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NSF Engineering Research Center

Advancing Sustainability through Powered Infrastructure for Roadway Electrification

A Novel Composite Hybrid Energy Storage System for Hybrid and Electric Vehicles

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Vision and Outcome

Aim
Need to establish sustainable mitigation pathways that limit greenhouse gas emissions by encouraging the widespread adoption of electric vehicles through countering range anxiety

The **first** capacitively-coupled **energy storage system** that **reduces electric vehicle battery system weight by 40%*** to **counter range anxiety**.

More energy for the same weight: increase in range
*compared to a conventional single-chemistry battery system

- Target the transportation sector
- Scalable
- Cost-effective
- Humanized approach

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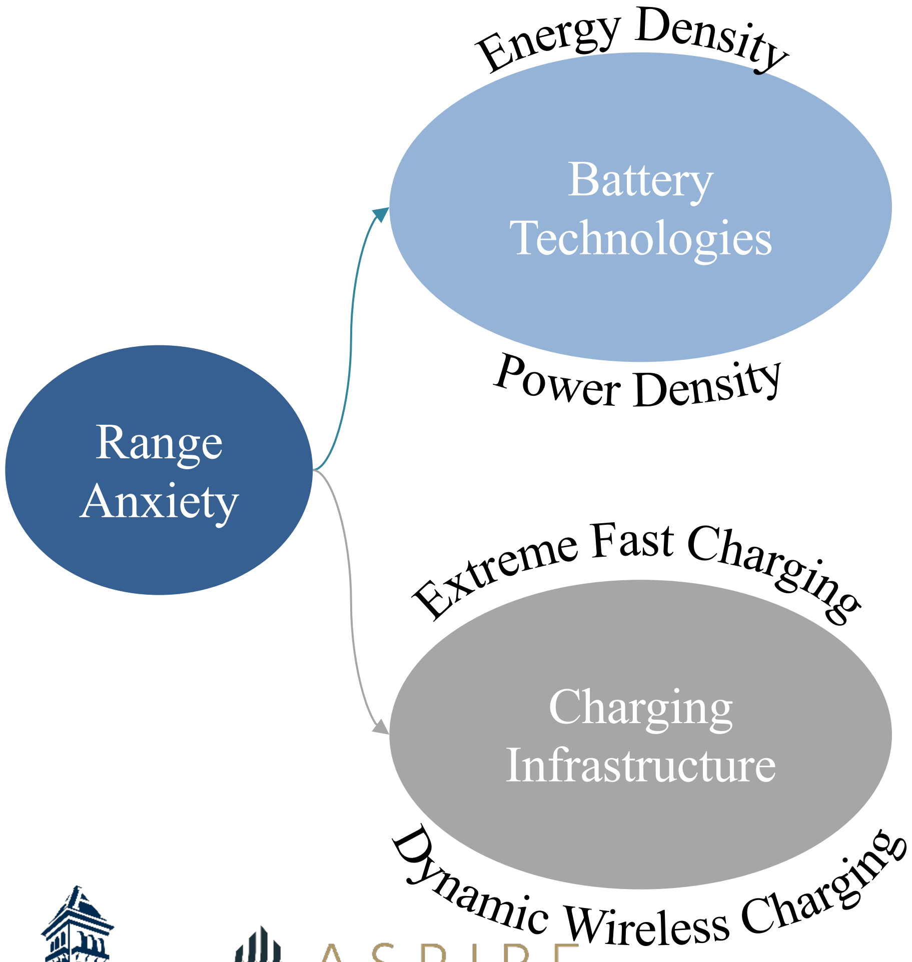
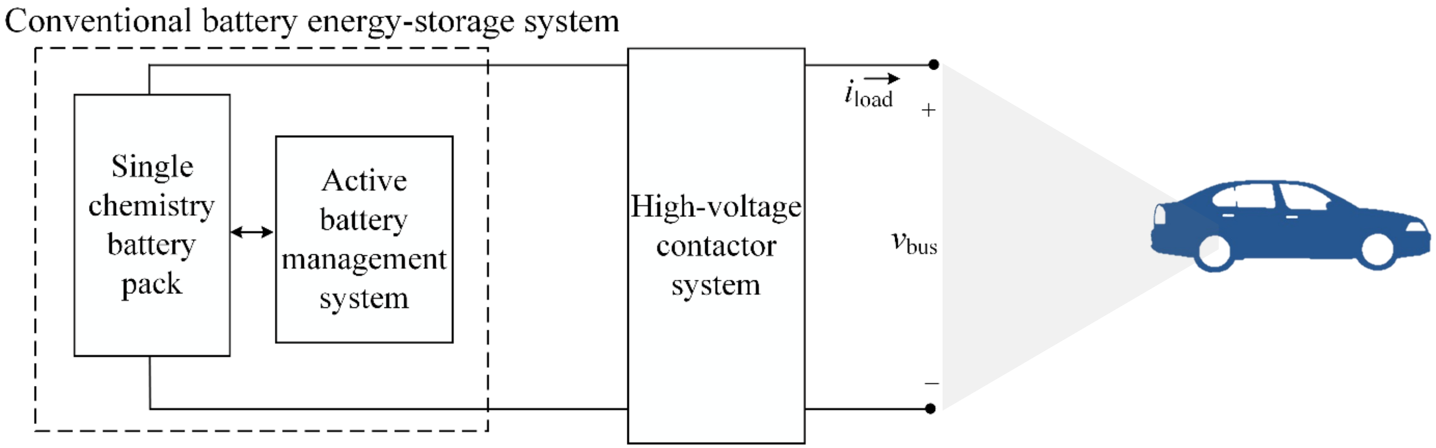
Research Problem- Motivation





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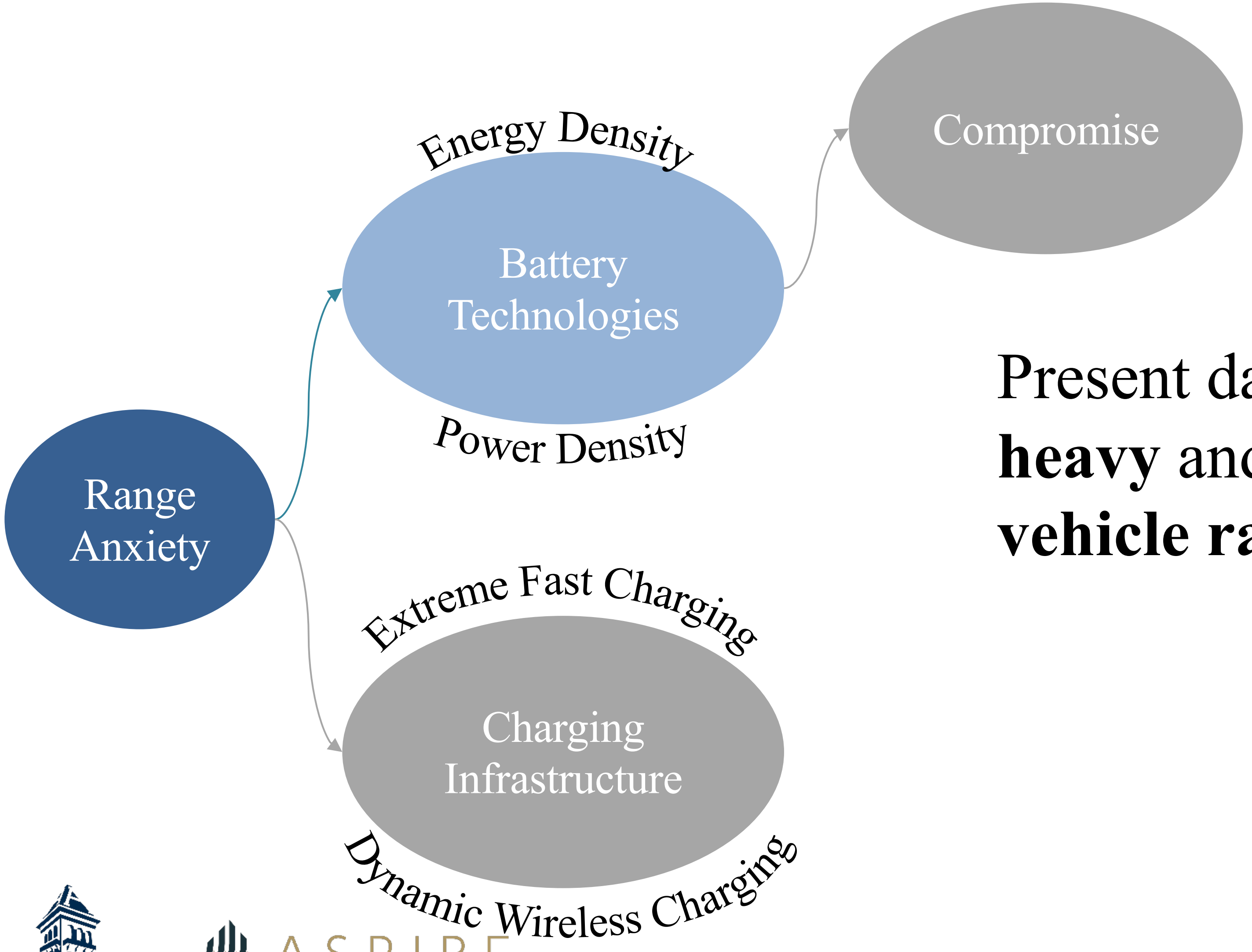

Present day **battery systems are large, heavy** and **costly** and **limit the electric vehicle range** and **charging capability**

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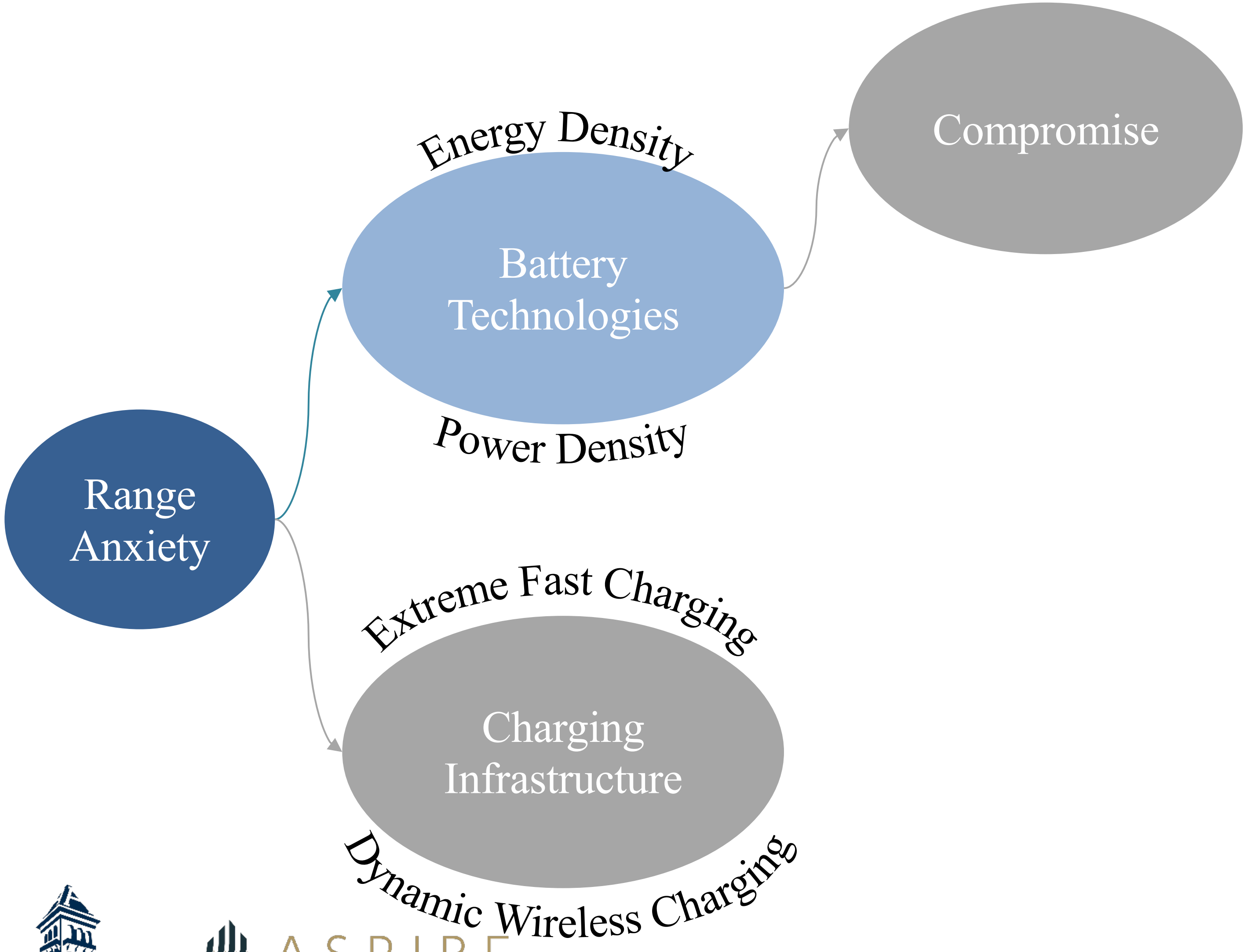
Research Problem- Motivation



Cell structure **limits power and energy capability**

- **High energy density cells**
  - Require thick electrodes and low porosity -> high resistance -> low specific power
- **High power density cells**
  - Require thin electrodes and high porosity -> low resistance -> low specific energy

[1-4]

Specific energy ∝ Range
Specific power ∝ Acceleration

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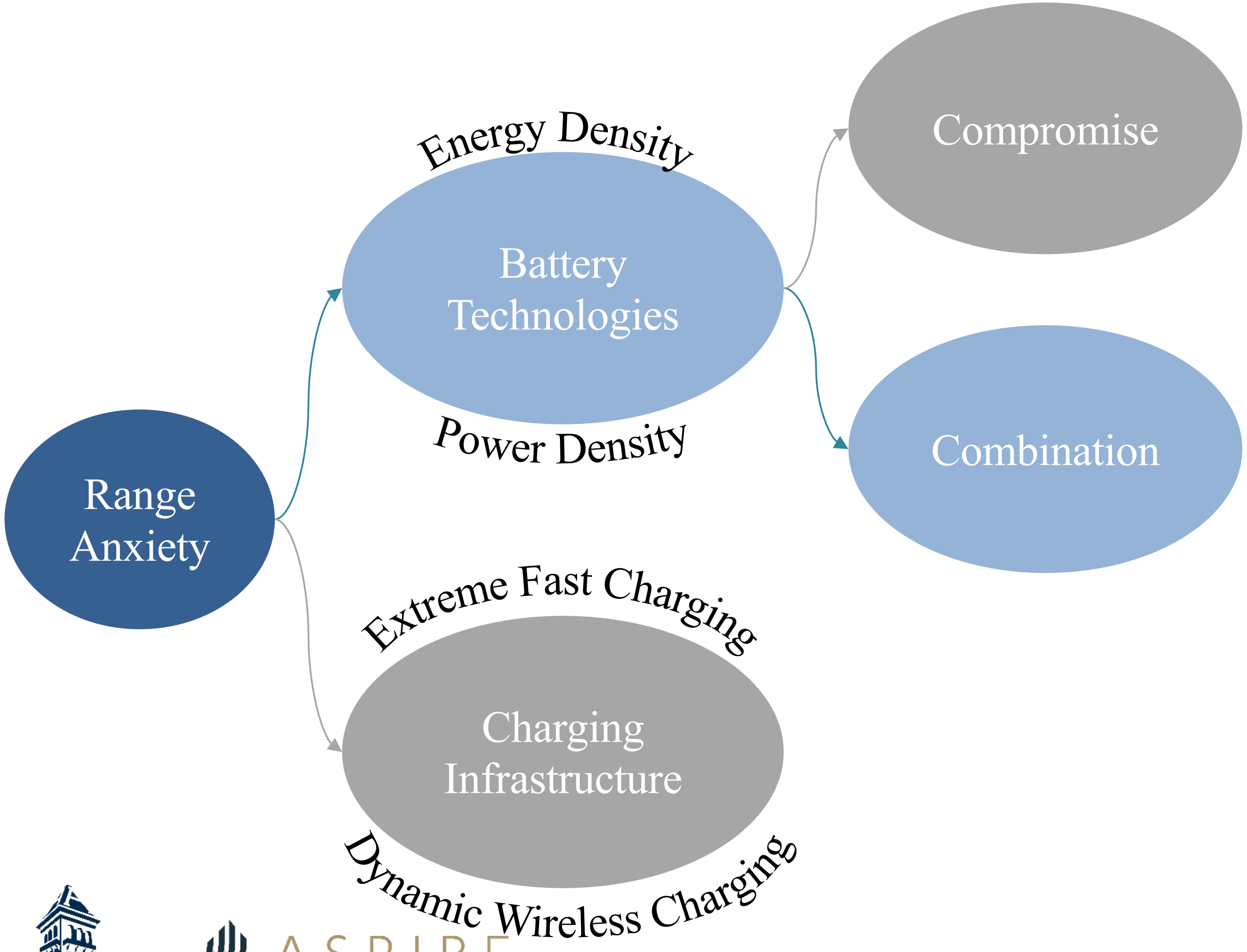
Research Problem- Motivation



Combining energy and power dense battery packs can

- Increase vehicle range
- Increase vehicle acceleration capability
- Improve health and life of batteries

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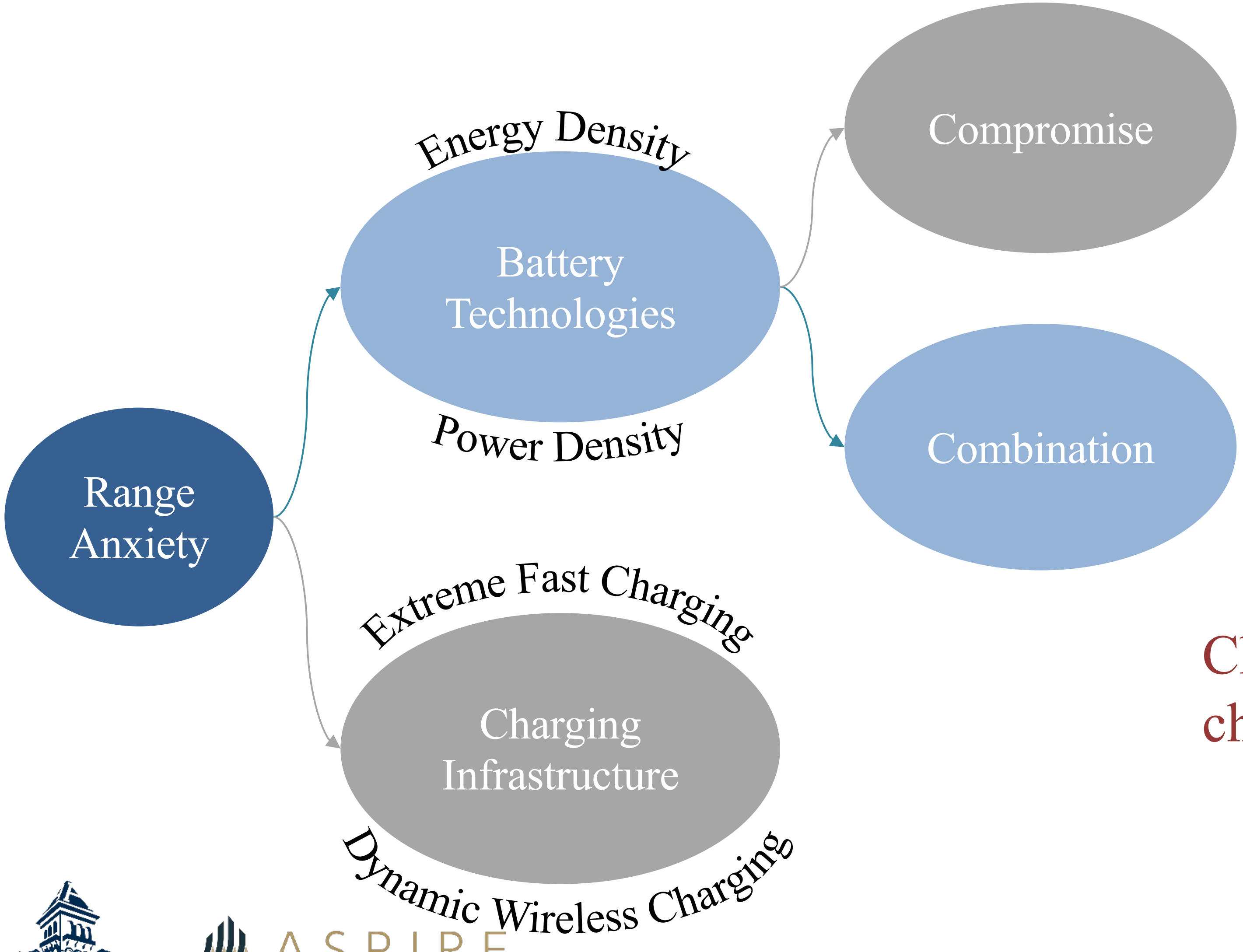
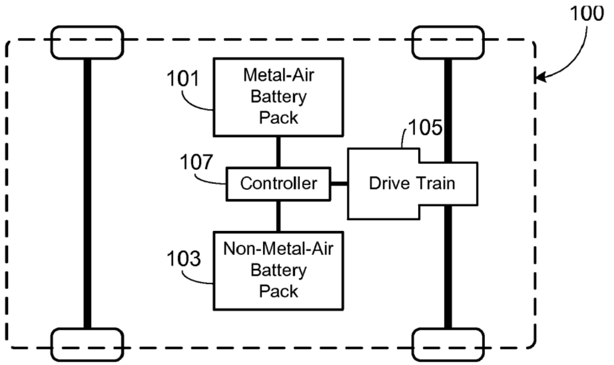
Research Problem- Motivation





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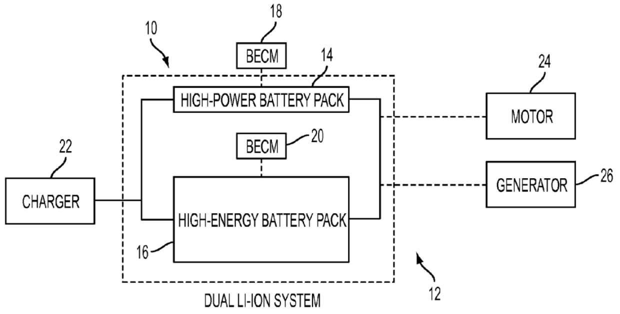

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Challenges to couple batteries of different chemistries

- Limited operation of batteries
- Full-power rated DC-DC converters
- Need additional contactors

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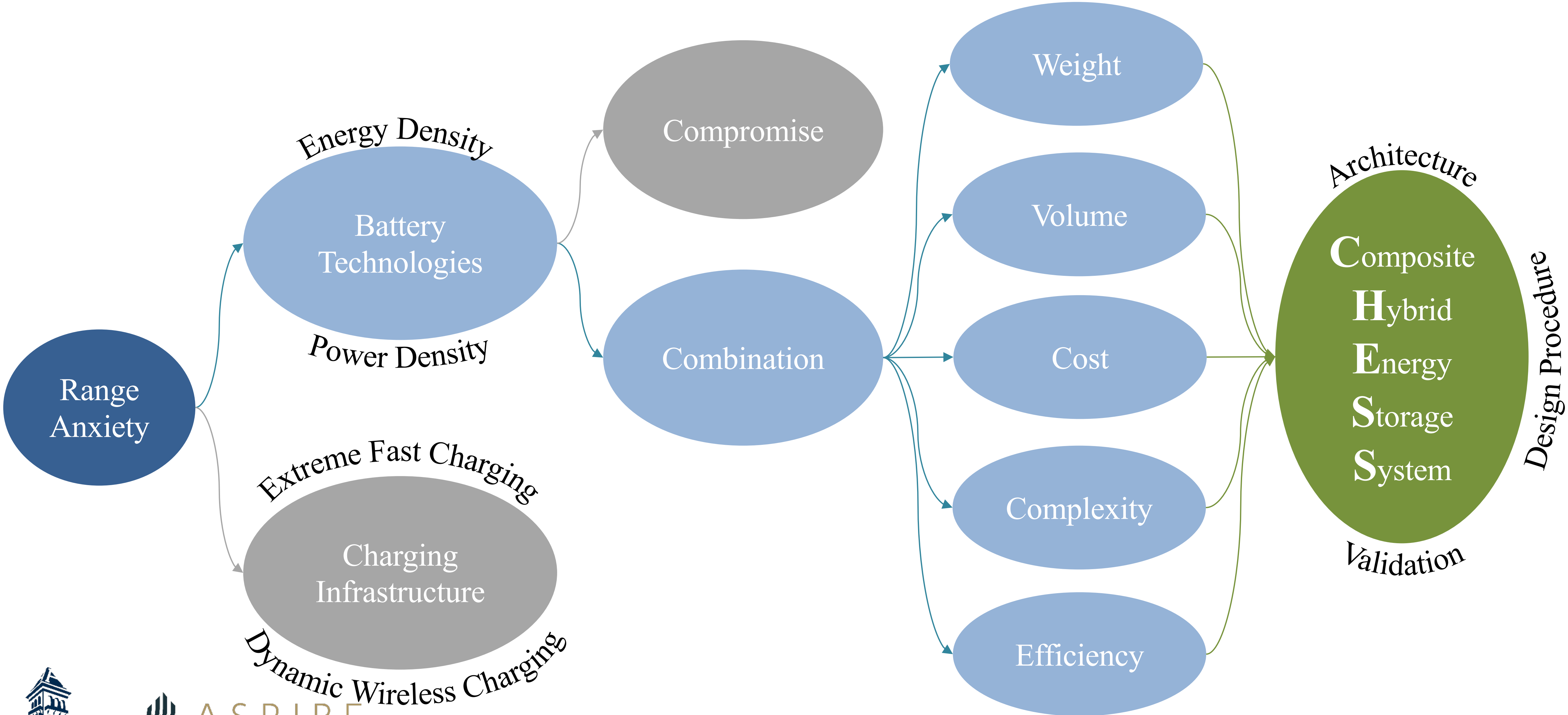
Research Problem- Motivation



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CHESS Architecture

- Combines an AC-coupled **power-dense** battery and **energy-dense density battery** in parallel
- Low-power **active battery management system**

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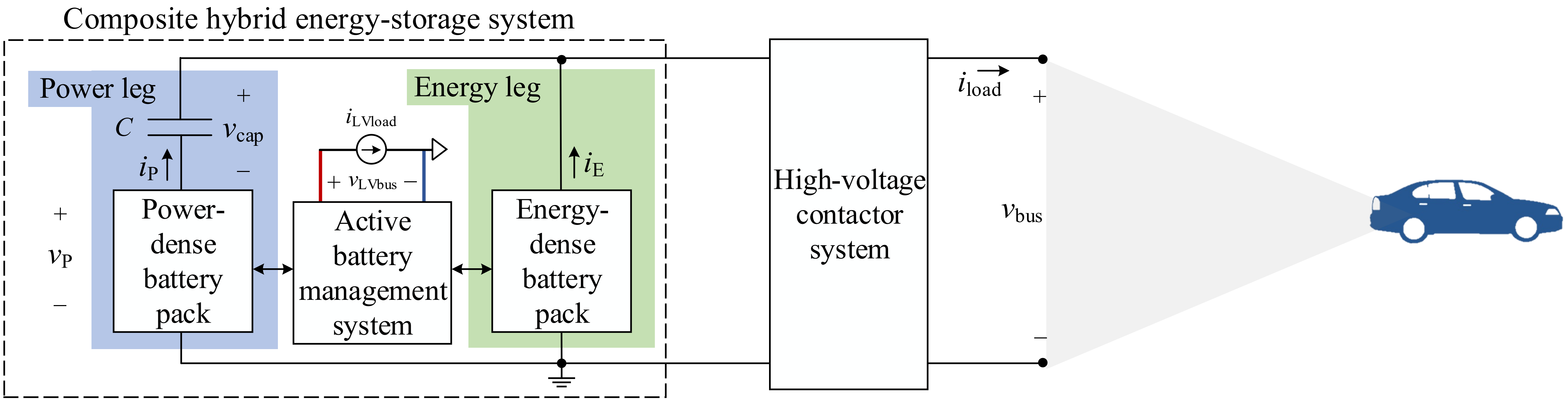

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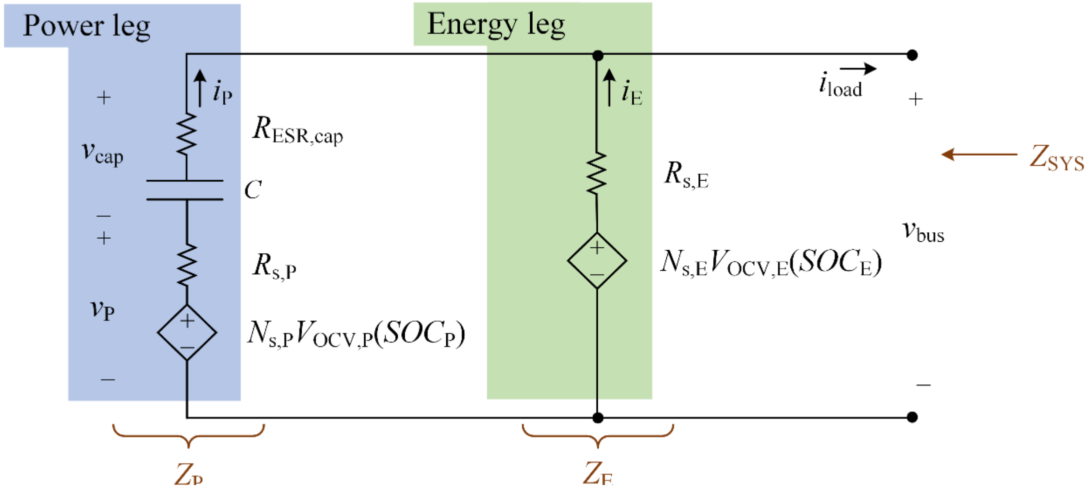
CHESS Architecture Operation

Equivalent circuit model of CHESS



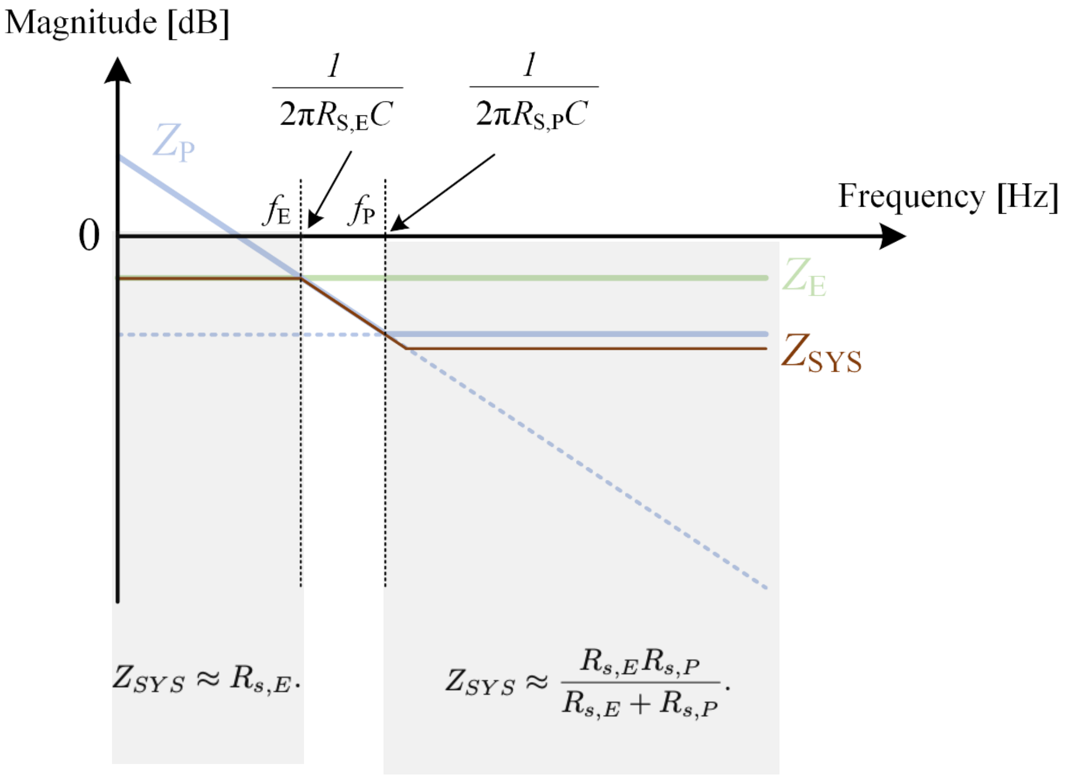
$$Z_E = R_{s,E},$$

$$Z_P = R_{ESR,cap} + \frac{1}{sC} + R_{s,P},$$

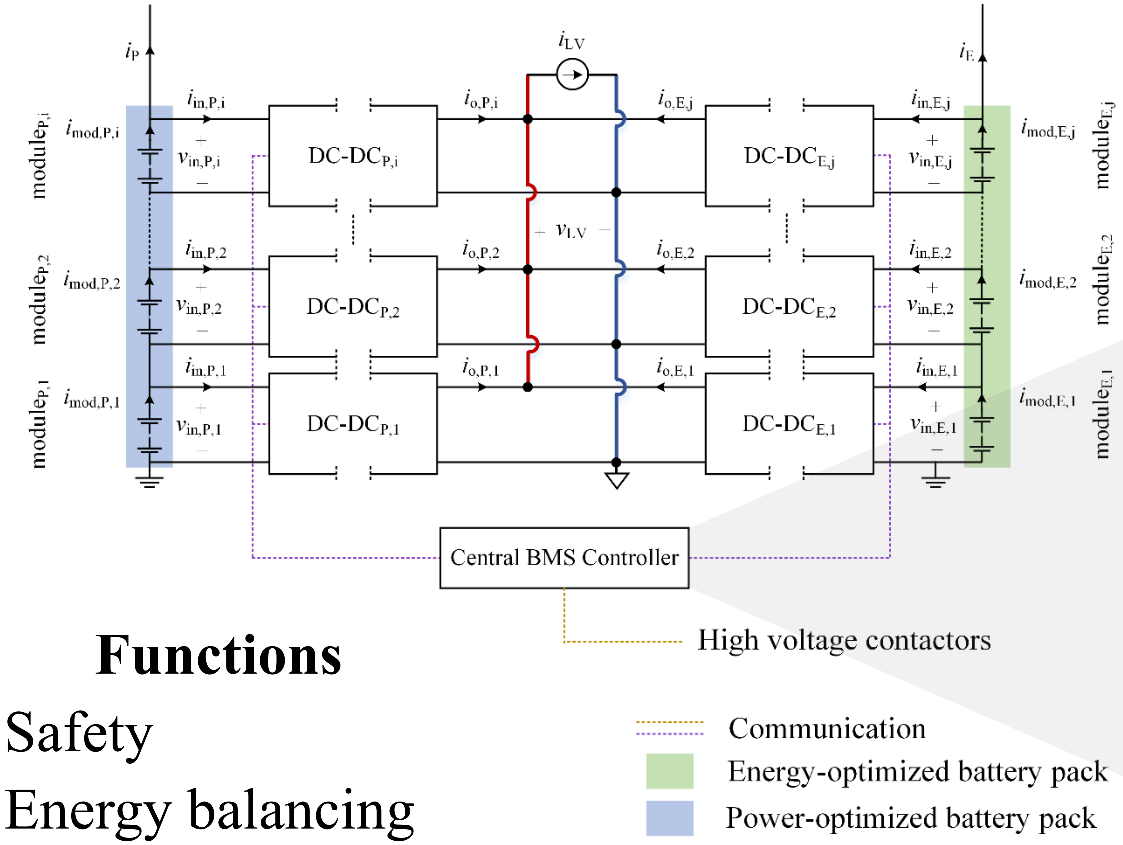
$$Z_P = \frac{1}{sC} + R_{s,P} = \frac{1 + sCR_{s,P}}{sC},$$

$$Z_{SYS} = Z_E || Z_P = \frac{R_{s,E}(1 + sCR_{s,P})}{1 + sC(R_{s,E} + R_{s,P})},$$

Impedance plot of CHESS



Active Battery Management System

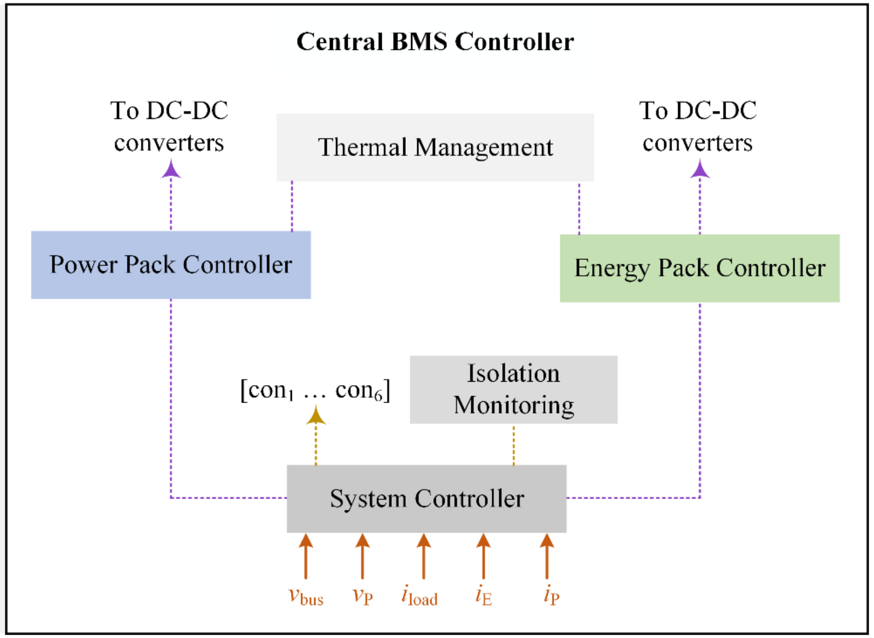


Functions

- Safety
- Energy balancing
- SOC balancing

Specifications

- Power = 1.2 kW
- Cost = USD 156
- Weight = 300 g



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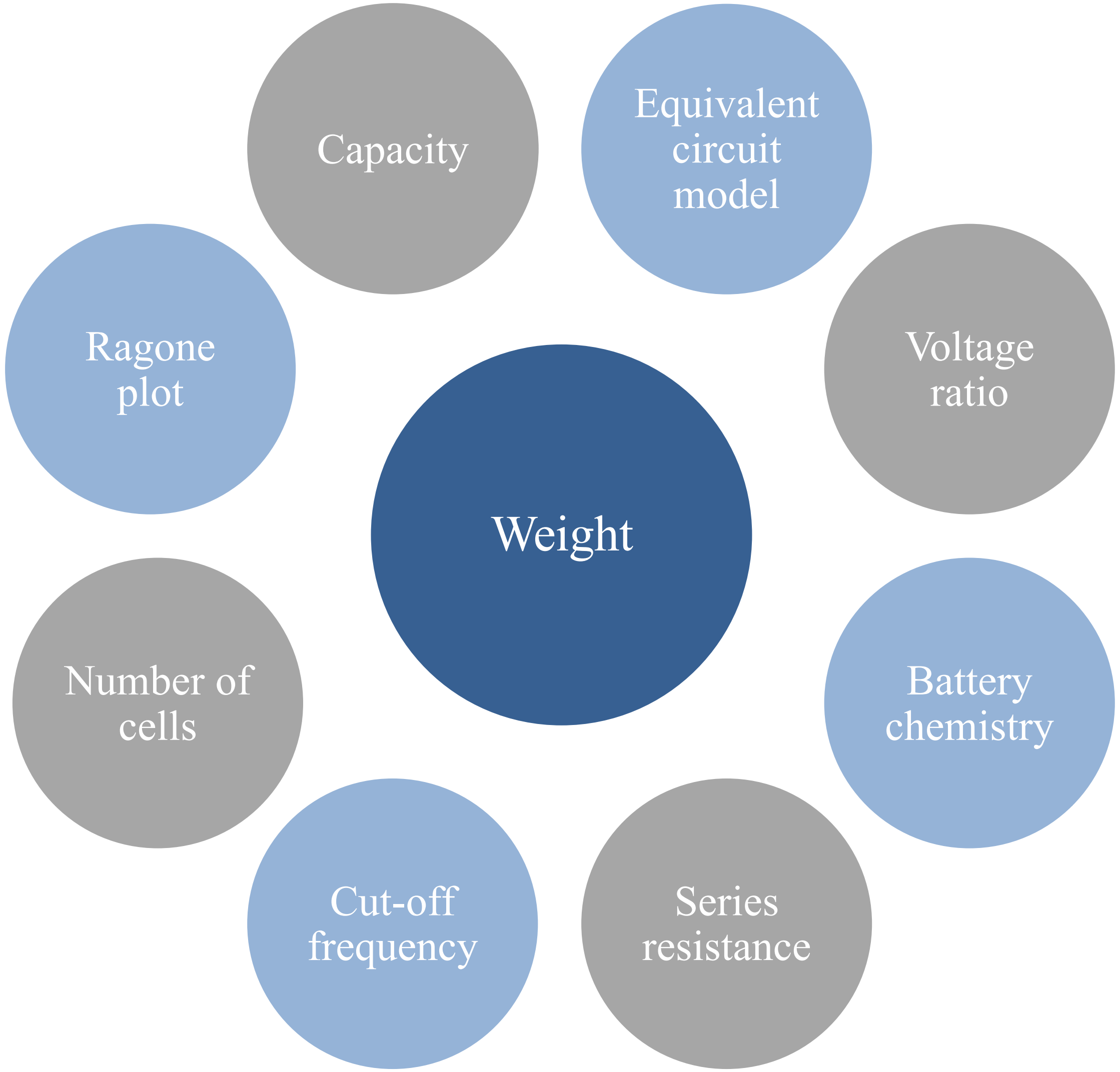
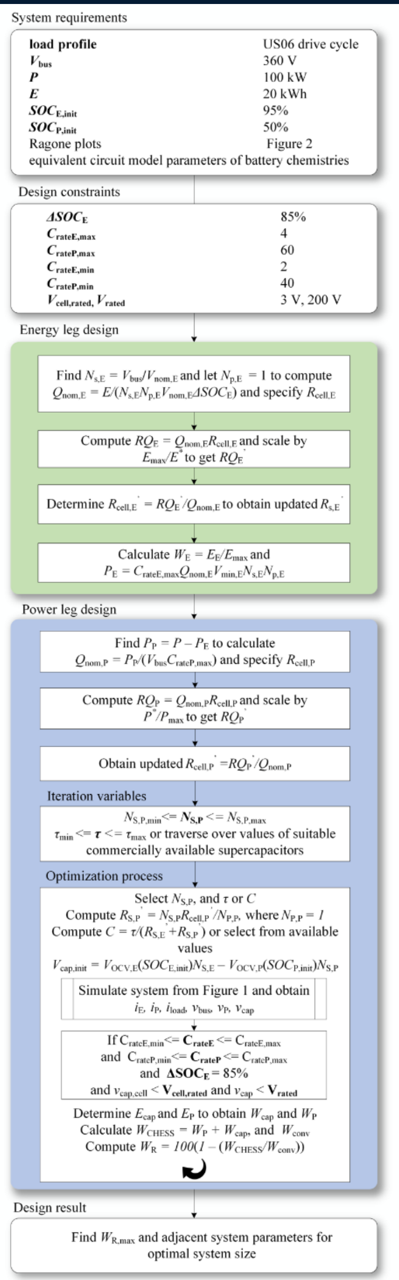
CHESS Design Parameters

- Complex and coupled system with several variables
- **Objective: reduce weight** compared to a conventional single-chemistry battery solution





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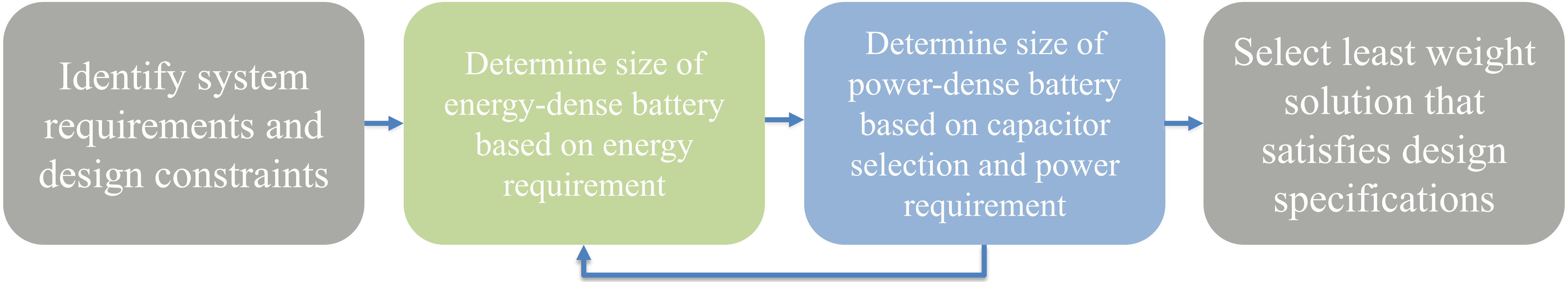
CHESS Design Procedure



Case Study

64 miles range PHEV (8 US06 drive cycles, 80 minutes total time)

System requirements

load profile	US06 drive cycle
V_{bus}	360 V
P	100 kW
E	20 kWh
$SOC_{E,init}$	95%
$SOC_{P,init}$	50%
Ragone plots	Figure 2
equivalent circuit model parameters of battery chemistries	

Design constraints

ΔSOC_E	85%
$C_{rateE,max}$	4
$C_{rateP,max}$	60
$C_{rateE,min}$	2
$C_{rateP,min}$	40
$V_{cell,rated}$, V_{rated}	3 V, 200 V

Parameter	**Architecture**		
	Single chemistry *	CHESS	
		Ideally optimized elements	Commercially available elements
Weight [kg]	177	107	139
Volume [m^3]	0.081	0.055	0.075

*Comprises of 50 Ah NMC cells

Weight reduction 40 % 22 %

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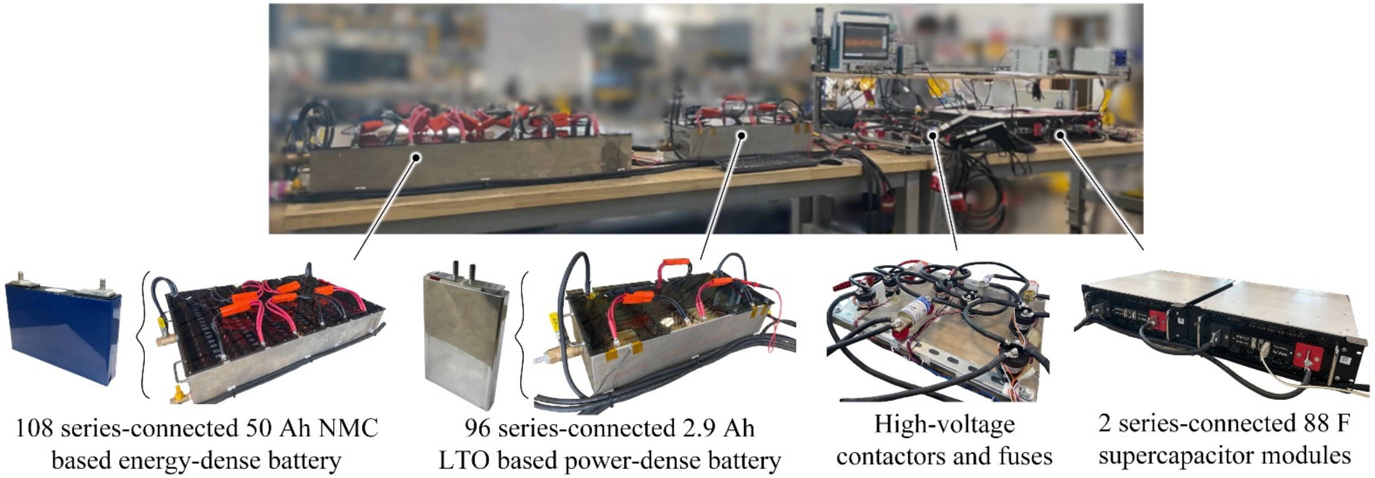
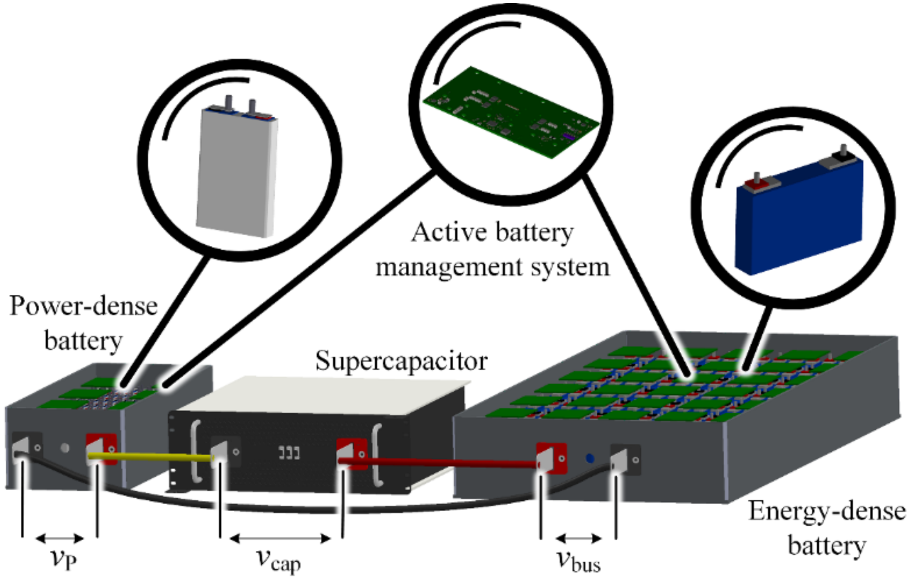
20 kWh, 100 kW CHESS Hardware Setup

Energy storage element	Parameter	Value	
Battery	Chemistry	NMC-Energy	LTO-Power
	Manufacturer	CATL	Toshiba
	Q_{nom} [Ah]	50	2.9
	N_s	108	96
	N_p	1	1
Supercapacitor	Manufacturer	Skeleton Technologies	
	C/module [F]	88	
	$R_{ESR,cap}$/module [mΩ]	6.2	
	Modules	2 connected in series	





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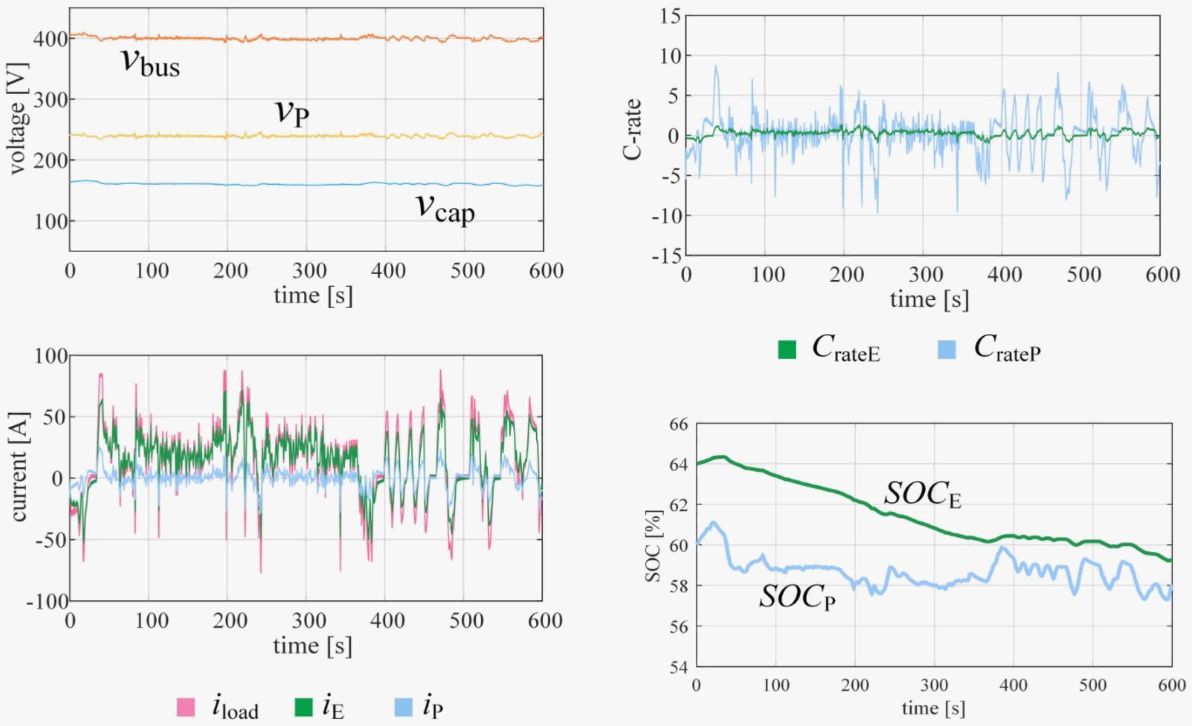
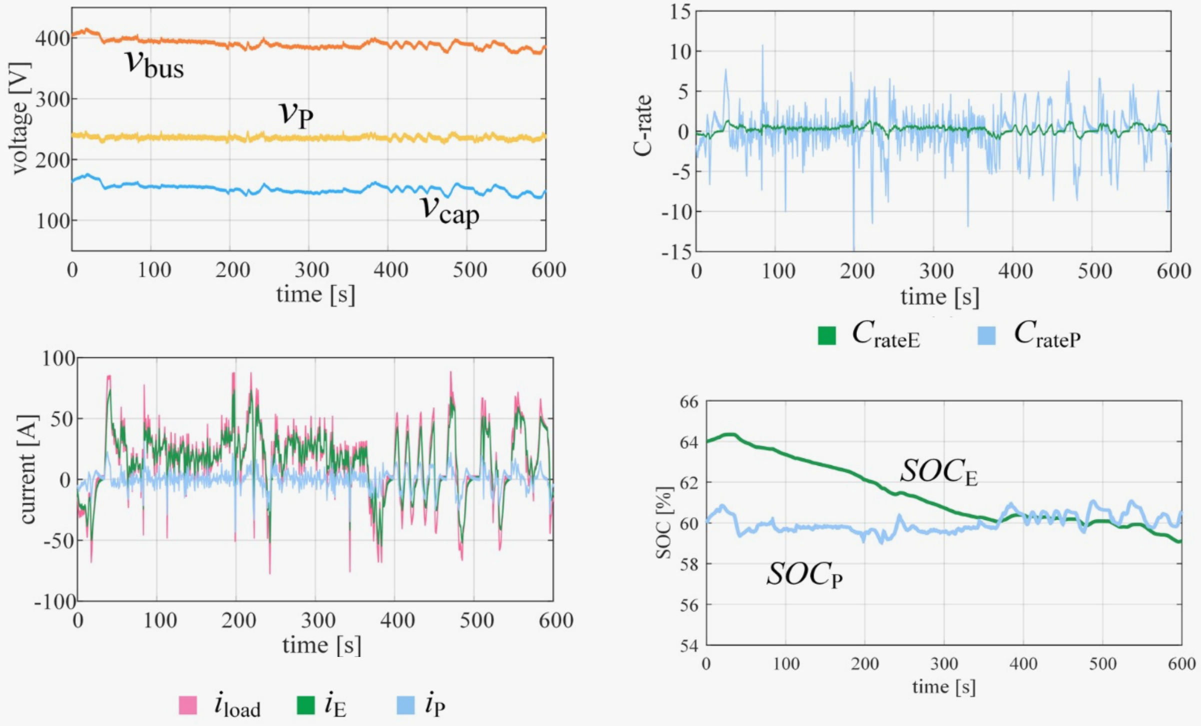
CHESS Hardware Validation

Simulation



Hardware



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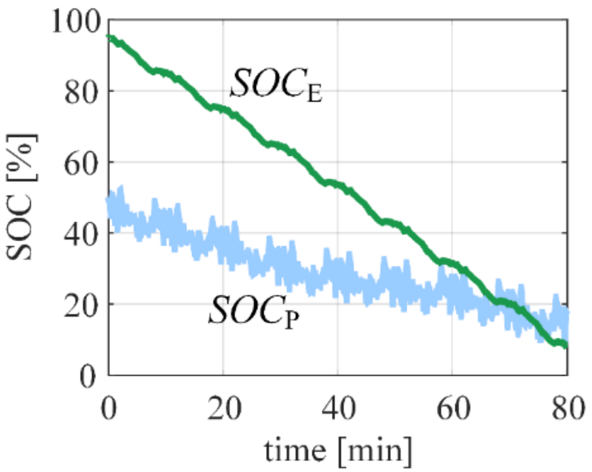
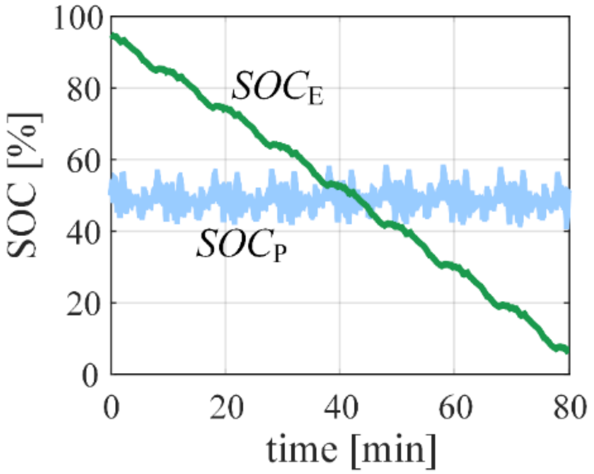
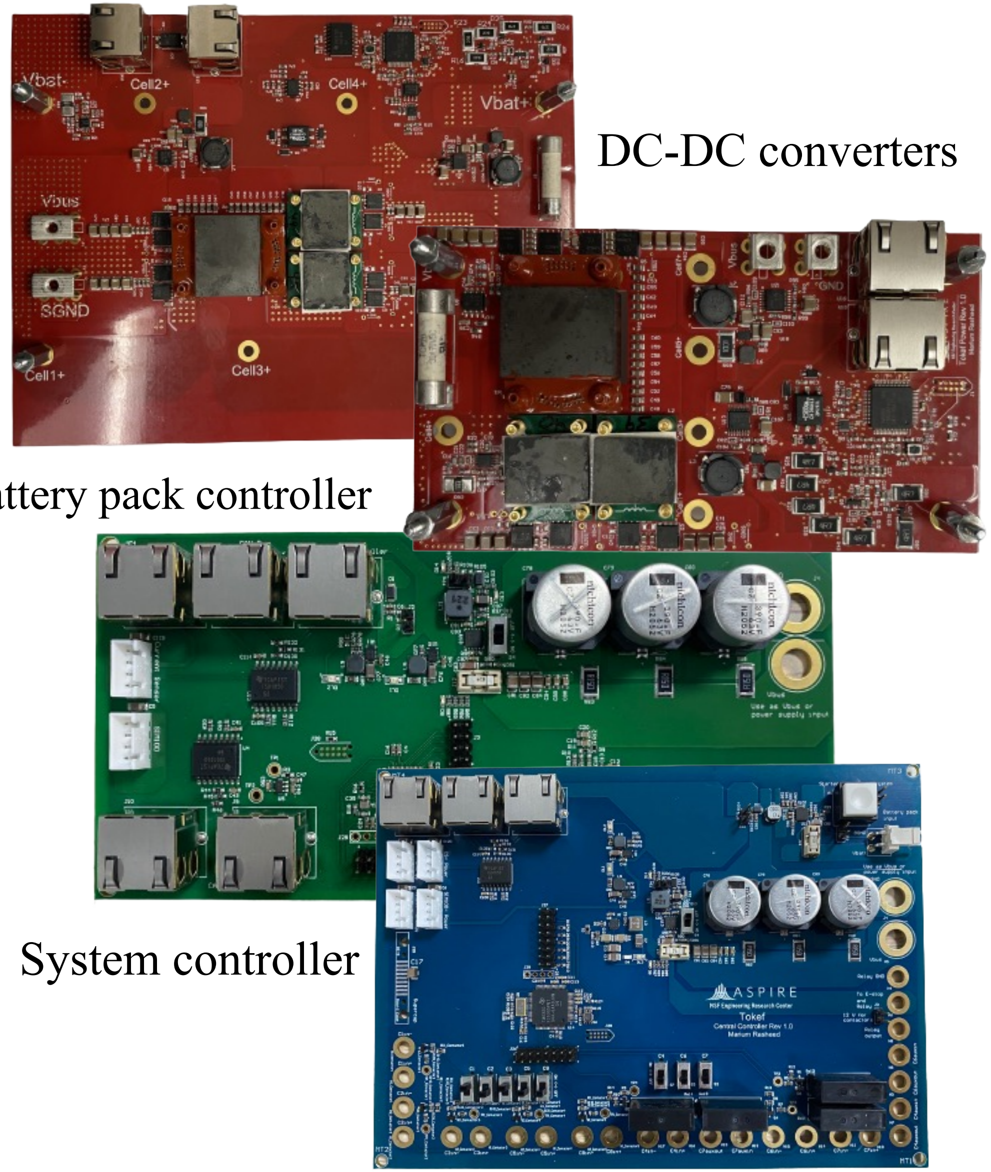
Improving Health of Batteries through Energy Balancing

Without energy balancing



With energy balancing





DC-DC converters

Battery pack controller

System controller

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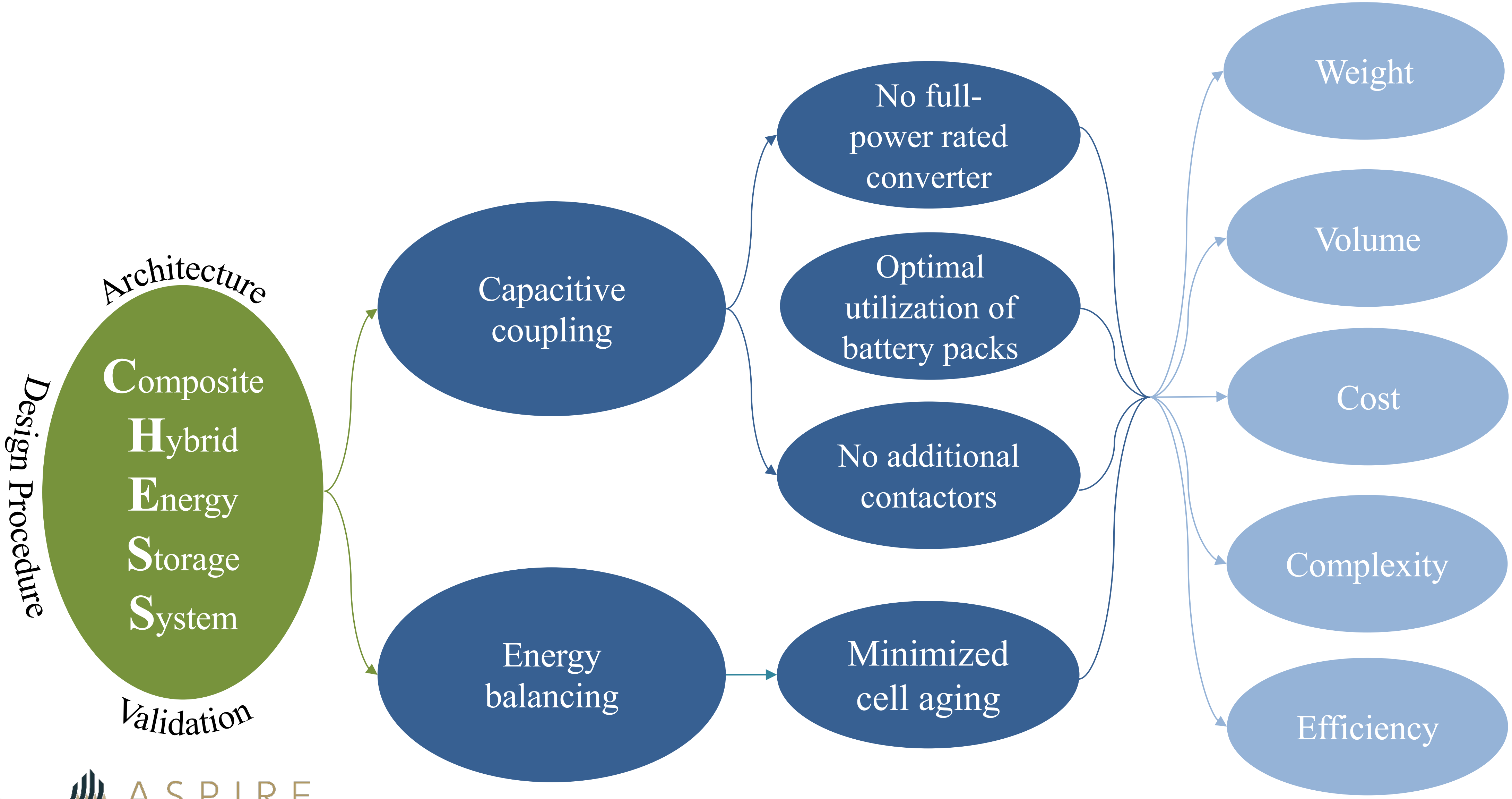
Conclusions and Future Work



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Pathway to Sustainable Electrified Transportation

Same range with smaller batteries

\+

Greater range with same batteries

\+

Longer and healthier batteries

\+

Pathway to widespread adoption of electric vehicles and dynamic charging

The first capacitively-coupled energy storage system that reduces electric vehicle battery system weight by 40%* to counter range anxiety.

More energy for the same weight: increase in range

*compared to a conventional single-chemistry battery system

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References

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Thank You

Take a picture to view the full paper and the hardware demonstration video

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