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FUEL CELL SYSTEMS

THE CHALLENGE OF MULTIPHYSICS SIMULATION

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Fuel Cell Systems
The Challenge of Multiphysics Simulation

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Special Thanks To
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Eva Pelster
from MathWorks

Agenda

- Motivation
- Fuel Cell System
- Development and Simulation Approach
- Challenges
- Summary and Outlook

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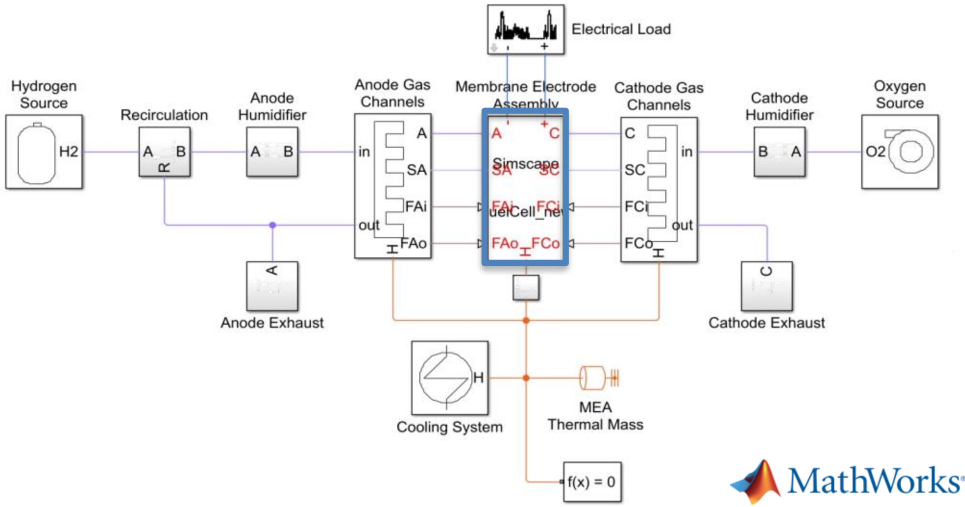
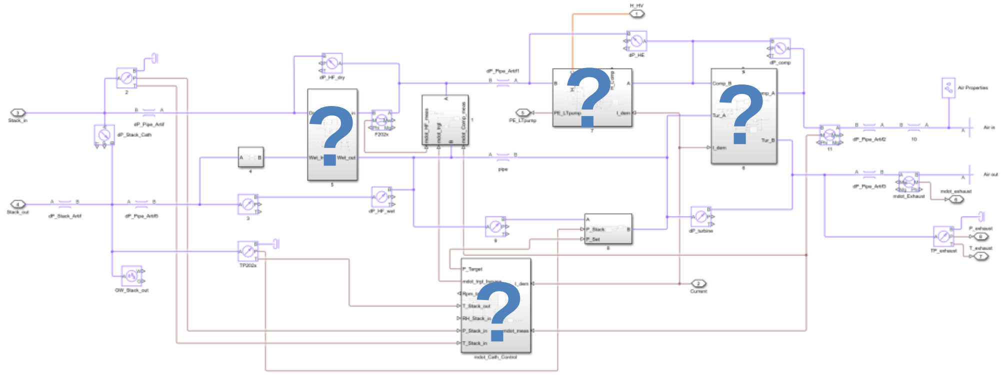
THE CHALLENGE OF MULTIPHYSICS SIMULATION

Motivation

- Our Goal = Proof of Concept
  - Specify “Balance of Plant” (BoP) components of a complete fuel cell system
  - Provide control strategies
  - Support software development with Co-Simulation → provide initial calibration for test bench
  - Acceptable simulation performance
  - Use MathWorks environment → MATLAB/ Simulink/ Simscape/ Stateflow
- Status at project start
  - Basic Simscape model from MathWorks used





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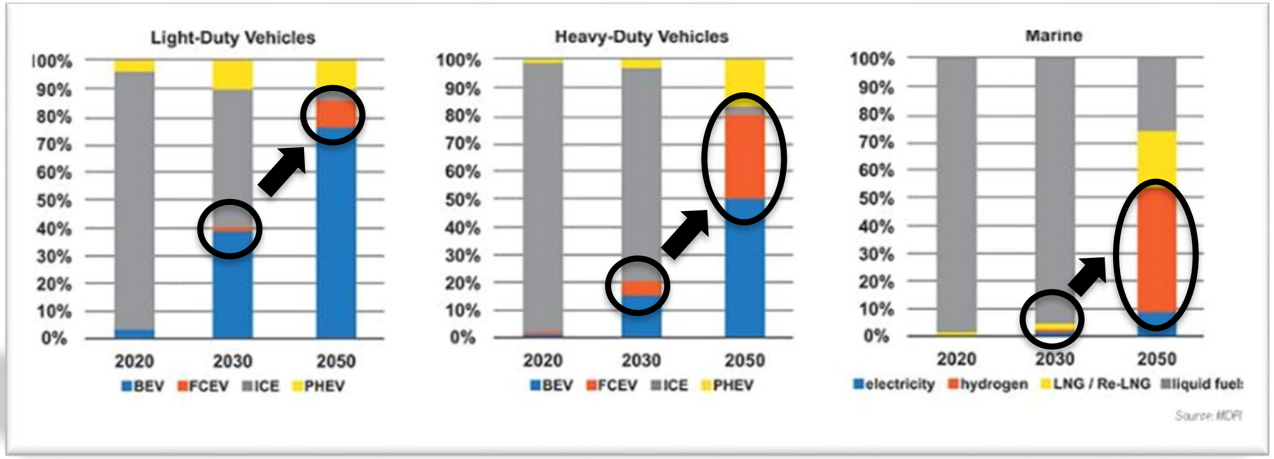
Motivation

- Why Fuel Cell?
  - Sustainable Mobility
  - CO_2 fleet target
  - **High average power demands**
  - **Short charging time requirements**
  - Continuous operation demand
  - **Payload critical applications**
  - **Weight critical applications**



Requirements - Fuel Cell

→ Competitive TCO (Total Costs of Ownership)

→ Holistic approach – Modularity, scaling

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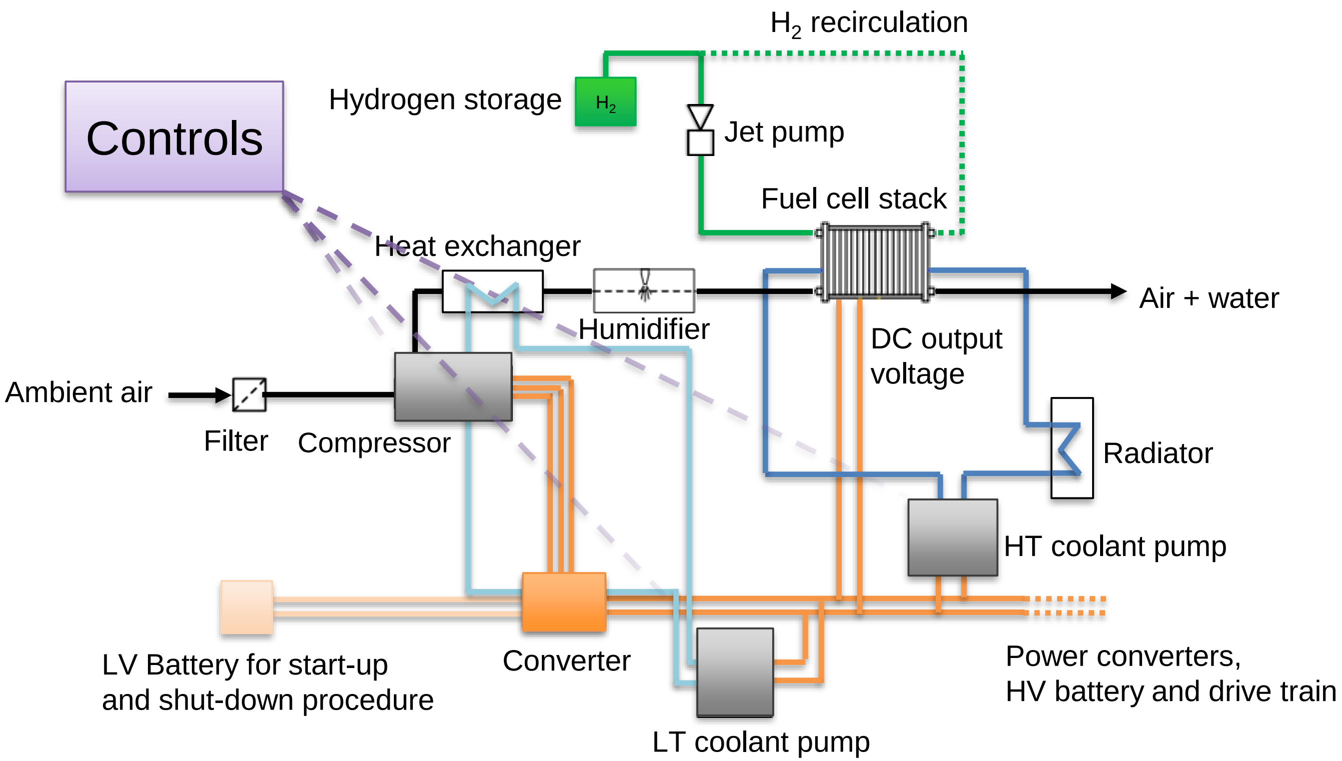
A CHALLENGE OF MULTIPHYSICAL SIMULATIONS

Fuel Cell System – Physical Domains/ Subsystems

- Thermo-Fluids
  - Hydrogen supply (Anode)
  - Air supply (Cathode)
  - Low and high temperature coolant circuit
- Electrical
  - Low & high voltage system
- Mechanical
  - Compressor, Pumps
- Controls



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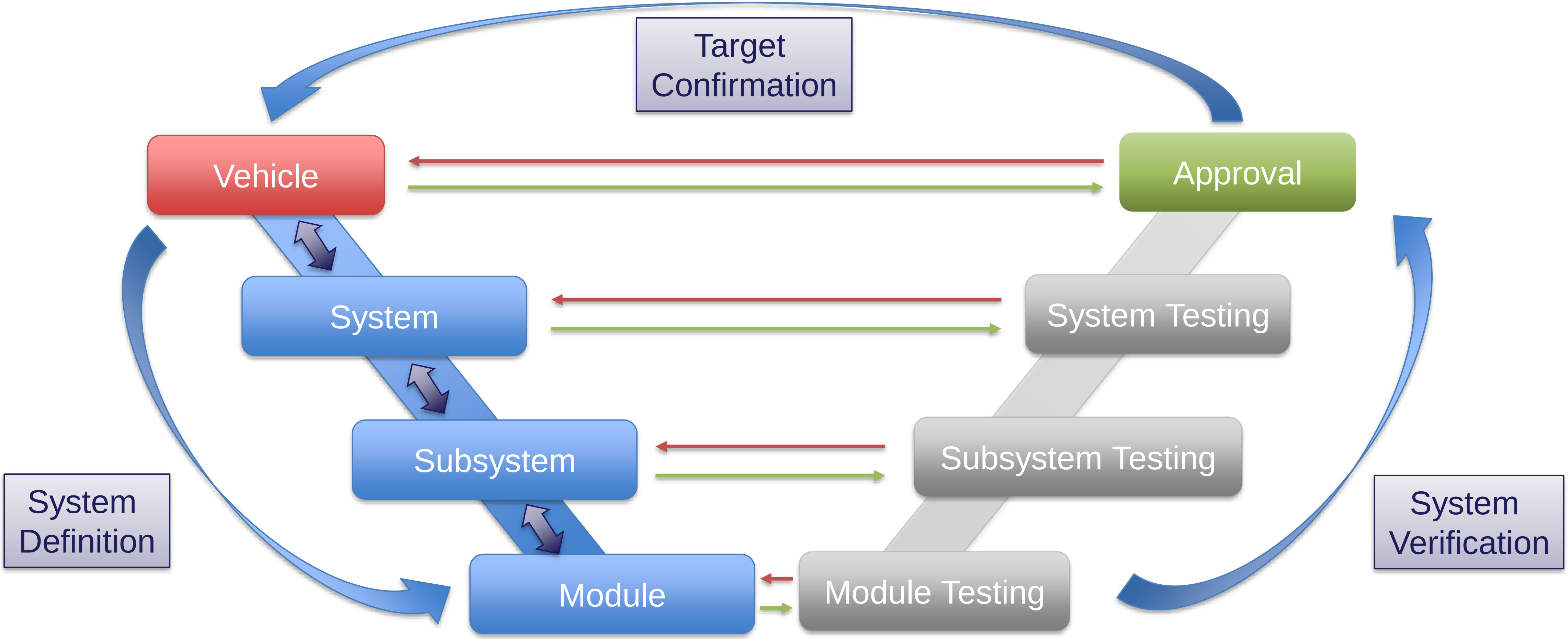
Development/ Simulation Approach



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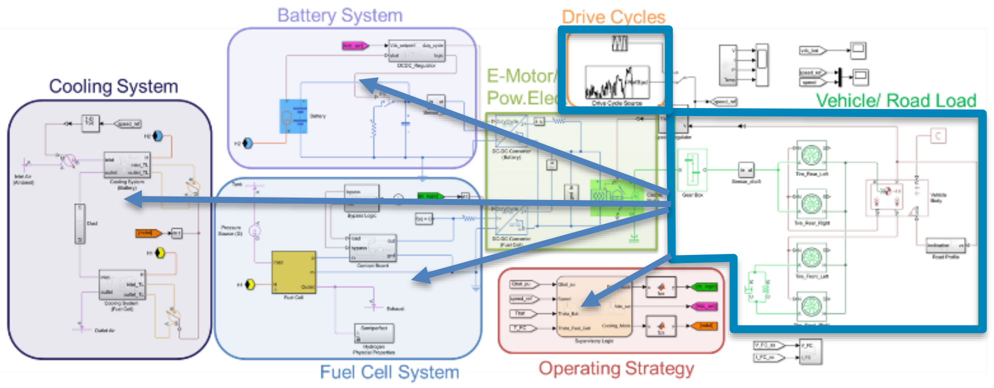

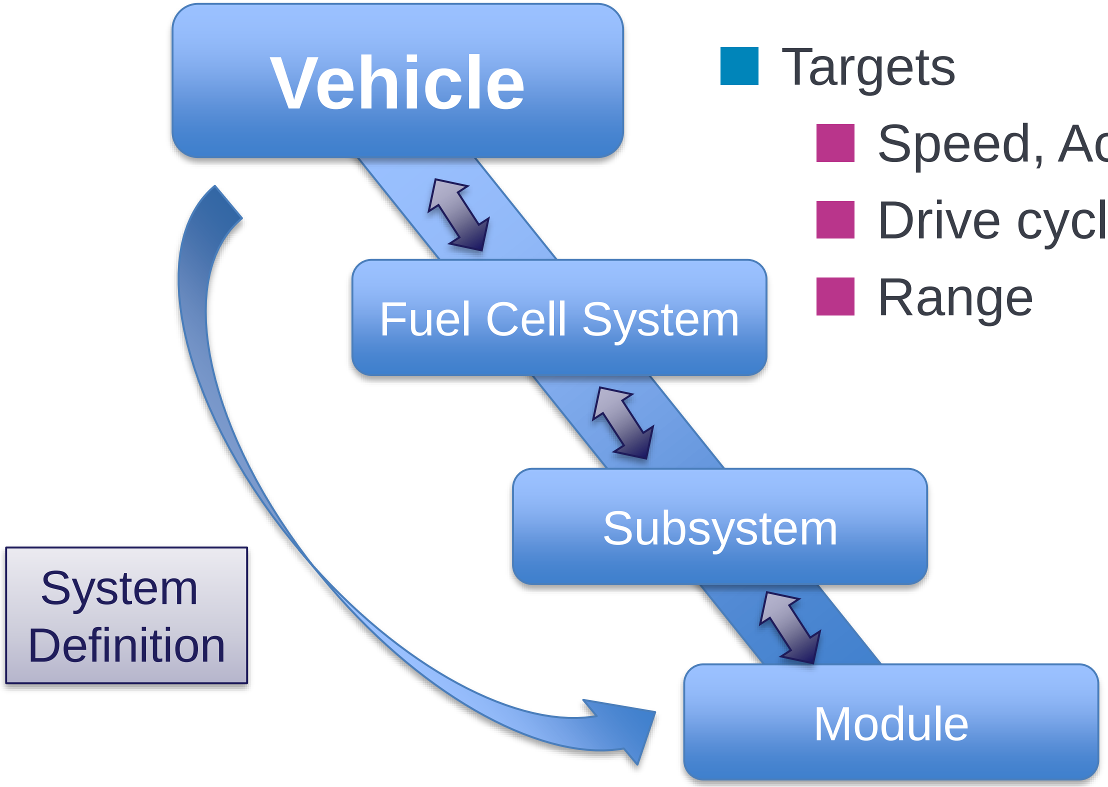

- Targets
  - Speed, Acceleration
  - Drive cycles
  - Range
  - Fuel economy
  - Pay load
  - Driving performance (e.g. power-weight ratio)

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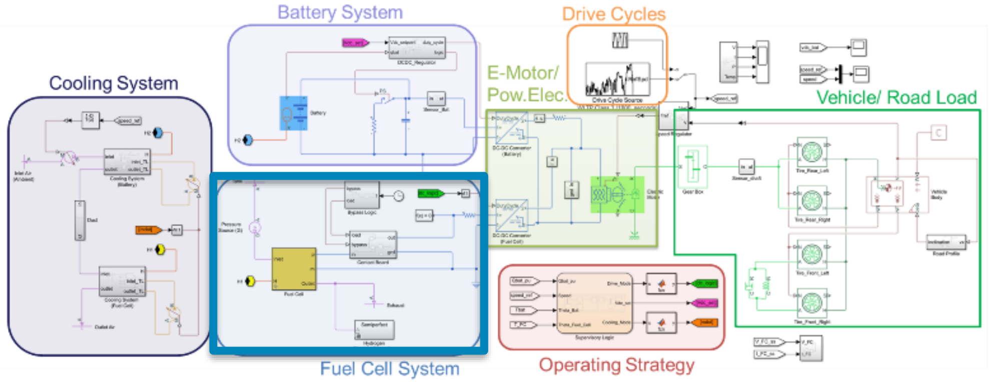
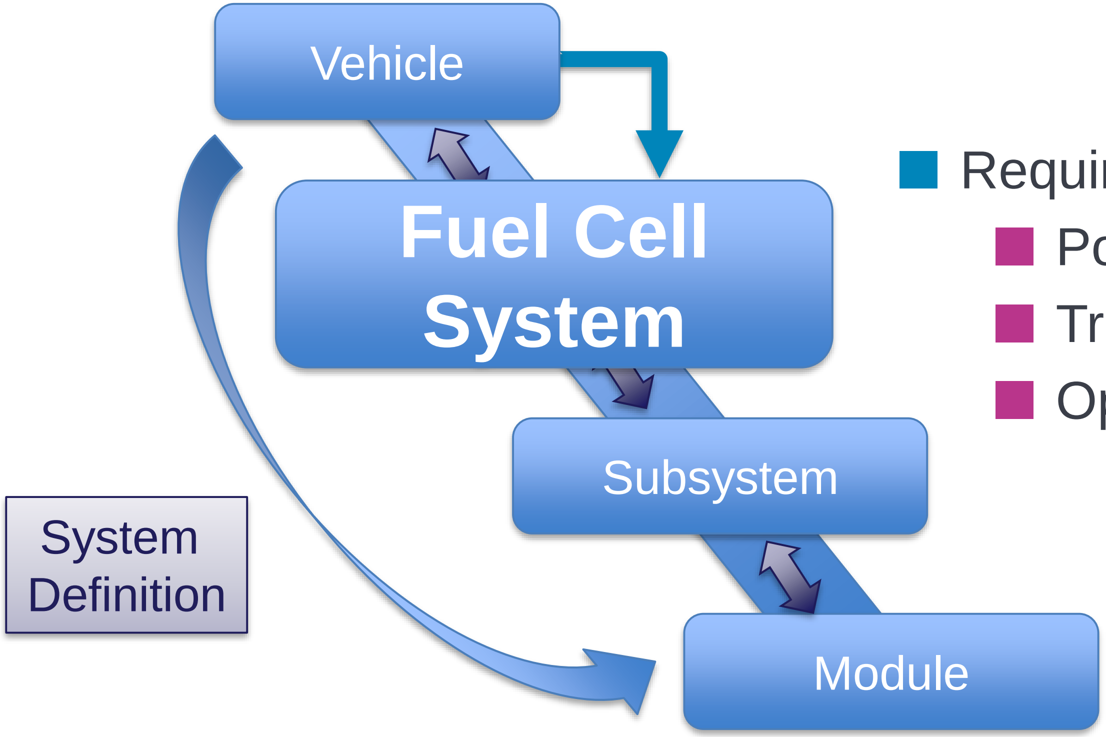
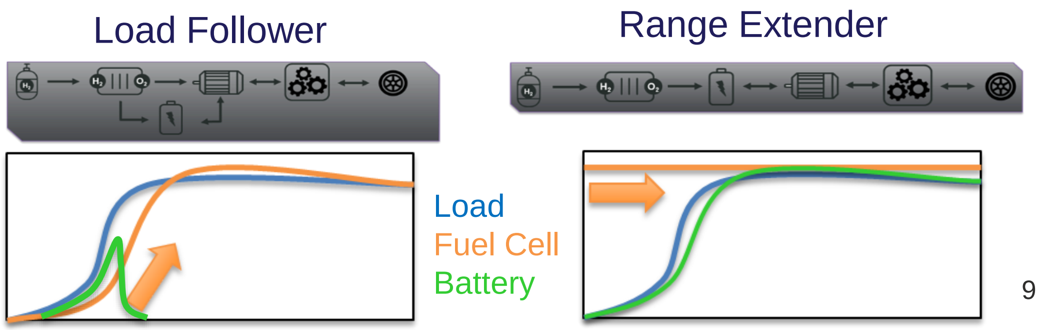
Development/ Simulation Approach





- Requirements to powertrain
  - Power output
  - Transient behavior
  - Operating strategy
  - Vehicle integration
  - Tank capacity



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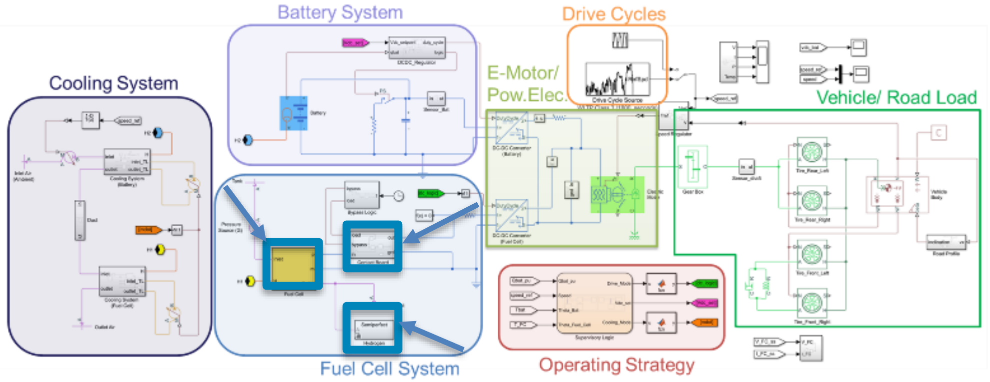

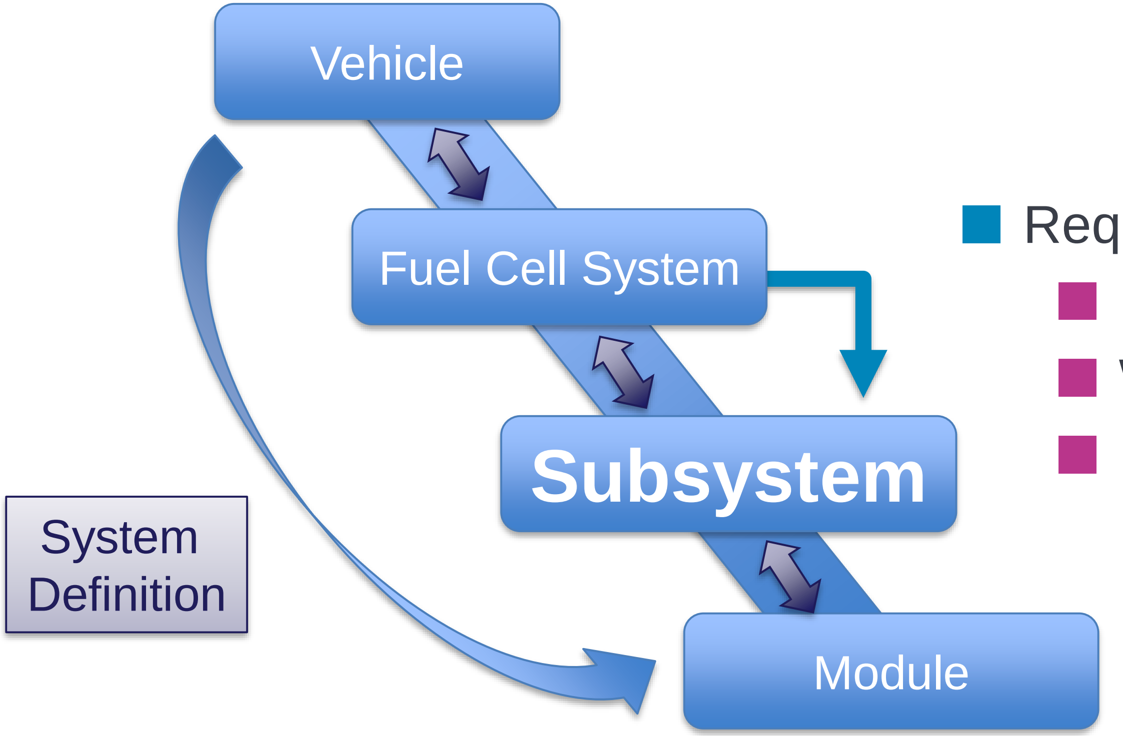

- Requirements to subsystem
  - How to achieve the required system power?
  - Which components are needed, e.g compressor?
  - Layout of subsystem circuits

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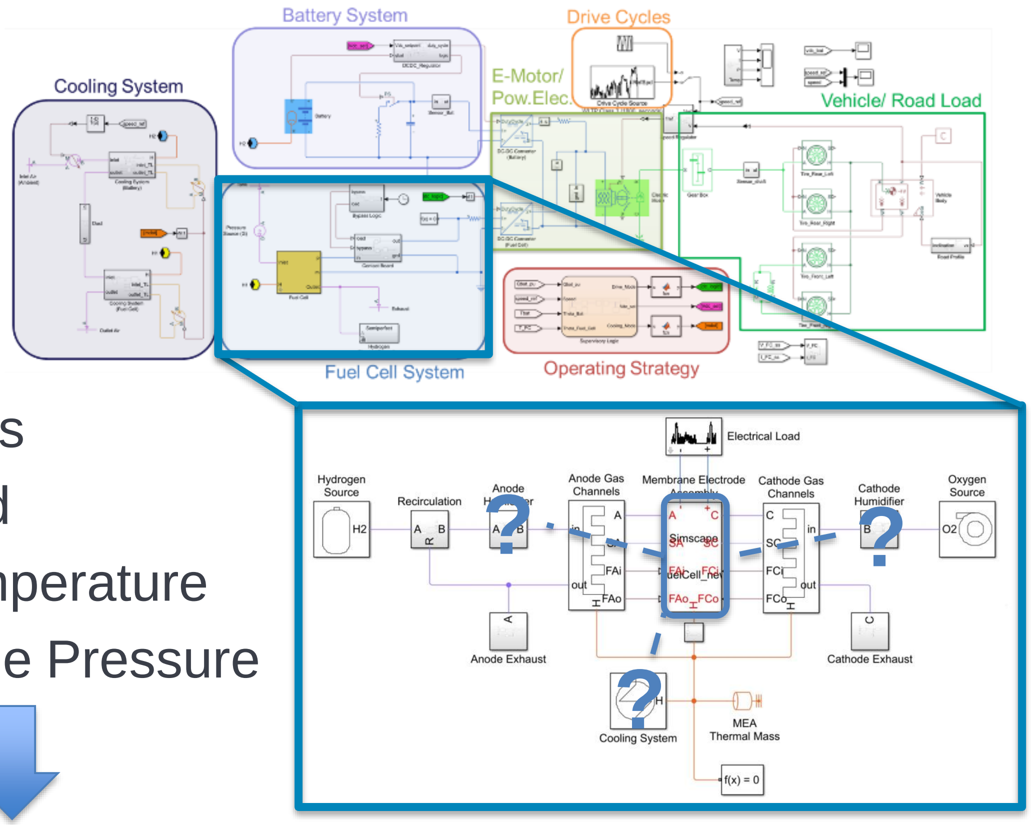
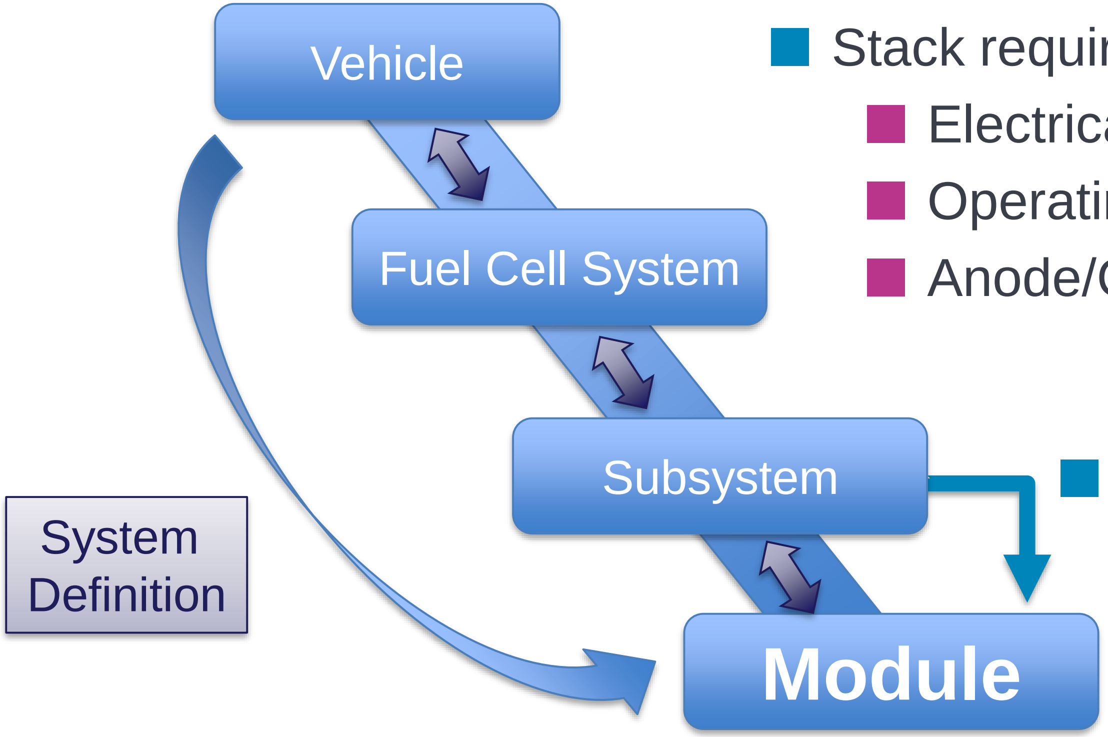
Development/ Simulation Approach





- Stack requirements
  - Electrical Load
  - Operating Temperature
  - Anode/Cathode Pressure
- Requirements of BoP components
  - Air delivery → compressor, charge air cooler
  - H2 delivery → tank capacity, jet pump, blower
  - thermal subsystems → radiators, pump size

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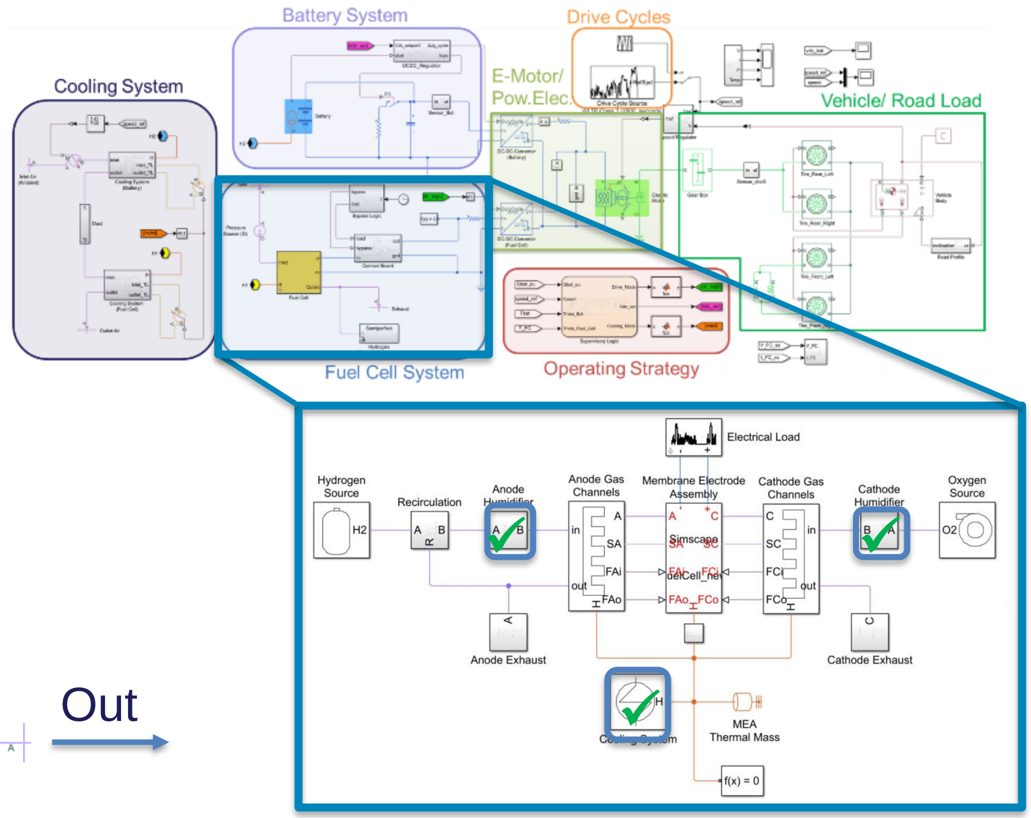
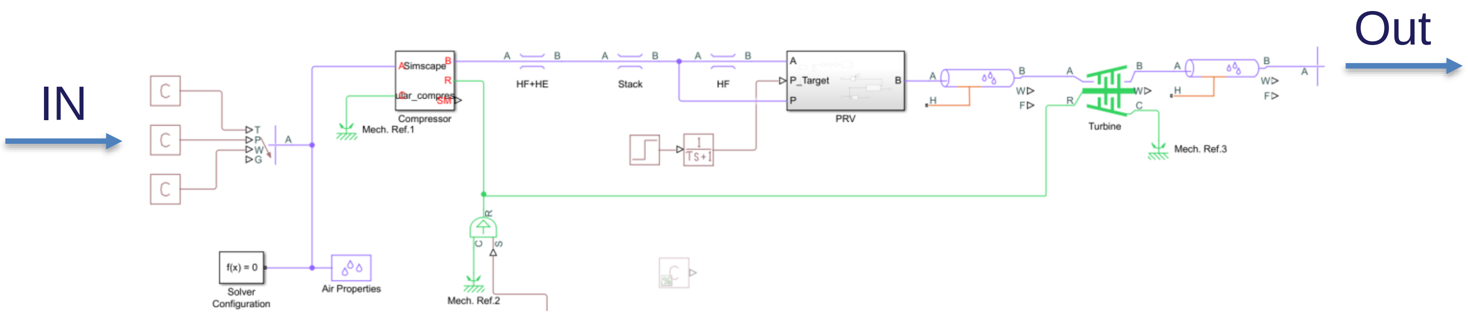
Development/ Simulation Approach

- Test harness for BoP components
  - Use fixed in- and outputs
  - Calibrate to stack requirements
  - Component supplier sourcing
  - Use referenced models





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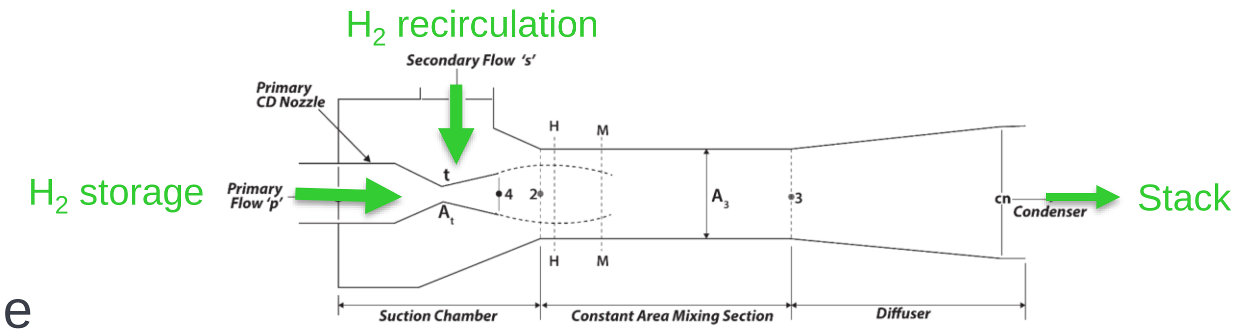
Challenges: Jet pump



Source: MDPI

- Supersonic conditions at primary nozzle
  - Additional math required to avoid supersonic conditions, (only supported through customizations)

- Overdetermined system
  - Information transfer between stack inlet, outlet and recirculation path
  - Reduce complexity
  - Modularize physical system model(moist air) and calculate them individually

- Purging interferes with “usual operation” (recirculation) – breaking the algebraic loop
  - Purge path into exhaust parallel to recirculation path
  - Additional math required

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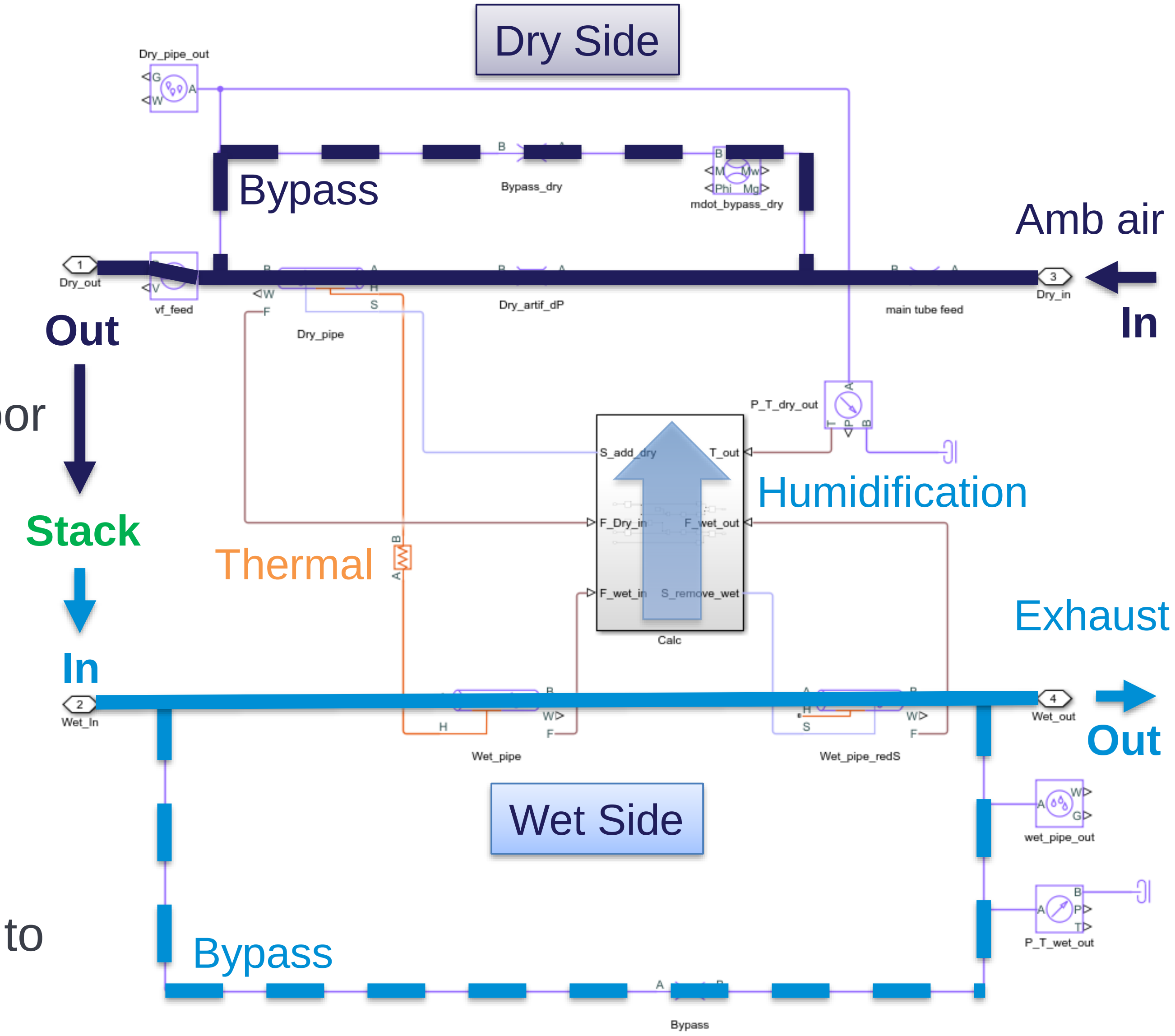
Challenges: Passive Humidifier

- Water transport
  - create piping enabling transport from wet side to dry side
  - removal of transferred water vapor from wet side
- Thermal coupling
  - coupling of wet and dry side to improve accuracy of simulation
- Bypass design
  - modelling of local restrictions in terms of pressure drop
  - sizing of passive bypass throttle to maintain a specific mass flow



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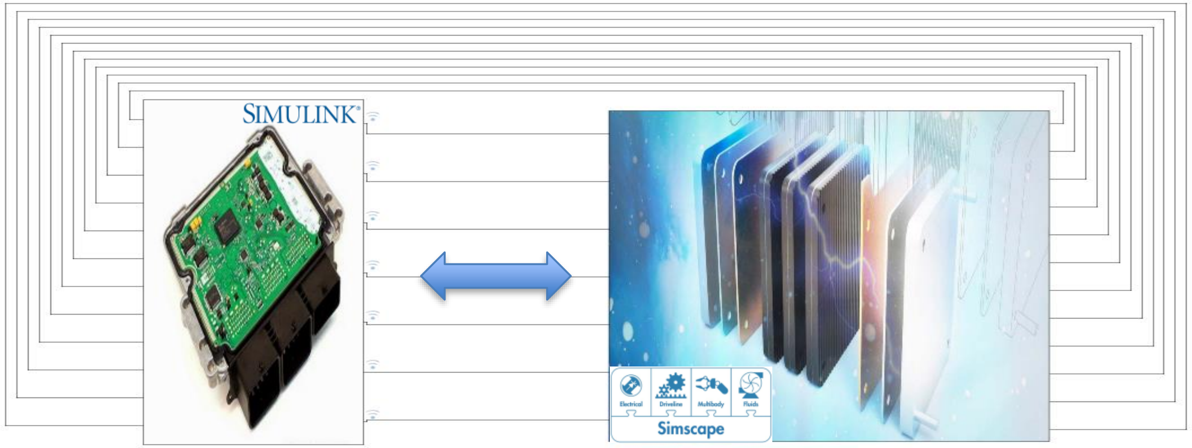
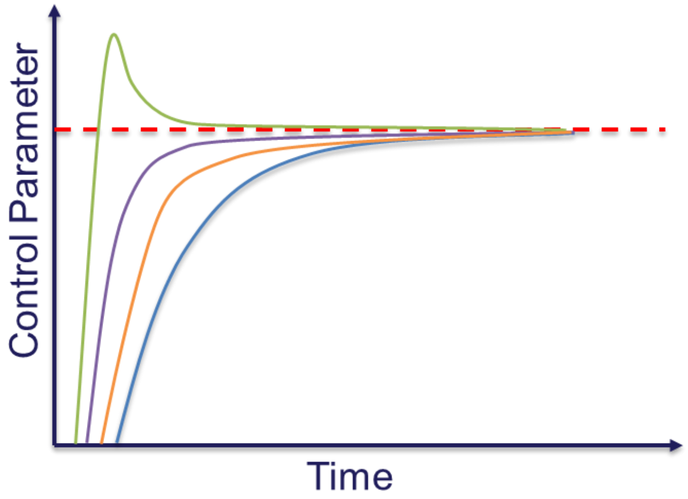
Challenges: Controls/ Co-Simulation

- Fixed time step – model discretization
  - Performance-accuracy tradeoff (optimal time step)
  - Continuous ↔ Discrete domains
- Tuning gains in cascaded controller
  - Cascaded control architecture
  - Sampling time selection
- Continuous development of plant environment
  - Integration through reference subsystems





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Summary and Outlook

- Summary:
  - Model accuracy improved
  - Control strategies implemented
  - Deeper understanding of Simscape modeling & troubleshooting thanks to MathWorks support
- Outlook:
  - Validate model with fuel cell test bench data
  - Increase flexibility by using referenced/variant models for component selection
  - Move from moist-air to a custom multi-species domain in Simscape to track more species, like N_2, O_2, H_2...

THANKS

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