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Sizing the Battery Power for PHEVs Based on Battery Efficiency, Cost and Operational Cost Savings

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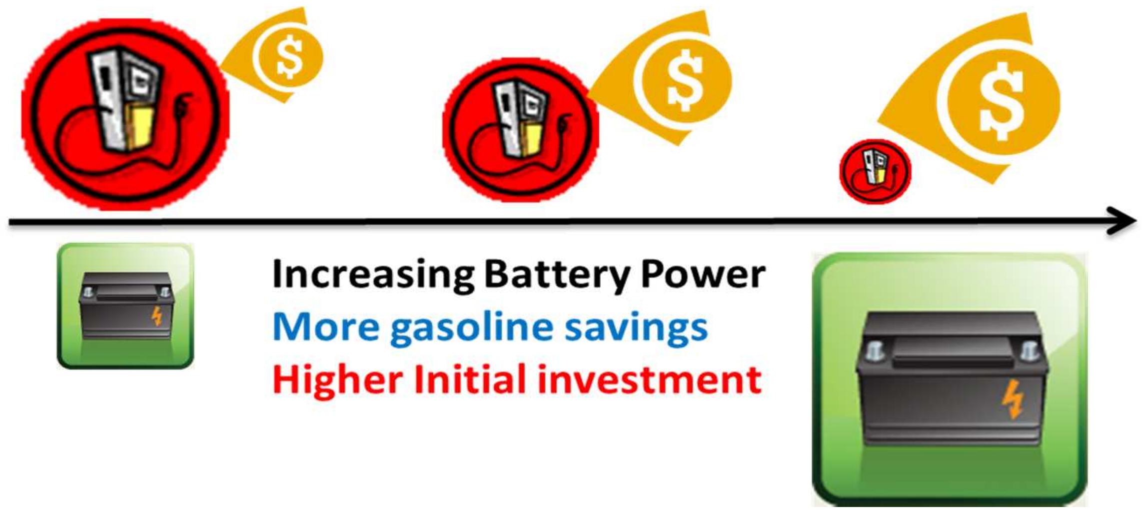
Objectives

- Evaluate the cost & benefit associated with sizing the initial power of the battery
  - Differences in Battery Power & Initial Cost
  - Fuel Consumption & Net Present Value (NPV) of gasoline savings
- Evaluate dependence of benefits on
  - PHEV powertrain type
    - Split
    - EREV
  - Battery chemistry
    - LMO-G
    - NCA-G



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Vehicles
Split PHEV-10 & EREV PHEV-40

- Vehicle models are from Autonomie
  - based on USDRIVE 2020 assumptions.
  - PHEV-10 sized for all electric UDDS cycle operation
  - PHEV-40 sized for all electric US06 cycle operation

Vehicle Specifications		PHEV-10 Split	PHEV-40 Series
Engine power	kW	75	75
Motor power	kW	60	113
Generator power	kW	43	75
Battery energy (usable)	kWh	2.0	8.0
Peak battery power	kW	30-90	60-140
Control strategy		Blended	CD + CS
Test weight	kg	1467	1675

AUTONOMIE

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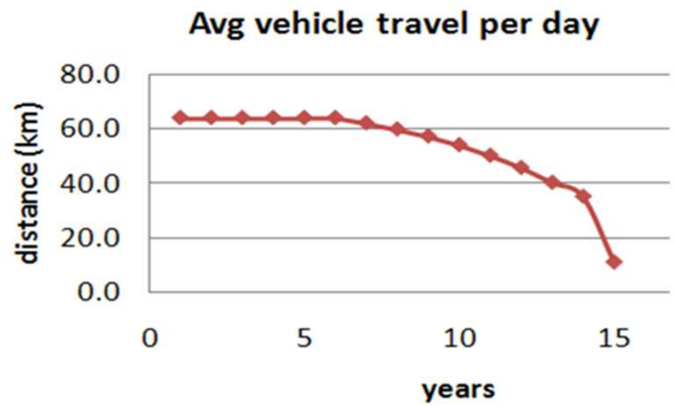
Battery data from BatPaC NCA-G & LMO-G

	NCA-G	LMO-G
Positive Electrode		
Composition of active material	$LiNi_{0.80}Co_{0.15}Al_{0.05}O_2$	$Li_{1.06}Mn_{1.94-x}M'_xO_4$
Capacity, mAh/g of act. Mat.	160	100
Cost of active material, $/kg	33	10
Negative Electrode		
Composition of active material	Graphite (C_6)	Graphite (C_6)
Capacity, mAh/g of act. Mat.	330	330
Cost of active material, $/kg	19	19
Cell OCV at 50% SOC	3.551	3.806
Electrode System ASI		
10-sec burst, ohm-cm^2	23.6	20
3-h discharge	51.9	44

Net Present Value (NPV) Calculation Assumptions

- Net Present Value of Gasoline Savings
  - Baseline: 30mpg conventional vehicle
  - 7% discount rate
  - Gasoline @ $4/gallon, Electricity @$0.10/kWh
- Real World Cycles from Kansas City, USA
- Vehicle usage
  - 15 years, 150k miles
  - Usage reduces over years (ref NHTSA survey)



Is NPV of savings is more than the additional investment needed in a PHEV, it is economically feasible

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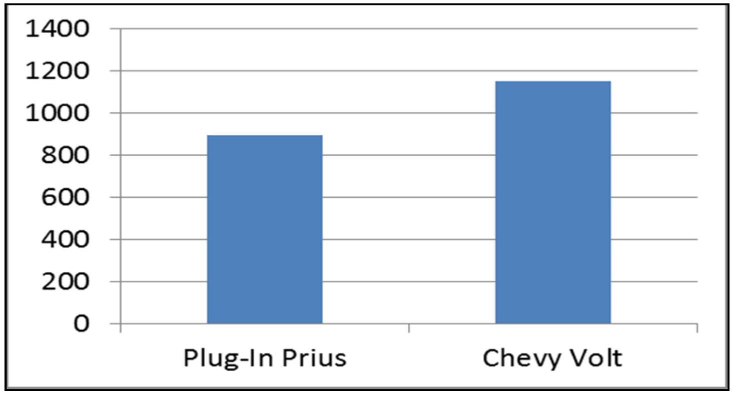
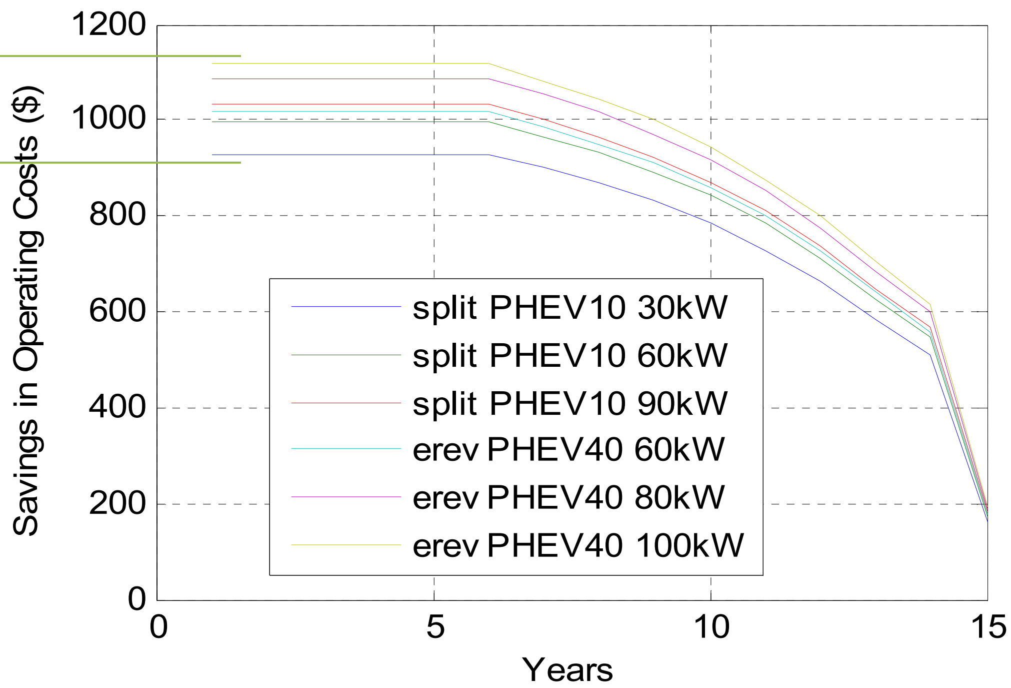
PHEV10 can deliver substantial gasoline $ savings

Fuel/Electric Cost	$ to run 25 miles	$ / year (15k miles)	$ savings per year
Baseline (30 mpg)		1800	
Plug-In Prius	1.51	906	894
Chevy Volt	1.08	648	1152
	data from fueleconomy.gov		

Savings per year compared to baseline



~$200/year



PHEV40 provide more savings than PHEV10

$$\frac{\text{PHEV10 savings}}{\text{PHEV40 savings}} > 75\%$$

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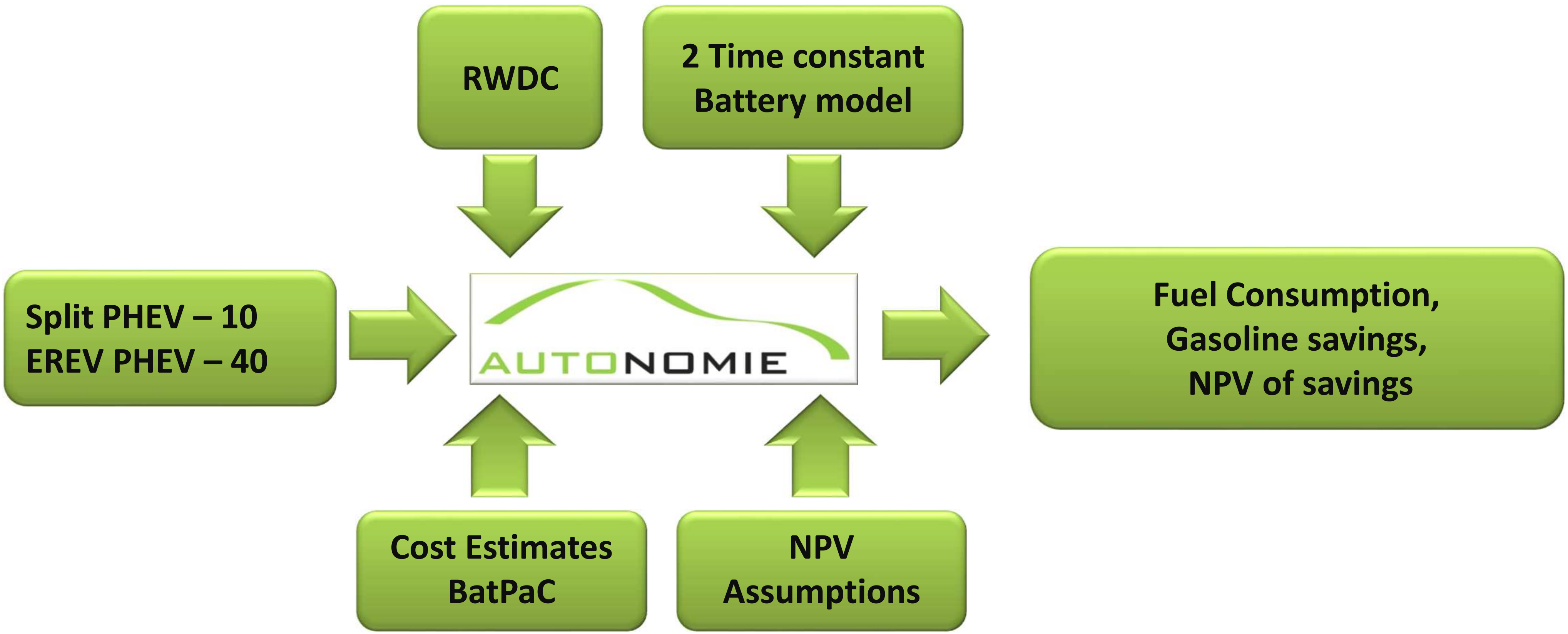
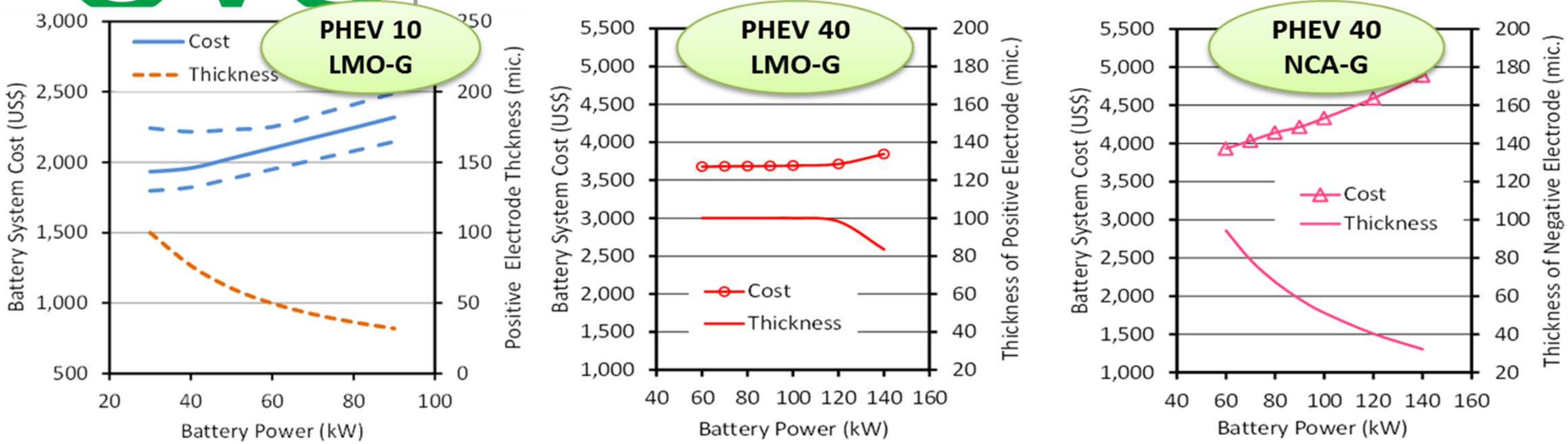
Factoring in the effect of RWDC, Battery power, cost & NPV



2x30x7 = 420 simulations

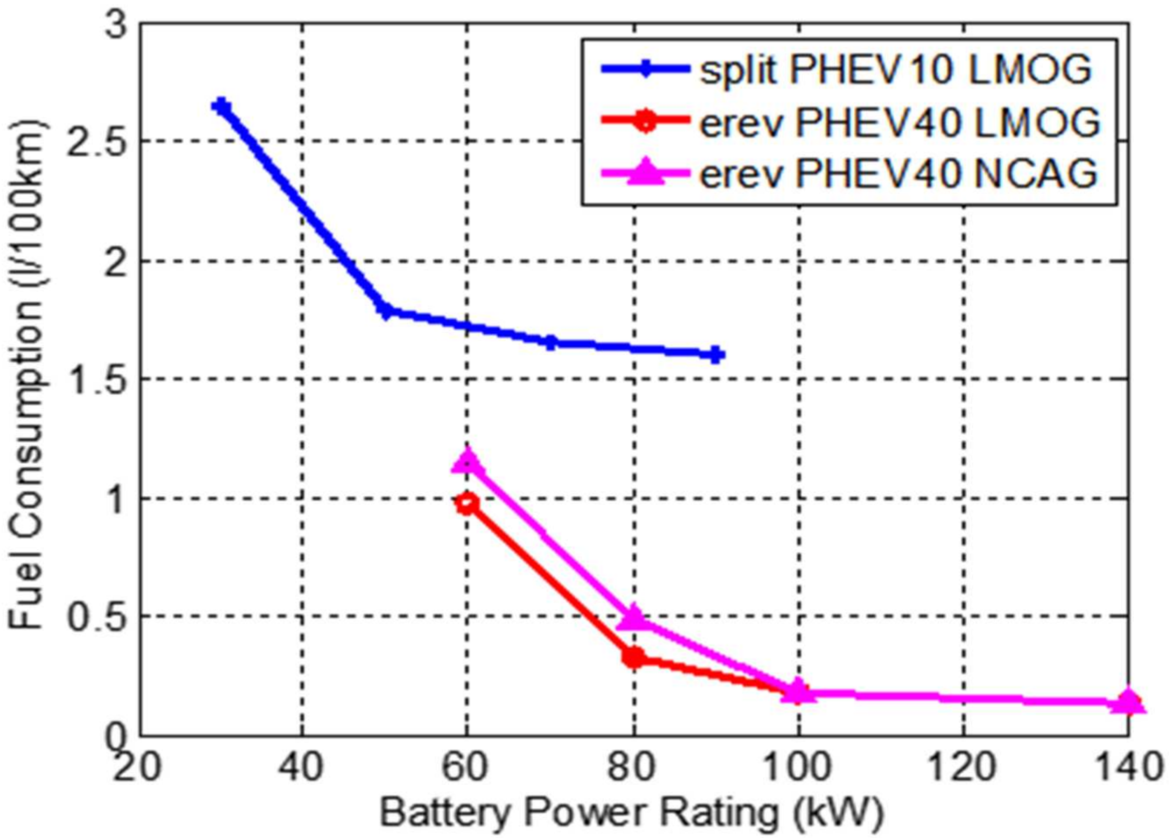
Battery Cost vs. Power for different chemistries



Battery Pack Parameters	LMOG-split- PHEV10	LMOG-erev-PHEV40	NCAG-erev- PHEV40
Power, kW	30 to 90	60 to 140	60 to 140
Usable energy (70% of total), kWh	2.0	8.0	8.0
Cell capacity, Ah	13.0	30.3	32.7
Number of cells	56	96	96
Number of modules	4	6	6
Length, mm	531-538	897-896	898-896
Width, mm	279-317	394-400	359-401
Height, mm	111-119	149-150	141-150
Volume, L	16.7-20.3	52.8-54.0	45.4-54.0
Mass, kg	26.5-36.0	95.1-99.8	78.6-101.8

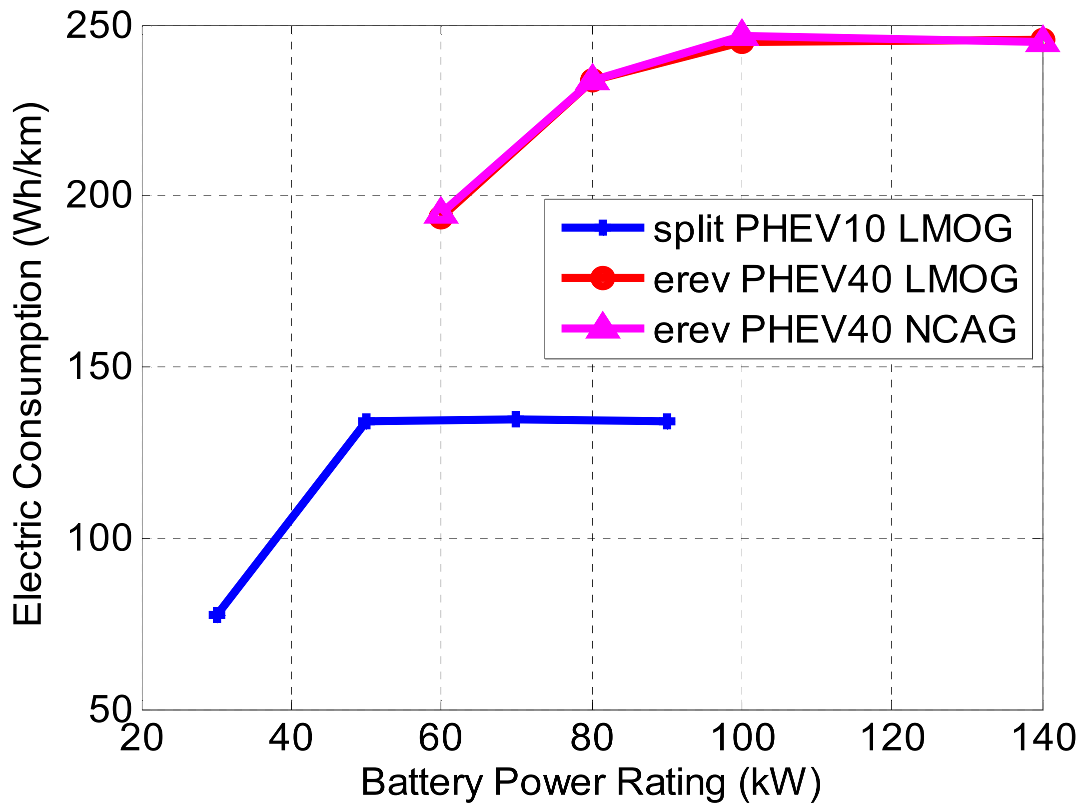
Both vehicles benefit from increase in battery power

- Vehicle sizing logic determines motor power
- Usable battery power may get limited by
  - Motor power rating
  - Drive cycle properties



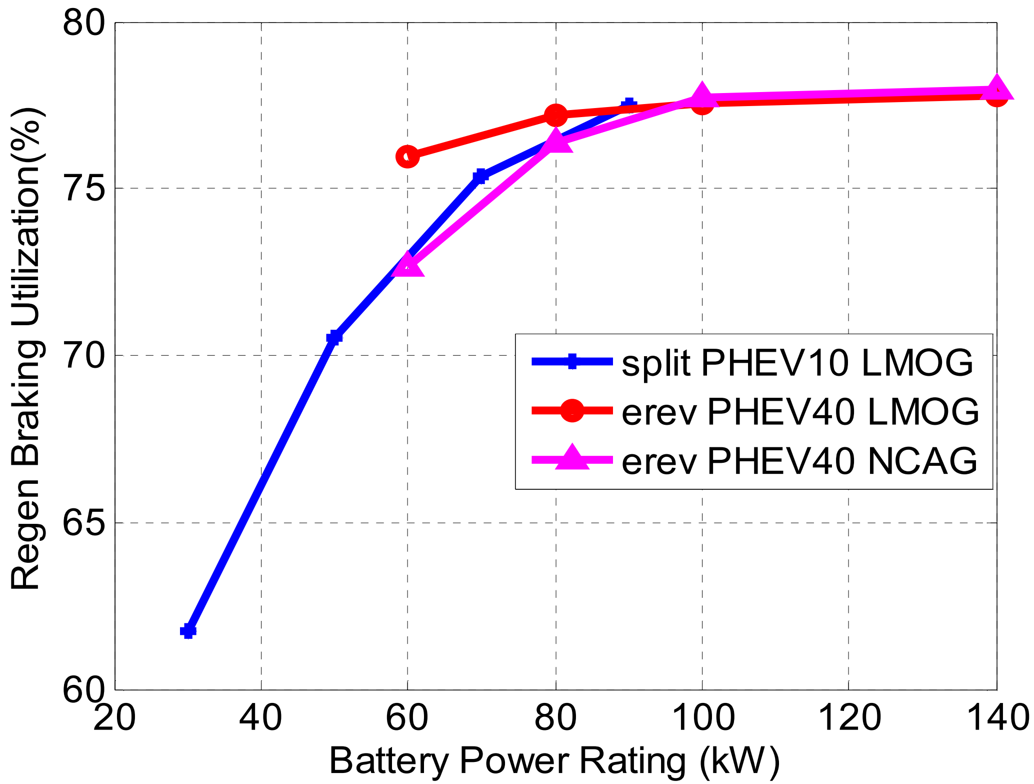
Higher power rating helps in using more electrical energy

- Energy required for driving is constant for all test cases
- Higher electrical consumption enables lower fuel consumption
- Usable electrical energy may get limited by
  - Vehicle control logic
  - Drive cycle requirements



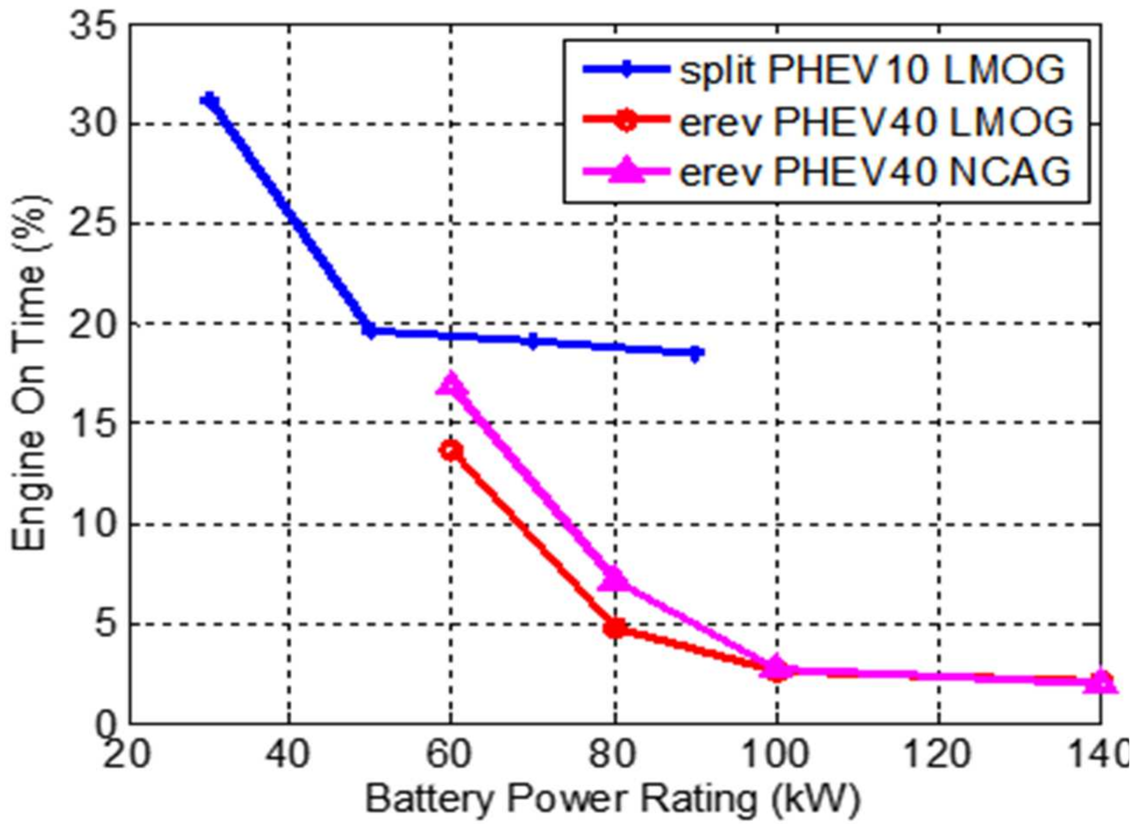
Better utilization of regenerative braking

- Both architectures have comparable regenerative braking capabilities
  - Higher battery power in PHEV 10 allows more regen energy to be recovered
  - PHEV 40s already had high power batteries, hence the improvement is less significant



Reduction in engine operating time reduces fuel consumption

- Powerful battery can support higher power demands, more EV operation in city for PHEV-10
- Larger battery allows more energy from regen braking
- Better operating points for engine



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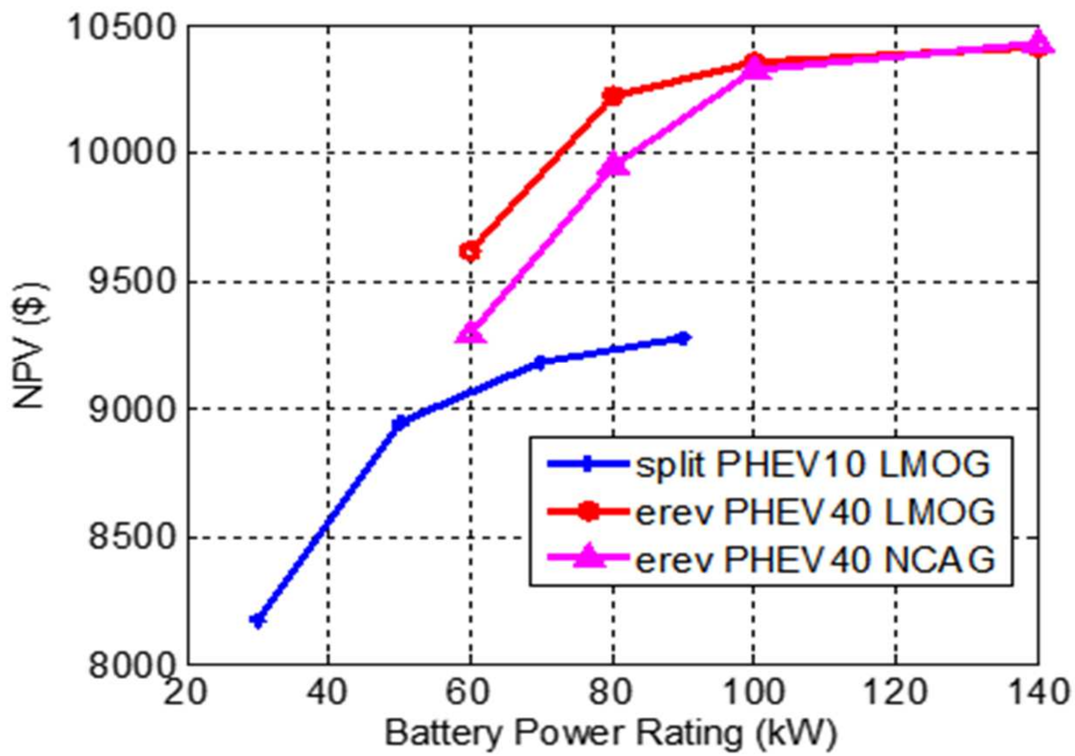
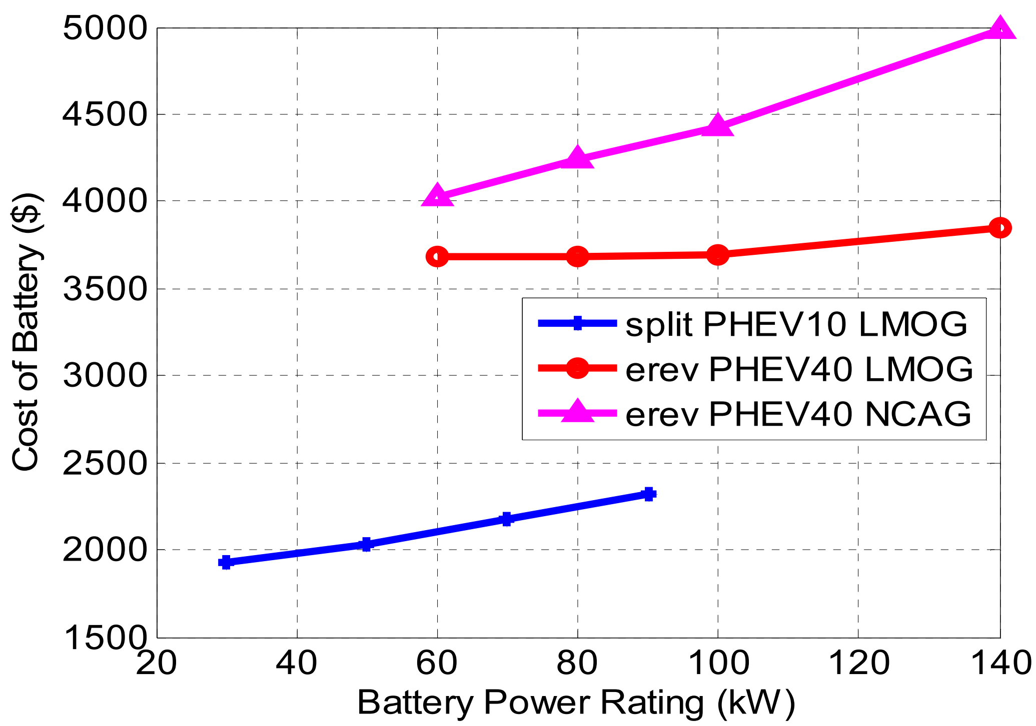
NPV of Savings: operational savings over vehicle lifetime

- Estimation is valid for drive cycles, vehicle & other NPV related assumptions.
- PHEV 40 gives you a higher savings.
- PHEV 10 can also provide significant savings
- Initial cost of vehicle is not considered in this case



Disadvantage: Higher battery cost

- BatPaC: manufacturing cost of battery
- Higher power battery results in
  - Higher battery cost
  - Higher gasoline displacement
  - Higher operational savings
- LMO-G for PHEV-40 has relatively steady cost for various power ranges



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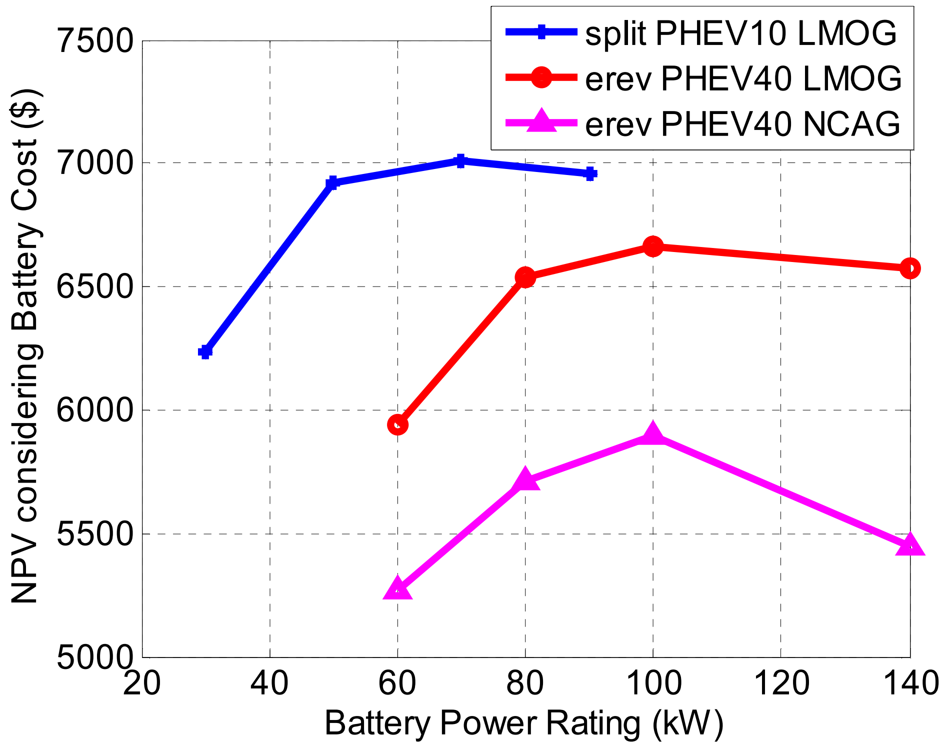
NPV considering the battery cost and future savings

- Under the assumed conditions, PHEV-10 gives the highest $ savings
- Other factors that can affect this estimate
  - Emission benefits
  - Cost of other components
    - Motors
    - Power electronics
    - Engine, Transmission etc.



Conclusion

- Estimated battery cost (for OEMs) by 2020

Vehicle Type	Battery Power	Battery Cost ($)
PHEV 10	90 kW	$2400
PHEV 40	100 kW	$3700

- For a midsize Split PHEV-10 & EREV PHEV-40
  - NPV of the fuel savings will be > $6500 (compared to a 30 mpg conventional midsize sedan)
- Impact on battery life needs to be studied

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