Energy Storage System Considerations for Grid-Charged Hybrid Electric Vehicles

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by

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Overview

- Study objectives
- Case study: plug-in HEV energy storage requirements and options for a mid-sized sedan
- Battery/engine sizing tradeoffs
- Conclusion

Motivation for this Study

- Traditional ZEV-range concept for plug-in HEV's requires ESS capable of high energy storage AND power capability = bigger, more-expensive battery

  (high power, high energy, low annualized cost ➔ pick any 2)*

  (high power, high energy, low volume ➔ pick any 2)

- Other HEV control strategy concepts (e.g. electric-assist) can still provide net-discharge, but with reduced battery power requirements.

  ➔ This might facilitate the use of cheaper and/or smaller batteries

** Annualized cost = battery replacement cost / lifetime*

Purpose of this Study

1. Calculate ESS power and energy requirements for plug-in HEV's with different control strategies

2. Consider implications for rest of system (in particular, engine efficiency and fuel economy)

Some Definitions

Degree of Hybridization (DOH):

$$DOH = \frac{battery\ /\ motor\ (kW)}{battery\ /\ motor\ (kW) + engine\ /\ generator\ (kW)}$$

Power-to-Energy Ratio (P2E):

$$P2E\left(\tfrac{1}{h}\right) = \frac{power\ (kW)}{energy\ (kWh^{*})} = \frac{specific\ \ power\ \left(\tfrac{W}{kg}\right)}{specific\ \ energy\ \left(\tfrac{Wh^{*}}{kg}\right)} = \frac{power\ \ density\ \left(\tfrac{W}{L}\right)}{energy\ \ density\ \left(\tfrac{Wh^{*}}{L}\right)}$$

- relates suitability of energy storage to power events with different timescales

$*\ useable\ Wh$

Case Study – Vehicle Specifications

Mid-size car from EPRI study:

- $C_DA = 0.71m^2$
- $C_{RR} = 0.008$
- Pacc = 500W
- Test mass ≈ 1700kg

Peak motive power ≈ 115kW

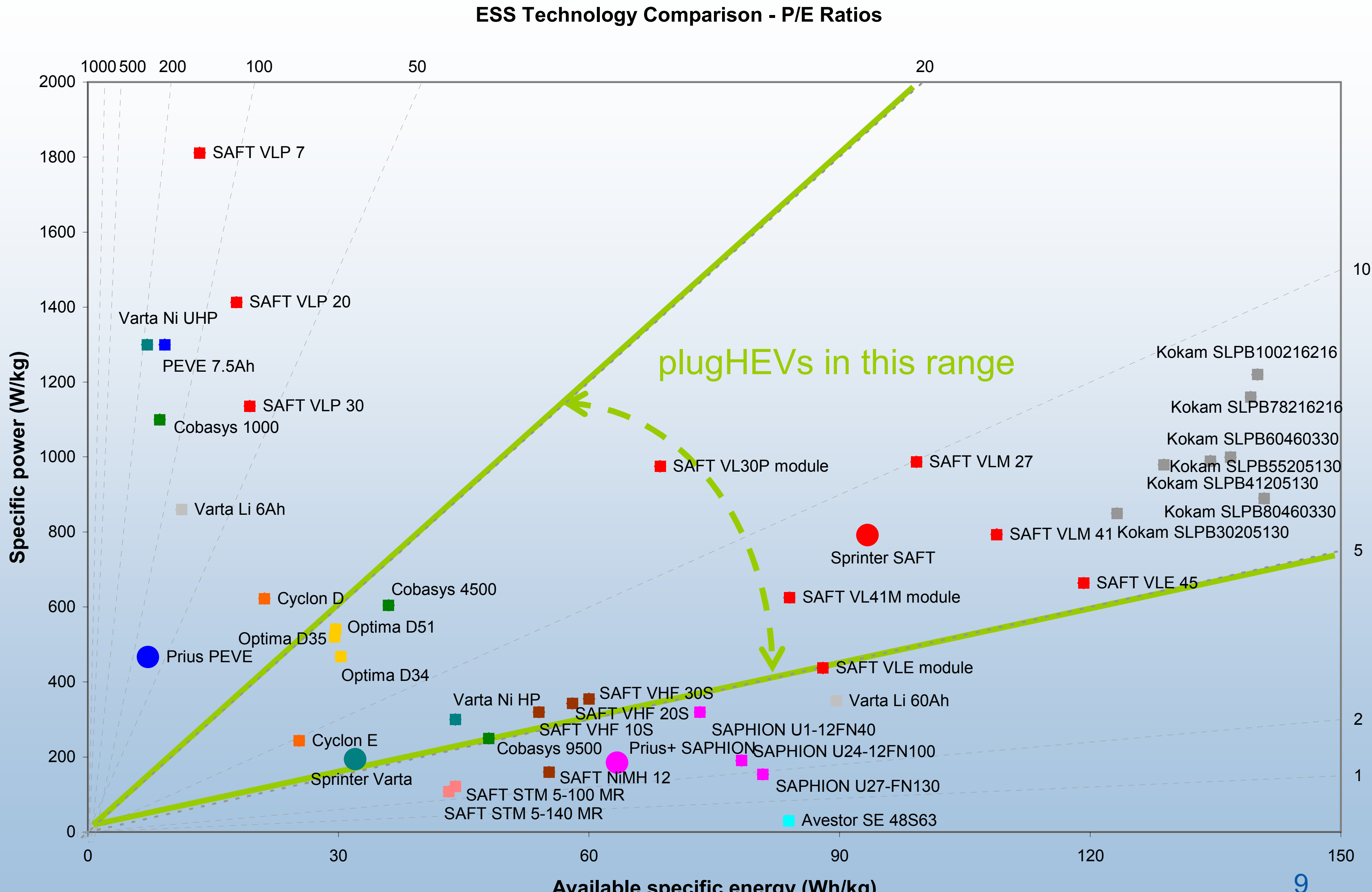
Continuous power requirement ≈ 45kW

- Top speed @ 90mph
- 7.2% gradeability @ 50mph

Electric energy consumption ≈ 300Wh/mile

Case Study – Battery Specifications

	No ICE help			With ICE help (45kW)		
	Power (kW)	Energy (kWh)	P2E (1/h)	Power (kW)	Energy (kWh)	P2E (1/h)
HEV10	115	3	38.3	70	3	23.3
HEV20	115	6	19.2	70	6	11.7
HEV60	115	18	6.4	70	18	3.9


ESS Technology Comparison - P/E Ratios
Specific power (W/kg)
Available specific energy (Wh/kg)
1000
500
200
100
50
20
10
5
2
1
plugHEVs in this range
SAFT VLP 7
SAFT VLP 20
Varta Ni UHP
PEVE 7.5Ah
SAFT VLP 30
Cobasys 1000
Varta Li 6Ah
Cyclon D
Cobasys 4500
Optima D51
Optima D35
Prius PEVE
Optima D34
Varta Ni HP
Cyclon E
Sprinter Varta
SAFT VHF 30S
SAFT VHF 20S
SAFT VHF 10S
Cobasys 9500
Prius+ SAPHION
SAFT NiMH 12
SAFT STM 5-100 MR
SAFT STM 5-140 MR
SAFT VL30P module
SAFT VLM 27
Sprinter SAFT
SAFT VL41M module
SAFT VLE module
Varta Li 60Ah
SAPHION U1-12FN40
SAPHION U24-12FN100
SAPHION U27-FN130
Avestor SE 48S63
SAFT VLM 41
SAFT VLE 45
Kokam SLPB100216216
Kokam SLPB78216216
Kokam SLPB60460330
Kokam SLPB55205130
Kokam SLPB41205130
Kokam SLPB80460330
Kokam SLPB30205130

Battery Products for Comparison

Battery	Wh/kg	Wh/L	W/kg	W/L	Useable SOC	P2E
High Energy (for EVs)						
SAFT VLE 45 cell	149	313	664	1392	~ 80%	5.6
Cobasys 9500 module	60	155	250	650	~ 80%	5.2
Mid Range (for plugHEVs?)						
SAFT VLM 27 cell	124	252	987	2000	~ 80%	9.9
Cobasys 4500 module	45	87	605	1180	~ 80%	16.8
High Power (for HEVs)						
SAFT VLP 20 cell	89	187	1413	2973	< 20%	>79
Cobasys 1000 module	43	83	1100	2200	< 20%	>128

Match with HEV60 (SAFT VLE 45 cell, Cobasys 9500 module)

Match with HEV20 (SAFT VLM 27 cell, Cobasys 4500 module)

Battery/Engine Sizing Tradeoffs

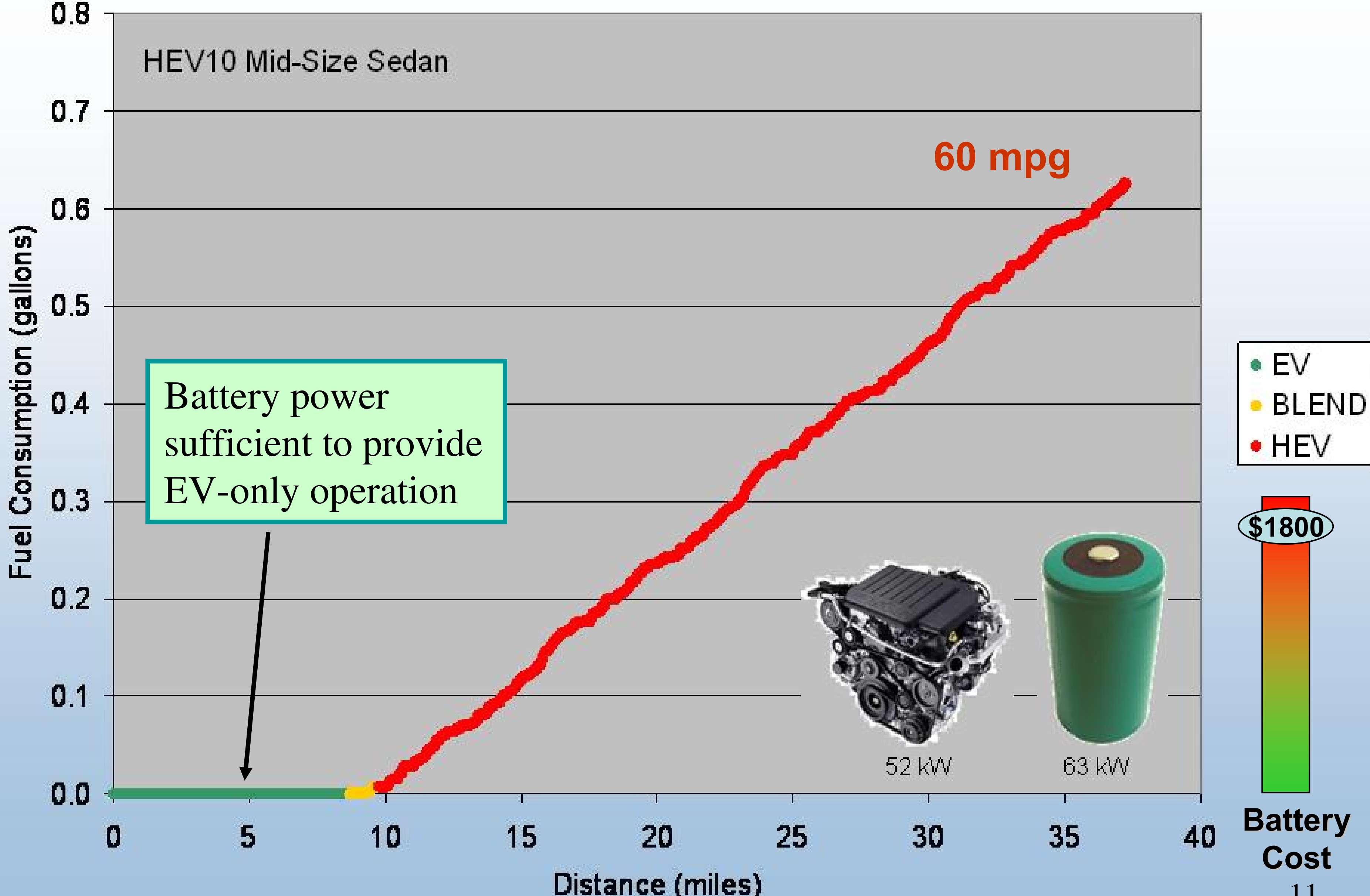
45kW is only a lower constraint, engine can be larger than this.

➔ This allows a smaller battery to be used…HEV20 example:

Battery	Total Power (kW)	Battery Energy (kWh)	Battery Mass (kg)	Battery Volume (L)	Battery Power (kW)	Engine Power (kW)
Lithium-Ion						
SAFT VLM 27 cell	115	6.0	61	30	60	55
SAFT VLE 45 cell	115	6.0	50	24	33	82
Nickel-Metal-Hydride						
Cobasys 4500 module	115	6.0	167	86	101	45
Cobasys 9500 module	115	6.0	125	49	31	84

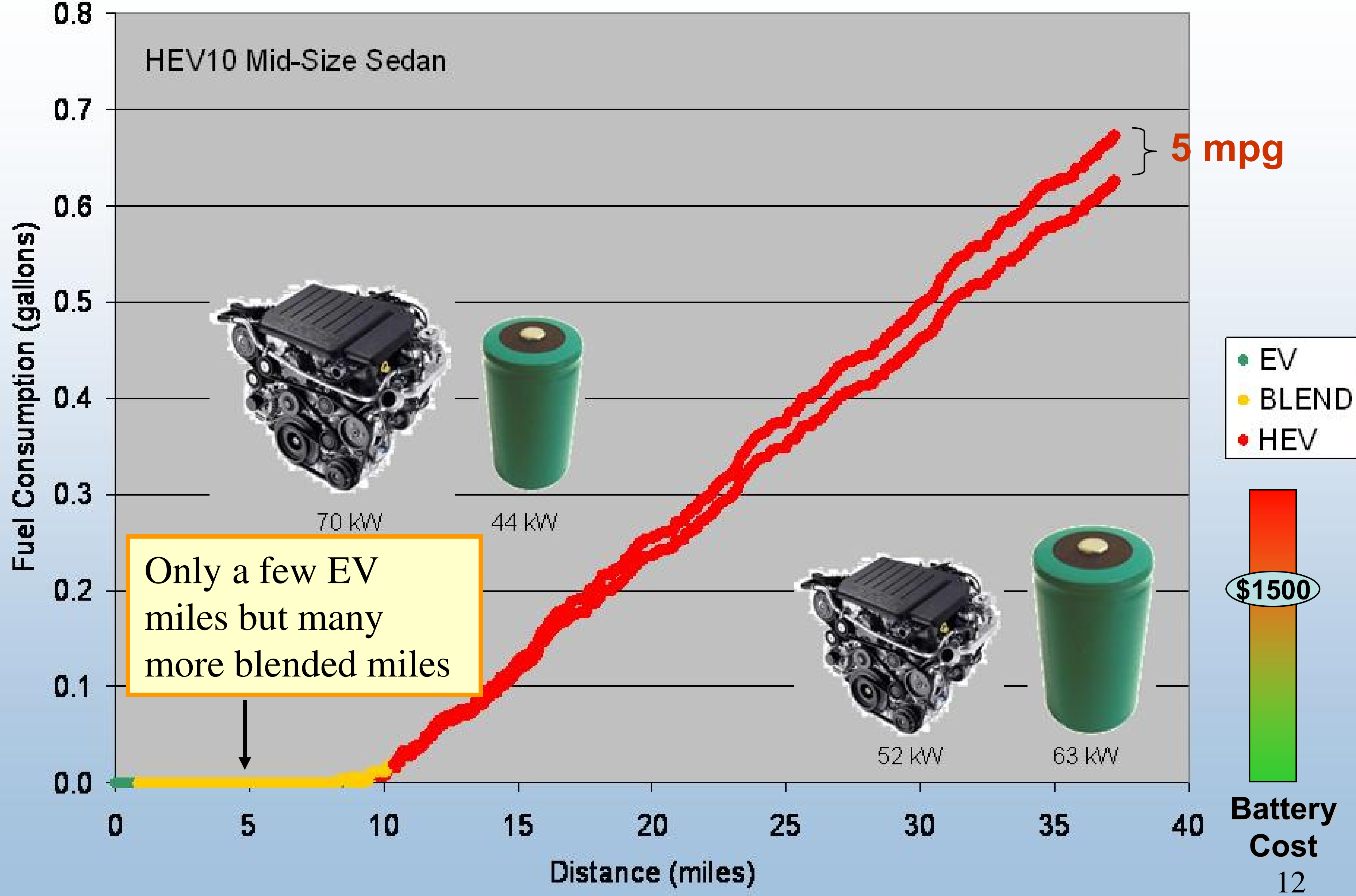
Component Sizing and Control Options

P/E = 20



Component Sizing and Control Options

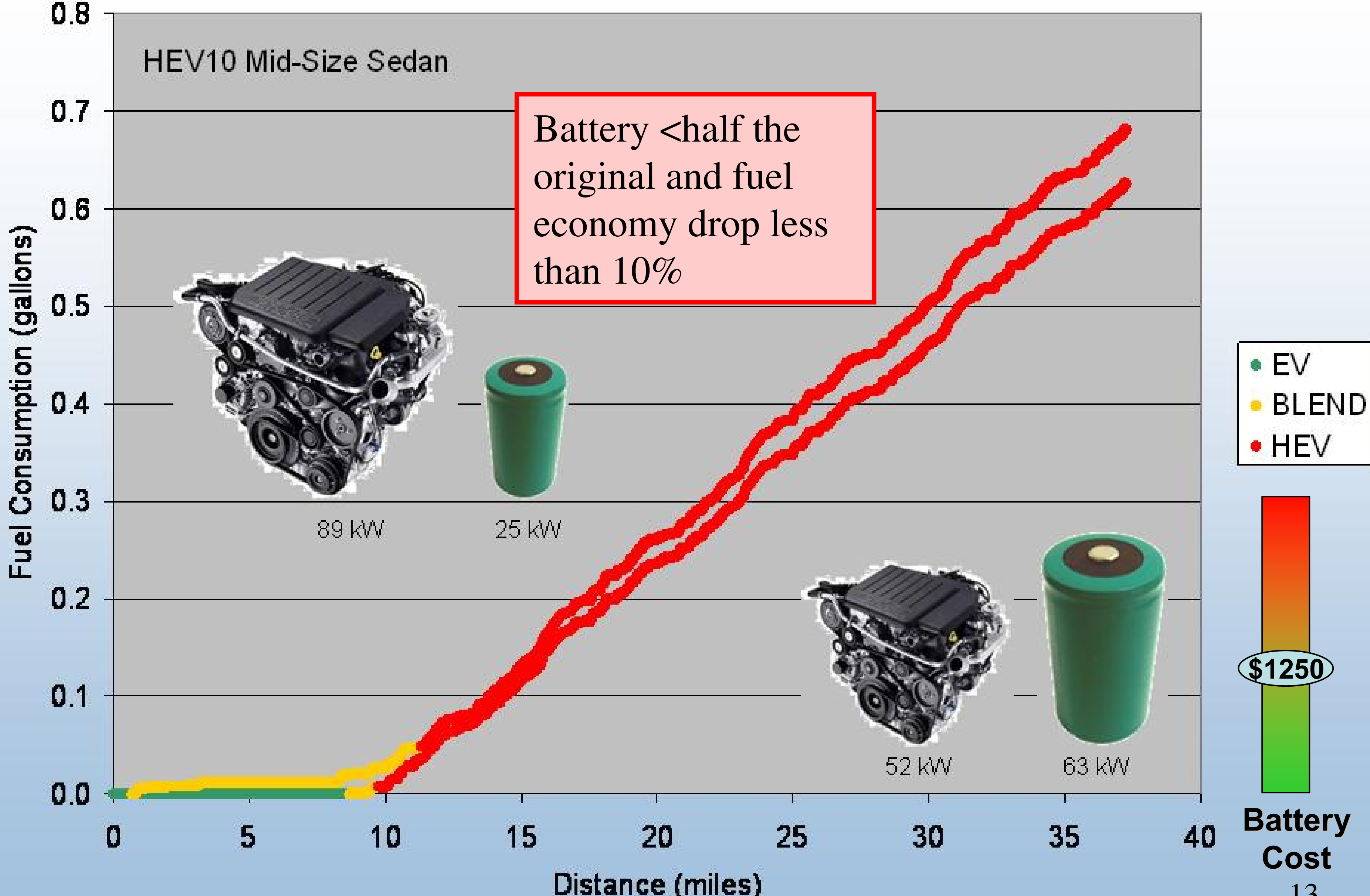
P/E = 14



Only a few EV miles but many more blended miles

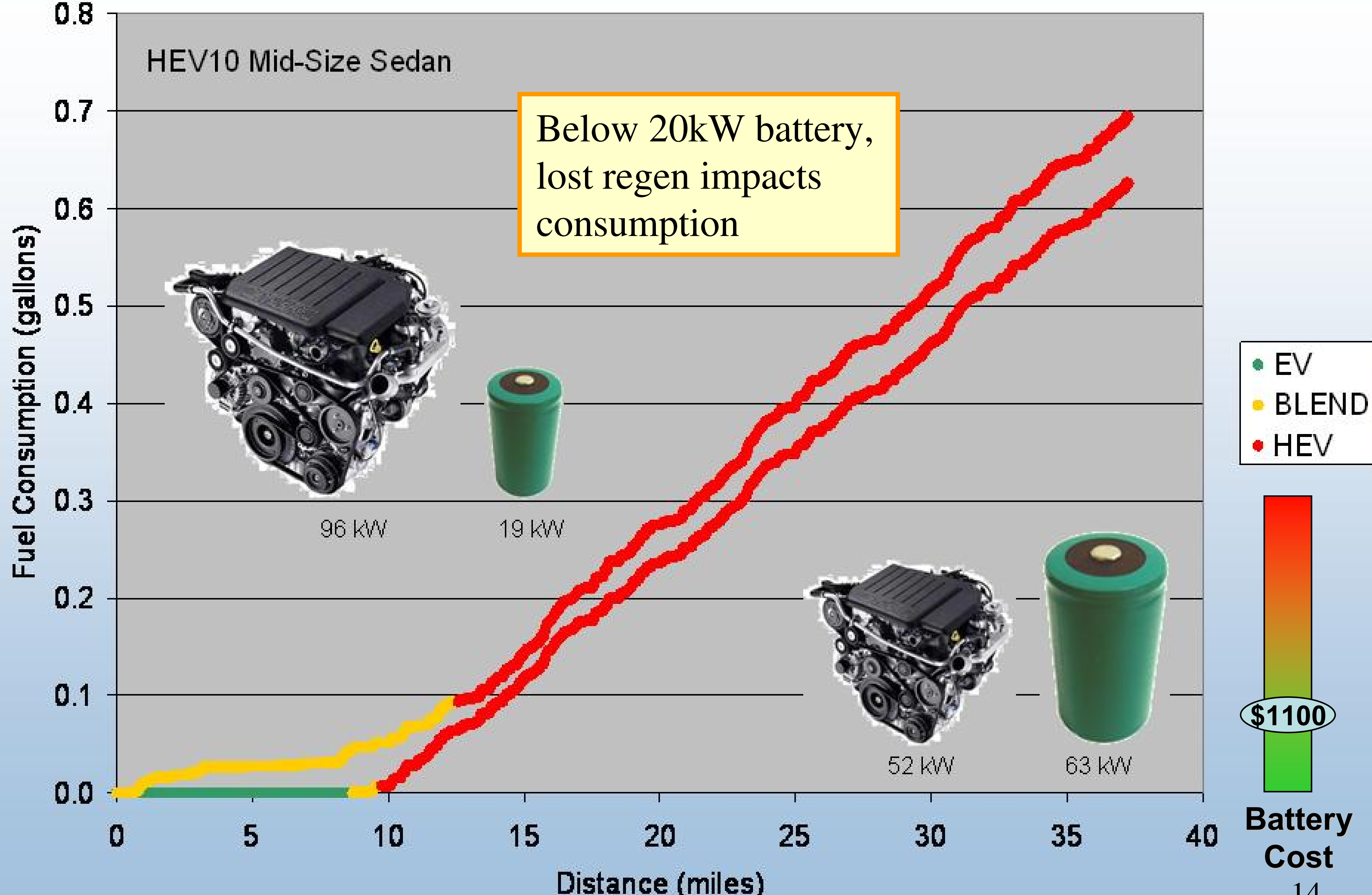
Component Sizing and Control Options

P/E = 8



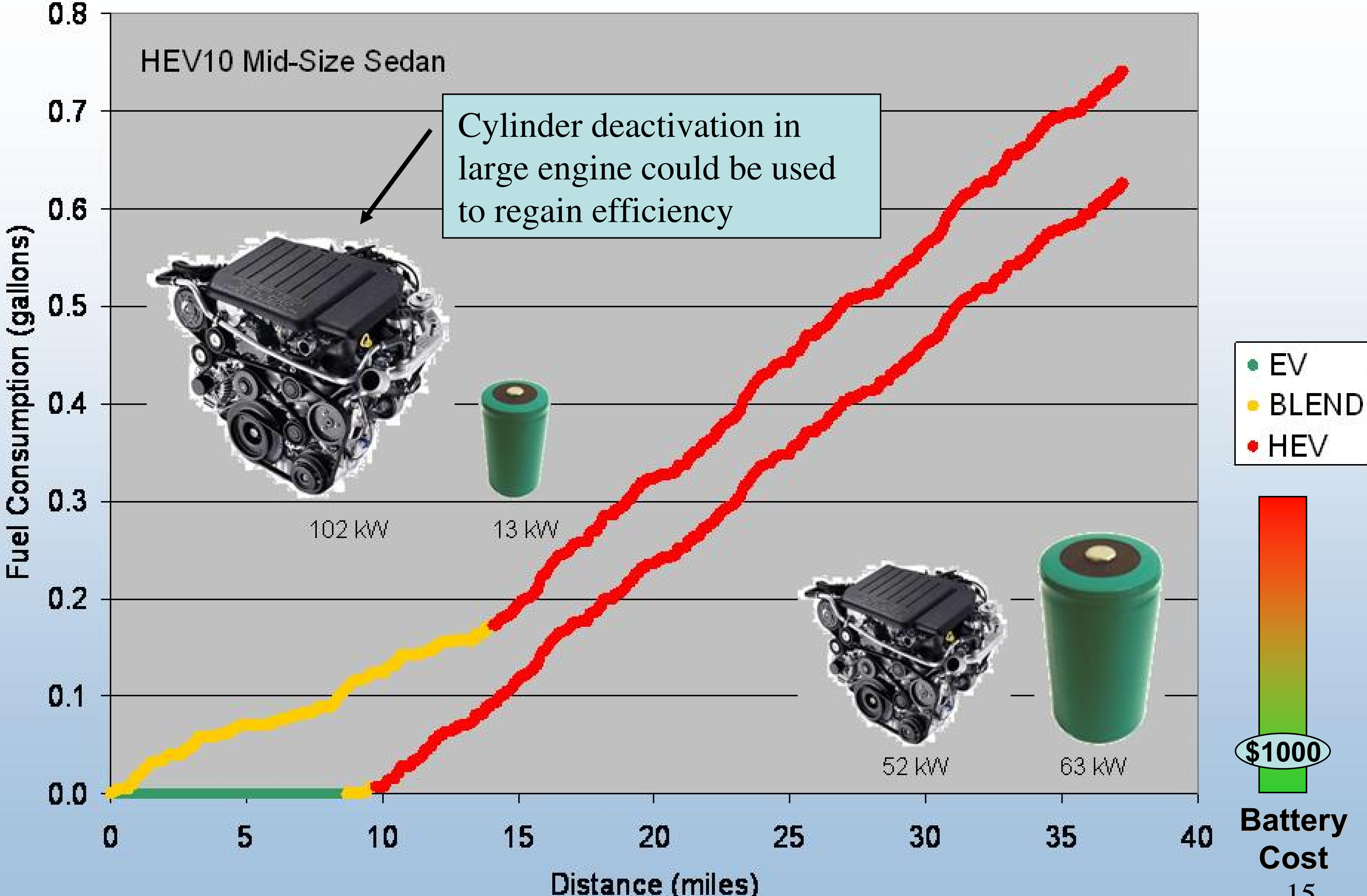
Component Sizing and Control Options

P/E = 6



Component Sizing and Control Options

P/E = 4



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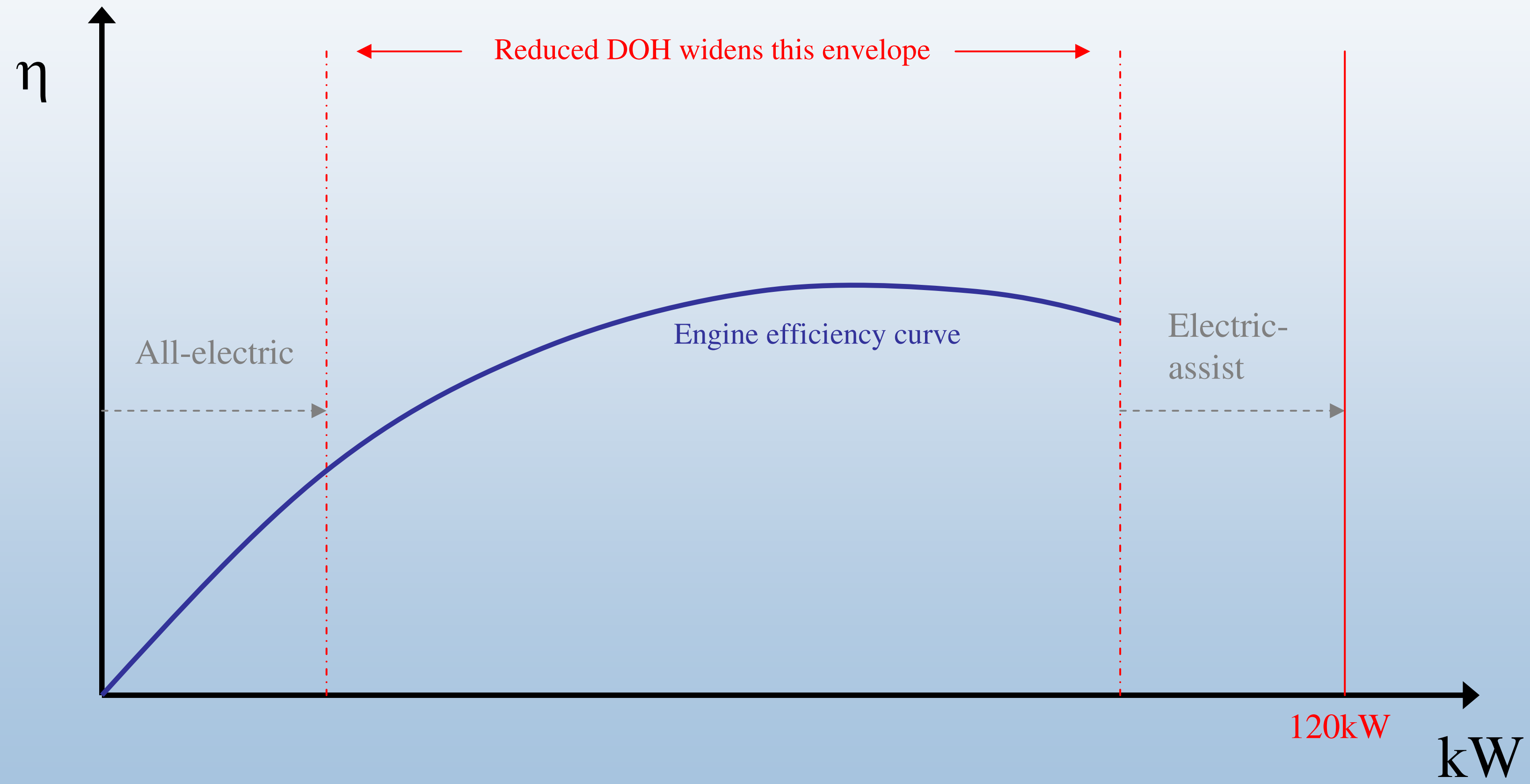
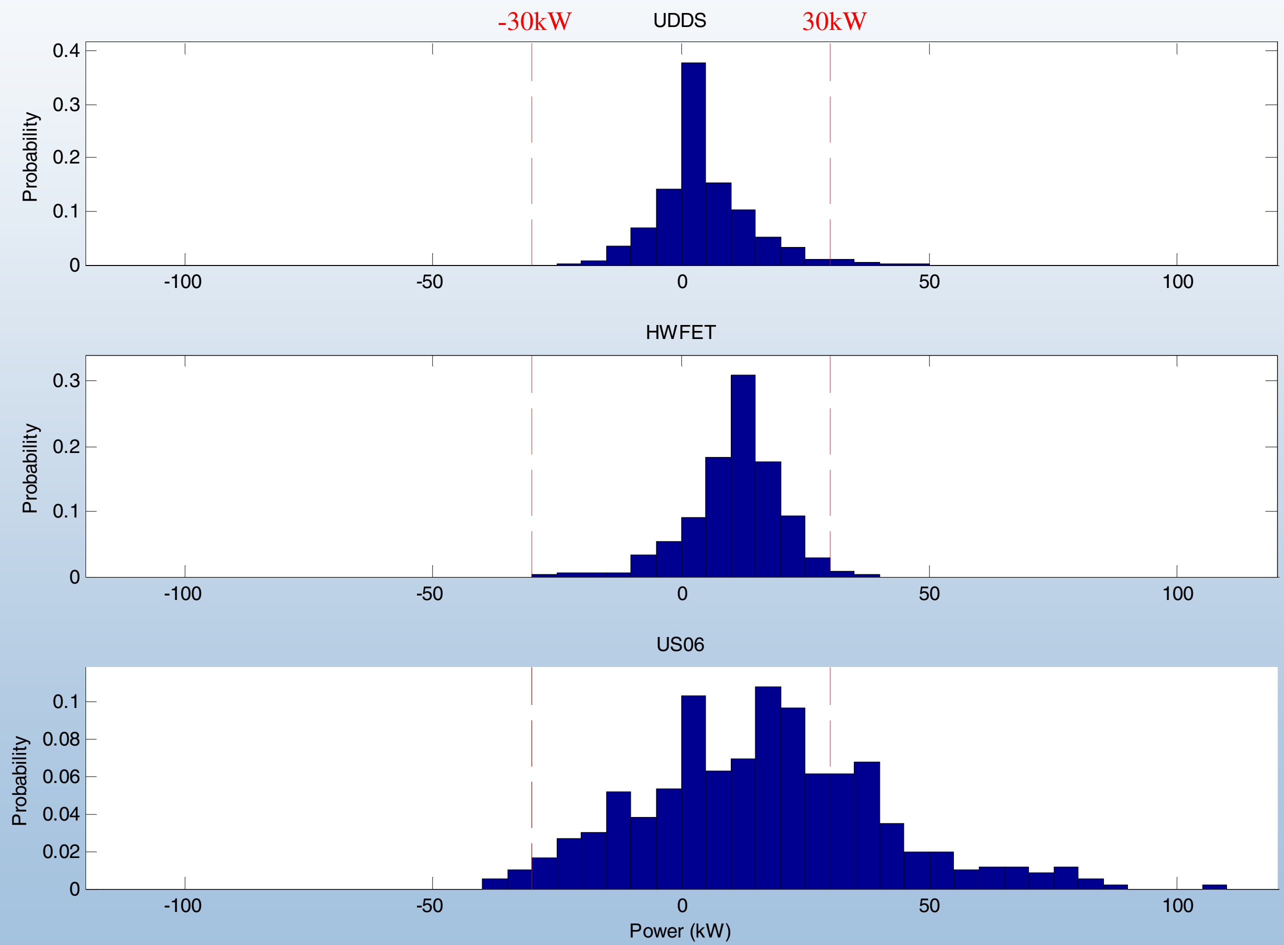
Battery/Engine Sizing Tradeoffs

So what's the catch? 1) Lower engine efficiency!



Battery/Engine Sizing Tradeoffs

2) Sacrificed all-electric operation and regenerative braking



Conclusions

- P2E ratios for existing high-energy and mid-range battery products match with P2E requirements for plug-in HEVs
  - However, mid-range batteries may be bigger, more expensive due to simultaneous power and energy requirements
  - Note that high-value V2G services (i.e. regulation events) have high P/E ratios – does this affect ESS requirements?
  - *Do dual-source ultracaps & EV batteries make a good alternative to mid-range batteries?*

Conclusions (cont.)

- Engine size (power) can be increased to facilitate the use of smaller batteries with lower P2E ratios (i.e. EV types)
  - However, this incurs the cost of:
    - Reduced engine efficiency
    - Sacrificed all-electric capability and maybe some loss of regenerative braking
    - Potential reduction in vehicle fuel economy during both charge-depleting and –sustaining operation
  - Reduced mass/volume of ESS & motor must be traded against increased mass/volume of ICE
  - *These issues should be explored further with dynamic simulation (including consideration of control strategy practicalities)*