MATLAB EXPO 2021

Fuel Cell Virtual Vehicle Models for Fuel Economy, Performance, and Thermal Analysis

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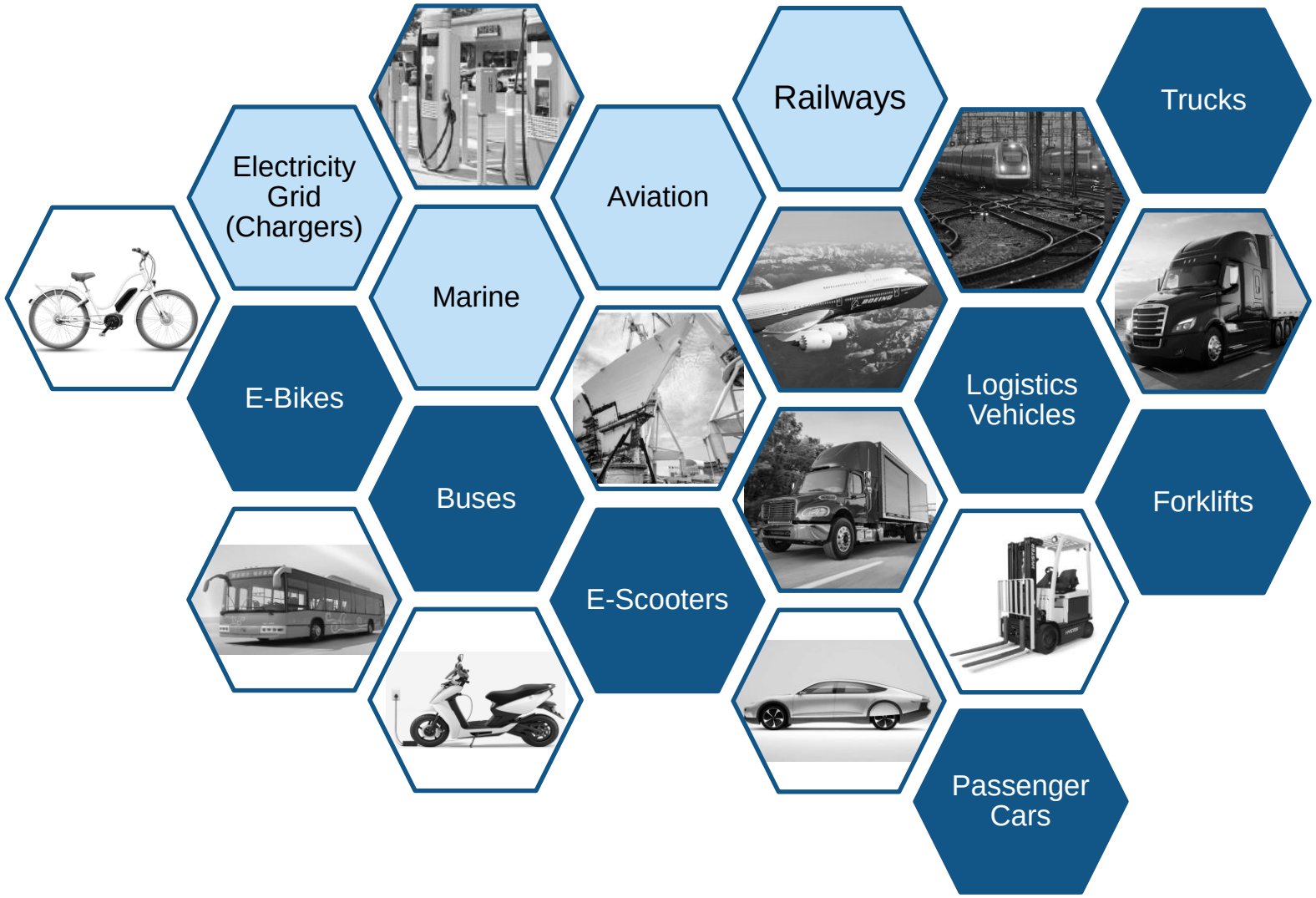
MathWorks

Key Takeaways

- Fuel cell virtual vehicles models enabled by MathWorks tools
  - Realistic environment and testing scenarios
  - Analysis, control design and optimization based on full vehicle simulation

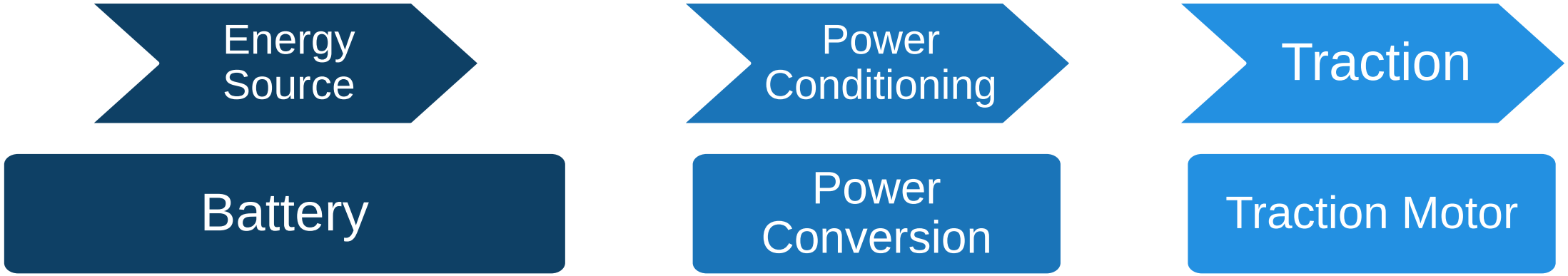
- Methodology and workflows for modeling fuel cell systems
  - First-principles approach based on Physics & Chemistry
  - Data-driven, statistical approach using experimental data or high-fidelity simulations

Transportation Segment: What is Electrification?

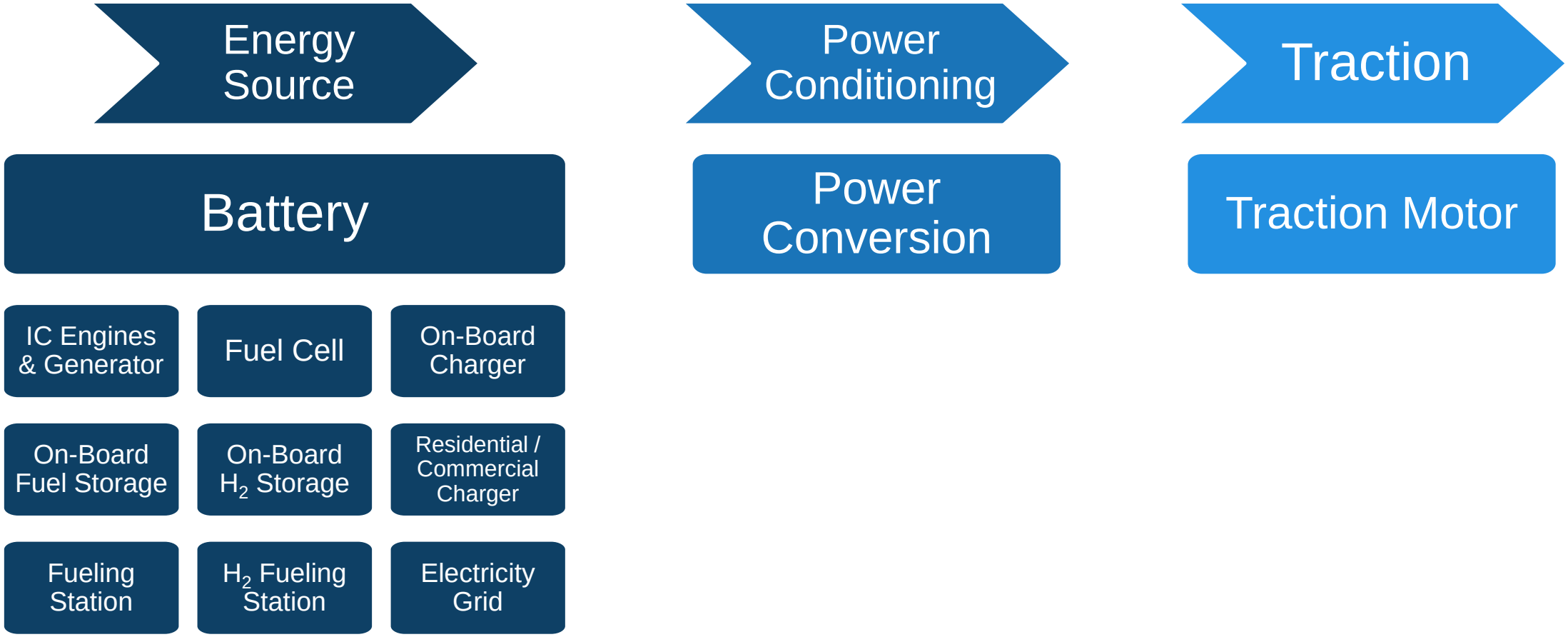


Electrification is the increasing use of electrical technology and energy management to achieve enhanced efficiency, performance and reliability in transportation, industrial systems, consumer and professional equipment, and power generation and transmission.

Automotive Electrification Technologies



Automotive Electrification Technologies



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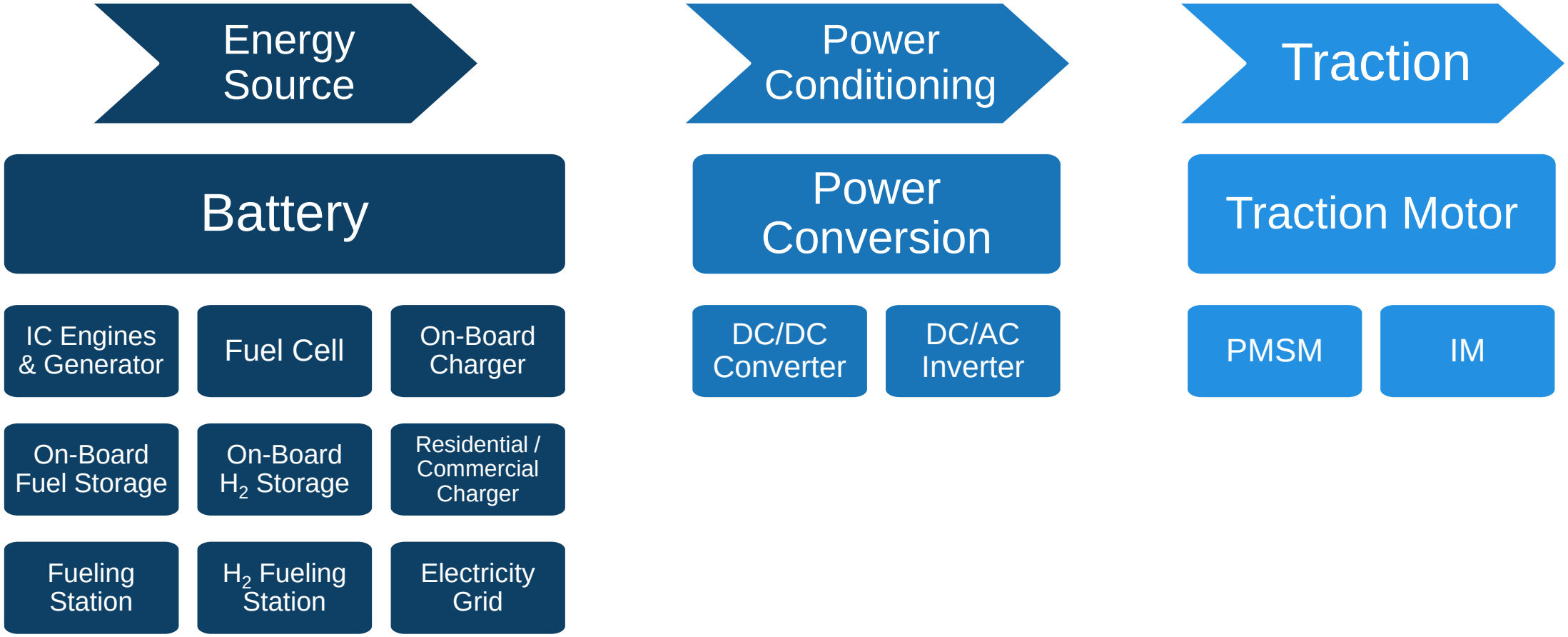

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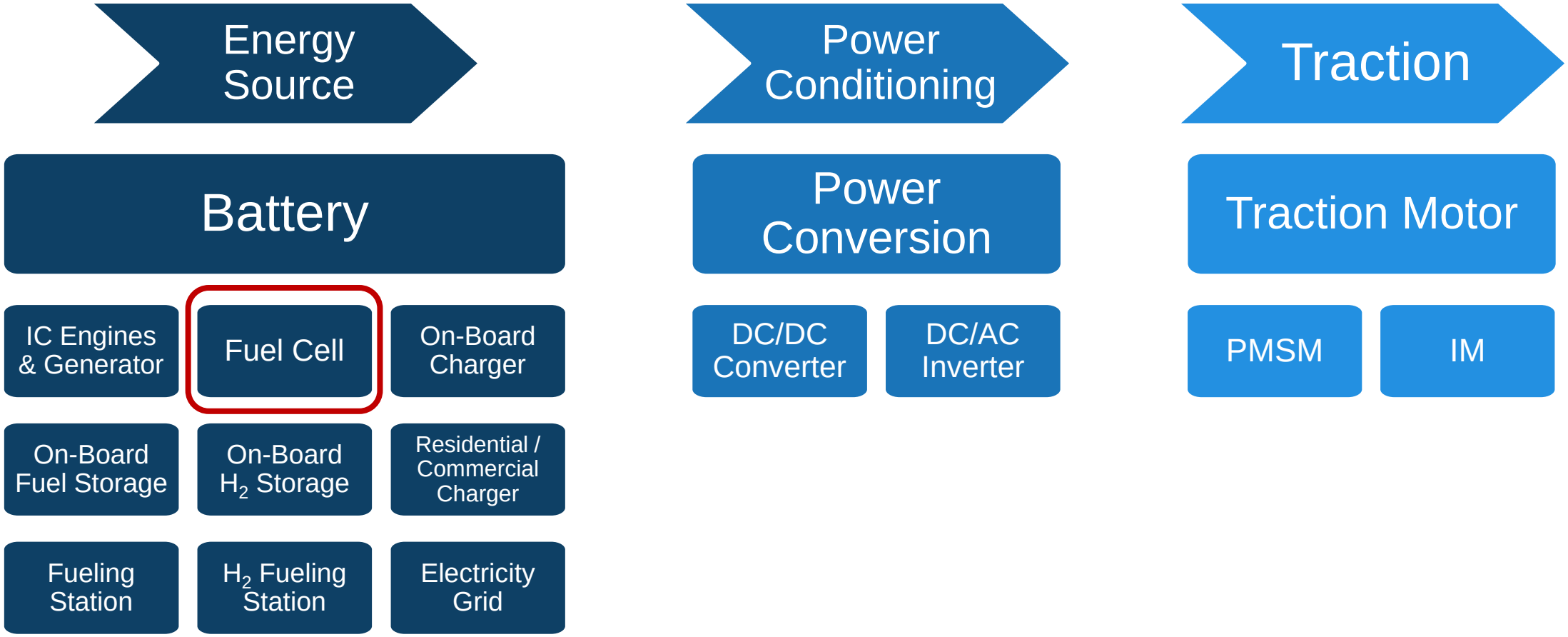

Types of Fuel Cells

Fuel cell type	Electrolyte type	Operating temperature	Catalyst type	Advantages	Weakness	Areas of application
PEM	Polymer Electrolyte Membrane	50-100	Platinum	• Quick start • Operation at room temp. • Air as oxidant	• Sensitive to CO • Reactants need to be humidified	• Vehicle power • Portable power
AFC	Alkaline	90-100	Nickel / Silver	• Quick start • Operation at room temp.	• Need pure O_2 as oxidant	• Aerospace • Military
PAFC	Phosphoric Acid	150-200	Platinum	• Insensitive to CO2	• Sensitive to CO • Slow start	• Distributed generation
SOFC	Solid Oxide	650-1000	$LaMnO_3$ / $LaCoO_3$	• Air as oxidant • High energy efficiency	• High operating temperature	• Large distributed generation • Portable power
MCFC	Molten Carbonate	600-700	Nickel	• Air as oxidant • High energy efficiency	• High operating temperature	• Large distributed generation

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PEM fuel cell is the primary choice in automotive segment.

- Advantages
  - Lower emissions than conventional fuel
  - Better fuel economy than conventional fuel
  - Easier scalability than other systems
  - Lighter than batteries for same power
- Disadvantages
  - Costs are higher
  - Pure H_2 storage and transport is challenging
  - Impurities can degrade system
- Open area – lots of investment!

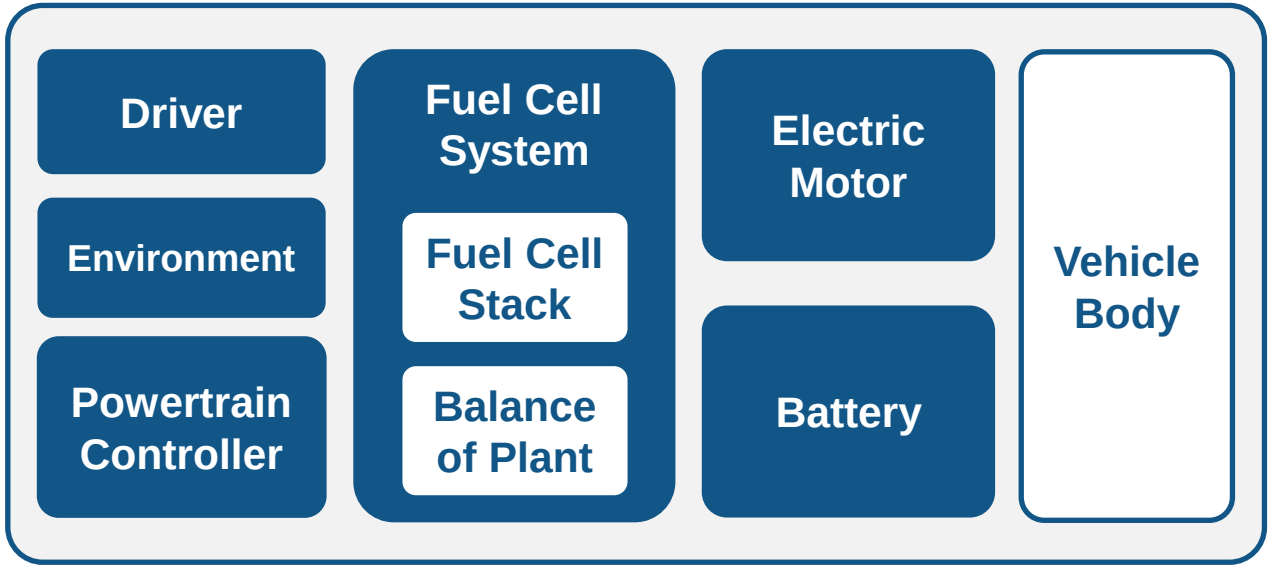
Poll Question 1

- What areas in the Hydrogen value-chain are you working on?
  - PEM fuel cell systems
  - Non-PEM fuel cell systems
  - On-vehicle hydrogen storage and delivery systems
  - Hydrogen re-fueling stations
  - Hydrogen generation systems (e.g., electrolyzers)
  - Other
  - Not Applicable

Poll Question 2

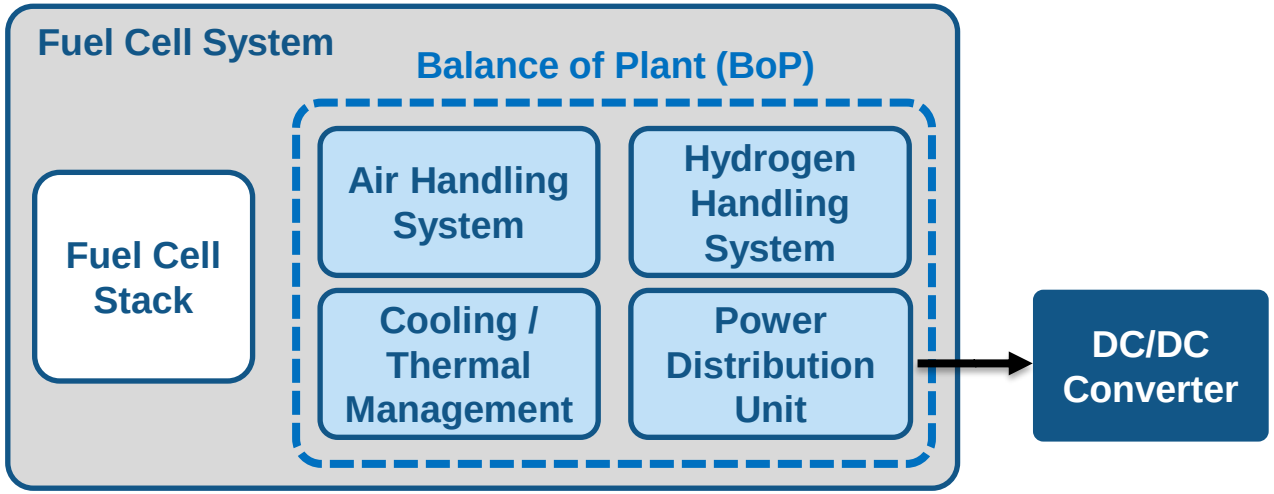
- What areas of fuel cell system modeling and simulation are you working on?
  - Fuel cell stack
  - Air handling side
  - Hydrogen handling side
  - Thermal management system
  - Vehicle integration (hybridization strategy / energy management / component sizing / design tradeoff analysis / verification and validation, etc.)
  - Control development and/or code generation
  - Other
  - Not Applicable

Fuel Cell Virtual Vehicle (FCEV) Architecture



Challenge: fuel cell system interacts with the rest of the electrical powertrain

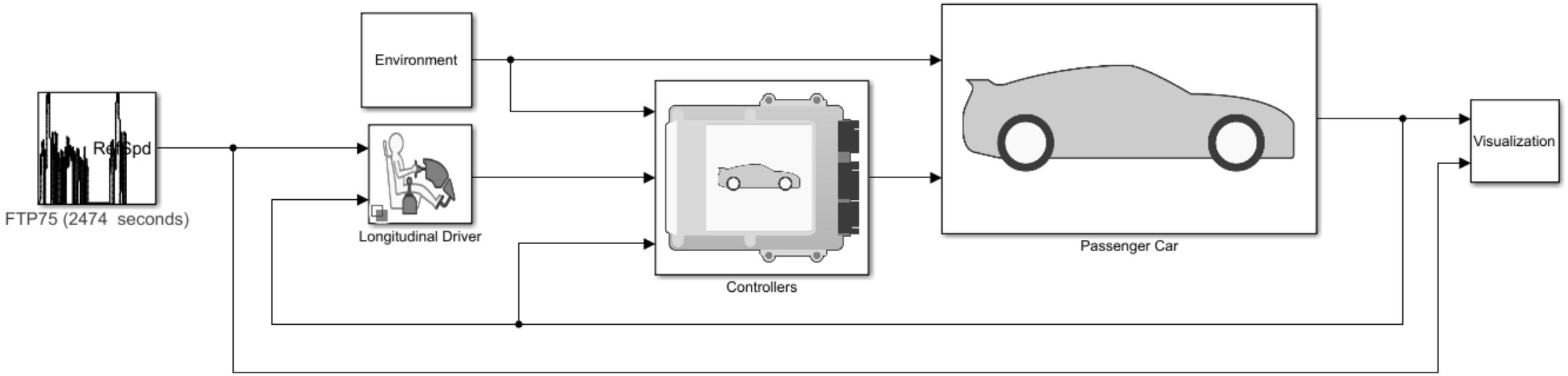
- Drive cycles and operation scenarios
- Motor, battery, DCDC converter, drivetrain
- Supervisory and local control algorithm



Fuel cell system operation in a FCEV

- Determine instantaneous power demand
- Convert power demand to current demand
- Distribute current demand between battery and fuel cell
- Translate current command to H_2 / Air flow commands

Use Case Video: Control Development for Fuel Cell EV



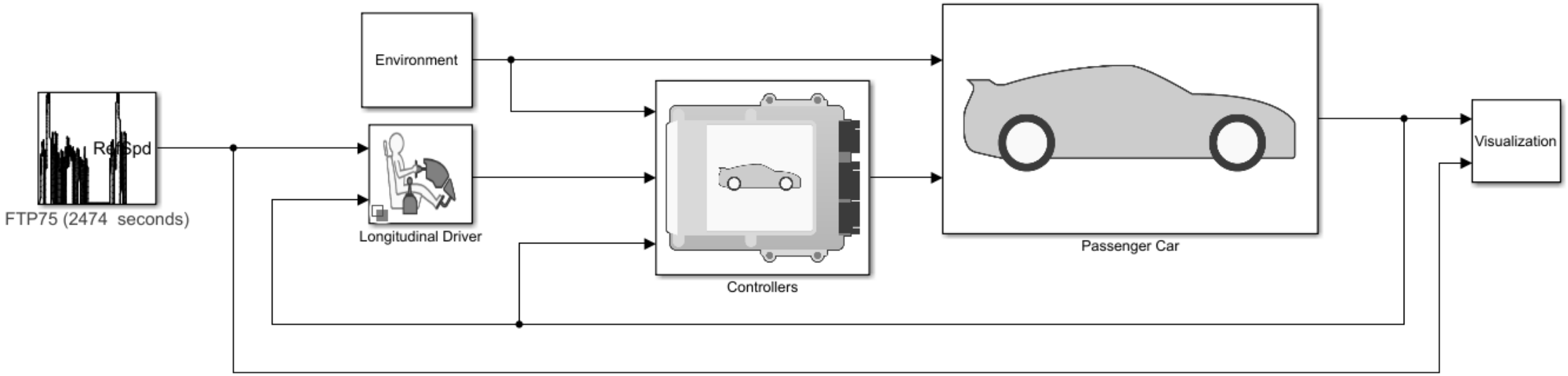
Modeling Fuel Cell Virtual Vehicle

Enable delivery of fuel cell based systems, through vertical integration

model fuel cells, electrified powertrain and virtual vehicle

integrate fuel cell in virtual vehicle models

calibrate and **analyze** fuel cell virtual vehicles



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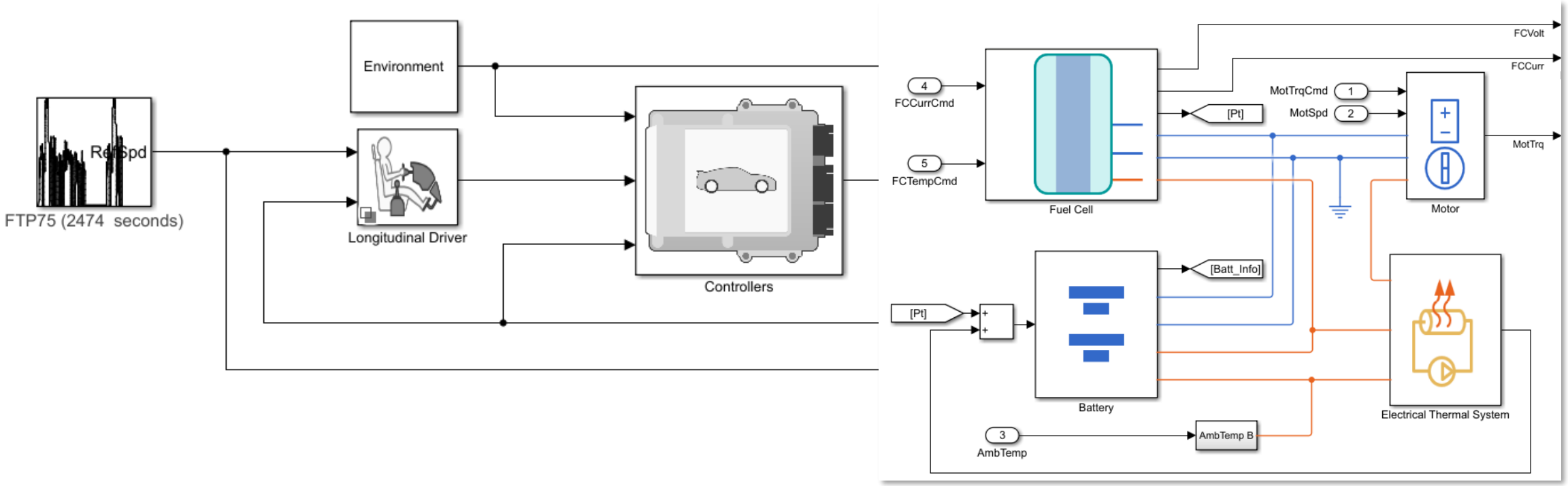
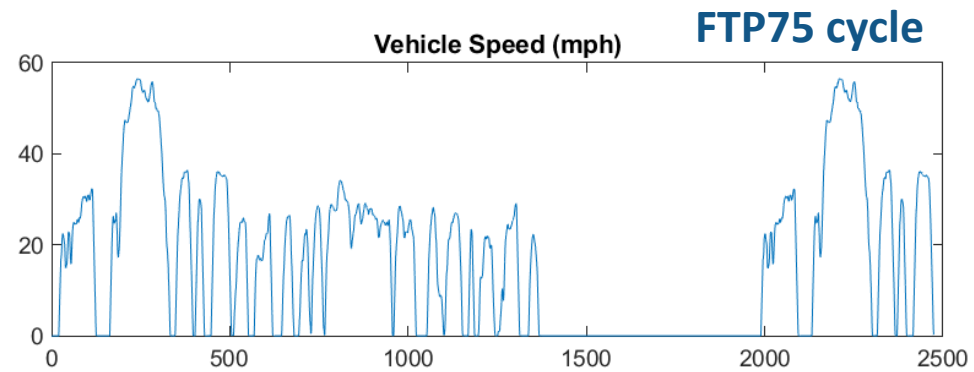
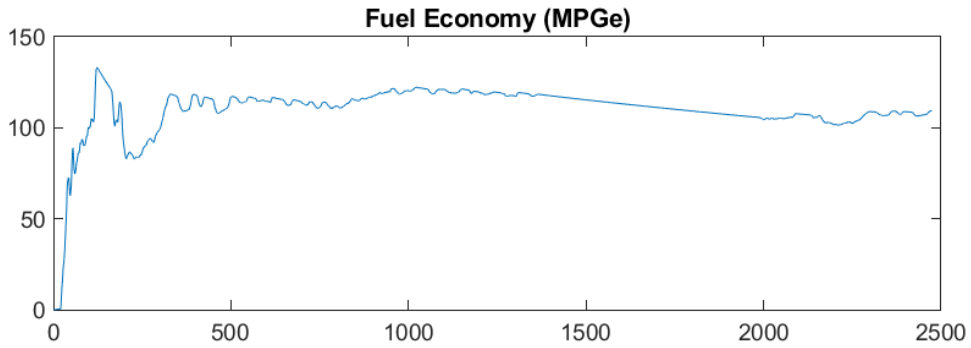


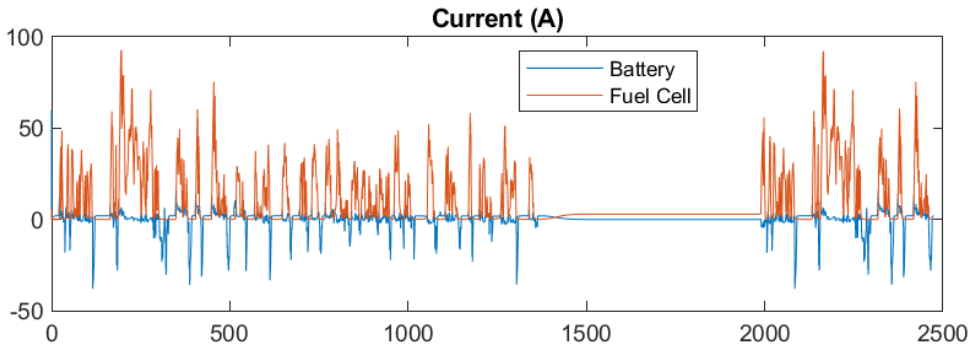
Electric plant model

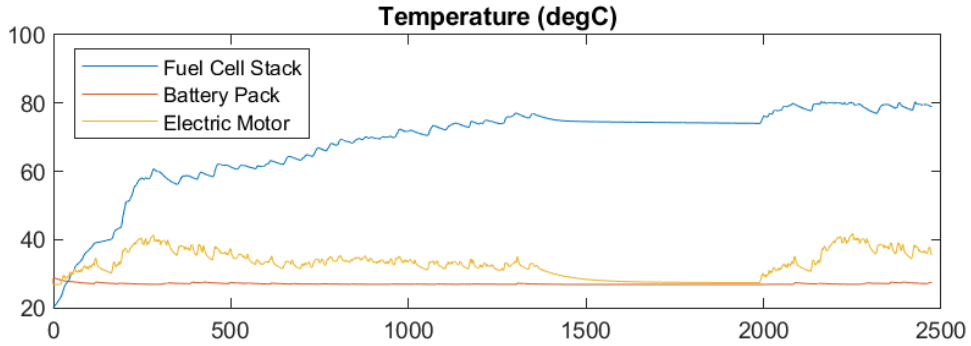
Example: Fuel Cell Virtual Vehicle Simulation

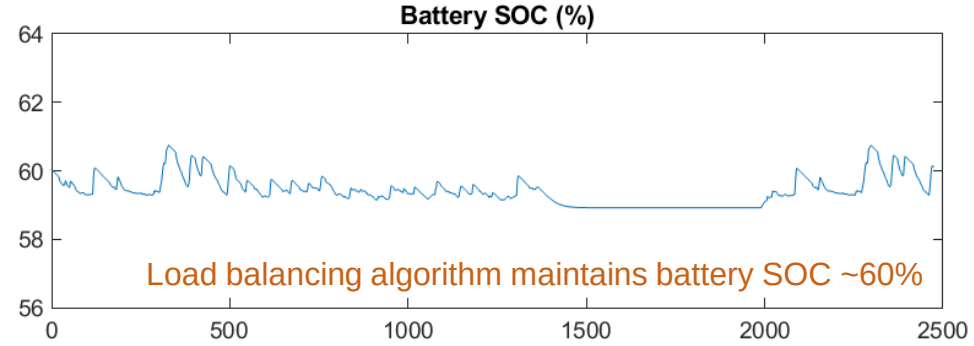
- Full vehicle fuel economy, performance and thermal analysis
- Enables model-based control design











Modeling Fuel Cell System

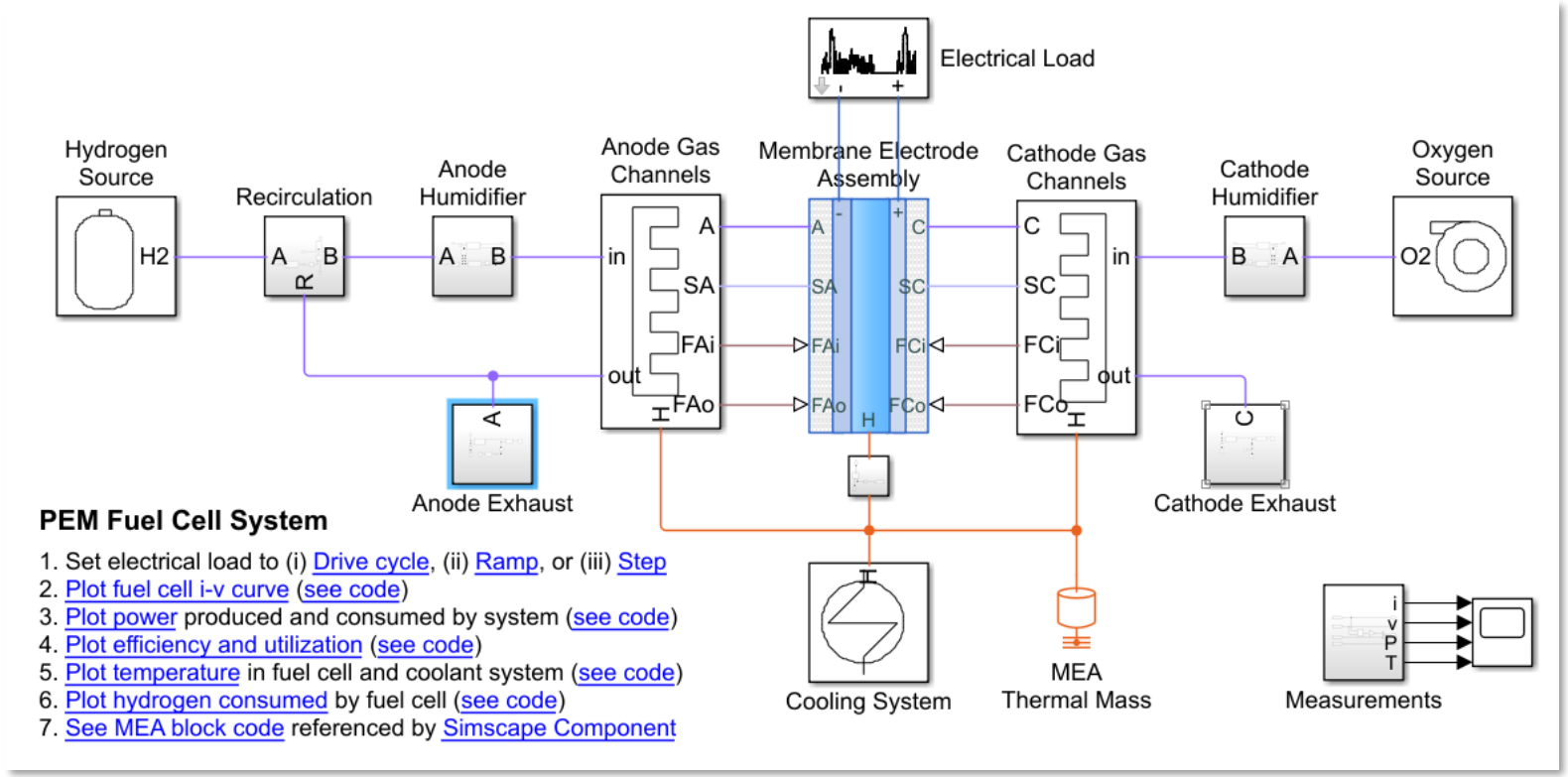
- Thermodynamics Oriented Methodology
  - Electrochemistry & balance of plant
  - Design and optimize FC system
  - Higher fidelity, more details
  - Physical modeling tools

- System-Integration Oriented Methodology
  - Input-output / lookup table / statistics based
  - Integration and supervisory control
  - Fast running, less details
  - Statistical modeling tools

Fuel Cell System Model: Thermodynamics Oriented

- Fuel Cell Stack
  - Implemented in Simscape language for reactions
- Balance of Plant
  - Compressor
  - Humidifier
  - Cooling system
  - H2 recirculation
  - Water management

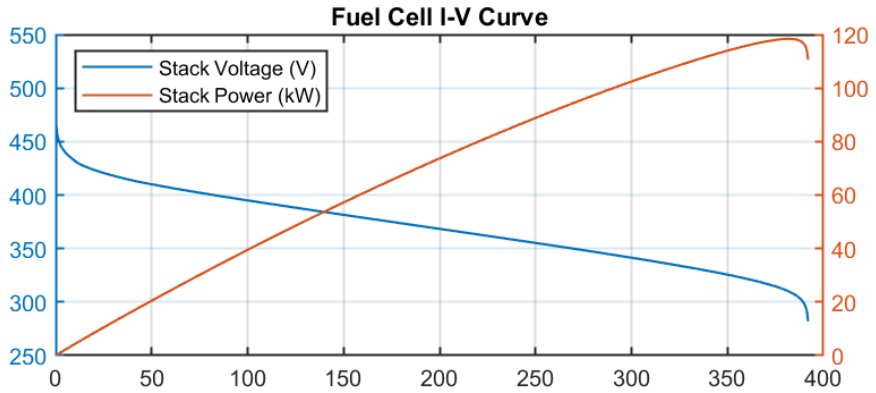
Shipping example in R2021a: PEM Fuel Cell System

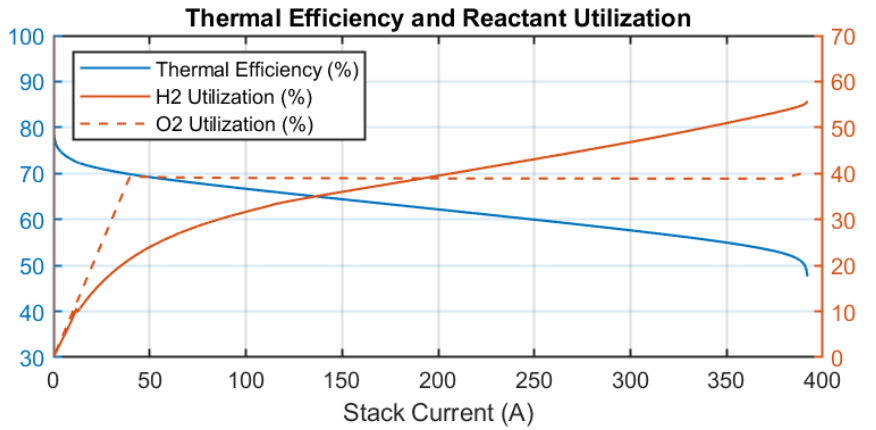


Example: Characteristic Curves and Drive-Cycle Study

Stack Characteristic Curves

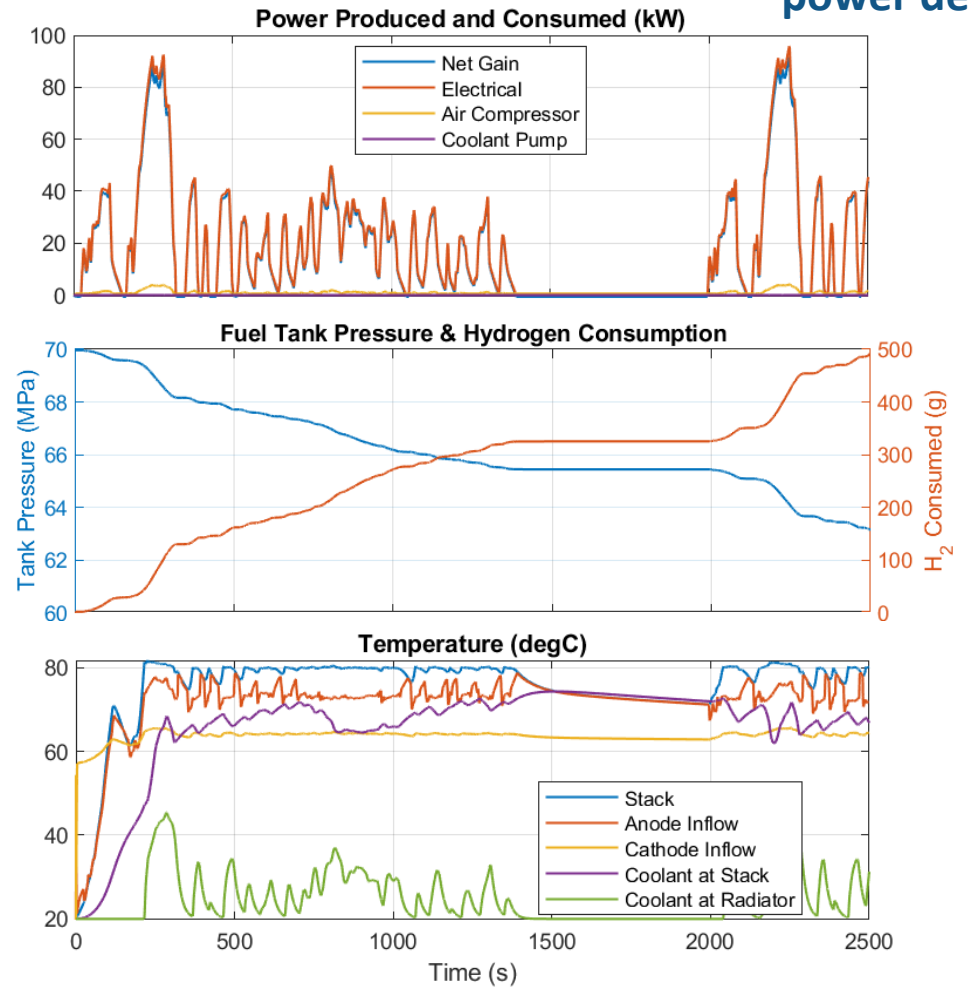
(Current sweep)





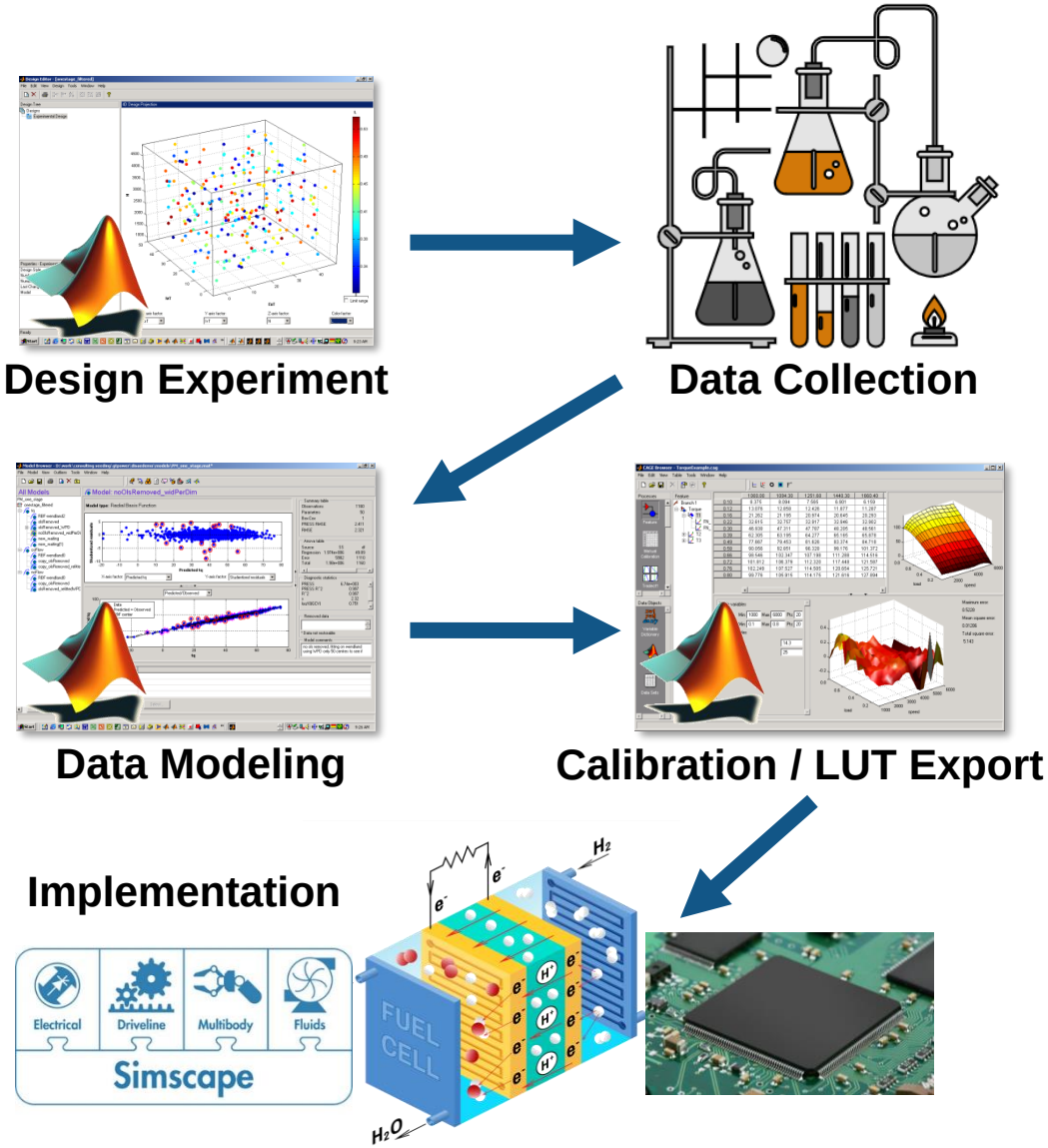
Drive-Cycle Response

Based on FTP75 power demand



Fuel Cell System Model: System-Integration Oriented

- Workflow to build lookup table (LUT), statistics-based model
  - From lab/experimental datasets
  - Or from high-fidelity simulations
  - Fast-running models suitable for integration study and control development
- Model-Based Calibration Toolbox
  - Apps and design tools for modeling and calibrating complex nonlinear systems



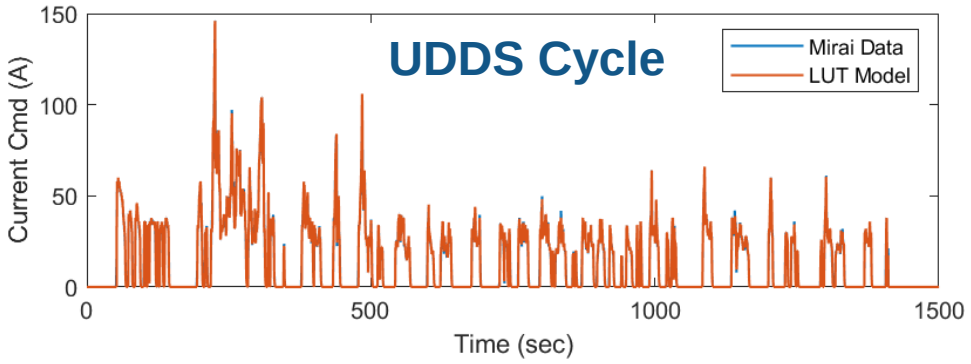
Example: Build Fuel Cell System Model from Lab Data

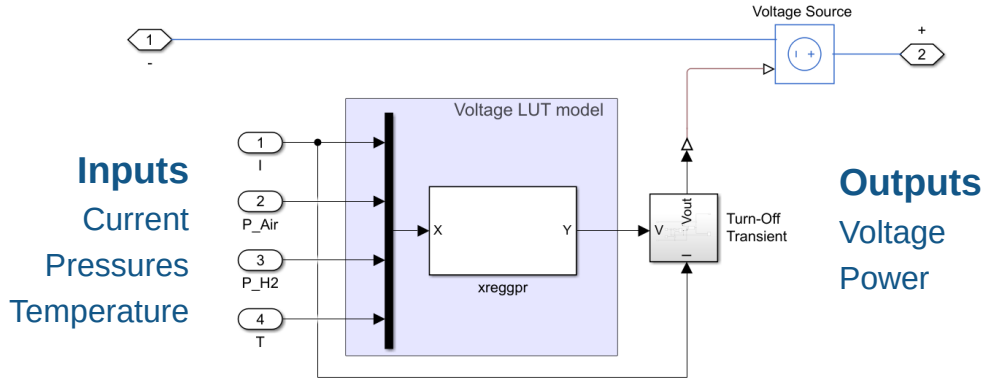
- Lab data collected from an instrumented fuel-cell vehicle

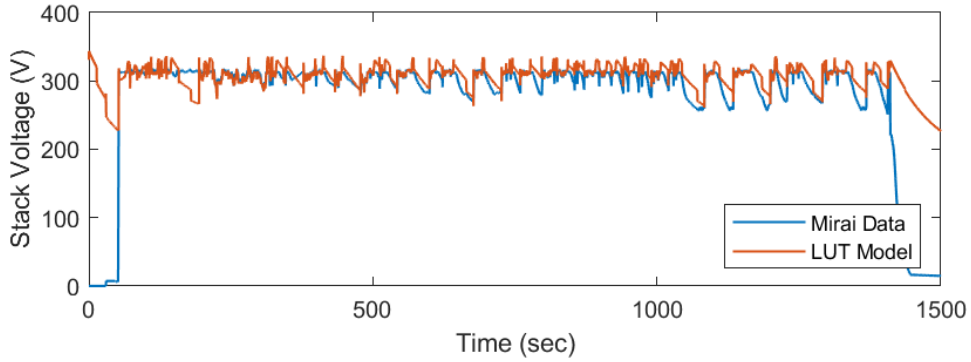
  Argonne National Laboratory, "*Technology Assessment of a Fuel Cell Vehicle: 2017 Toyota Mirai*", ANL/ESD-18/12

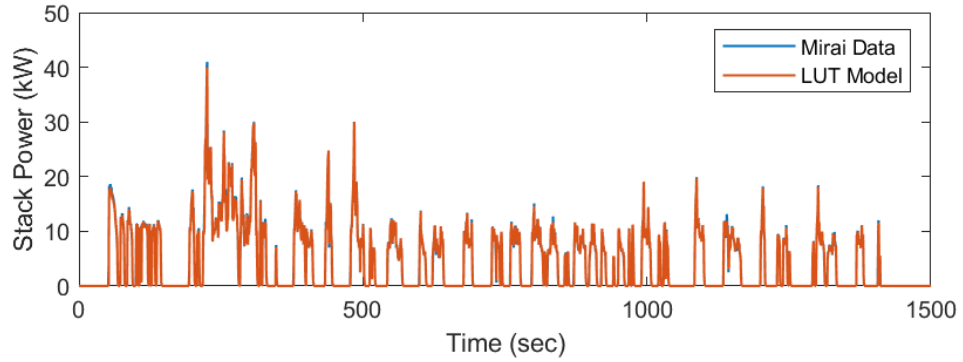
  – MBC model generated and exported for further simulation & validation

  – Fast-track from lab data to simulation model









Conclusion

- PEM fuel cell systems are trending in powertrain electrification
- MathWorks tools enables fuel cell virtual vehicle models
- MathWorks tools and workflows to model fuel cell systems using
  1) First-principles approach based on the electro-chemistry of fuel cell stacks
  2) Data-driven, statistical approach using experimental data or high-fidelity simulations
- Efficient, customizable solutions for fuel economy, performance, and thermal analysis of fuel cell electric vehicles

Final Poll Question

- Are you interested in more information?
  - Yes, I have some questions and would like to talk
  - Yes, I would like to schedule follow up session on this topic with my team
  - Not at this time

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Thank you