Hydraulic Hybrid Vehicle Fuel Consumption Potential

2012 DOE Hydrogen Program and Vehicle Technologies Annual Merit Review

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Namwook Kim, Aymeric Rousseau
Argonne National Laboratory

Sponsored by David Anderson

Project ID # VSS071

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Project Overview

Timeline

- Start: September 2011.
- End: September 2012.
- Status: 40% complete.

Barriers

- Evaluate the fuel displacement potential of hydraulic hybrids.
- Provide guidance on future funding decisions.
- Continual evolving technology

Budget

- FY12
  - $300K

Partners

- U.S. EPA

Relevance

The objective is to evaluate the fuel consumption potential of hydraulic hybrid vehicles

- Evaluate the trade-offs between energy storage system power and energy for different vehicle applications and drive cycles
  - Hydraulic storage: high power, low energy
  - Battery storage: lower power, higher energy
- Evaluate the impact of different powertrain configurations (i.e., series, parallel…)

Approach

Correlate EPA and Autonomie Models

- Integrate EPA plant models
- Develop vehicle level control
- Simulate vehicle
- Compare results

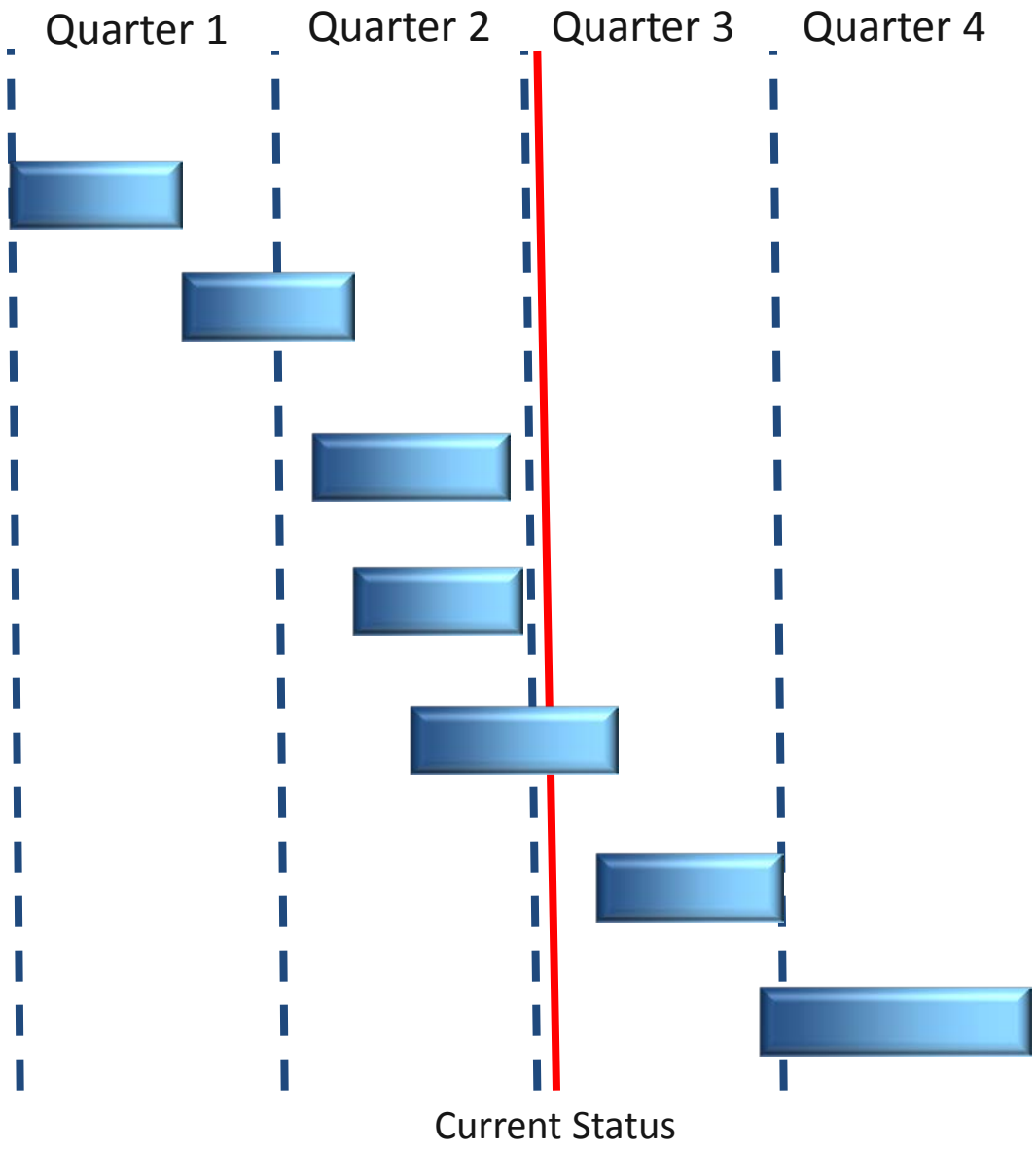
Evaluate HHV fuel displacement for Minivan

- Develop pre-transmission HHV powertrain and control
- Size parallel HHV components
- Develop conventional and HEV vehicles
- Simulate vehicles
- Compare results

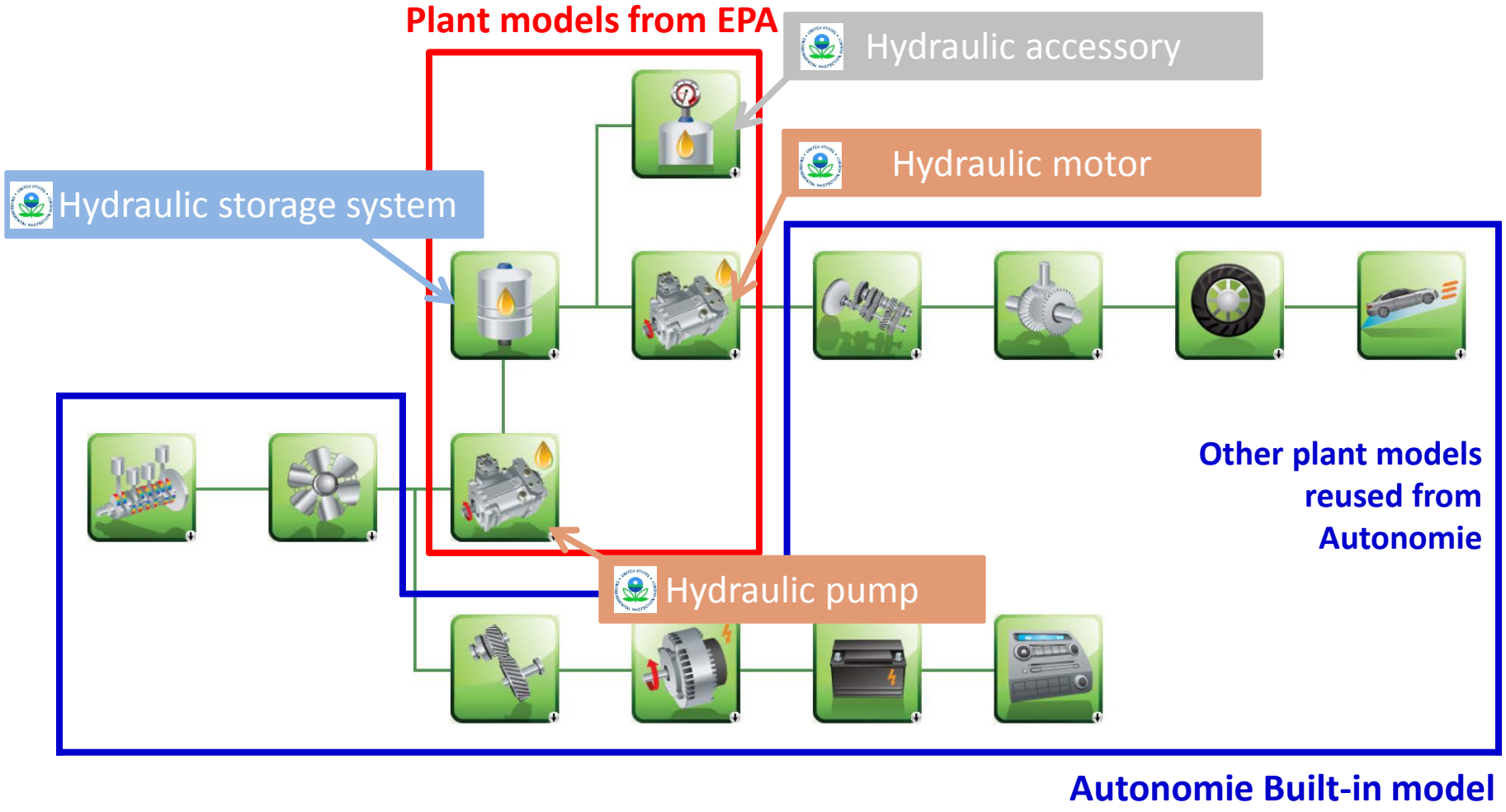
Evaluate HHV fuel displacement for delivery truck

- Size components
- Tune vehicle level control strategies
- Select drive cycles
- Simulate vehicles
- Compare results

Milestones


Quarter 1
Quarter 2
Quarter 3
Quarter 4
Integrate high fidelity EPA plant models
Develop series HHV configuration and vehicle level control
Correlate EPA and Autonomie Reference Models
Develop parallel HHV configuration and vehicle level control
Evaluate fuel displacement potential on reference vehicle class (minivan)
Size components for a delivery vehicle
Evaluate fuel displacement potential on delivery vehicle
Current Status

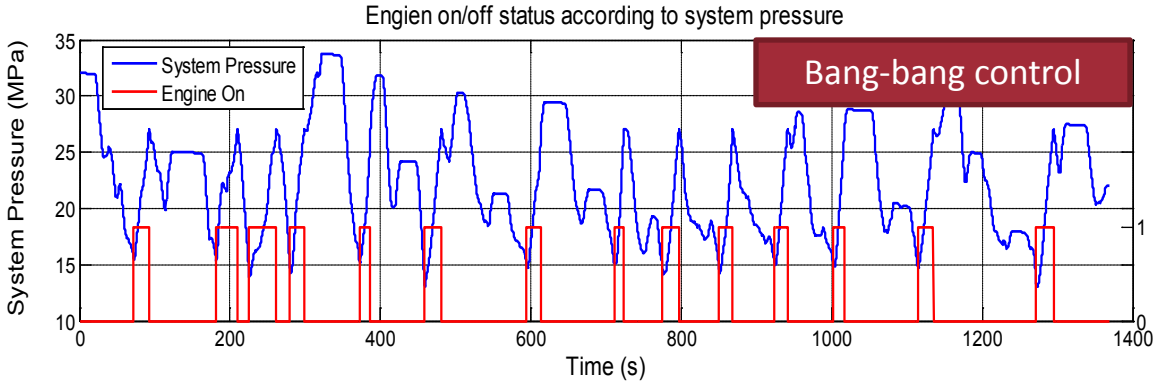
Technical Accomplishments
Series HHV Configuration in Autonomie



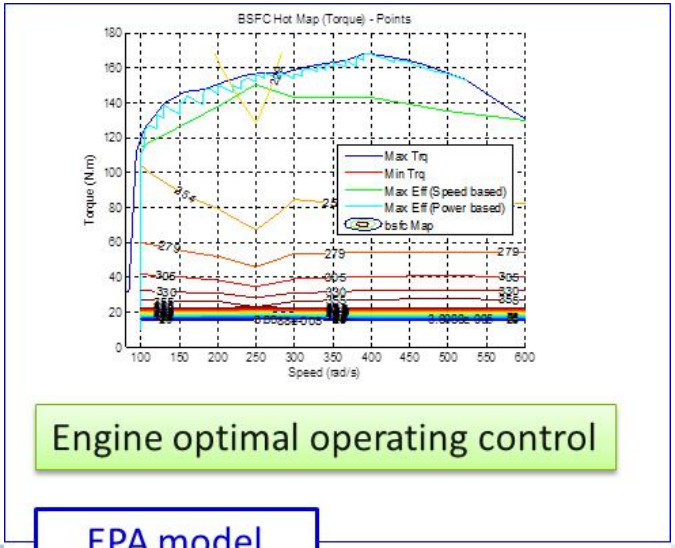
Technical Accomplishments

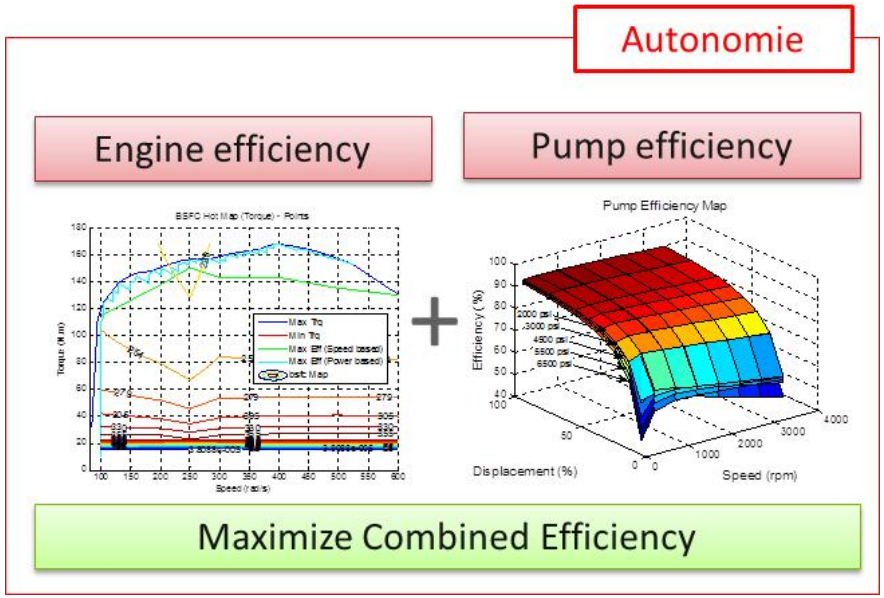
Series HHV Vehicle Level Control Developed

Control concepts for gearbox and engine on/off are similar to EPA



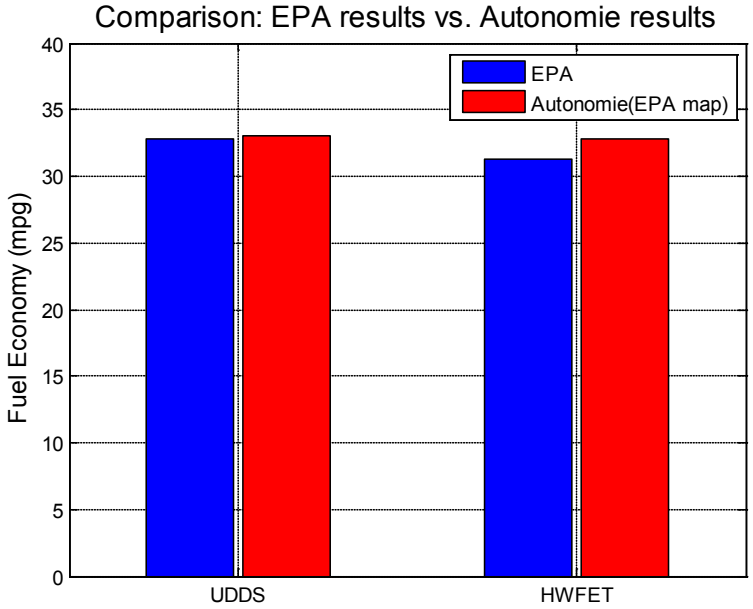
Engine operating control is different from EPA



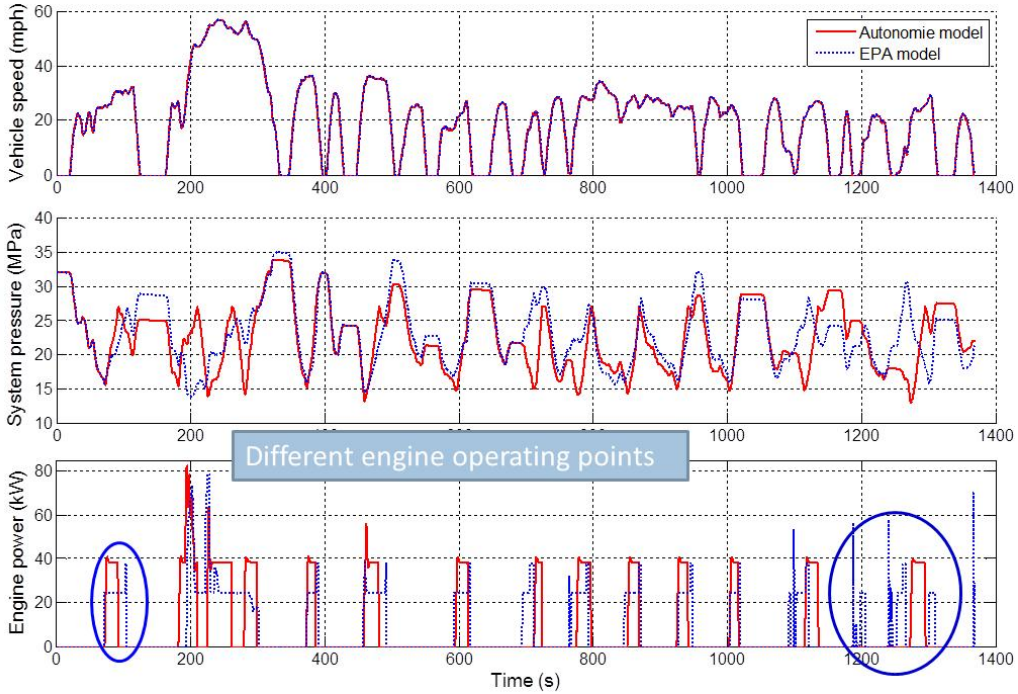


Technical Accomplishments

Series HHV Models Correlated

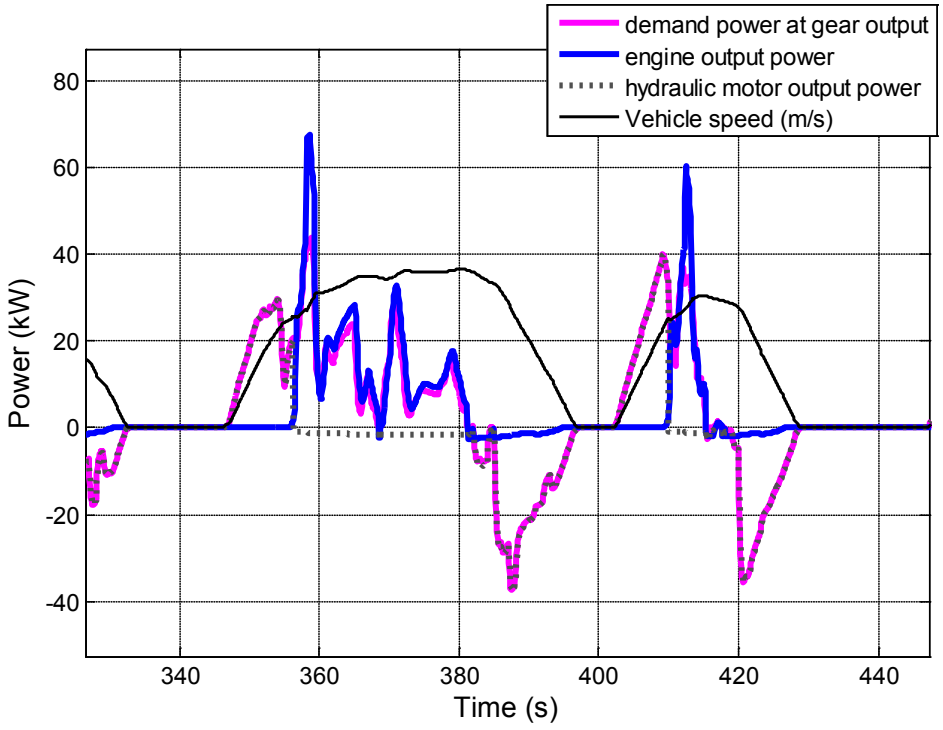


Comparison with EPA Shows Similar Behavior Outside of Engine Operating Points

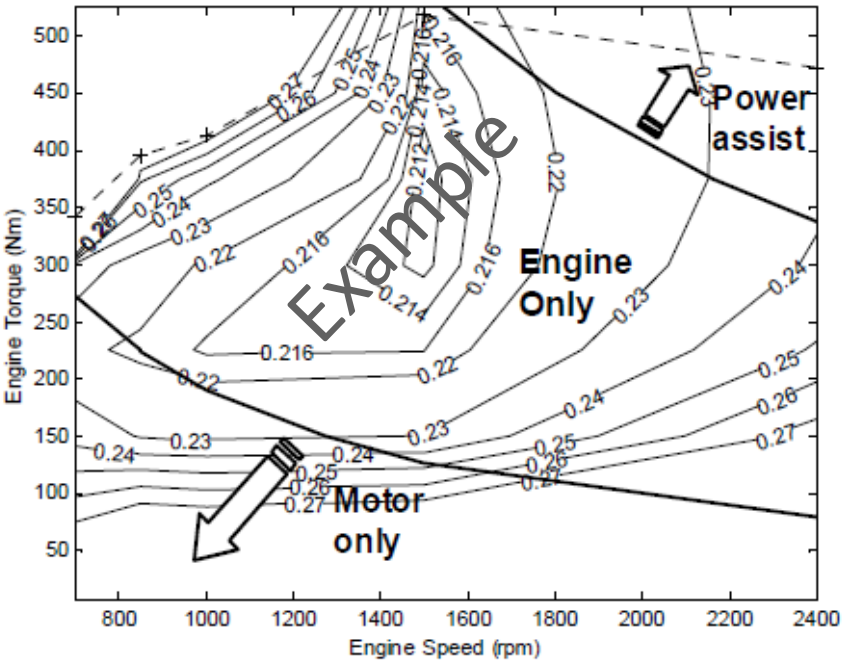


Technical Accomplishments
Parallel HHV Vehicle Configuration and Control

Option #1
Rule Based Similar to Mild HEV

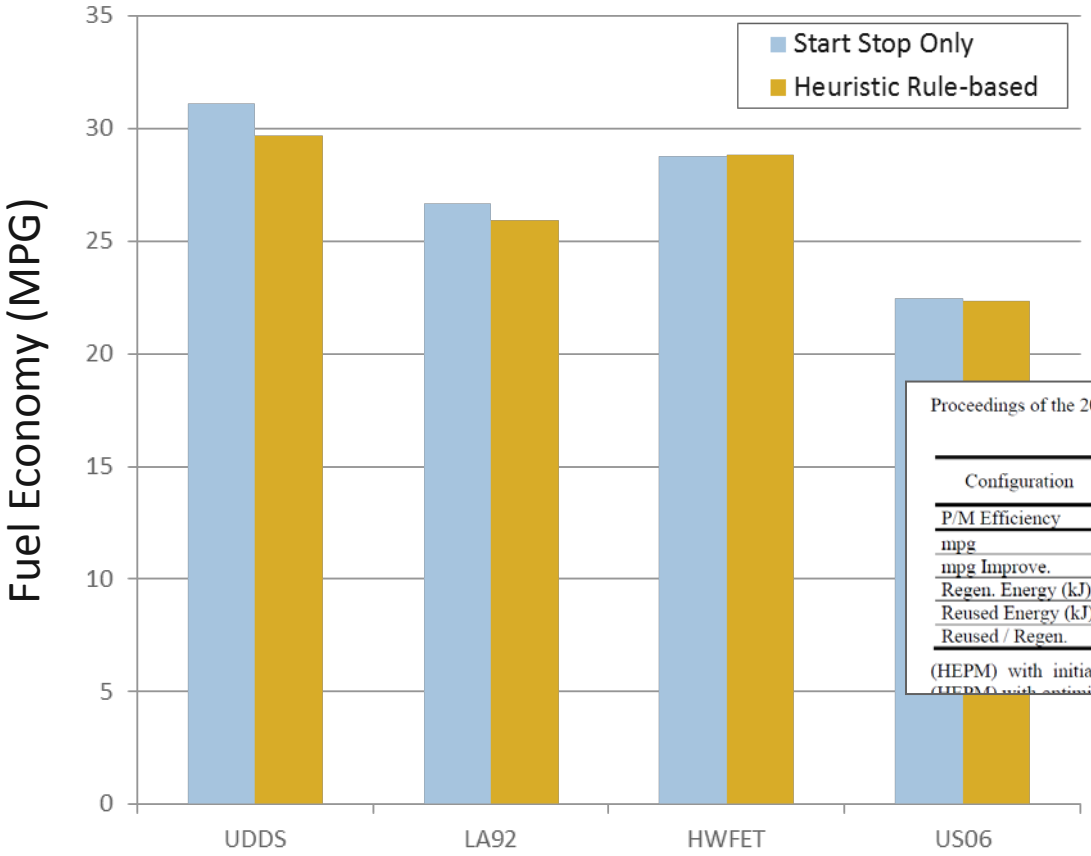


Option #2
Rule Based Similar to Full HEV



Technical Accomplishments
Parallel HHV Vehicle Configuration and Control

- Heuristic algorithm is not favorable to optimize fuel consumption.



Same conclusion at a published study

Proceedings of the 2002 Advanced Vehicle Control Conference, Hiroshima, Japan, September 2002.

Table 1 Summary of Simulation Results

Configuration	Conven-tional	Initial Rule		Initial Rule + Improved Shifting		Improved Rule		Dynamic Programming	
P/M Efficiency	NA	High	Low	High	Low	High	Low	High	Low
mpg	10.39	13.75	12.01	14.08	12.40	15.32	13.28	18.37	14.34
mpg Improve.	NA	32.3%	15.6%	35.5%	19.3%	47.4%	27.8%	76.8%	38.0%
Regen. Energy (kJ)	NA	9748	9700	9652	9736	9459	9656	10013	10458
Reused Energy (kJ)	NA	6034	3187	5963	3229	7476	4524	8491	5134
Reused / Regen.	NA	61.9%	32.9%	61.8%	33.2%	79.0%	46.9%	84.8%	49.1%

(HEPM) with initial rules is compared to the HHV Tennessee, Wayne State University, and University of

heuristic

Micro hybrid

Bin Wu, Chan-Chiao Lin, Zoran Filipi, Huei Peng and Dennis Assanis, "Optimization of Power Management Strategies for a Hydraulic Hybrid Medium Truck," in Proc of 2002 AVCC, Hiroshima, Japan, Sept. 2002

Technical Accomplishments

Main Vehicle Assumptions Used for Comparative Study

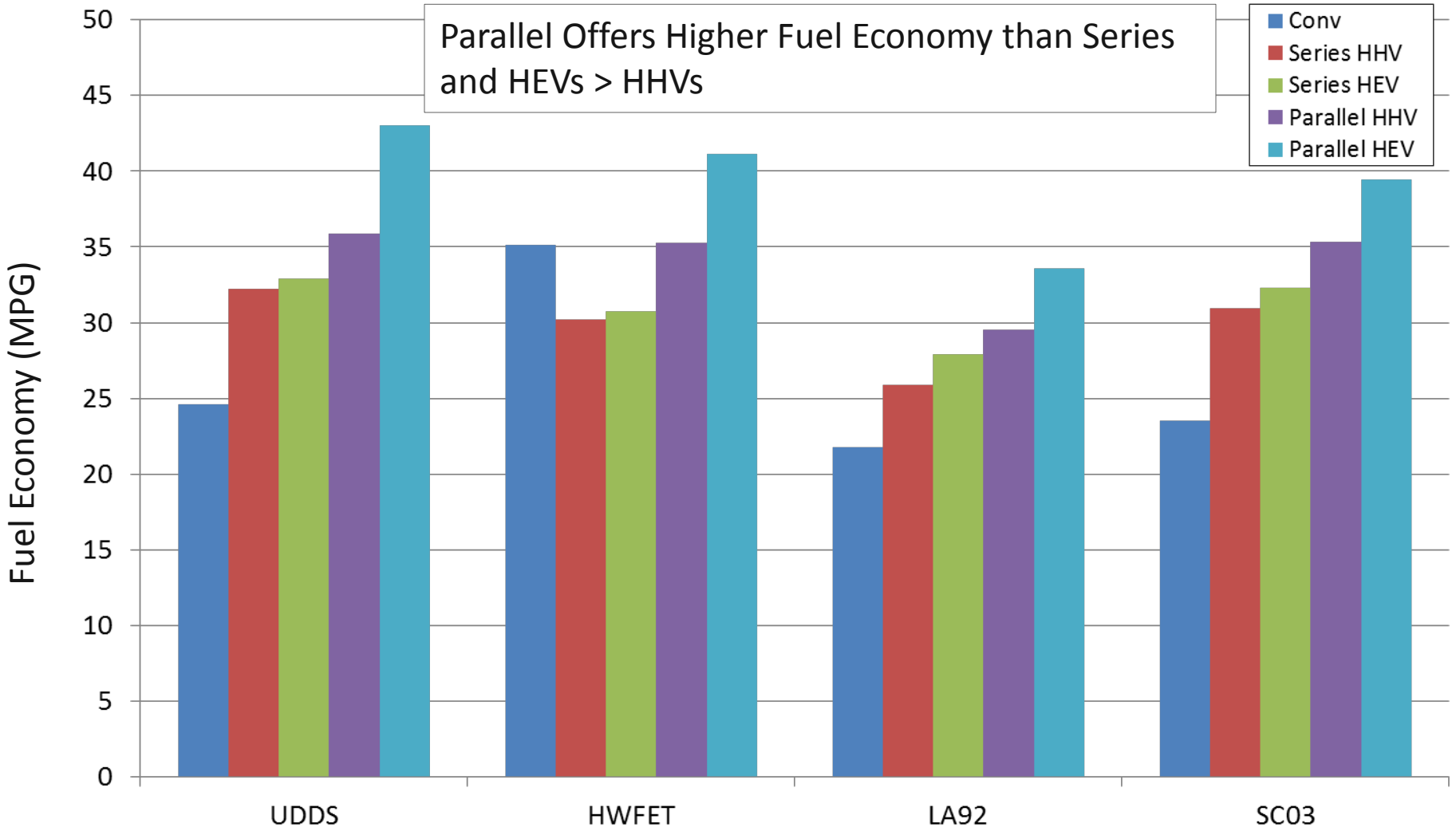
	Weight (kg)	Acc. perform.	Engine	Pump/ Generator	Motor	Energy storage		
						Size	Capacity	Max Power
Conventional	2132 kg	12.7	109 kW	-	-	-	-	-
Series HHV	2342 kg	12.7	80 kW	80CC (Up to 210kW)	117CC (Up to 220kW)	83 liters	0.23 kWh	Up to 520kW
Series HEV	2271 kg	12.7	80 kW	80 kW	106 kW	40 kW	2.5 kWh(1)	40kW
Parallel HHV	2284 kg	12.7	81 kW	-	48 cc	55 liters	0.15 kWh	Up to 350kW
Parallel HEV	2150 kg	12.7	82 kW	-	21 kW	21 kW	1.3 kWh(1)	21 kW

(1) Total Battery Energy

*Components are sized to satisfy the accelerating performance and to maximize fuel economy.

Technical Accomplishments

Fuel Consumption Comparison

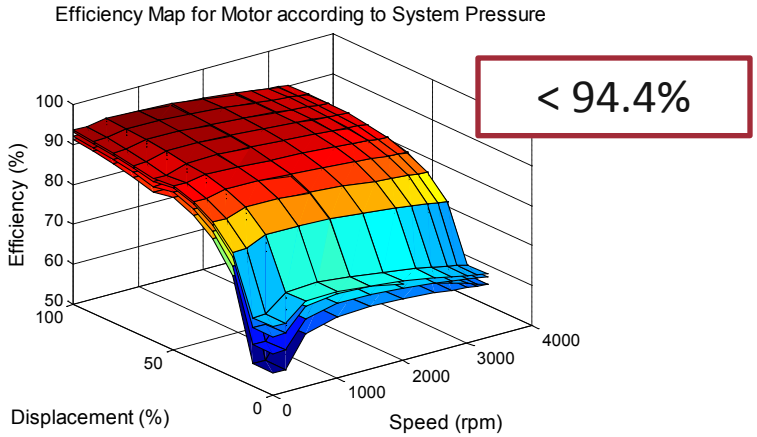


Each vehicle runs 10 repeated cycle.

Technical Accomplishments

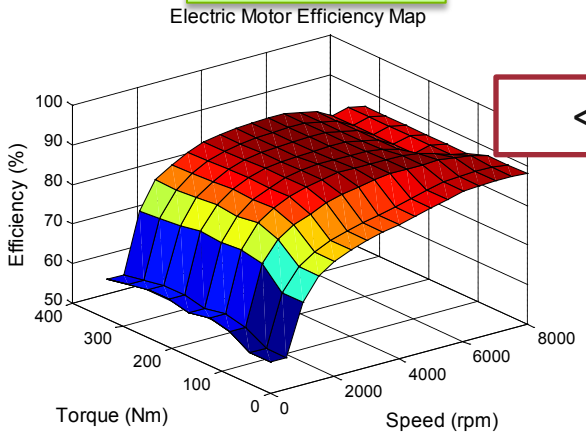
Reasons behind Fuel Consumption Results

HHV

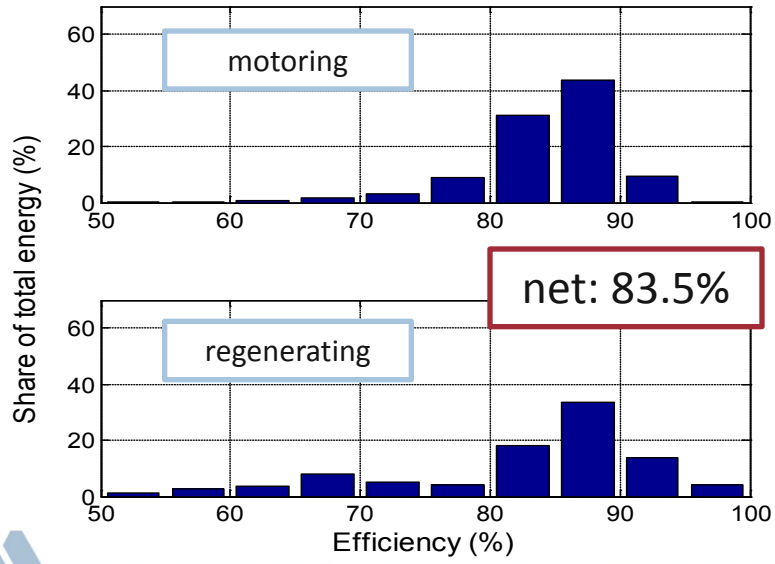


< 94.4%

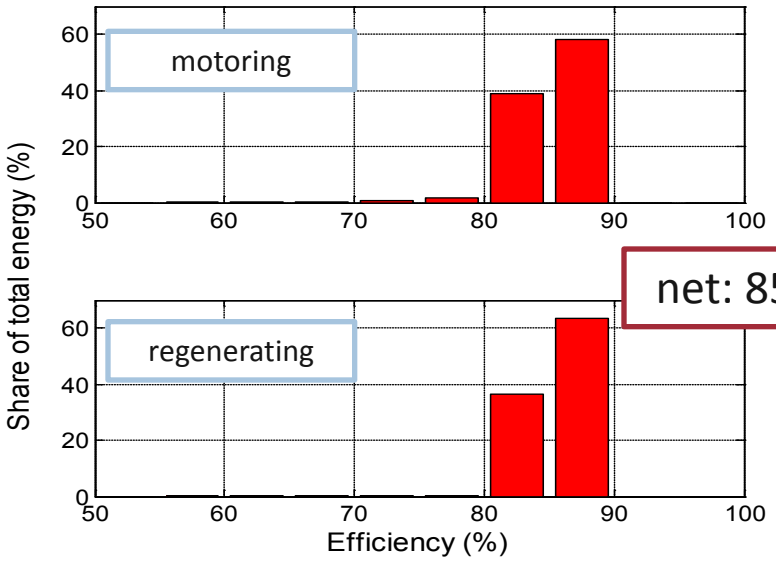
HEV



< 90%



net: 83.5%



net: 85.3%

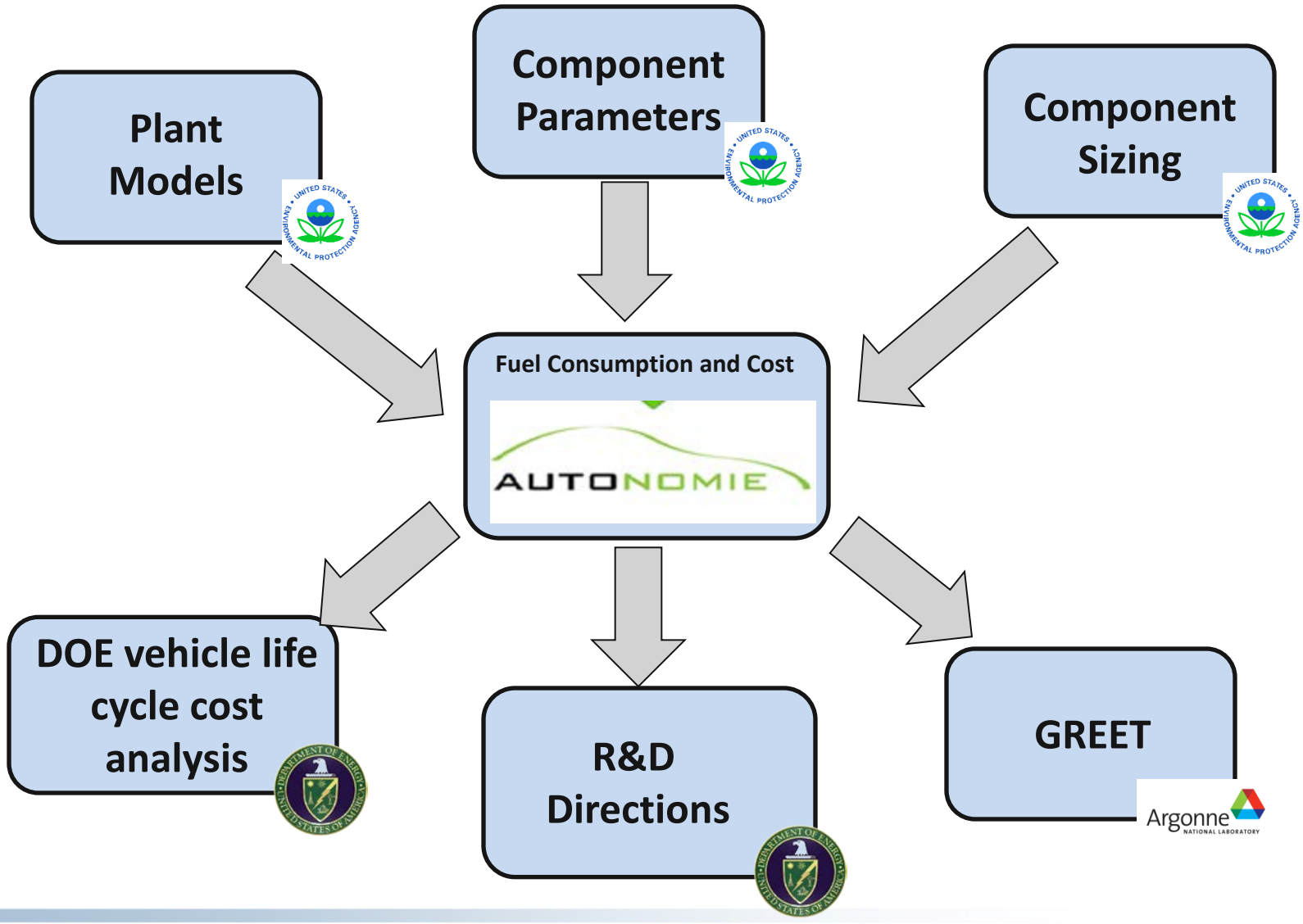
Technical Accomplishments

Potential Area Where HHV May Provide Greater Benefits than HEVs

When Simulating a Vehicle with Very Low Power to Weight Ratio, HHV Shows Potential during City Driving

High regenerating capacity of HHV provides some benefits on urban cycles.

Collaboration and Coordination with Other Institutions



Proposed Future Work

FY12 On going work

- Size the component for a delivery truck application.
- Evaluate the fuel displacement potential of HHV for a delivery truck for different HHV and HEV configurations
- Gather component cost information

FY13 Potential Activities

- Develop automated sizing routine for the different HHV configurations
- Evaluate the impact of HHV and HEV component sizing on fuel displacement and cost
- Evaluate potential of ultra capacitors for HEVs
- Evaluate different applications (i.e., garbage trucks)

Summary

- Study evaluates the fuel displacement potential of hydraulic hybrids compared to conventional and electric hybrid vehicles.
- For current light duty vehicle performance requirements,
  - HEVs consistently achieve higher fuel displacement than HHVs.
  - Parallel powertrains achieves higher fuel displacement than series
- When simulating a vehicle with very low power to weight ratio (low engine power, high vehicle weight), HHV shows potential during city driving.
- Future work will focus on evaluating different applications, component sizes and controls strategies on a variety of drive cycles from a fuel consumption and cost perspective.