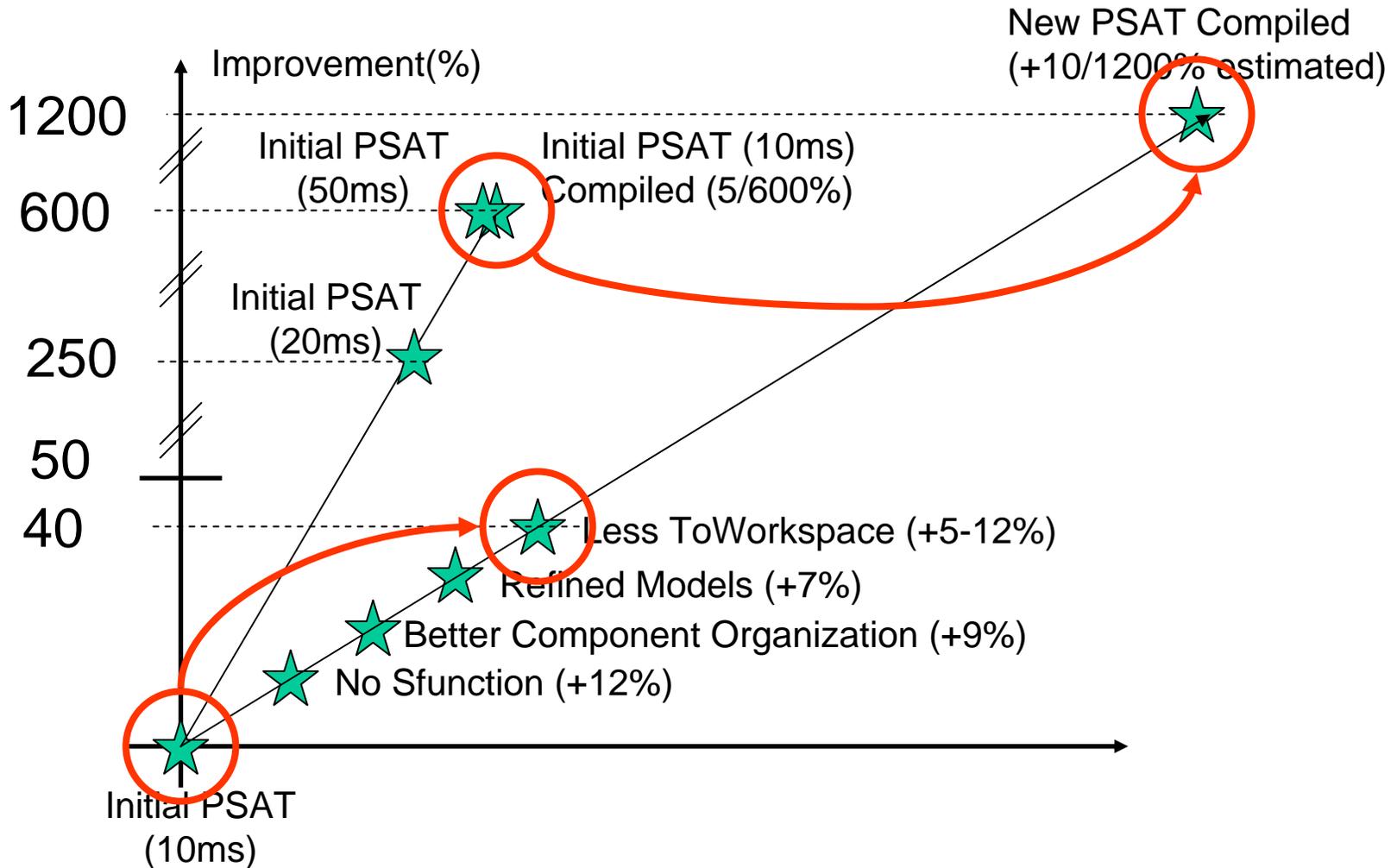
- **Drivetrains constructed from user choices**
- **Numerous configurations can be explored(>150: conventional, parallel, series, power split...)**
- **Several strategies can be compared within the same model using switches**
- **Can add new component data, models and control**
- **Model format is generic (3 inputs/3 outputs)**
- **Multiple uses of same model possible**
- **Software is highly parameterized**

PSAT Is User-Friendly

- **Easy integration of initialization files, component models or control strategies through its Graphical User Interface**
- **Easy comparison of different levels of model sophistication and control strategies**
- **Post simulation analysis is enhanced through use of a voltage bus for more realistic transient behavior**

PSAT has been designed to take transients into account and handle different levels of modeling detail ... allowing the user to match the level of sophistication with the application.

PSAT Speed Increased Up to 12X with Same Accuracy



Outline

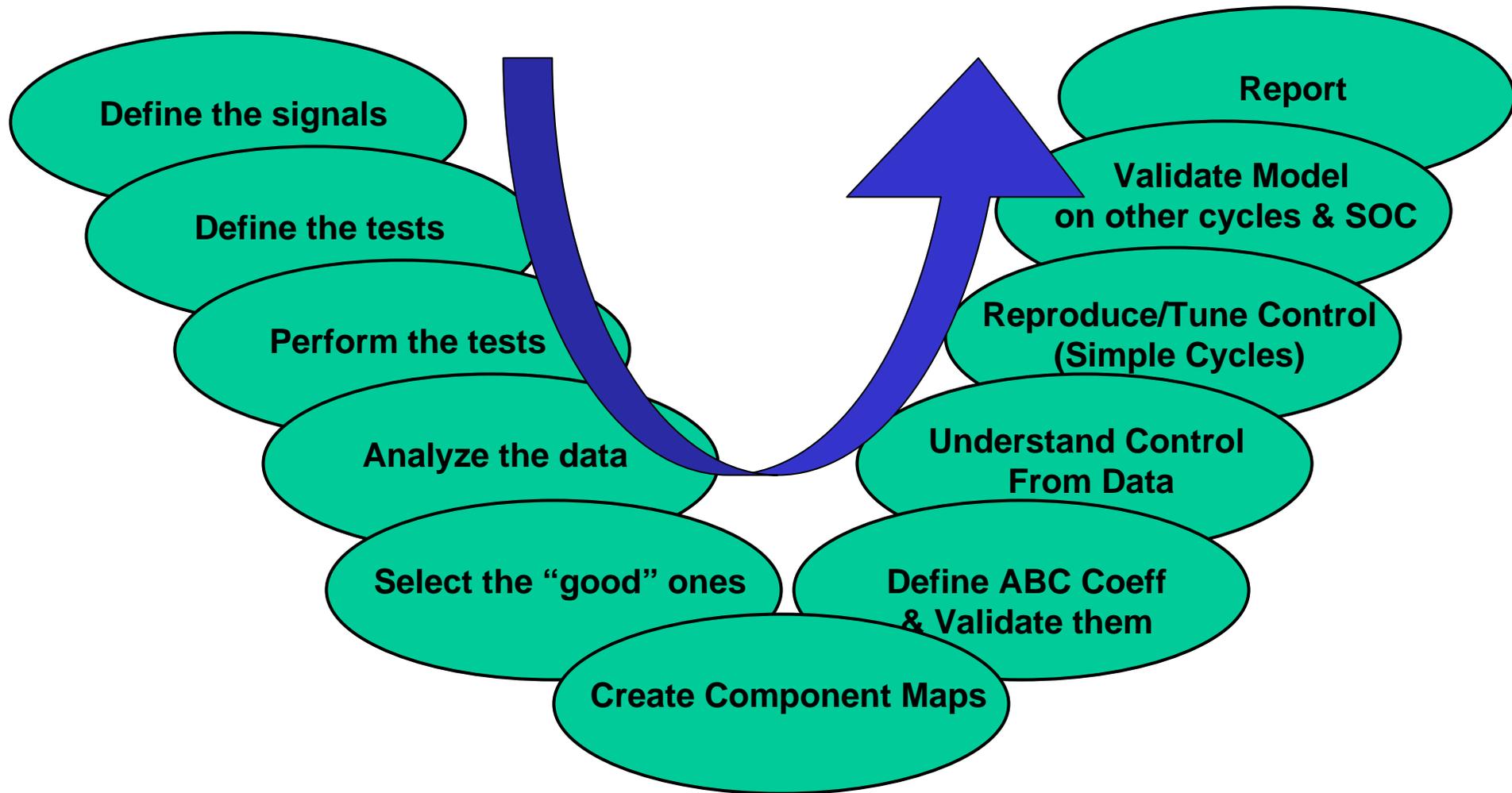
- ANL Philosophy
- PSAT Overview
- **Validation**
- Example of Work Done at ANL
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Accurate Validation Provides Confidence in Studies Results

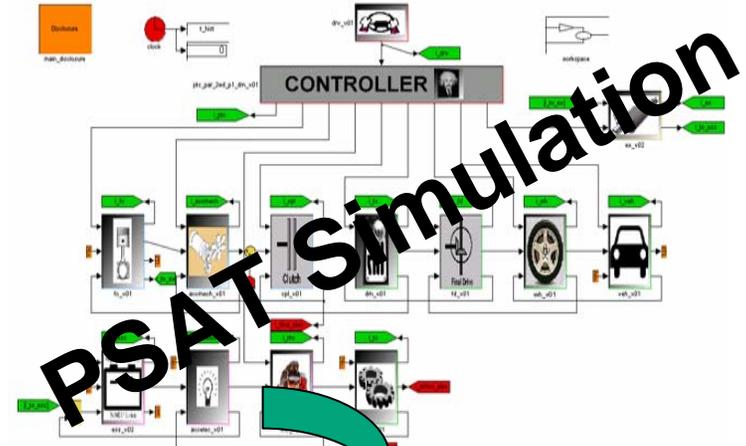
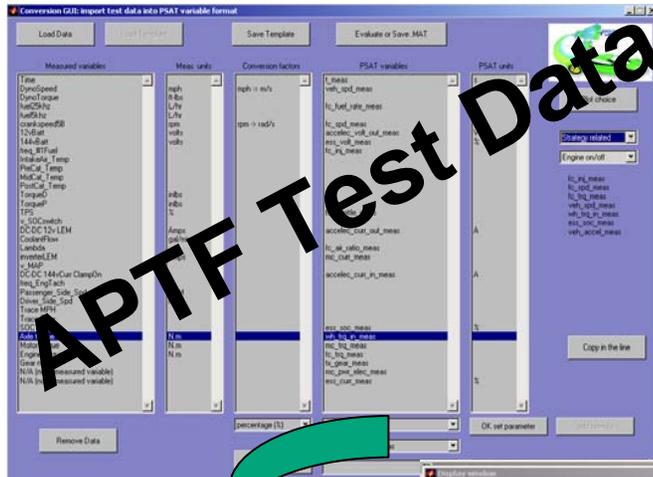
- **Ford Taurus 97 3.0L V6 has been validated within limits of test capabilities (1% FE, 10% Emissions)**
- **Japan Prius* & Honda Insight* Fuel Economy & SOC validated within 5% for several driving cycles**
- **Ford P2000* Validated within 5% for Fuel Economy & SOC**

*Japan Prius, Honda Insight & Ford P2000 validations have been realized with APTF Data

Validation Steps



New Tools Allow Users to Speed Up Validation



Integration of Test Data Is Immediate!

Step 1
Load Data
From TXT file

Step 2
Delete
Unwanted
Data

Step 3
Rename each
Data using PSAT
Nomenclature

Step 4
Calculate extra
parameters

Step 5
Select the
Appropriate
units

Step 6
Save the
template

Step 7
Plot parameters

Conversion GUI: Import test data into PSAT variable format

Load Data Load Template Save Template

Measured variables Meas. units Conversion factors PSAT units

Time
DynoSpeed
DynoTorque
fuel25khz
fuel5khz
crankspeed5B
12vBatt
144vBatt
freq_#1Fuel
IntakeAir_Temp
PreCat_Temp
MidCat_Temp
PostCat_Temp
TorqueD
TorqueP
TPS
v_SDCswitch
DC-DC 12v LEM
CoolantFlow
Lambda
inverterLEM
v_MAP
DC-DC 144vCurr ClampOn
freq_EngTach
Passenger_Side_Spd
Driver_Side_Spd
Trace MPH
Trace Time
SOC
Axle torque
Motor torque
Engine torque
Gear number
N/A (not a measured variable)
N/A (not a measured variable)

inlbs
inlbs
%
Amps
gal/min
Amps

mph -> m/s
rpm -> rad/s

t_meas
veh_spd_meas
fc_fuel_rate_meas
fc_rpd_meas
accelec_volt_out_meas
ess_volt_meas
fc_inj_meas
fc_throttle_meas
accelec_curr_out_meas
fc_air_ratio_meas
mc_curr_meas
accelec_curr_in_meas
ess_soc_meas
wh_trq_in_meas
mc_trq_meas
tx_gear_meas
mc_gwr_elec_meas
ess_curr_meas
elec accessories
accelec_curr_in_meas

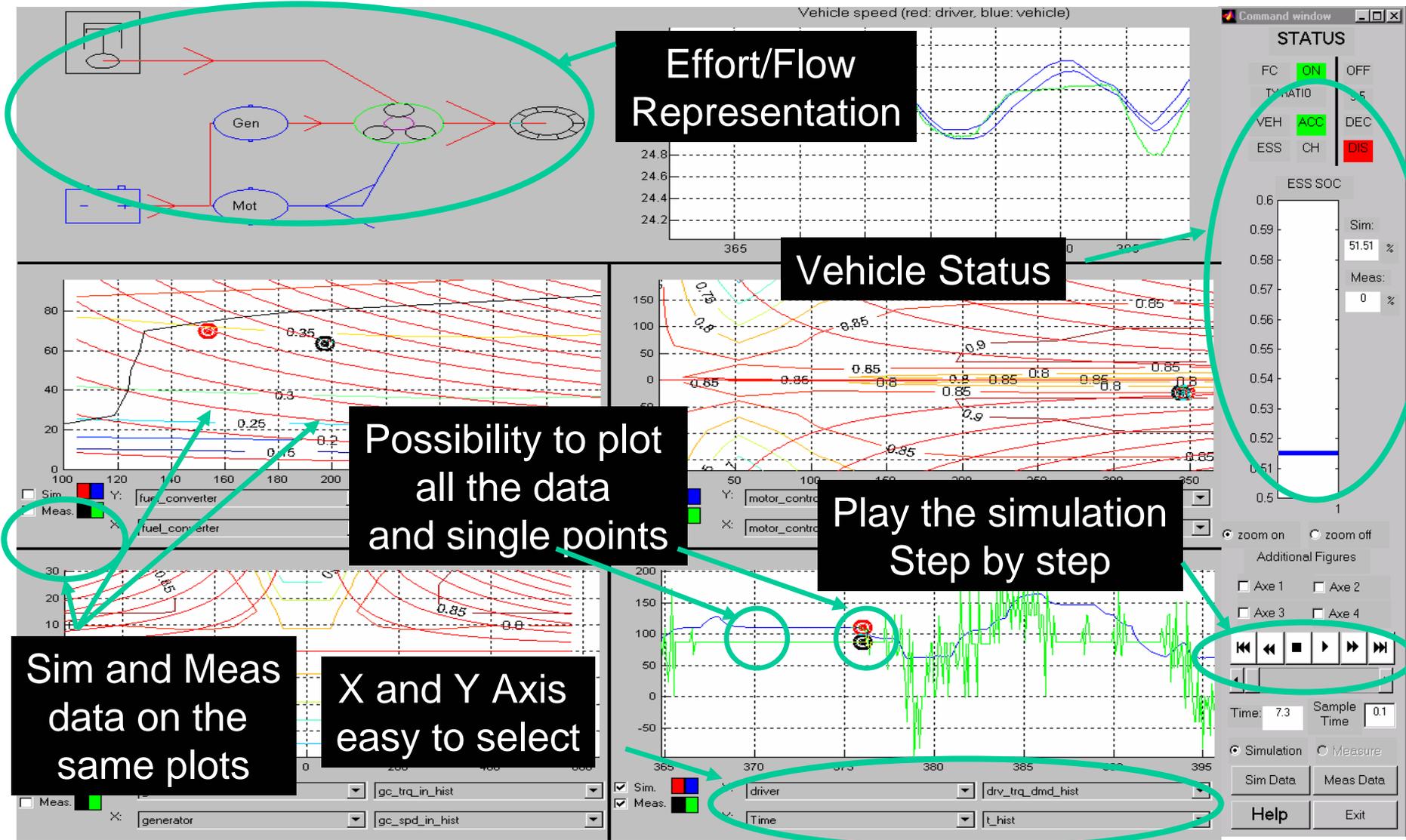
PSAT units
\$
V
%
A
A
%
%

Plot choice
Strategy related
Engine on/off
fc_inj_meas
fc_spd_meas
fc_trq_meas

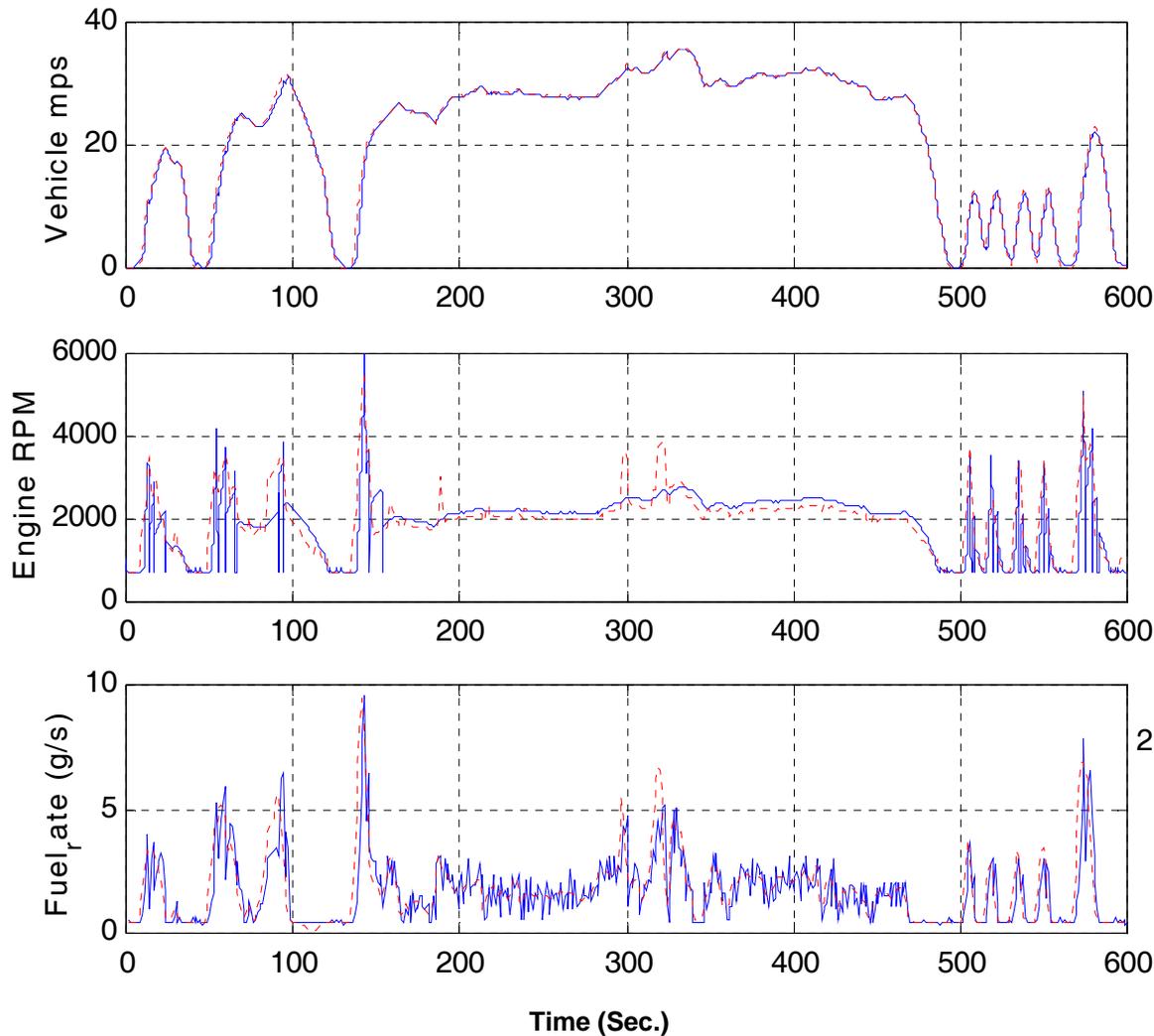
Copy in the line

Assign

Innovative Window to Replay Tests and Simulation



Conventional Validation - Taurus



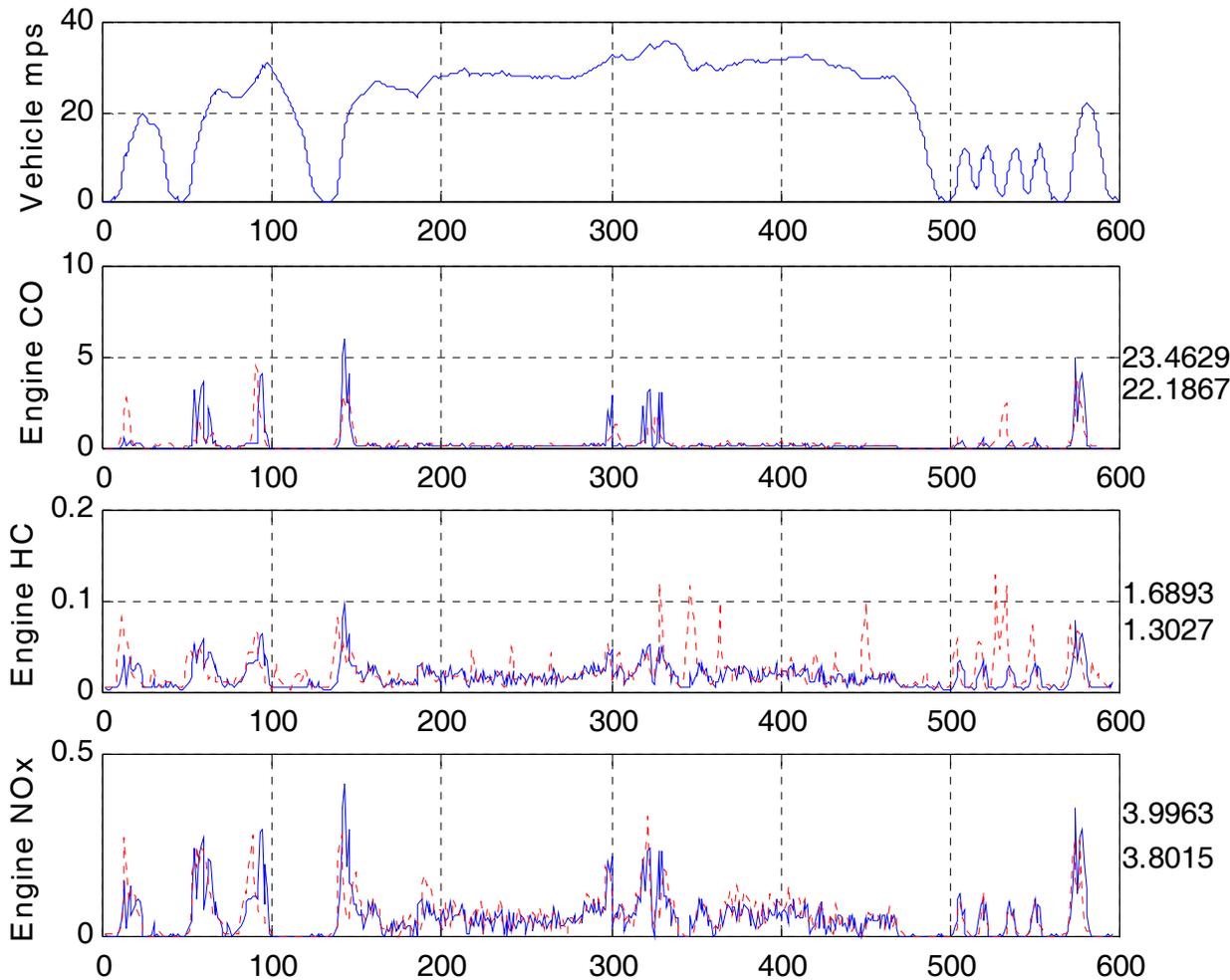
US06 Cycle

**Test/Simulated
Consumptions:
22.9 / 22.6 mpg**

**Blue = modeling
Red = testing**

21.8612

Conventional Validation - Taurus

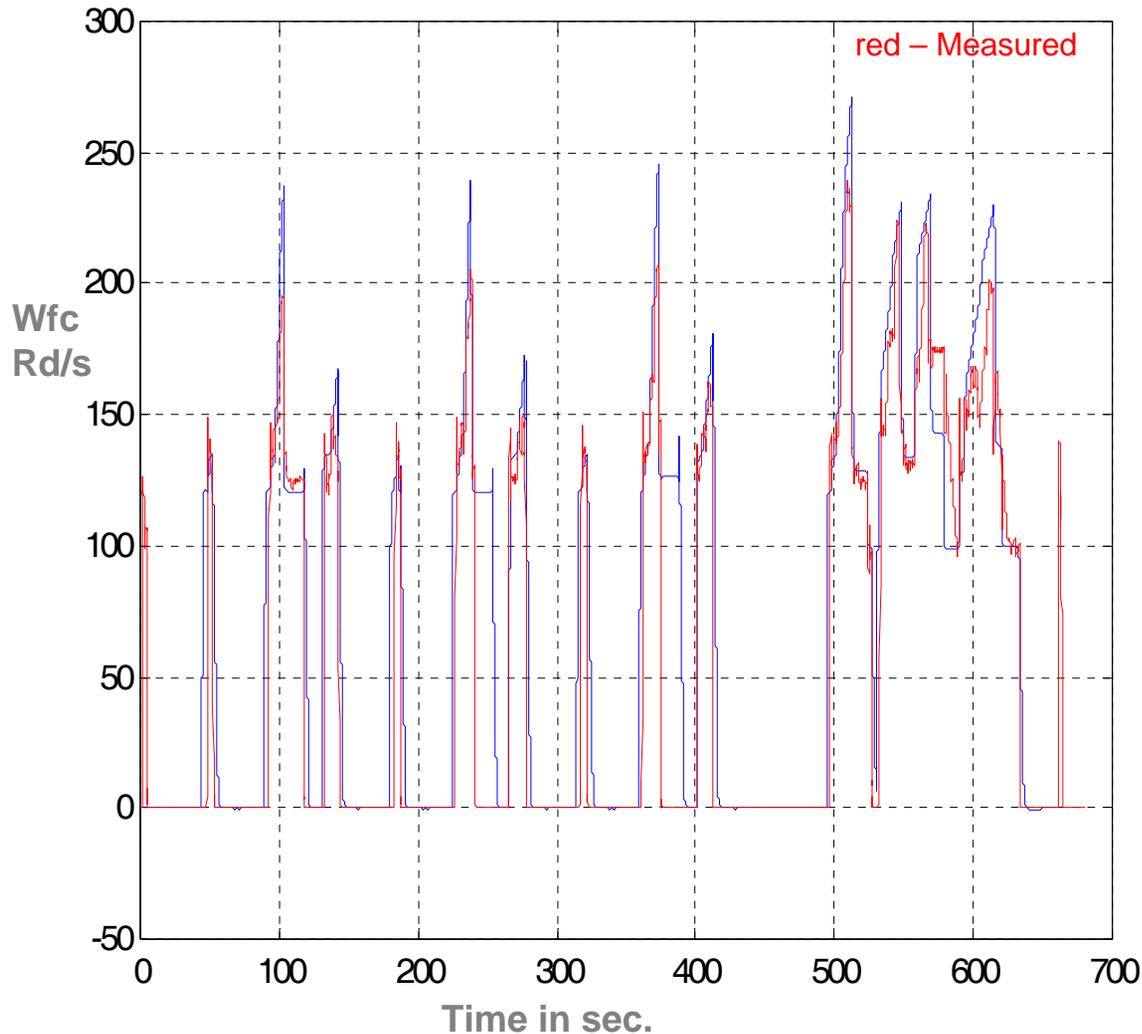


US06 Cycle

**Pre-catalyst
emissions**

**Blue= modeling
Red=testing**

HEV Validation - Japan Prius

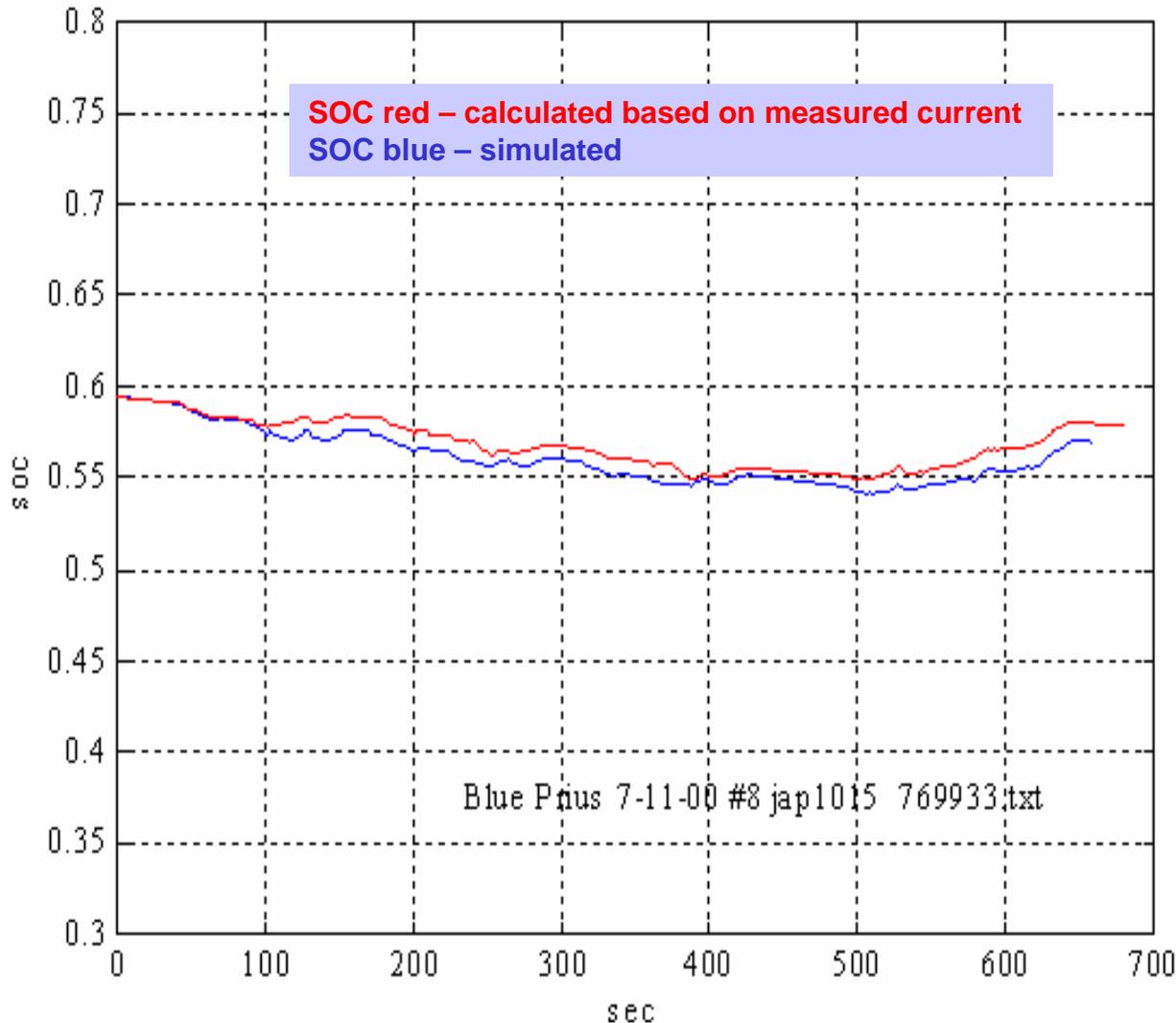


Japan 10-15 Cycle

**Test/Simulated
Consumptions:
47.6 / 45.6 mpg**

**SOC difference
between test
and
Simulation 0.01**

HEV Validation - Japan Prius

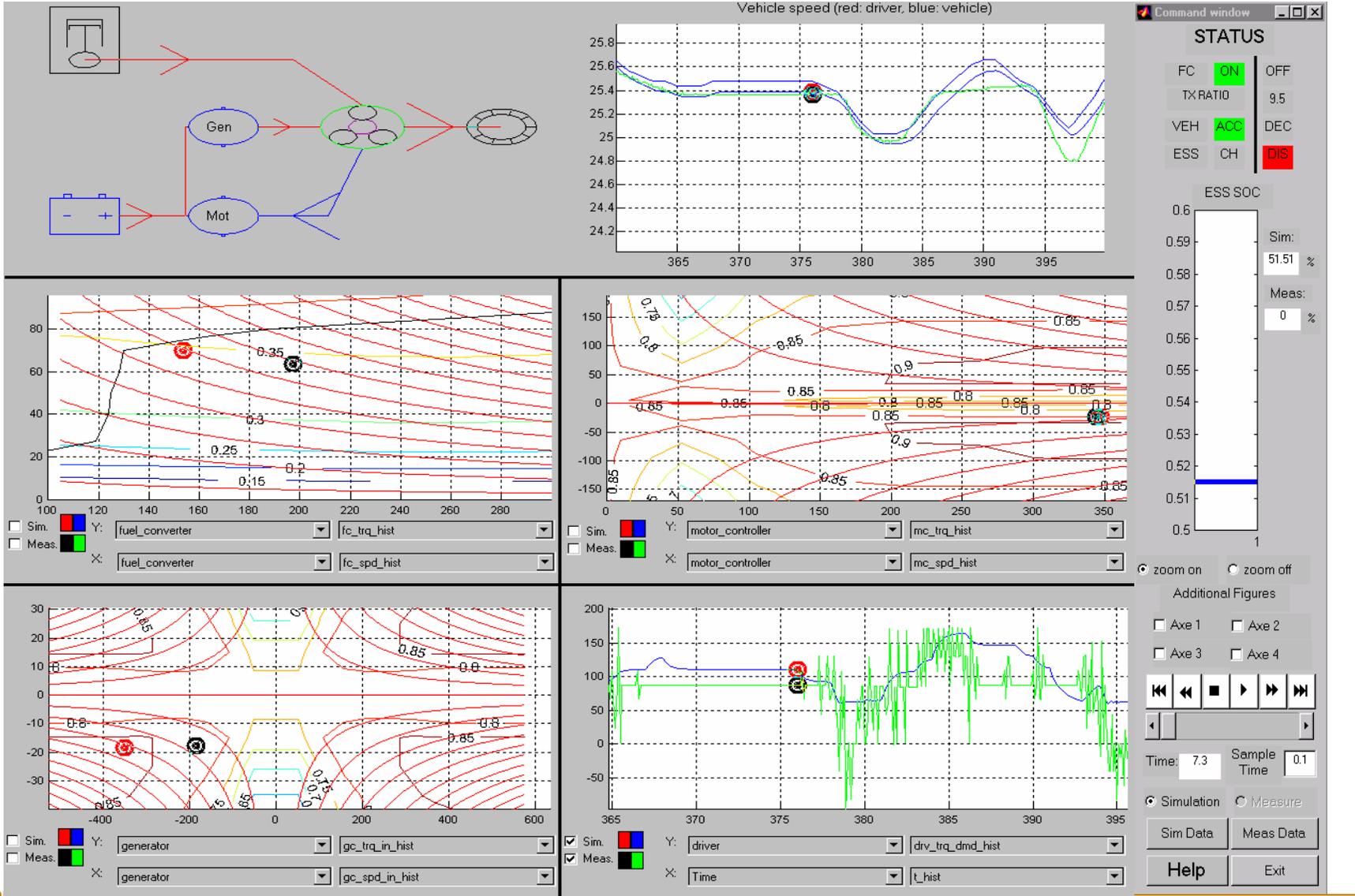


**Japan 10-15
Cycle**

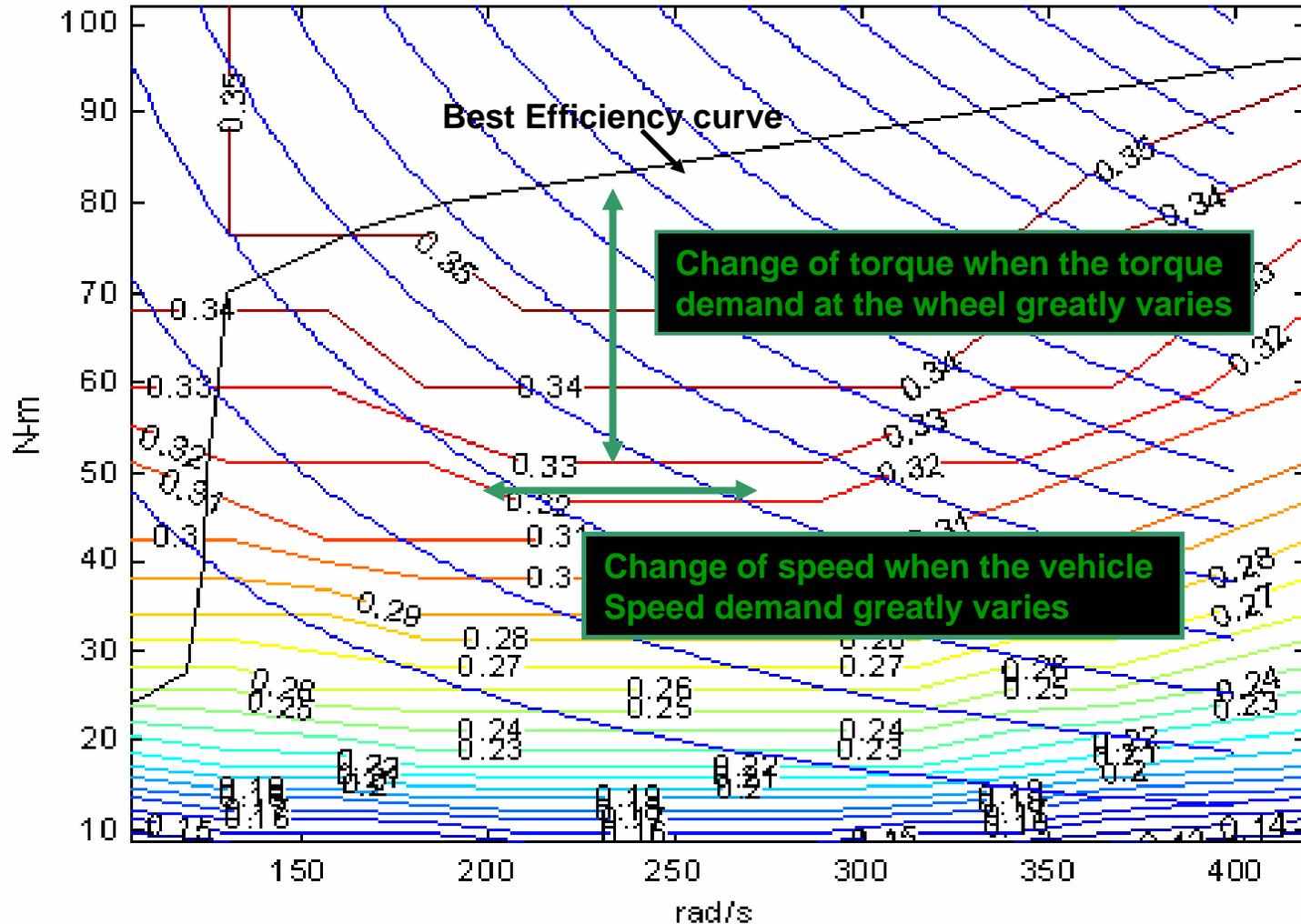
**Test/Simulated
Consumptions:
47.6 / 45.6 mpg**

**SOC difference
between test
and
simulation 0.01**

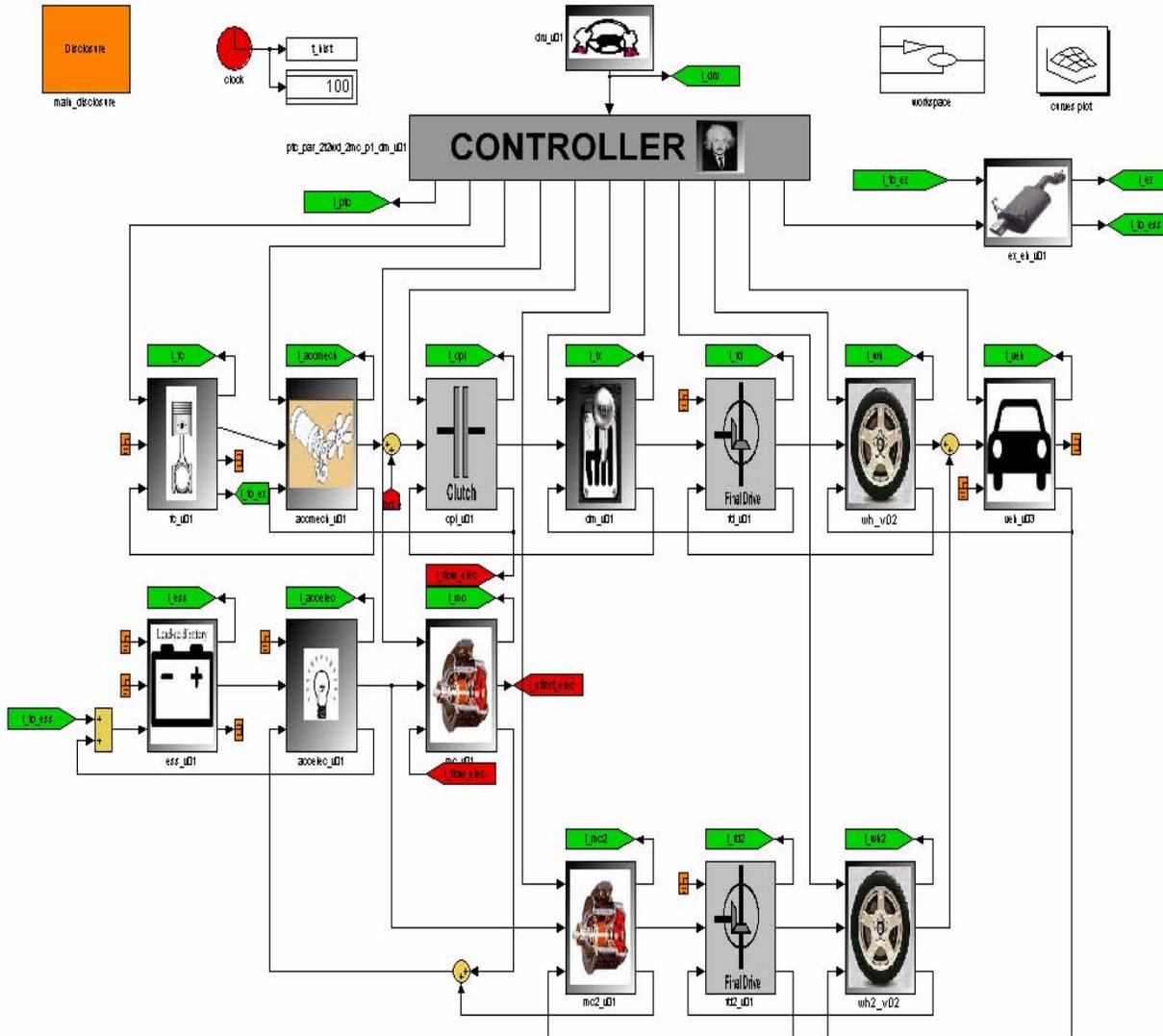
Specific Tools Are Necessary to Understand and Develop Advanced Controls



The Japan Prius Does Not Always Follow the Best Efficiency Curve



HEV Precept Correlation



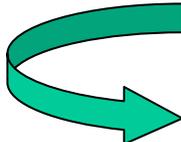
Combined

**Test/Simulated
Consumptions:
79.6 / 76 mpg**

**Small SOC
difference in
Simulation**

HEVs Validated Within 5% FE & SOC

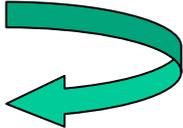
Japan Prius



Cycle	Cons test mpg	Cons simul mpg	Diff in %	SOC init	SOCf test	SOCf simul	Diff in %
Japan 10-15	44.9	45.1	0.4	0.600	0.580	0.583	0.5
Japan 10-15	48.8	50.7	3.9	0.610	0.575	0.561	2.3
EUDC	44.0	43.8	0.4	0.610	0.605	0.593	2.0
FHDS	48.2	46.7	3.2	0.550	0.571	0.573	0.3

Cycle	Cons test mpg	Cons simul mpg	Diff in %	SOC init	SOCf test	SOCf simul	Diff in %
Japan 10-15	57.9	58.8	1.5	0.596	0.610	0.611	0.4
NEDC	60.6	60.2	0.6	0.600	0.602	0.583	3.6
FHDS	74.2	75.3	1.4	0.590	0.588	0.589	0.2
FUDS	58.3	57.8	0.8	0.728	0.706	0.720	2.0

Honda Insight



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 - Fuel Cell Modeling
 - Transient Engine Emission Models
 - Trade-off between FE & Emission
 - Potential Gains for Class 2B Vehicle
- Perspectives

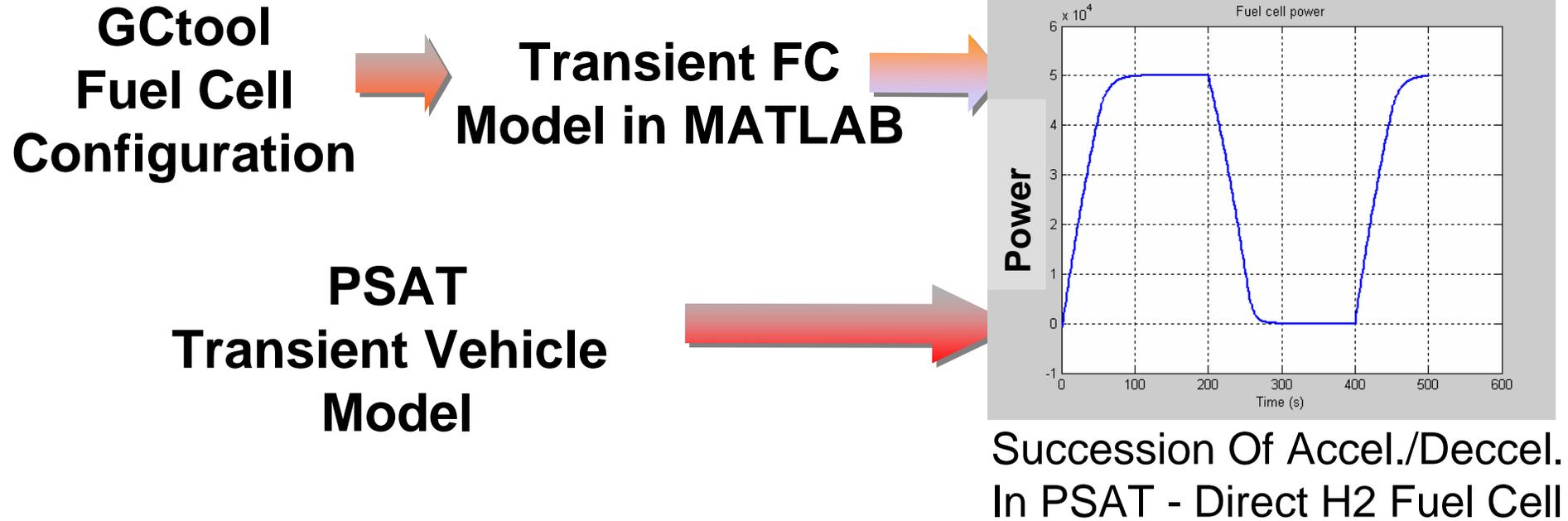
Transient Fuel Cell Modeling Needed for FreedomCAR

- **Develop engineering models of FC systems and components using the GCtool architecture.**
- **GCtool is design-oriented ... models are too slow (complex) for transient driving cycles**
- **Details may not be available for building mechanistic models**
- **Flexible to arrange component configuration**
- **Some existing models can be adapted**

Engineering Model

- **Solve conservation equations for energy, mass, species and momentum to develop performance maps.**
 - ATR: Composition (P, T, GHSV, A/F, W/F)
 - WGS: CO Conversion (P, T, GHSV, CO_{in}, H₂O/CO)
 - PROX: CO/H₂ Conv. (P, T, GHSV, CO_{in}, O₂/CO)
 - PEFC: V(P, T, I, CO, AB)
- **Performance maps are design-specific**
- **Models are transient, can be multinodal and may directly interact with other components**

GCTool-ENG Along with PSAT Allows Realistic Modeling

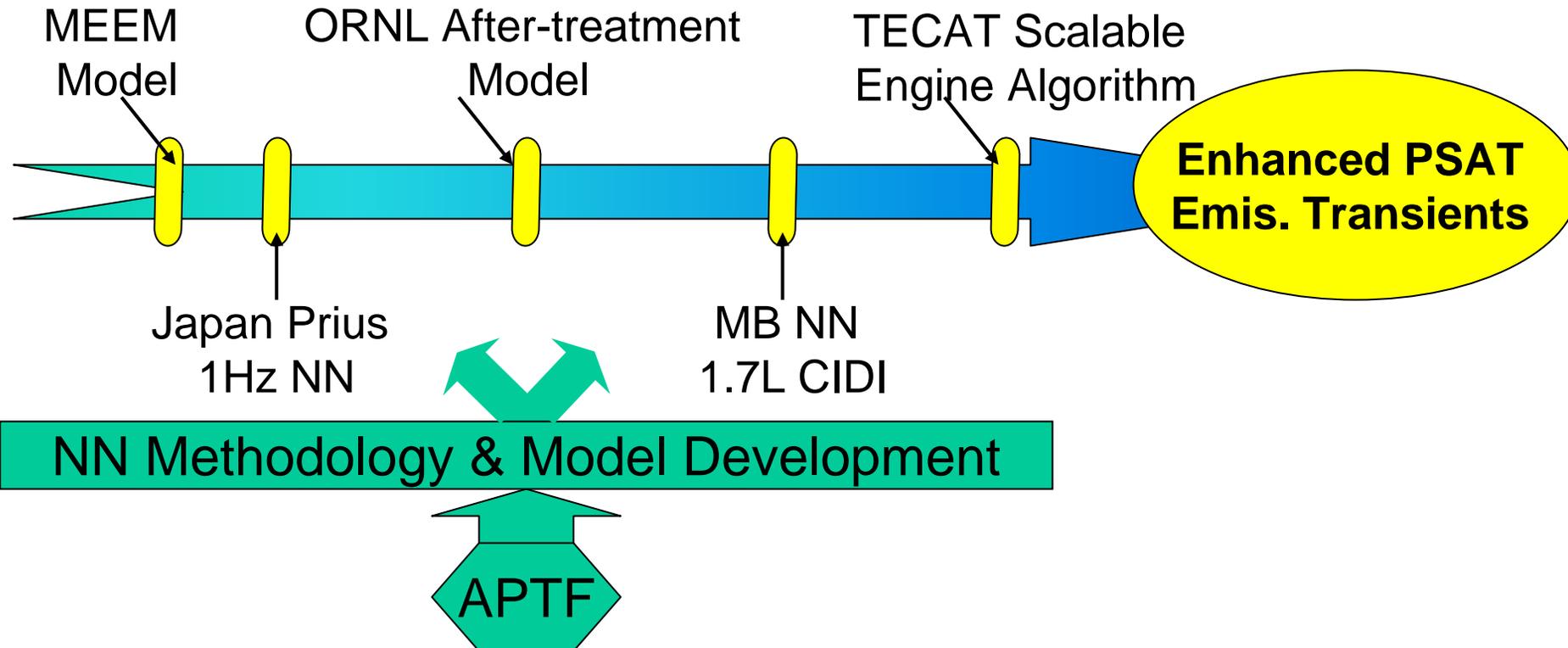


**Transient Fuel Cell Evaluation
within Transient Vehicle Model**

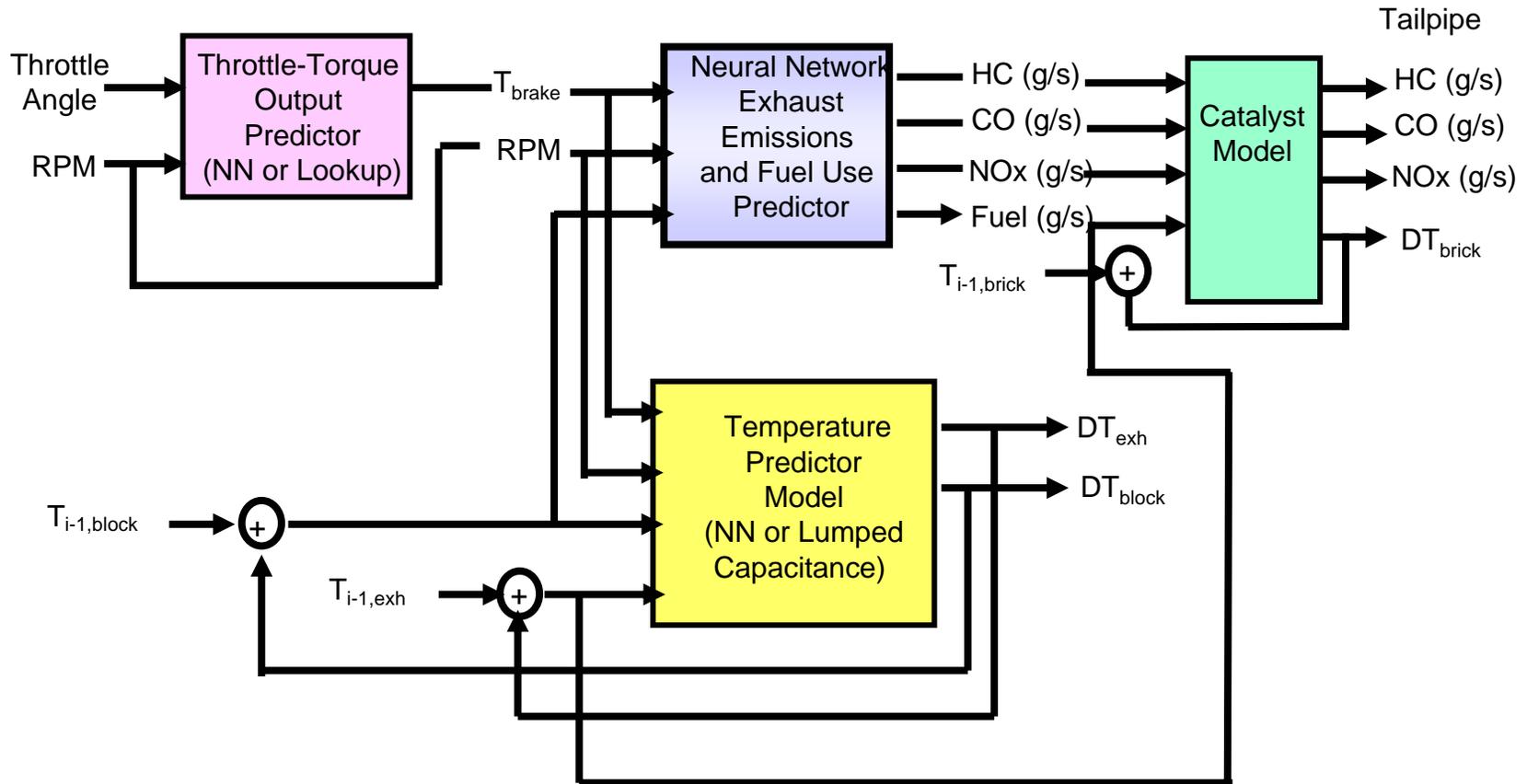
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Improved Transient Emission Modeling Needed

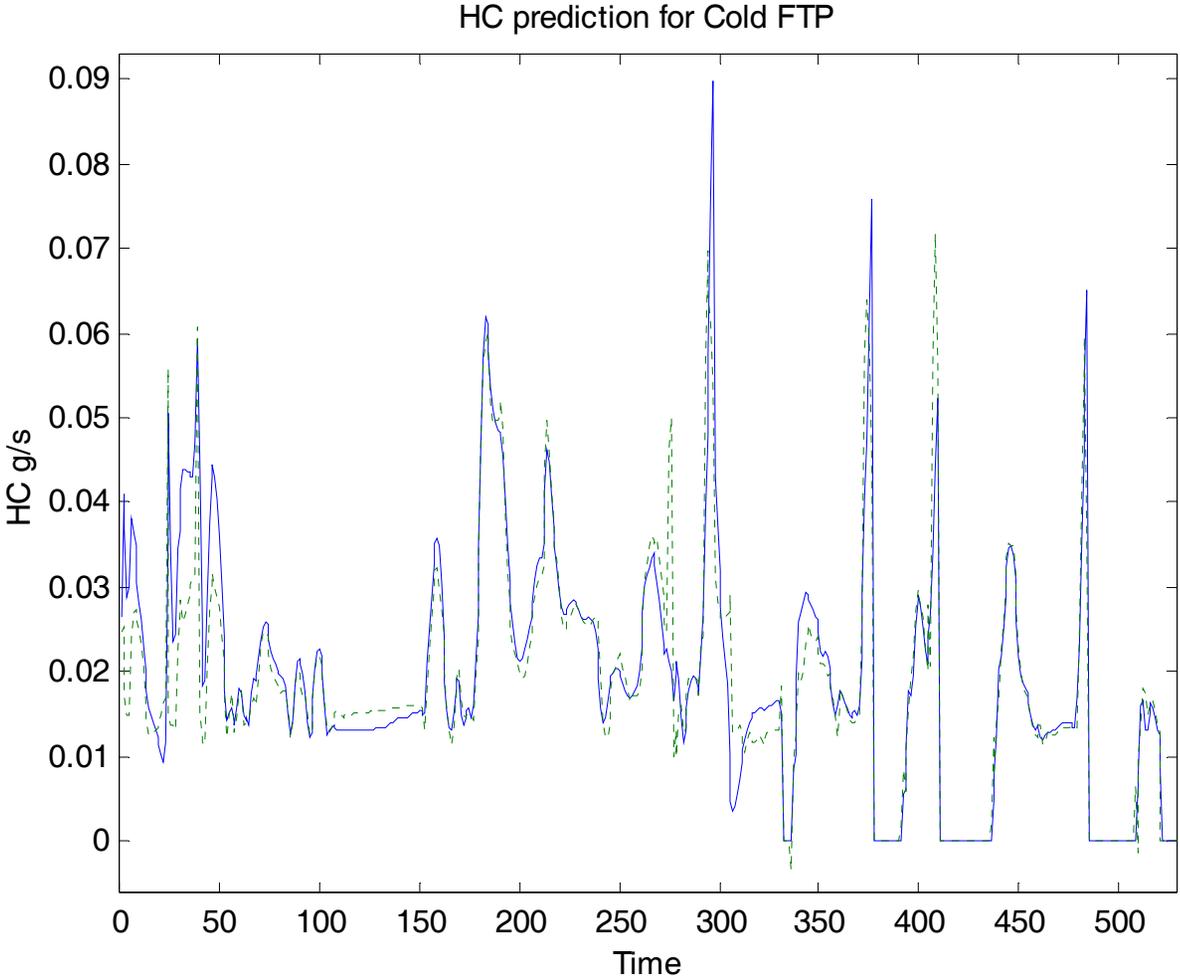


Overview of the Japan Prius Engine NN Model



T_{block} = Engine Block Temperature, T_{exh} = Engine Exhaust Temperature, T_{brick} = Catalyst Brick Temperature,
 t = Torque $i-1$ = last time step

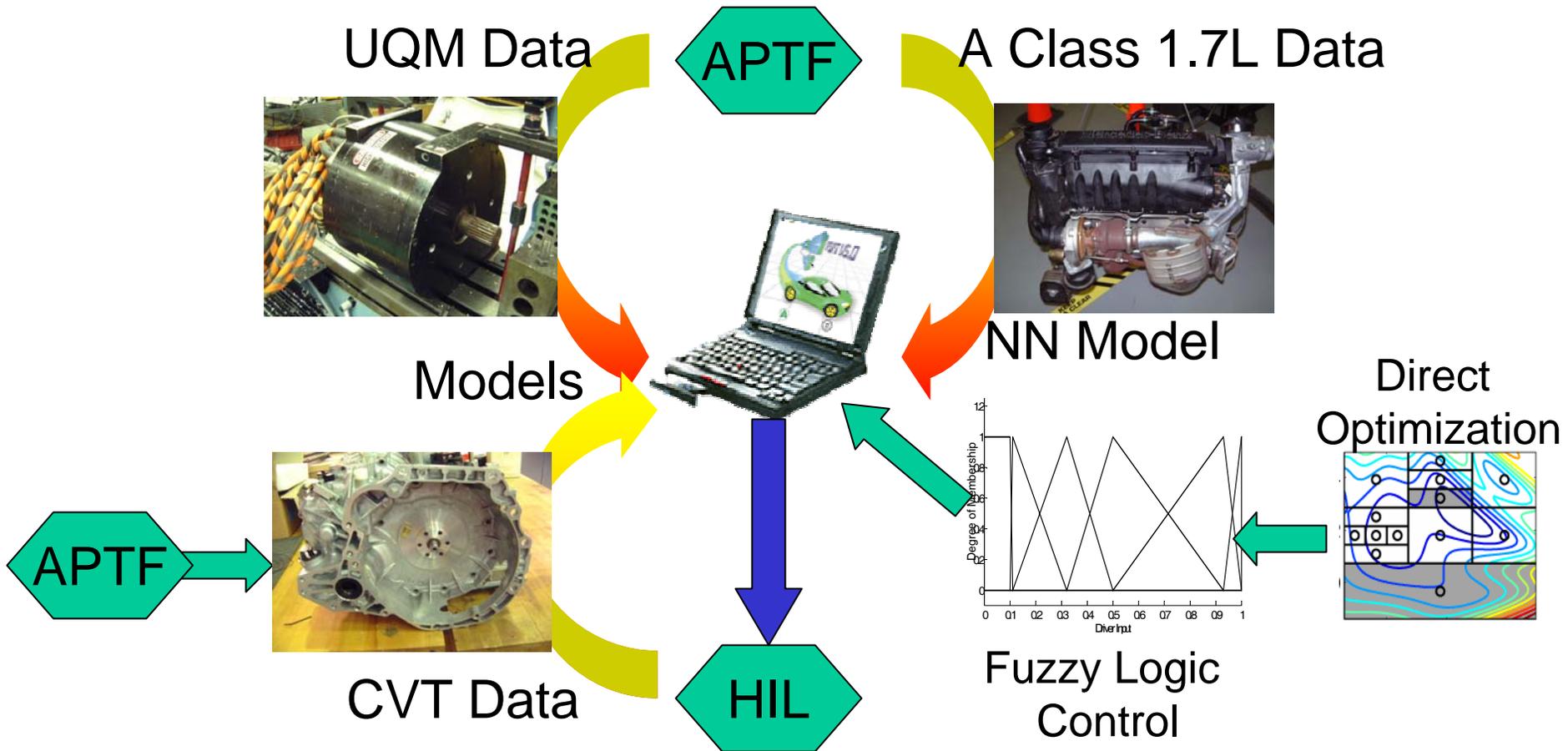
HC Plot for Cold FTP



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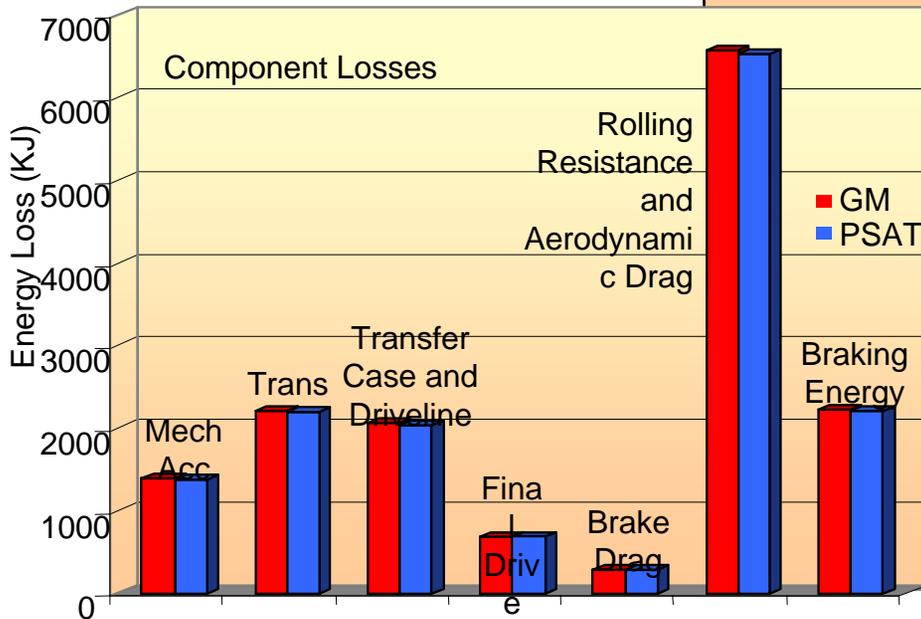
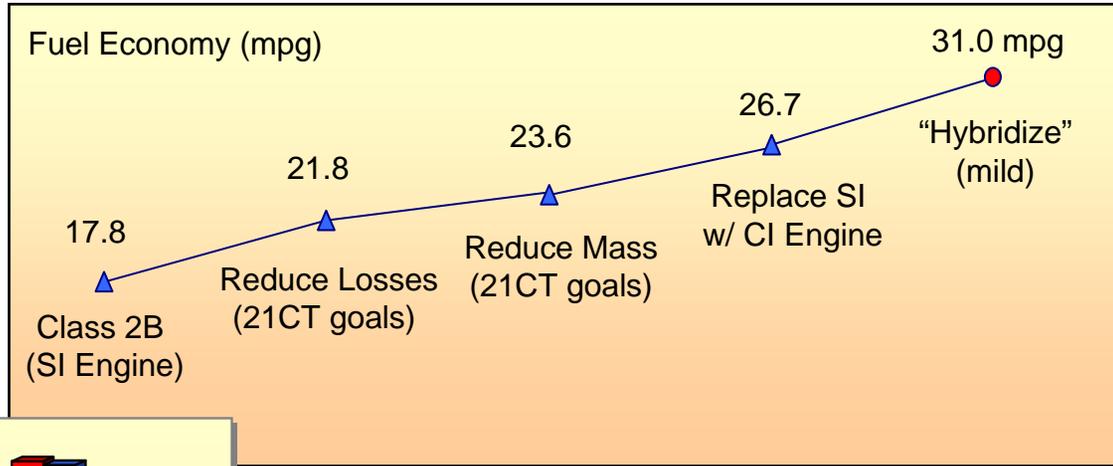
Trade-off Between Fuel Economy & Emission



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- ANL Philosophy
- PSAT Overview
- Validation
- **Example of Work Done at ANL**
 - Fuel Cell Modeling
 - Transient Engine Emission Models
 - Trade-off between FE & Emission
 - **Potential Gains for Class 2B Vehicle**
- Perspectives

Potential Gains for Class 2B Vehicle



Combined EPA Cycle
(55 FUDS/45 FHDS)

Comparison Between
GM Data And PSAT
Silverado Pickup

Outline

- ANL Philosophy
- PSAT Overview
- Validation
- Example of Work Done at ANL
- **Perspectives**

Summary/Perspectives

- **PSAT is a state-of-the-art powertrain modeling tools allowing users to simulate unrivaled number of predefined configuration (>130)**
- **PSAT has been developed for external users and development emphasized on easy integration of initialization files, component models, and control strategy integration**
- **PSAT simulates transients and allows realistic control**