# Dual-Source Energy Storage — Control and Performance Advantages in Advanced Vehicles

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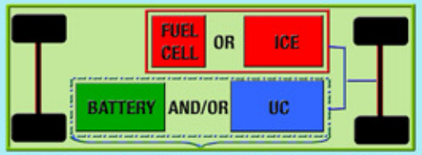
EVS 20 Powering Sustainable Transportation

## Objective

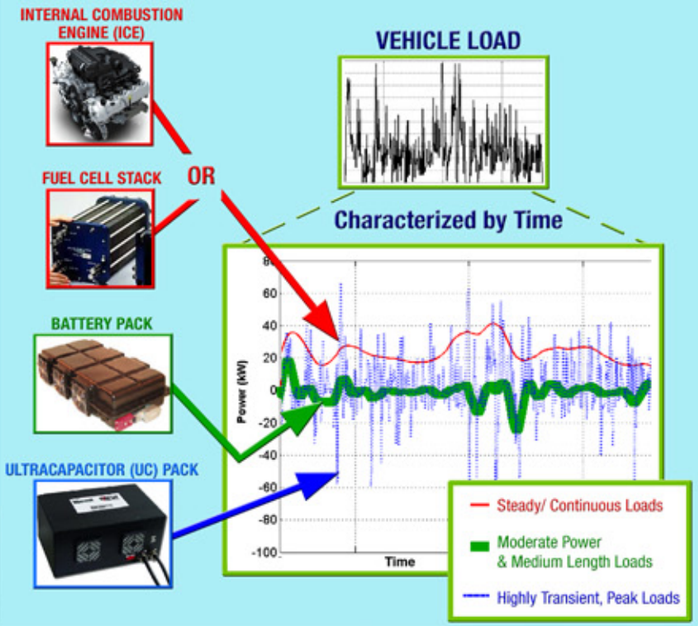
**To develop an analysis tool to parametrically study the optimal roles of the fuel converter (engine or fuel cell) and energy storage system (battery and/or ultracapacitor) for advanced hybrid vehicles.**

## Background

Hybridization enables optimal matching of vehicle load characteristics with multiple power sources—using each power source to supply the load characteristics for which it is best suited. The resulting specialized components may be smaller, less expensive, and more reliable and may result in improved fuel economy.

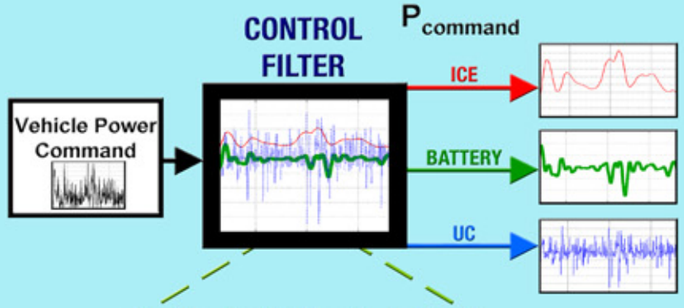



Dual-Source Energy Storage == Both Battery & Ultracapacitor

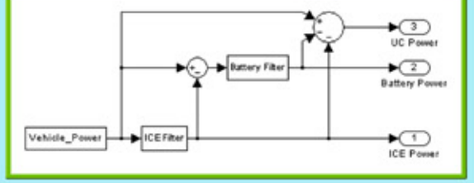



## Approach

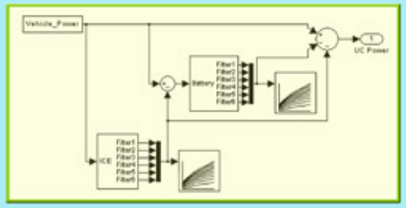
Develop and parametrically evaluate a control filter to divide drive cycle power profiles into different time and power segments. Match time and power segments with appropriate power sources.




### Control Filter Detail




What filter time constant (τ, level of load averaging) will result in optimal roles for the fuel converter (ICE), battery, and ultracapacitors?



## Results

### ICE Load Averaging

Load averaging > 10 s provides no downsizing benefits

Downsizing ICE requires $P_{ICE} + P_{EnergyStorage} \geq P_{MaxAccel}$

↑ICE load averaging: ↑battery power required (1)
↓battery energy required (2)
↔UCs largely unaffected (3,4)

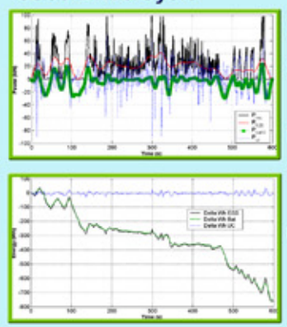
### Battery Load Averaging

↑Battery load averaging: ↓↓battery power required (1)
~↓battery energy required (2)
↑UC power required (3)
↑↑UC energy required (4)

### Ultracapacitors (instantaneous response)

$E_{MaxAccel}$ for full-hybrid typically requires more energy than $E_{UC}$ can provide alone, so batteries are necessary for aggressive hybridization.

### US06 Drive Cycle



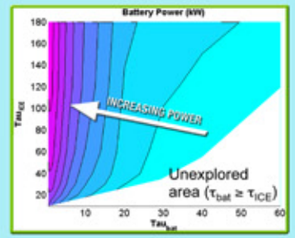
### Example Case

**ICE**
60 kW, 20 s load average

**Battery**
300 $V_{nominal}$, 1800 Wh, 30 kW $P_{max}$, 10 s load average

**Ultracapacitor**
300 $V_{nominal}$, 94 Wh (900 F/cell), 50-100 kW $P_{max}$, instantaneous response

1

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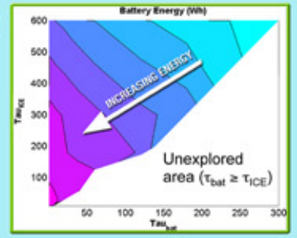


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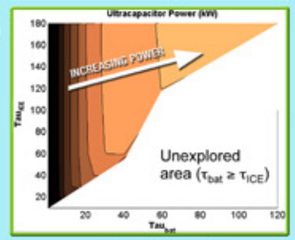


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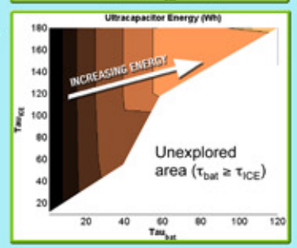


## Conclusions

An analysis tool was developed for parametric study of the optimal roles of the fuel converter (engine or fuel cell) and energy storage system (battery and/or ultracapacitor) for advanced hybrid vehicles. Hybridizing enables using each power source to supply the load characteristics for which it is best suited. Matching loads to appropriate sources should:

- Reduce undesirable component stresses
- Improve thermal conditions
- Mitigate early failure modes
- Improve operating points (efficiency, performance, etc.)
- Improve electrochemical balancing in the battery
- Enable hybrid vehicle designers to balance fuel economy, durability, and cost

www.ctts.nrel.gov/BTM

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For more information about this dual-source energy storage analysis tool contact Matthew Zolot at matthew_zolot@nrel.gov