MODELING BATTERY DEGRADATION IN PHEVS

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Battery Manufacturer: How long will my battery last in the field?

PHEV owner: Will I ever have to replace the battery?

V2G operator: How will my V2G app degrade the battery?

PHEV integrator: How long will I warranty the pack for?

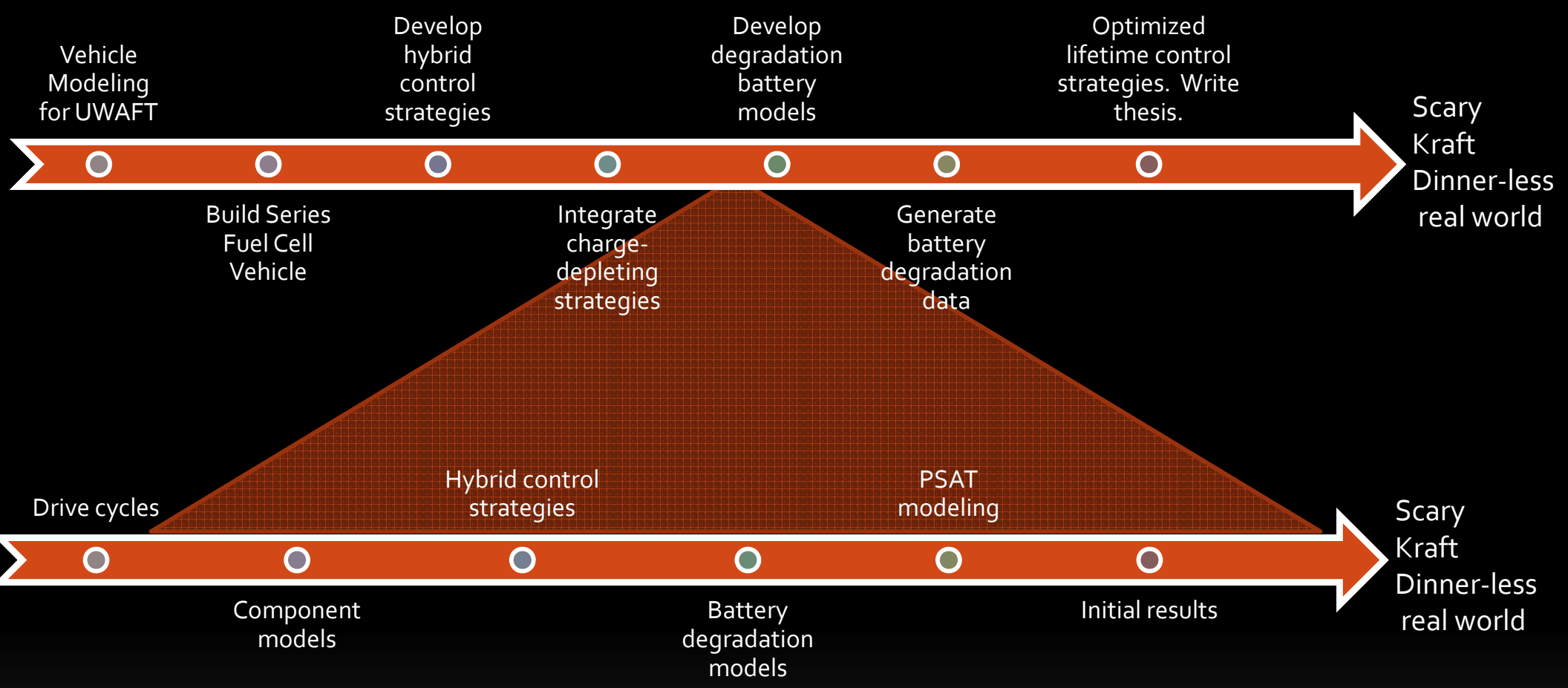
battery manufacturer

Purpose | Hybrid Headache

Develop lifetime vehicle models that can predict PHEV battery life.

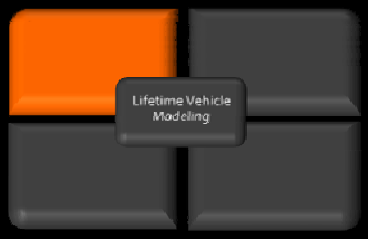
Use models to develop advanced hybrid control algorithms to maximize performance over the life of the vehicle.

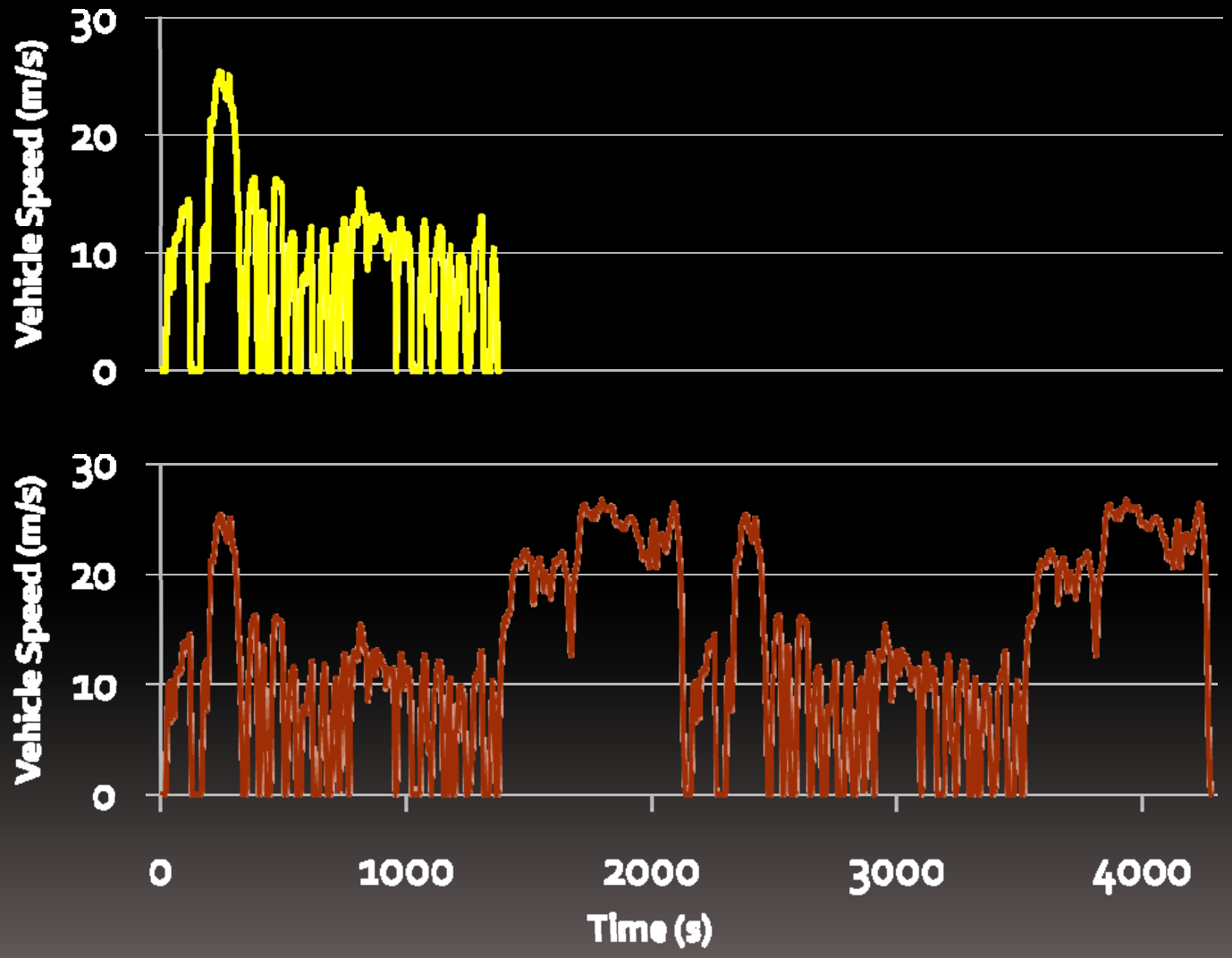
My Agenda



Your Agenda for the Next 15 Minutes

Agenda

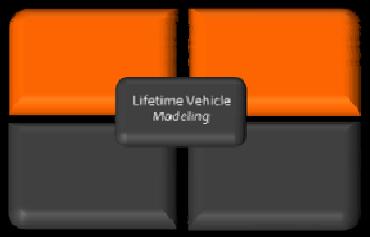




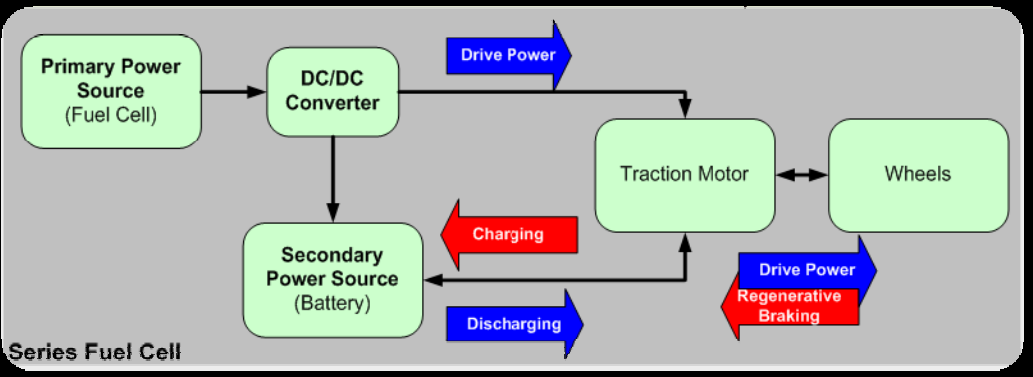
UDDS
12 km
91.2 km/h max
31.5 km/h average

2xEPA combined
57 km
96.4 km/h max
48.0 km/h average

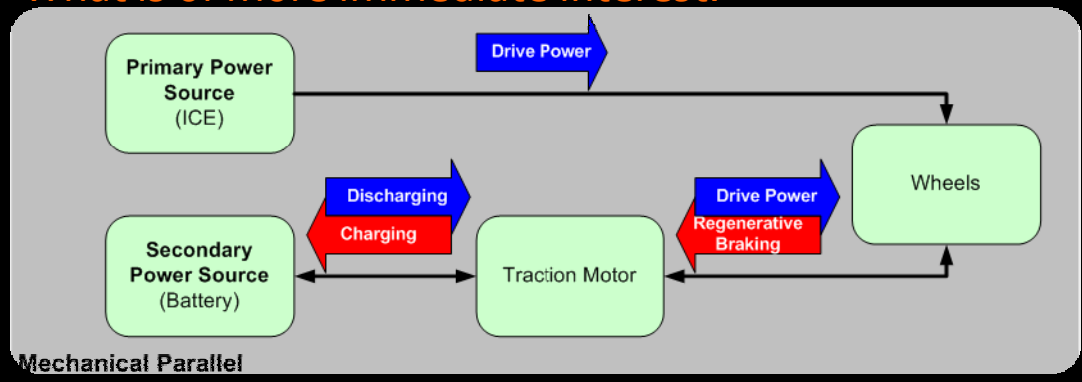
Modeling | Drive Cycles



What I have models for.

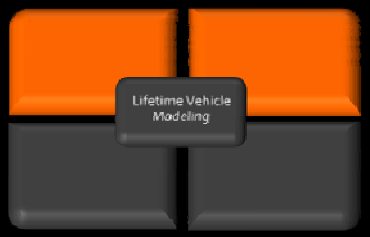


What is of more immediate interest.



	Motor Power	Fuel Cell Power	Battery Power
Power Split	$P_{Motor} \geq 0$	$0 \leq P_{FC} \leq P_{Motor}$	$0 \leq P_{Batt} \leq P_{Motor}$
Fuel Cell Propulsion and Charge	$P_{Motor} \geq 0$	$P_{Motor} \leq P_{FC} \leq P_{FCmax}$	$P_{Batt} \leq 0$
Regenerative Braking	$P_{Motor} \leq 0$	$0 \leq P_{FC} \leq P_{FCmax}$	$P_{Batt} \leq 0$

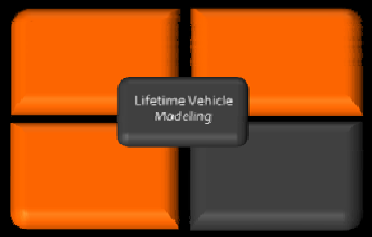
Modeling | Components

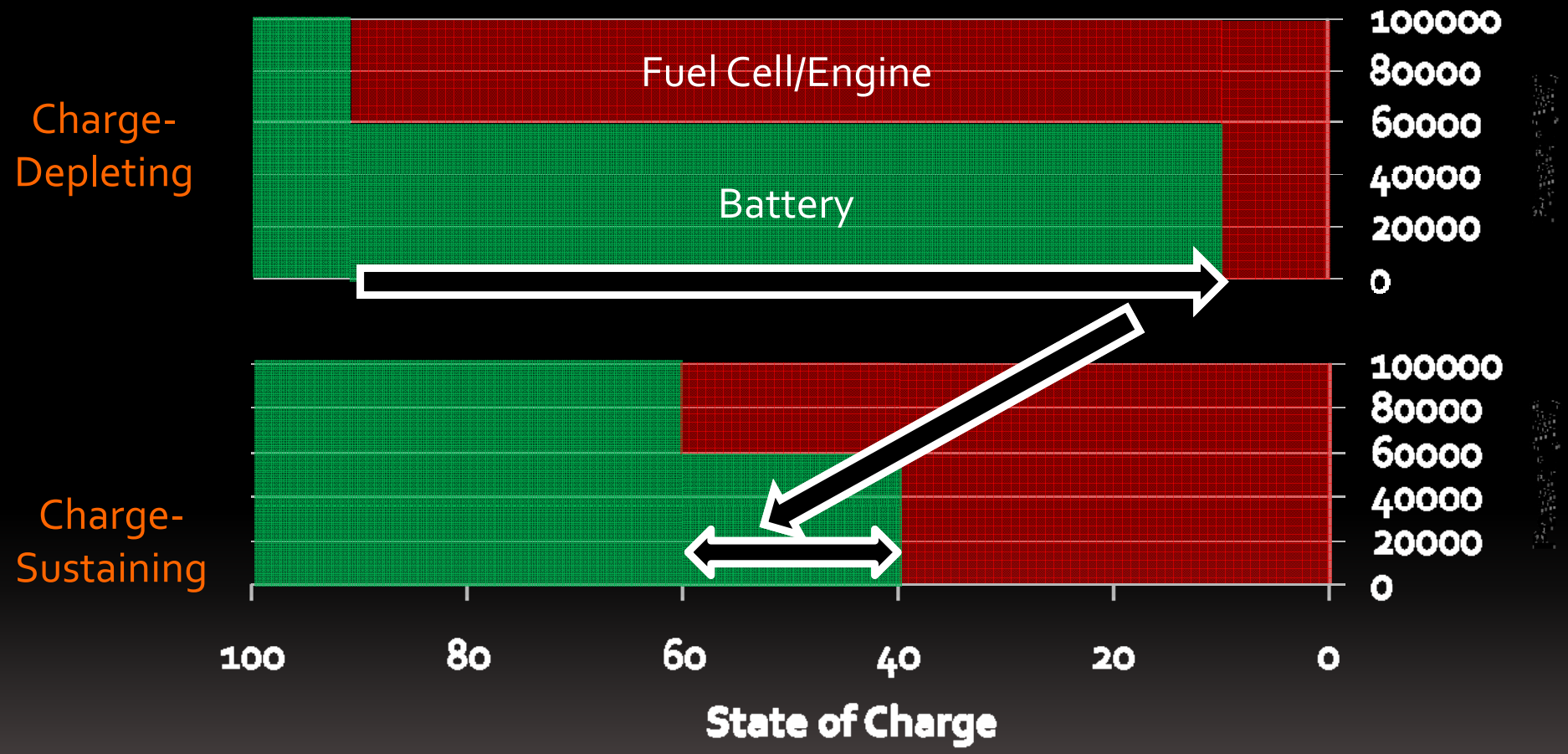


Component	Make/Model	Specifications	
Fuel Cell Stack	Hydrogenics/HYPM 65kW	Max Power: Voltage Range: Current Range:	65kW 190-300V 0-300A
Hydrogen Storage	Dynetek/ZM180	Max Pressure: Tank Capacity: Tank Volume:	5000 psi 4.31kg H2 178L
DC/DC Converter	Custom UWAFT Design and Construction	Input Voltage Range: Output Voltage Range: Converter Type:	190-310V 300-385V Boost
Motors (2 units)	Ballard/312V67	Peak Power: Continuous Power: Max Torque:	67kW 32kW 190Nm
Motor Controllers (2 units)	Ballard/312V67	Continuous Power: Input Voltage: Output Current:	67kW 260-385V 280A RMS
Battery Pack	Cobasys/NiMHax288-60	Voltage Range*: Capacity: Energy:	275-336V 8.75 Ah 3.8 kWh

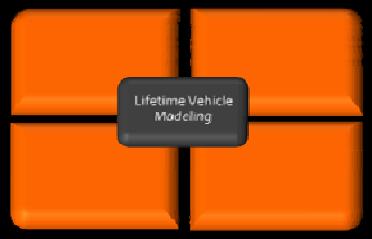
8.75 Ah ← Charge-sustaining
...double?

Modeling | Components





Modeling | Hybrid Controls



Values Estimated

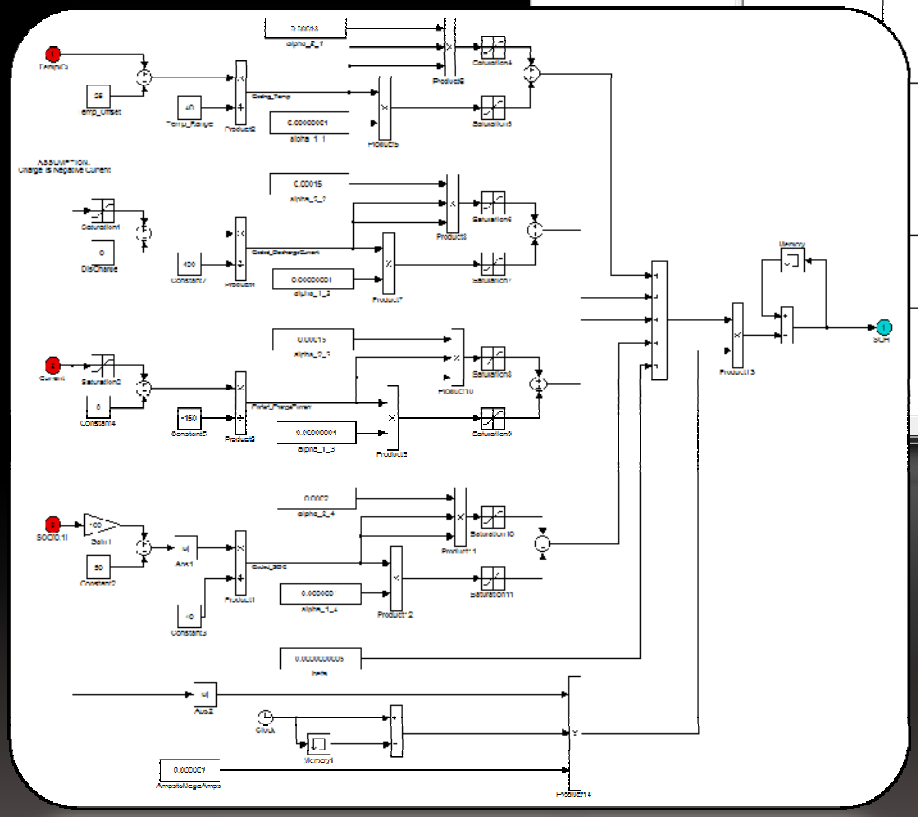
$$\text{[illegible]} = \frac{\text{[illegible]}}{\text{[illegible]}}$$

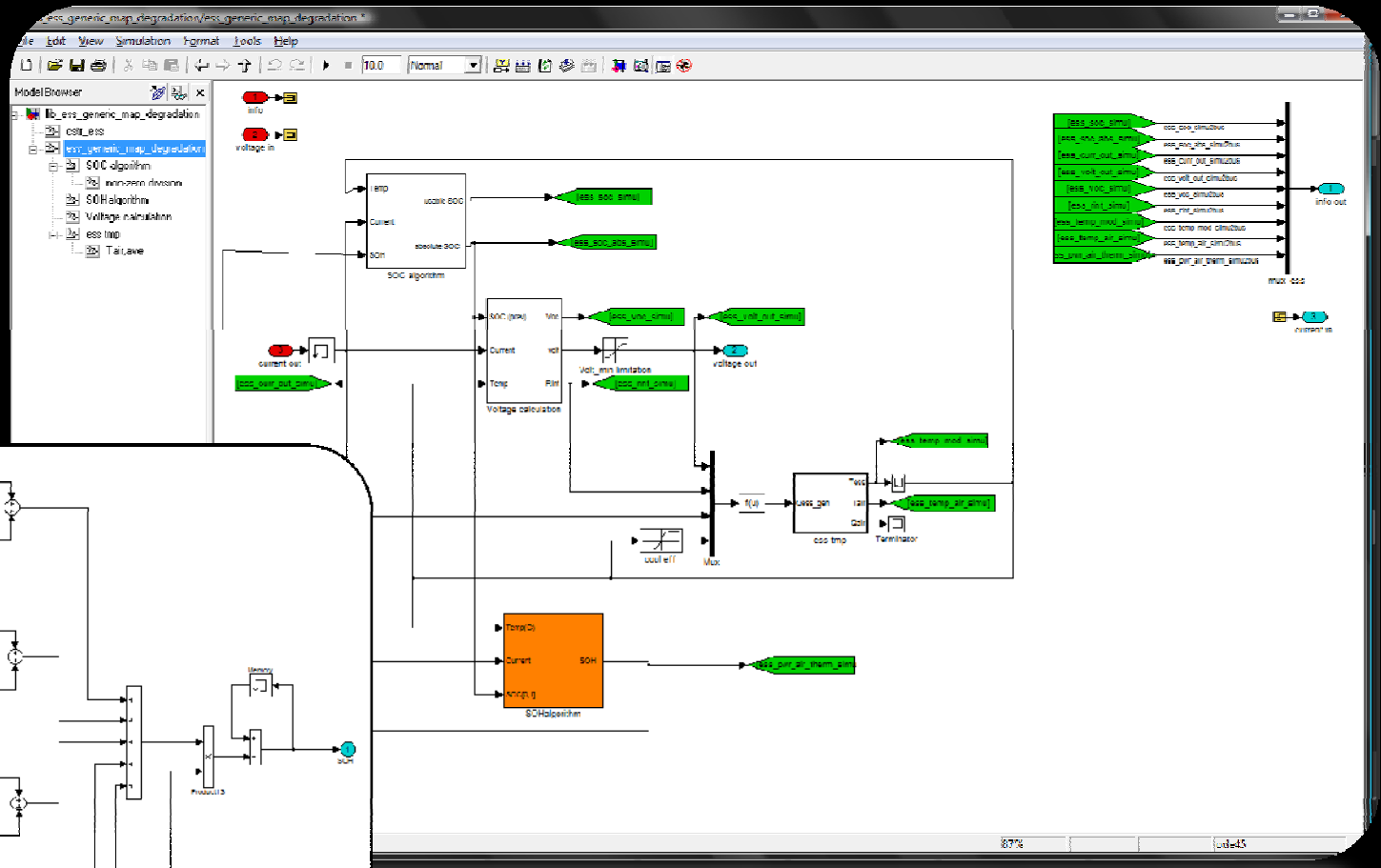
$$\frac{\text{[illegible]}}{\text{[illegible]}} = \text{[illegible]}_{,2}\ \text{[illegible]}^2 + \text{[illegible]}_{,1}\ \text{[illegible]} + \text{[illegible]} \qquad \text{[illegible]} = \text{[illegible]}, \text{[illegible]}, \text{[illegible]}, \text{[illegible]}$$

$$x_j = \frac{(\text{[illegible]} - \text{[illegible]})}{(\text{[illegible]} - \text{[illegible]})}$$

Lifetime Vehicle Modeling

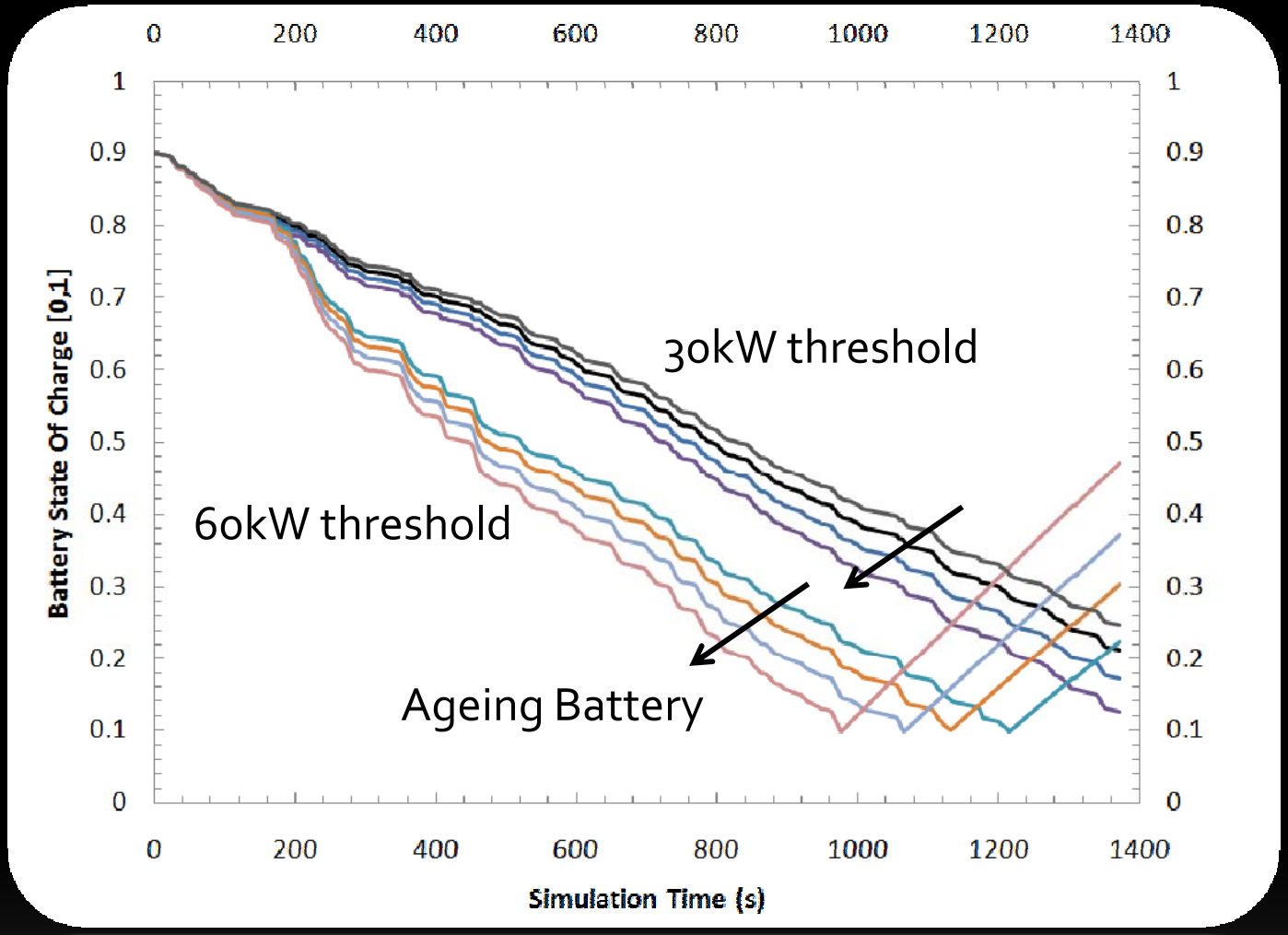
Adapted PSAT model





	Follow Threshold	
	30kW	60kW
UDDS	85,90,95,100	85,90,95,100
2xEPA	85,90,95,100	85,90,95,100

Modeling | Software

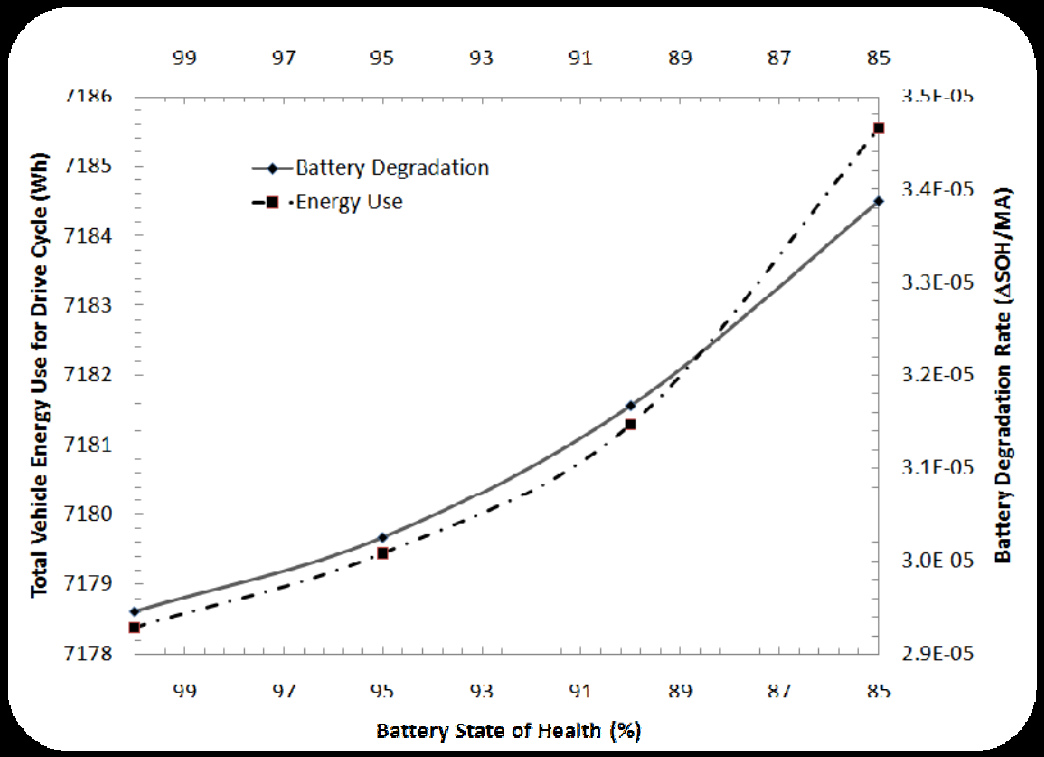


UDDS

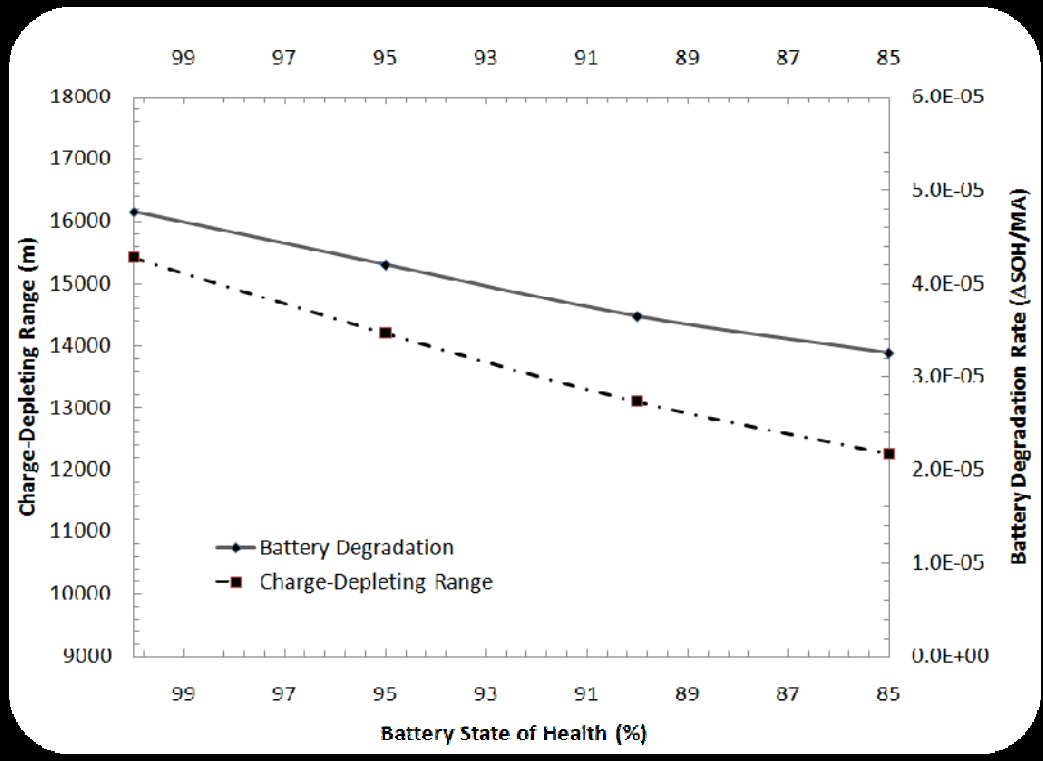
-all depleting with 30 kW
-3kW parasitic load
-2200kg vehicle
-significant decrease in depleting range with decreasing SOH

Results | State Of Charge

UDDS – 30kW – All Depleting



2xEPA – 30kW – Includes Charge-Sustaining



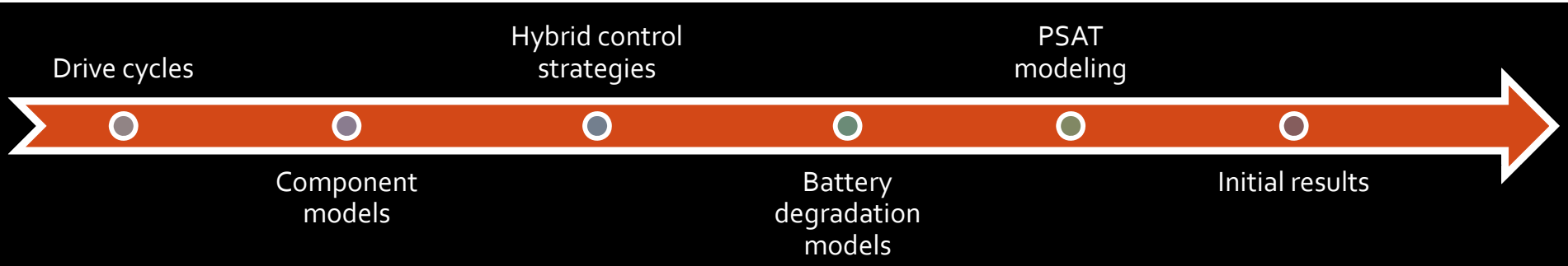
Battery model parameters estimated, only trends are relevant

-Degradation rate for all-depleting drive cycles increase as battery ages

-Degradation rate decreases for change-depleting & charge-sustaining cycles decreases

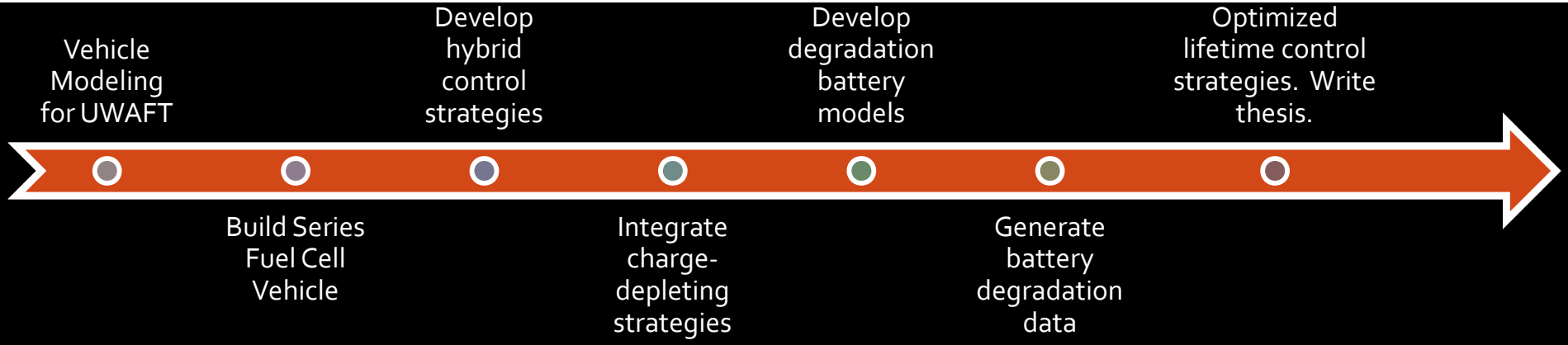
-Energy use increases as battery ages, significance only relevant when parameters not estimated

Results | Degradation Rate



- A battery degradation model has been successfully integrated into PSAT
- A degrading PHEV vehicle model with estimated battery parameters has been simulated
- The extensive interaction between drive cycle, control strategy, and component degradation was illustrated via the battery degradation rate
- Ability to evaluate different control strategy parameters demonstrated

Conclusions | Next Steps



- Integrate power fade
- Update degradation model with actual battery data
- Integrate more sophisticated control algorithms
- Transition to ICE based PHEV model
- Evaluate algorithms on HIL Test Stand
- Integrate V2G impacts

Conclusions | Next Steps

Acknowledgements

- Natural Sciences and Engineering Research Council (NSERC)
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University of Waterloo

Thank you for your time

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Thank You | Questions