MATLAB EXPO

Enabling the Green Hydrogen Supply Chain with MATLAB and Simulink

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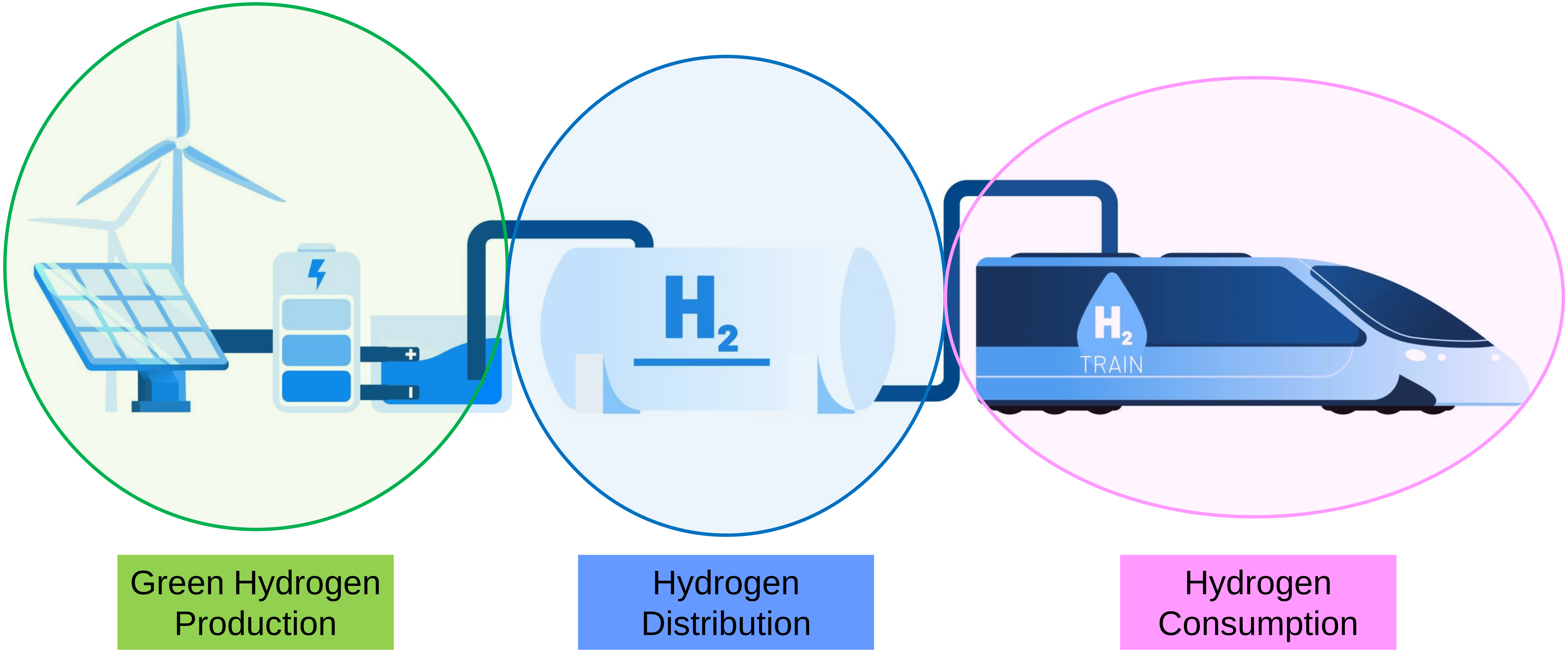
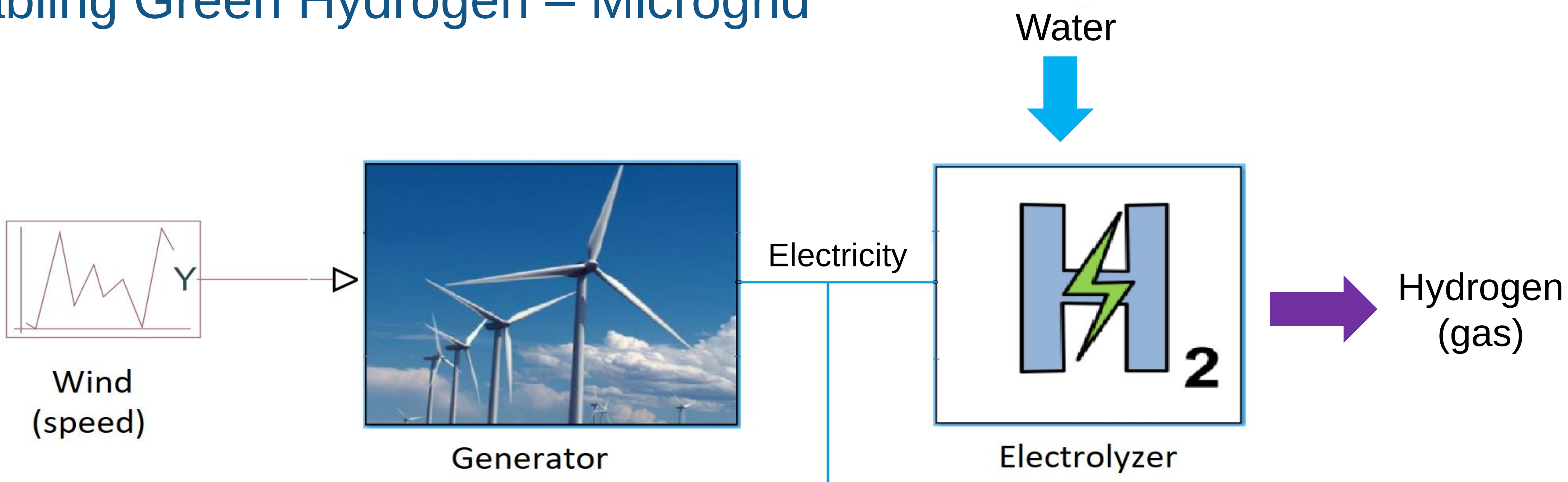
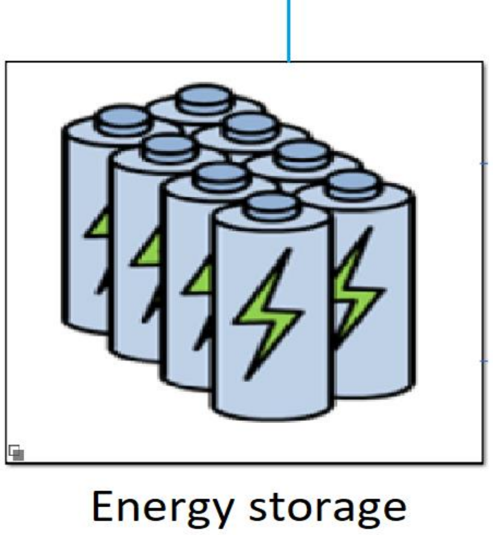
#MATLABEXPO

Enabling Green Hydrogen – Supply chain

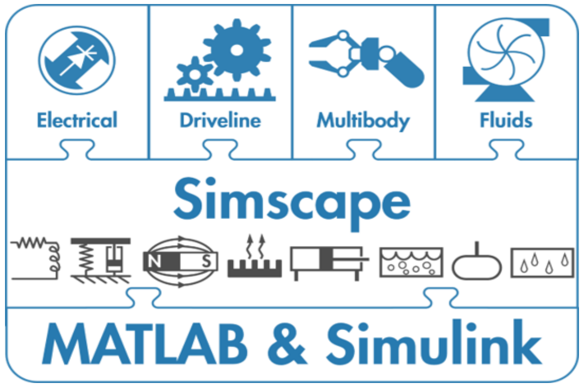


Enabling Green Hydrogen – Microgrid





Multi-domain simulation



Enabling Green Hydrogen – Motivation

Advantages

- 100% sustainable
- storable
- versatile
- transportable

"Green hydrogen: an alternative that reduces emissions and cares for our planet"
Iberdrola > Sustainability > Green Hydrogen

Deltas

- high energy consumption
- safety (managing H2)
- high cost

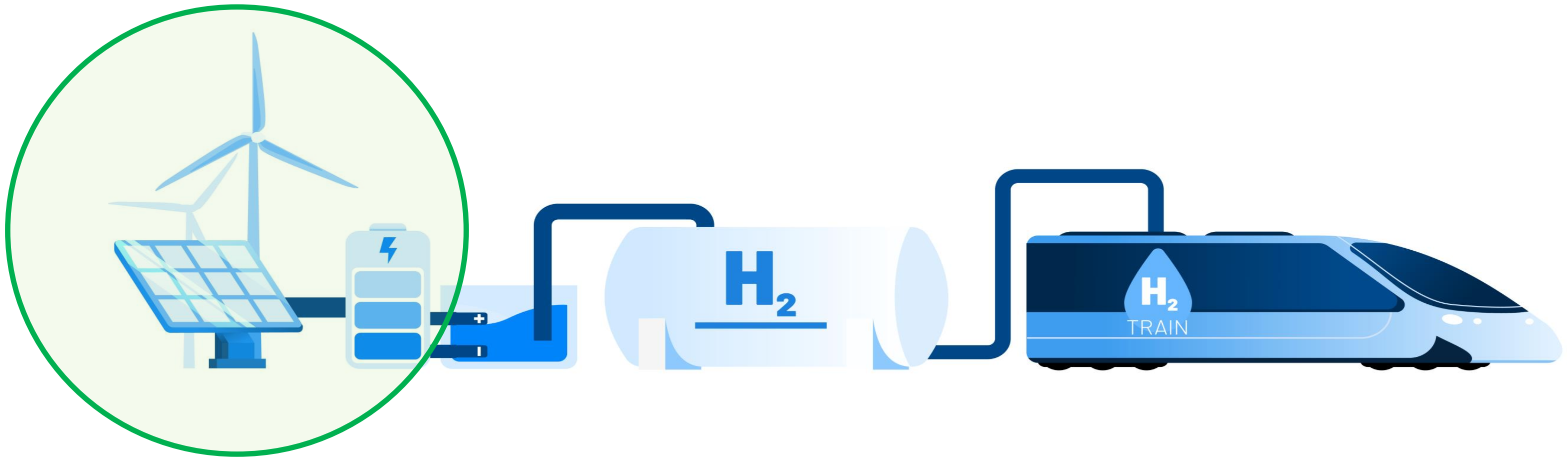
⇕

Simulation Based Engineering

Enabling Green Hydrogen – Key takeaways

- Assert feasibility
  - Techno-economic analyses
  - Proven concept
- Secure sustainable and robust operation
  - Design Automation
  - Optimization
- Collaborative Engineering
  - Sharing know-how & IP
  - Deployment

Stage 1. Green Hydrogen Production (from renewable energy to gas)



Enabling Green Hydrogen - Challenges

Production (Micro-grid)

Unit Level

Component design

- electrolyzer
- energy storage
- power converter unit
- generator

Asset digitalization

- anomaly detection
- lifetime estimation
- prognostics development

System Level

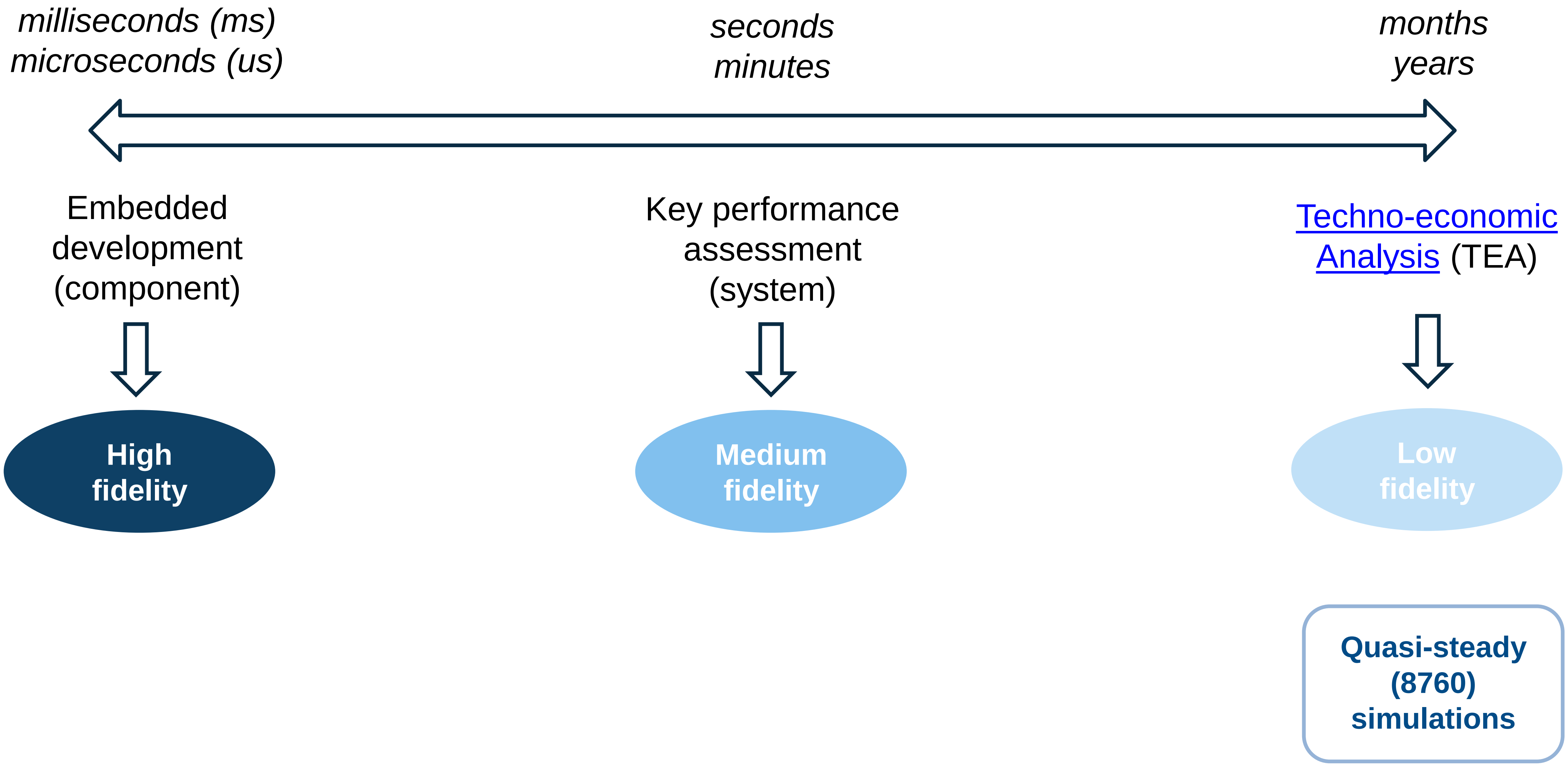
Plant design

- concept evaluation
- physical requirements
- energy balance

High-level algorithmic design

- supervisory logic
- setpoint definition

Enabling Green Hydrogen – Model fidelity



Enabling Green Hydrogen – TEA (solar microgrid)

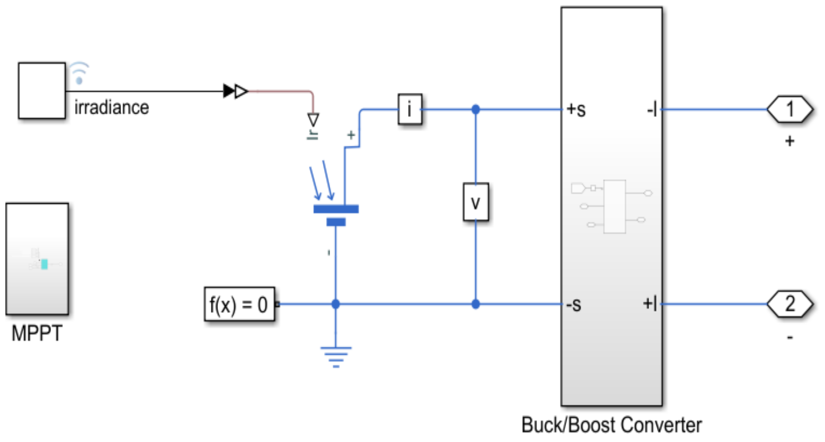
Performance assessment

Medium fidelity

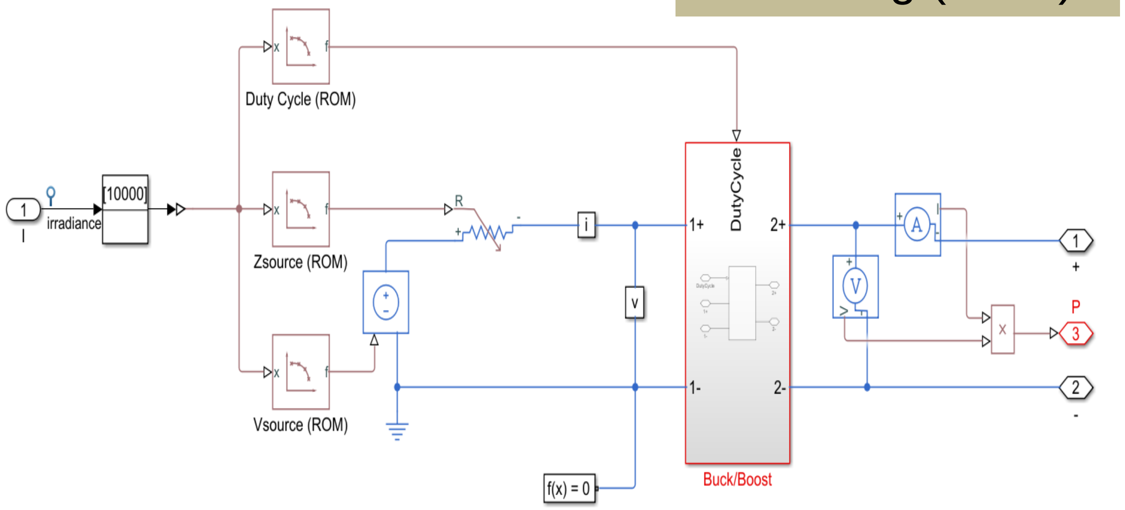
Techno-economic analyses

Low fidelity

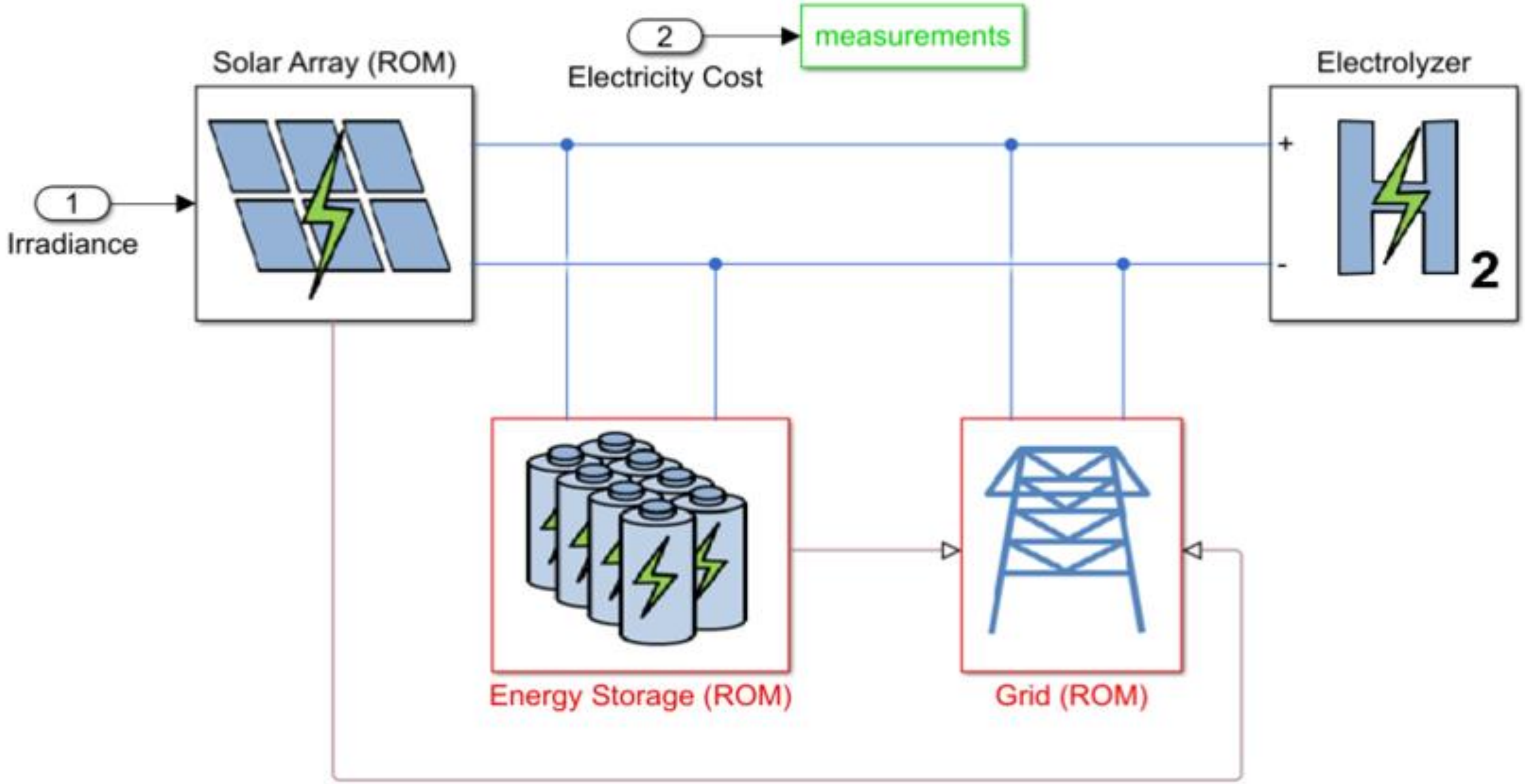
Solar cell & MPPT algorithm



Reduced Order Modeling (ROM)



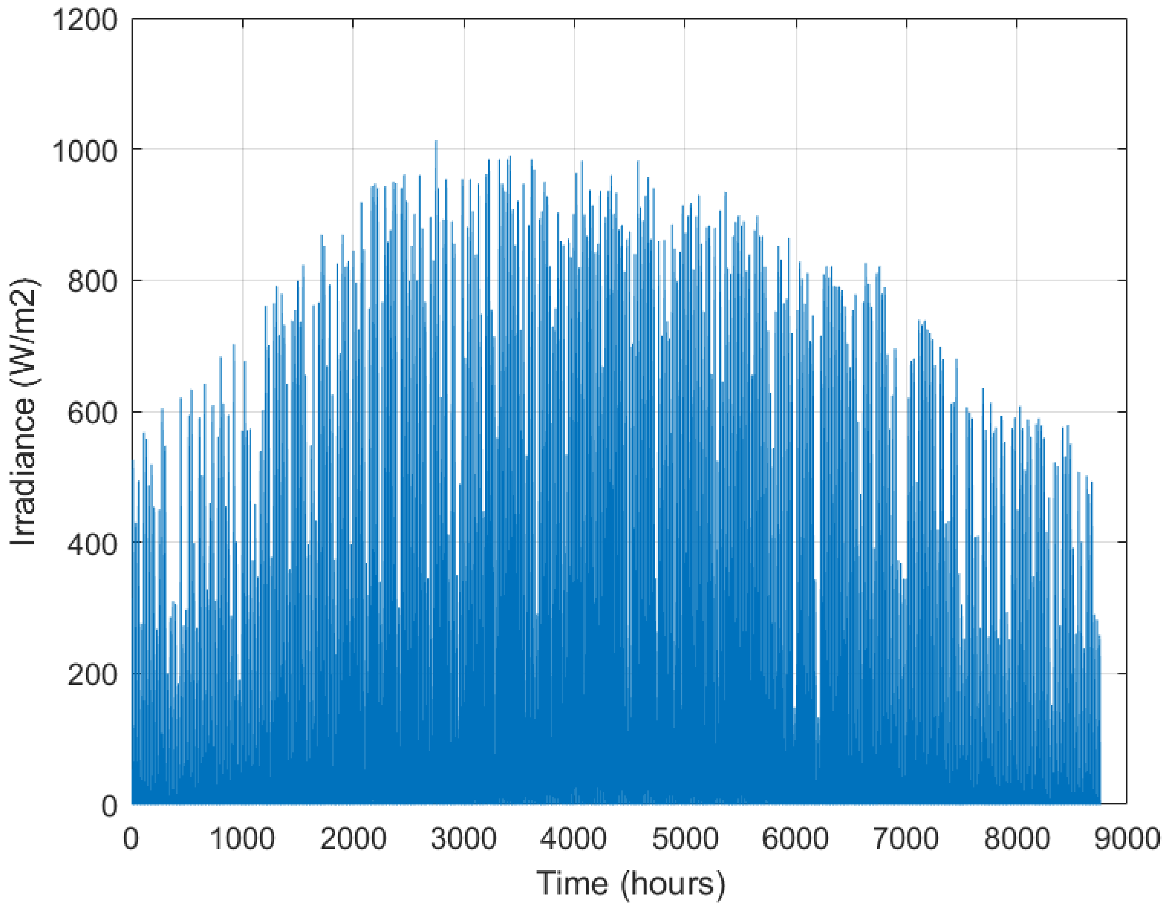
Green hydrogen production – TEA (solar microgrid)

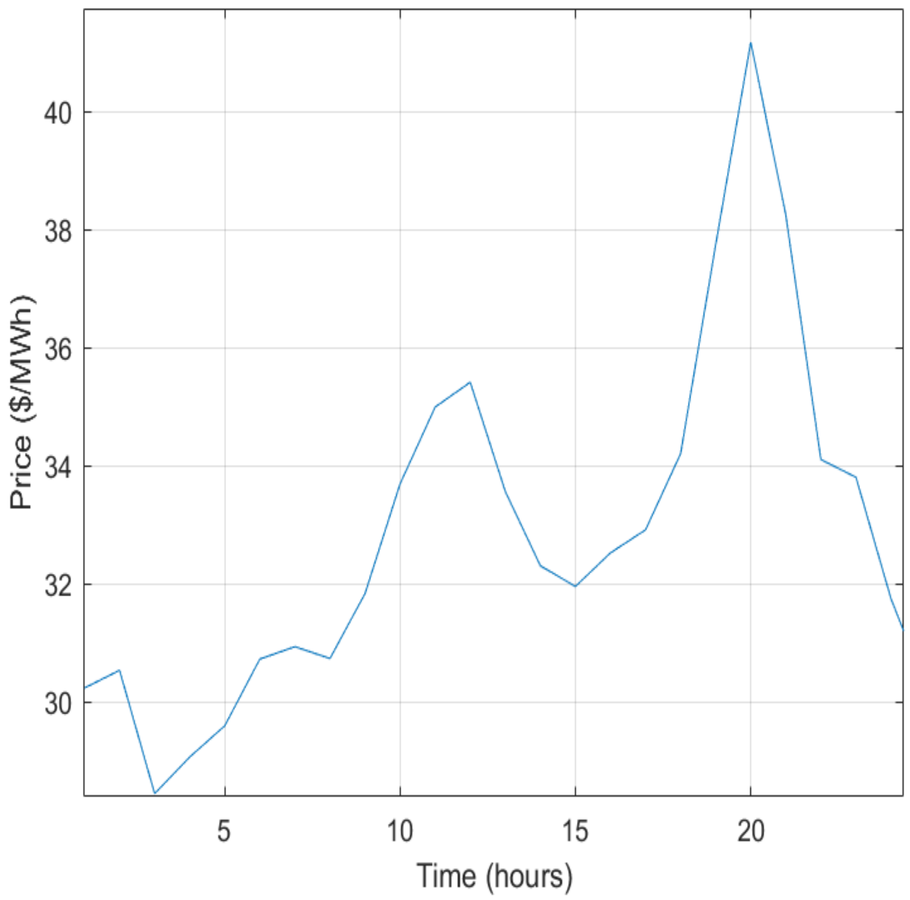


Enabling green hydrogen – TEA (data re-use)

The irradiance data is 8760 TMY3 from National Renewable Energy Laboratory.

Electricity price data is one day of data from system operators.





Enabling green hydrogen – TEA (outcome)

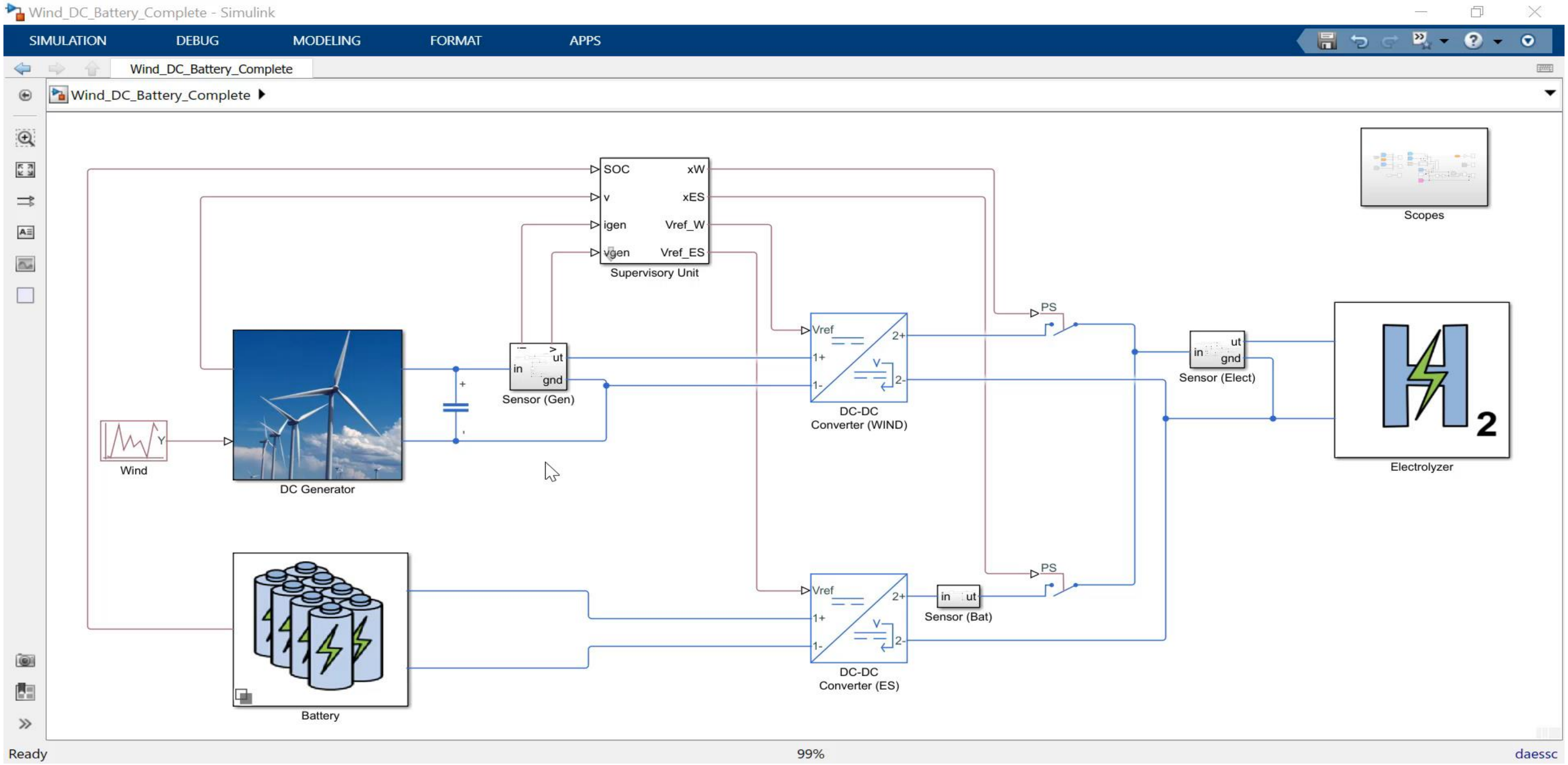
H_2 production: Highest grid cost & Lowest solar resource

```
Elapsed time is 510.209014 seconds.
--------------------------------------


Lowest grid cost is USD 6761.6456 at Phoenix Sky Harbor Intl AP
Highest solar resource is 497.1227MWh at Daggett Barstow-Daggett AP

Highest grid cost is USD 13217.5585 at Quillayute State Airport
lowest solar resource is 291.2997MWh at Quillayute State Airport


--------------------------------------
```

242 years in 500 seconds
i.e.
1 year every 2 seconds

Reduced Order Models + **Parallel Computing** = **Agile Insights (decision-making)**

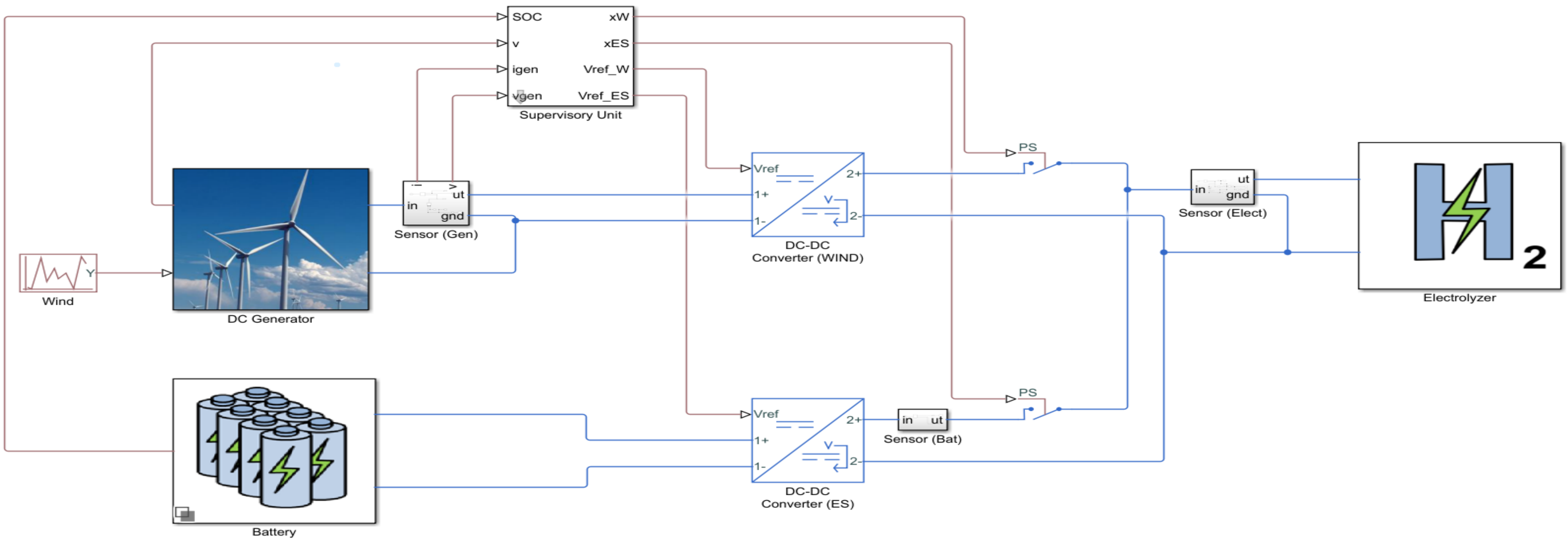
Enabling green hydrogen – System performance



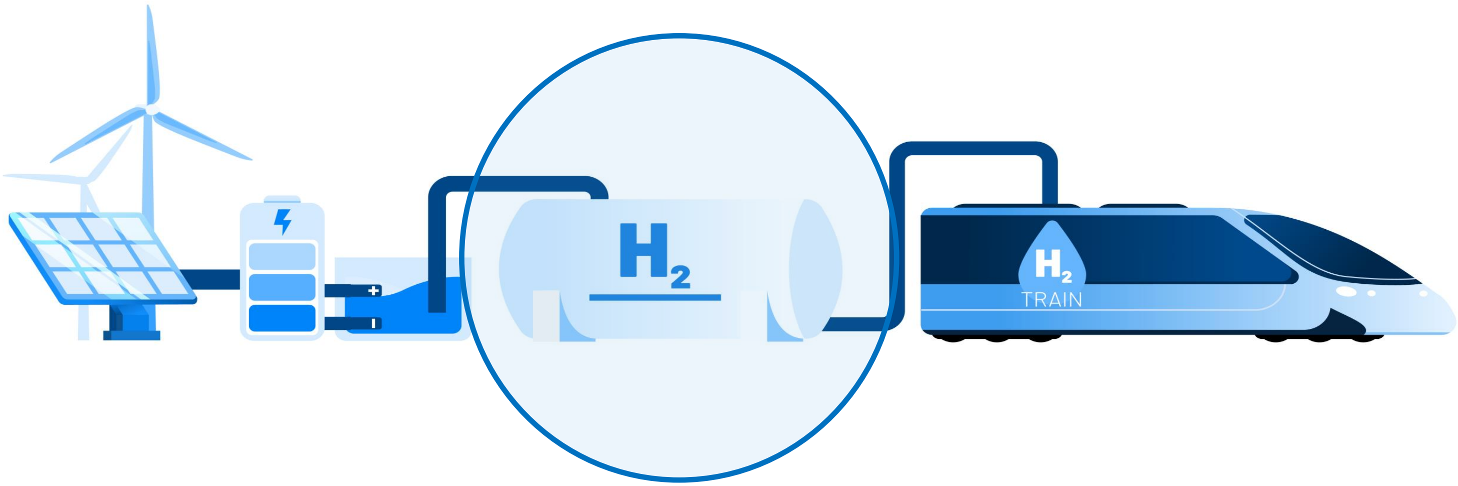
Enabling green hydrogen – System performance

Medium fidelity

- expected H_2 production & water consumption
- suitable control strategy (conditions, use of physical assets)
- energy storage (dimensioning, expected duty regime)
- planning of operations (collect – replace - maintain)



Stage 2. Hydrogen Distribution (from tank to consumers)



Enabling Green Hydrogen – Challenges H2 handling and usage

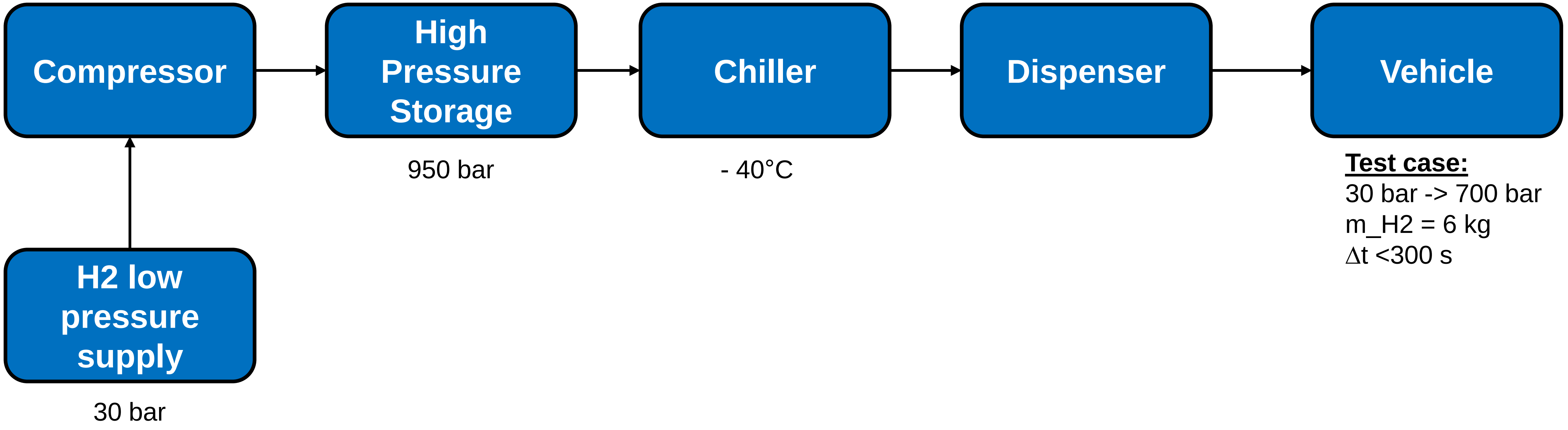
(Stage 2)

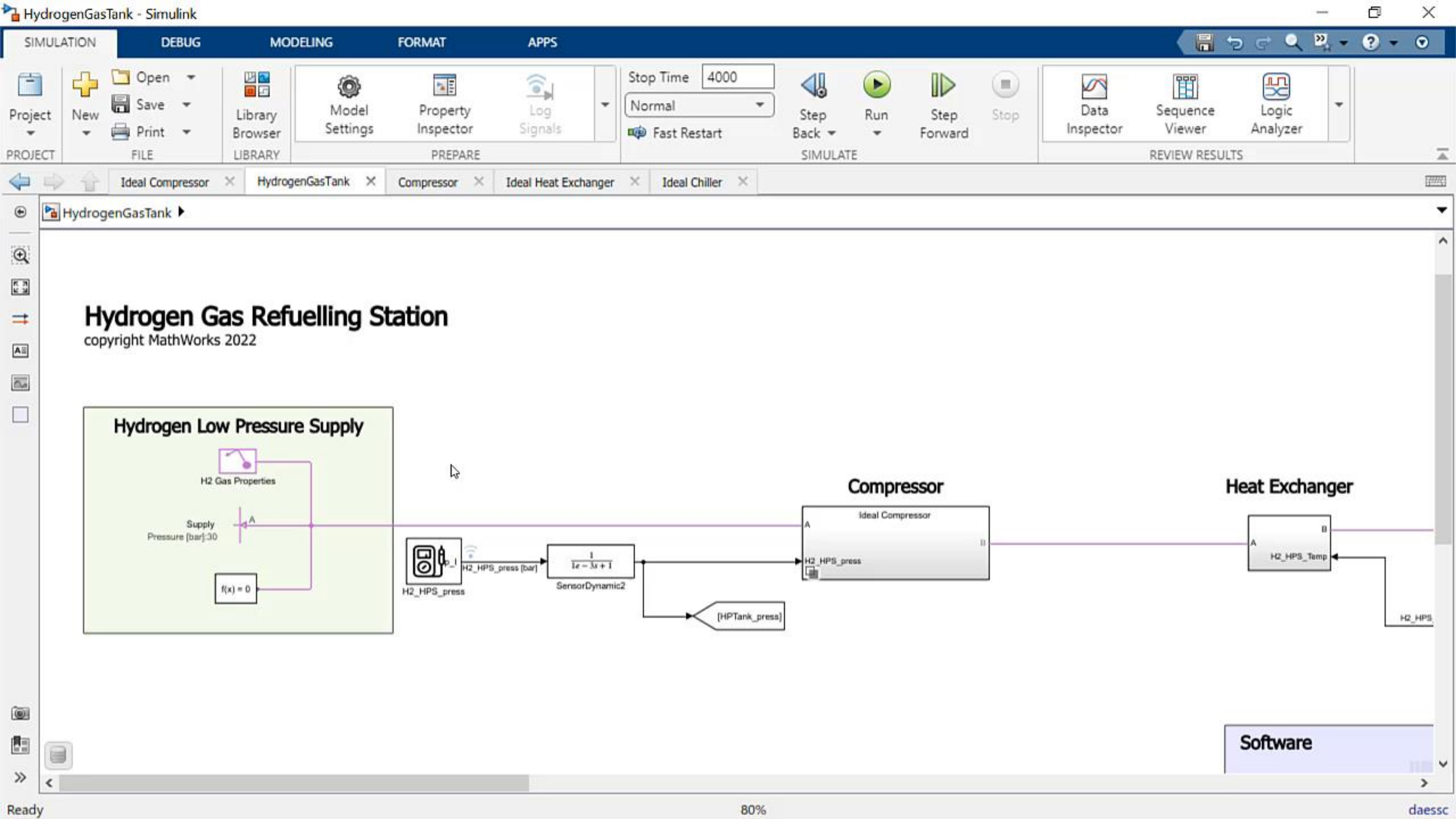
Transfer
(tank-to-cell)

- Optimal components sizing
  (cooling, storage, compressors)
- Reliable 24/7 software operation
- Meet critical safety requirements

Modeling gas systems with Simscape

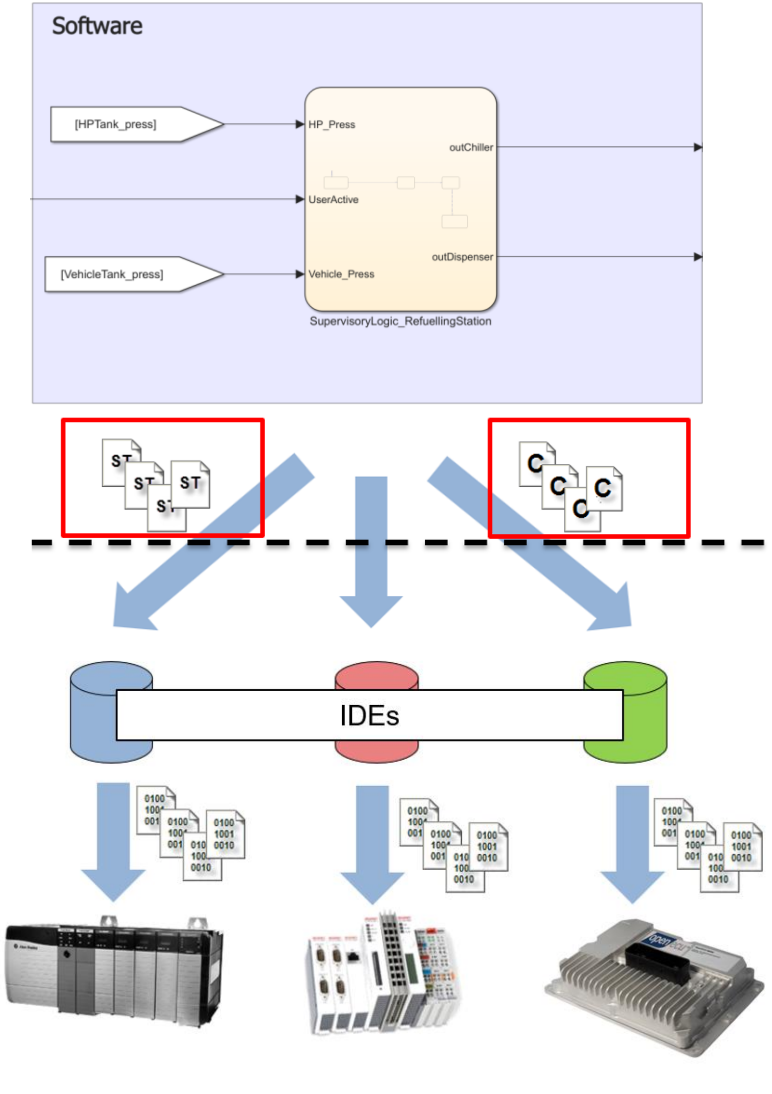
- Case study: Hydrogen Refueling Station




HydrogenGasTank - Simulink
SIMULATION
DEBUG
MODELING
FORMAT
APPS
Project
New
Open
Save
Print
PROJECT
FILE
Library Browser
LIBRARY
Model Settings
Property Inspector
Log Signals
PREPARE
Stop Time
4000
Normal
Fast Restart
Step Back
Run
Step Forward
Stop
SIMULATE
Data Inspector
Sequence Viewer
Logic Analyzer
REVIEW RESULTS
Ideal Compressor
HydrogenGasTank
Compressor
Ideal Heat Exchanger
Ideal Chiller
HydrogenGasTank
Hydrogen Gas Refuelling Station
copyright MathWorks 2022
Hydrogen Low Pressure Supply
H2 Gas Properties
Supply
Pressure [bar]:30
f(x) = 0
H2_HPS_press
H2_HPS_press [bar]
SensorDynamic2
[HPTank_press]
Compressor
Ideal Compressor
H2_HPS_press
Heat Exchanger
H2_HPS_Temp
Software
Ready
80%
daessc

Algorithm model and deployment on real-time controller

- Automatic code generation from models
- Reduced coding time & errors
- Hardware independent source code
- Know-how captured in single source (model)



PLCs, ECU, custom hardware

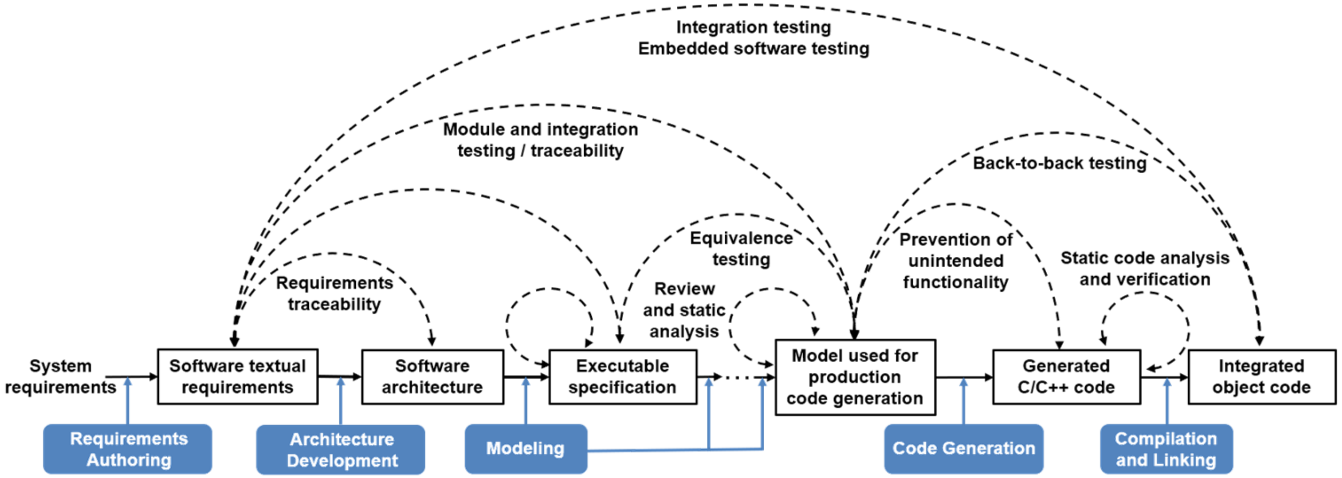
All relevant PLCs supported

Vendor	IDE	IEC 61131-3	C/C++	Connections Partner
3S - Smart Software Solutions	CODESYS	✓		✓
B&R Industrial Automation	Automation Studio	✓	✓	✓
Bachmann Electronic	SolutionCenter	✓	✓	✓
Beckhoff Automation	TwinCAT	✓	✓	✓
Bosch Rexroth	IndraWorks	✓	✓	✓
Mitsubishi Electric	CW Workbench		✓	✓
Omron	Sysmac Studio	✓		✓
Phoenix Contact	PC WORX	✓	✓	✓
Rockwell Automation	RSLogix / Studio 5000	✓		✓
Siemens	TIA Portal / STEP 7	✓	✓	✓

Scalable to certification workflows ensuring highest quality & safety

- IEC 61508 - Safety-related systems
- ISO 26262 - Automotive / Motorcycle
- ISO 25119 - Agriculture and Forestry
- EN 50128 - Rail
- IEC 62304 - Medical
- IEC 61511 - Process Control
- DO-178 & DO-254

[MATLAB and Simulink](#)
[For Verification, Validation and Test](#)



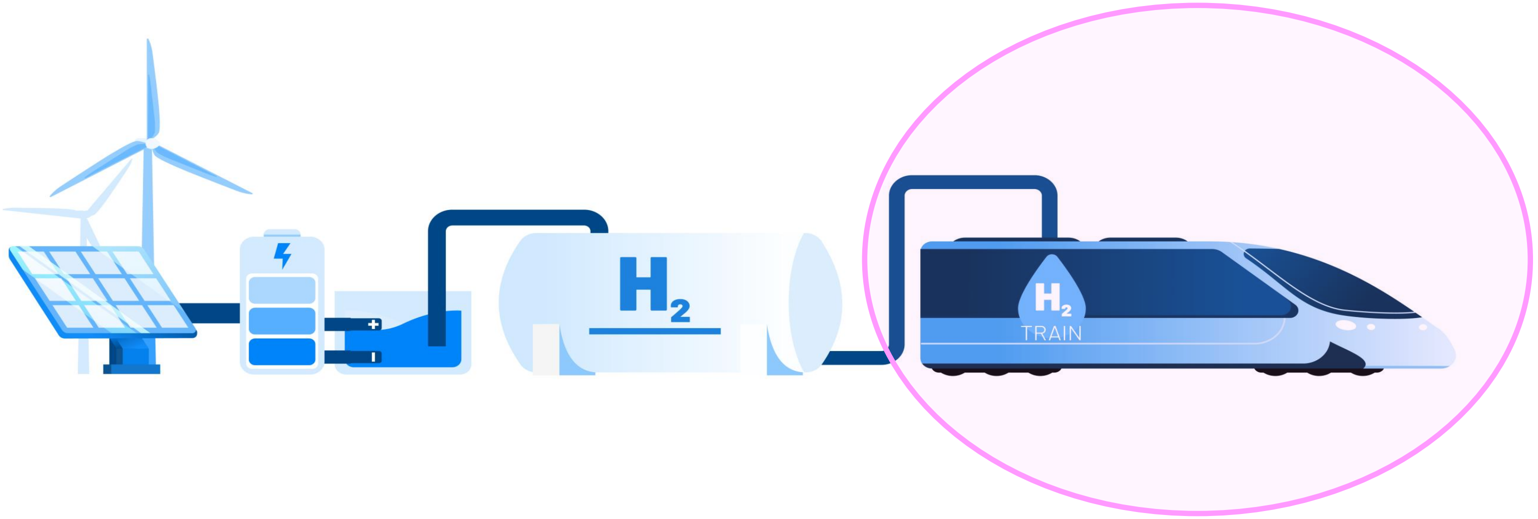
Enabling Green Hydrogen – Challenges H2 handling and usage

(Stage 2)

Transfer
(tank-to-cell)

- Optimal components sizing
(cooling, storage, compressors)
    - Leverage multi-domain simulation platform
- Reliable 24/7 software operation
    - Develop supervisory logic
with state-of-the-art V&V capabilities
- Meet critical safety requirements
    - Model-Based Design streamline certification of your embedded systems

Stage 3. Hydrogen Consumption (e-mobility, electrification)



Enabling Green Hydrogen – Challenges H2 handling and usage

(Stage 2)

Transfer (tank-to-cell)

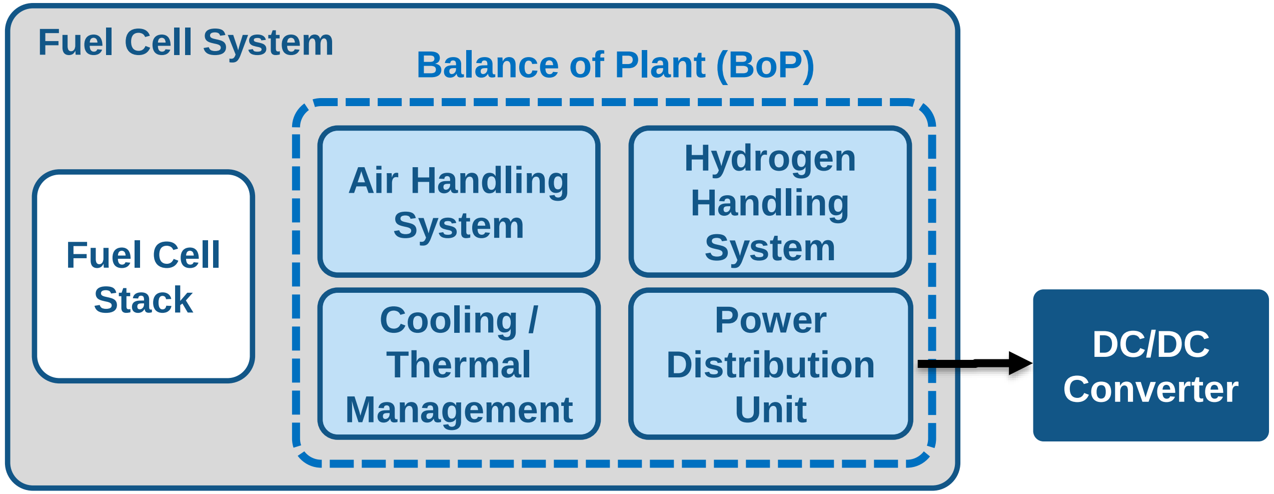
- Optimal components sizing (cooling, storage, compressors)
  - ➢ Leverage multi-domain simulation platform
- Reliable 24/7 software operation
  - ➢ Develop supervisory logic with state-of-the-art V&V capabilities
- Meet critical safety requirements
  - ➢ Model-Based Design streamline certification of your embedded systems

(Stage 3)

Consumption (E-mobility)

- Component-level vs system-level simulation
- Optimal system architecture (e.g., fuel cell multi-stack, battery)
- Expensive physical prototype testing

Fuel Cell System in Vehicle



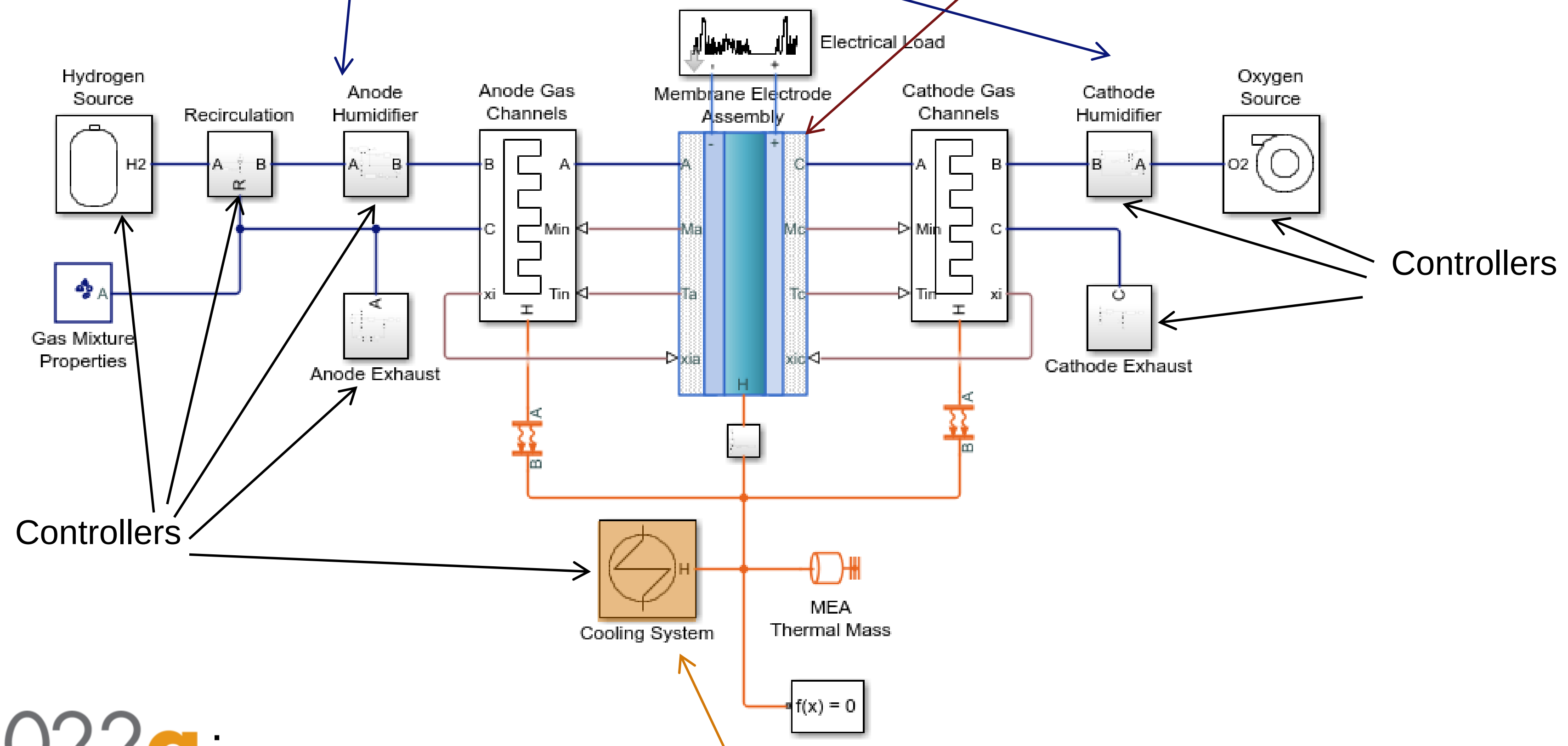
Multiple Domains used to Simulate Fuel Cell Systems….

Custom Fuel Cell Domain

Multispecies gas network
for N_2,O_2,H_2, H_2O

Membran

Exchange species and generate elec. power & heat, N_2 diffusion

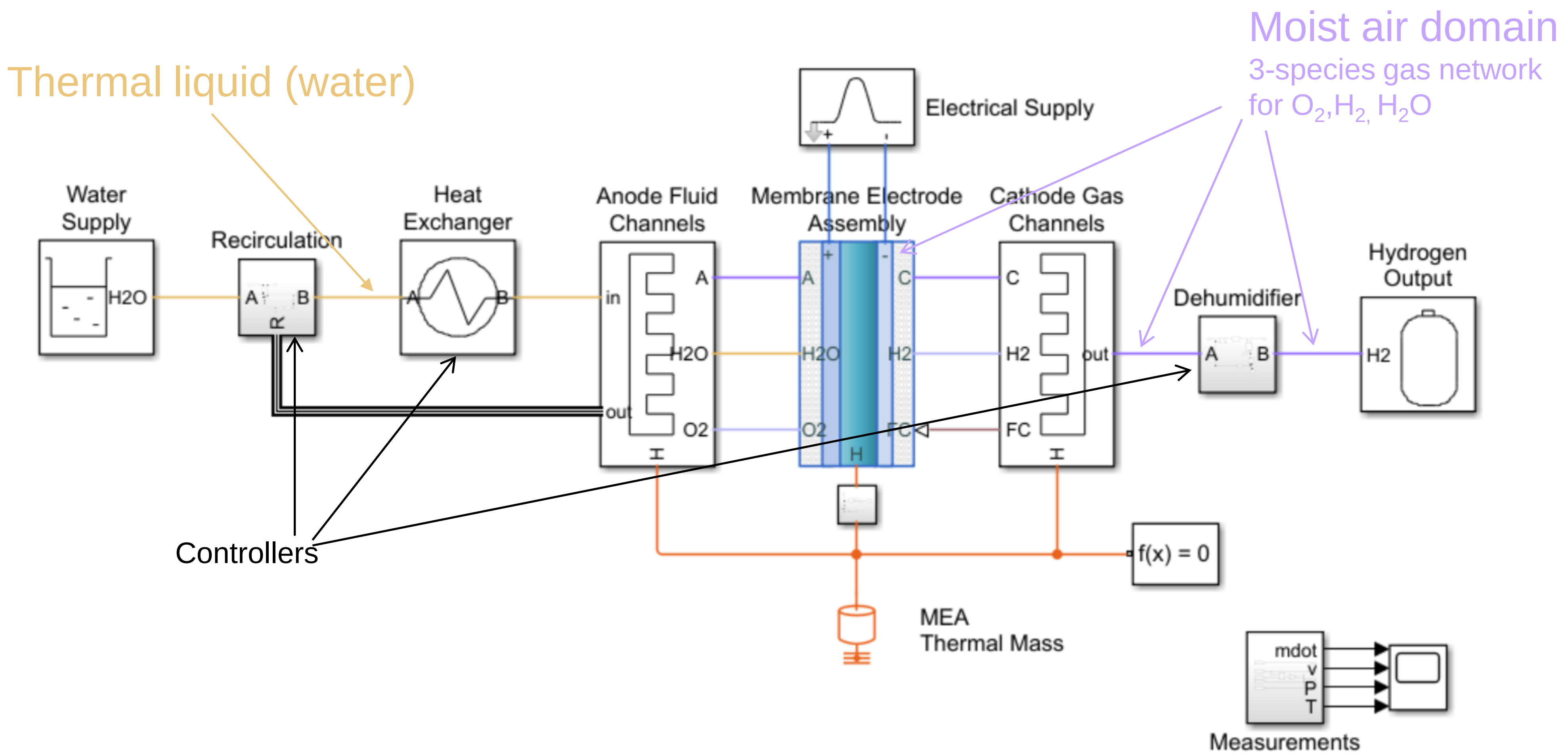


Liquid cooling system

Try it out in R2022a:

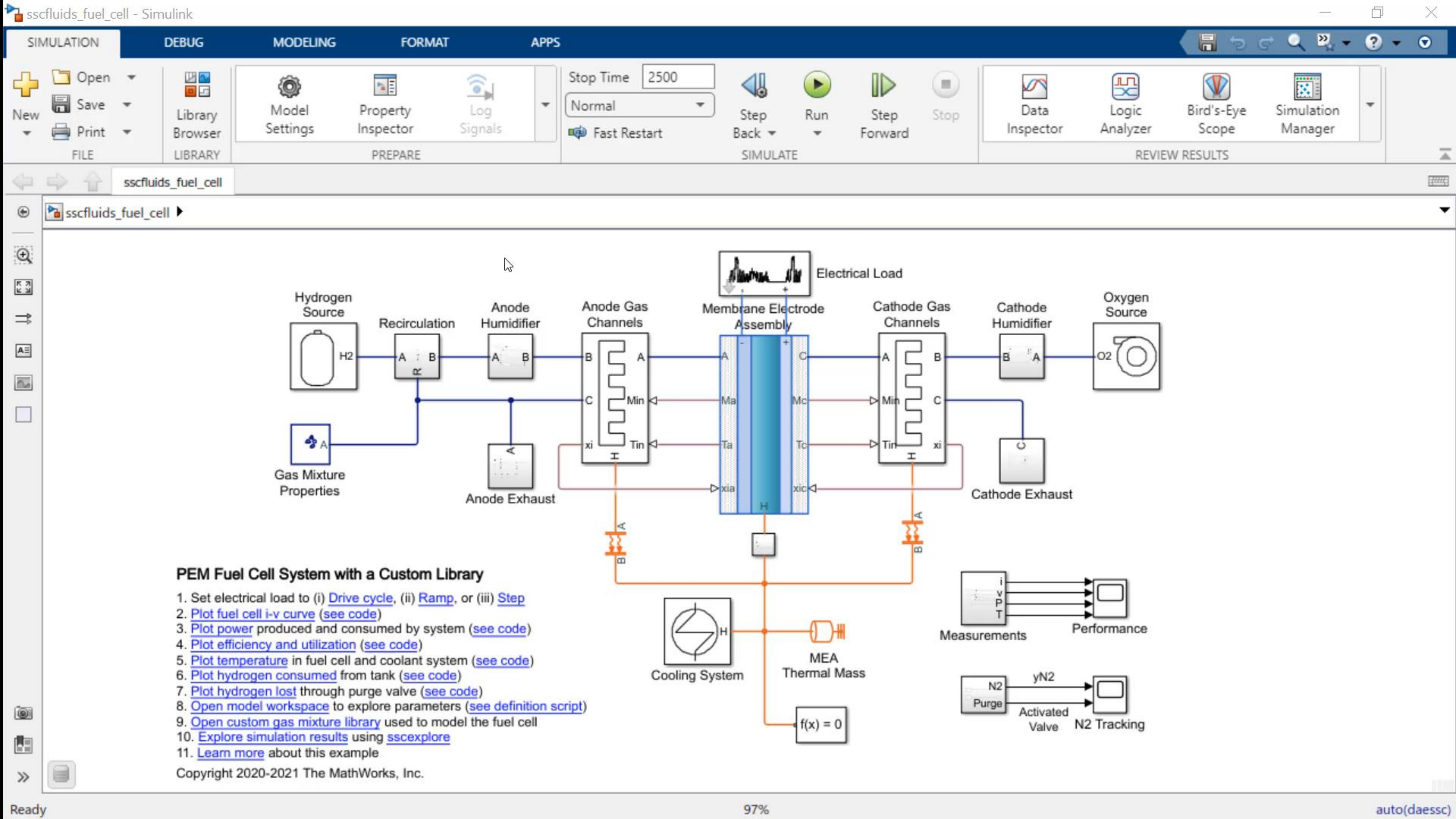
```
>> sscfluids_fuel_cell
```

… and Electrolyzers!

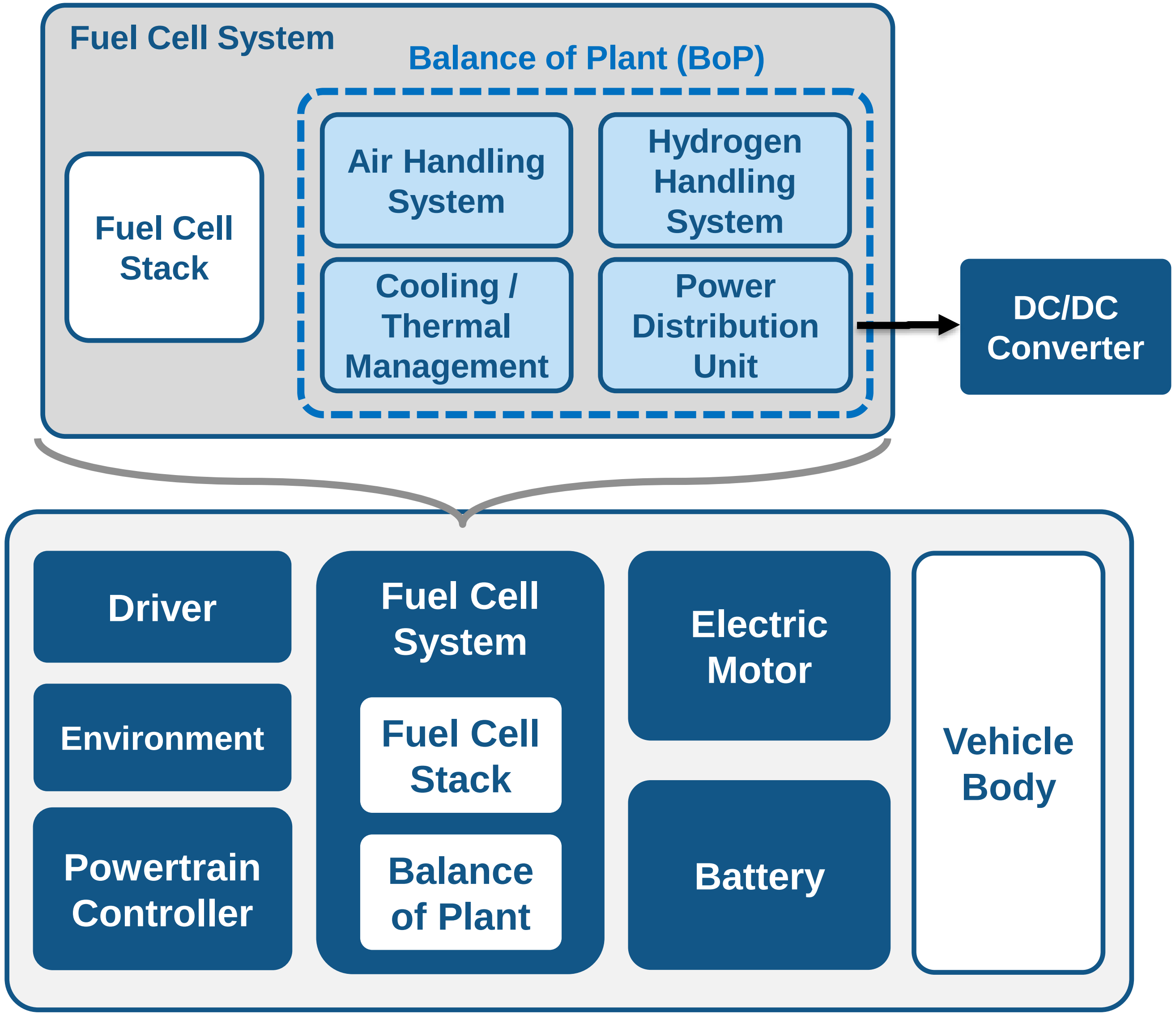


Try it out in R2022a:

`>> ssc_electrolyzer`


sscfluids_fuel_cell - Simulink
SIMULATION
DEBUG
MODELING
FORMAT
APPS
New
Open
Save
Print
FILE
Library Browser
LIBRARY
Model Settings
Property Inspector
Log Signals
PREPARE
Stop Time
2500
Normal
Fast Restart
Step Back
Run
Step Forward
Stop
SIMULATE
Data Inspector
Logic Analyzer
Bird's-Eye Scope
Simulation Manager
REVIEW RESULTS
sscfluids_fuel_cell
Electrical Load
Hydrogen Source
Recirculation
Anode Humidifier
Anode Gas Channels
Membrane Electrode Assembly
Cathode Gas Channels
Cathode Humidifier
Oxygen Source
Gas Mixture Properties
Anode Exhaust
Cathode Exhaust
PEM Fuel Cell System with a Custom Library
1. Set electrical load to (i) Drive cycle, (ii) Ramp, or (iii) Step
2. Plot fuel cell i-v curve (see code)
3. Plot power produced and consumed by system (see code)
4. Plot efficiency and utilization (see code)
5. Plot temperature in fuel cell and coolant system (see code)
6. Plot hydrogen consumed from tank (see code)
7. Plot hydrogen lost through purge valve (see code)
8. Open model workspace to explore parameters (see definition script)
9. Open custom gas mixture library used to model the fuel cell
10. Explore simulation results using sscexplore
11. Learn more about this example
Copyright 2020-2021 The MathWorks, Inc.
Cooling System
MEA Thermal Mass
f(x) = 0
Measurements
Performance
yN2
N2 Tracking
Activated Valve
Ready
97%
auto(daessc)

Fuel Cell System in Vehicle



Fuel cell system operation in an FCV

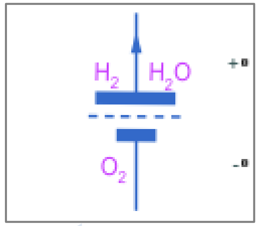
- Determine instantaneous power demand
- Convert power demand to current demand
- Distribute current demand between battery and fuel cell
- Translate current command to H_2 / Air flow commands

Choose the Appropriate Fidelity Level for Fuel Cell System Modeling

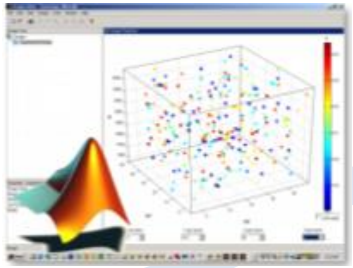
Model what you need …
when you need it

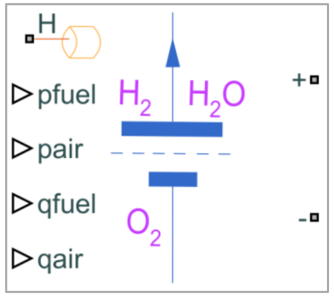
Computational Time

Voltage vs.
current curve

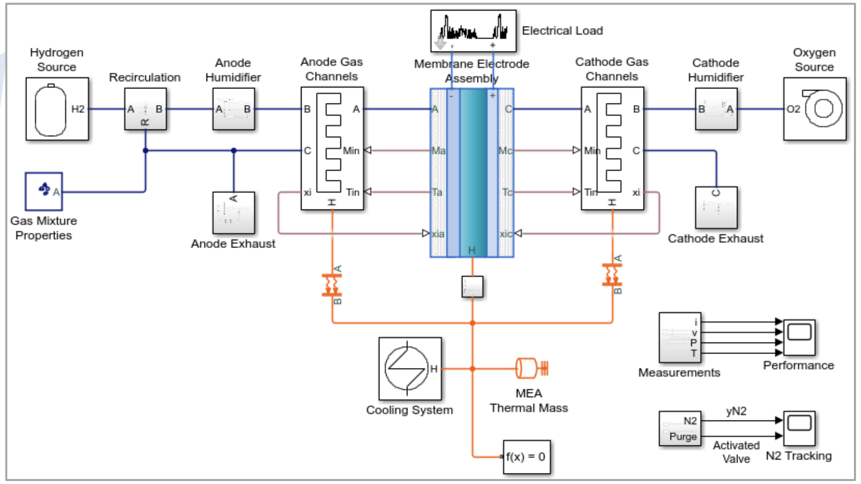


Lookup-table
statistical model
no dynamics





Detailed first principles
model without
gas dynamics



Detailed first principles
model with gas dynamics

Model Complexity and Details

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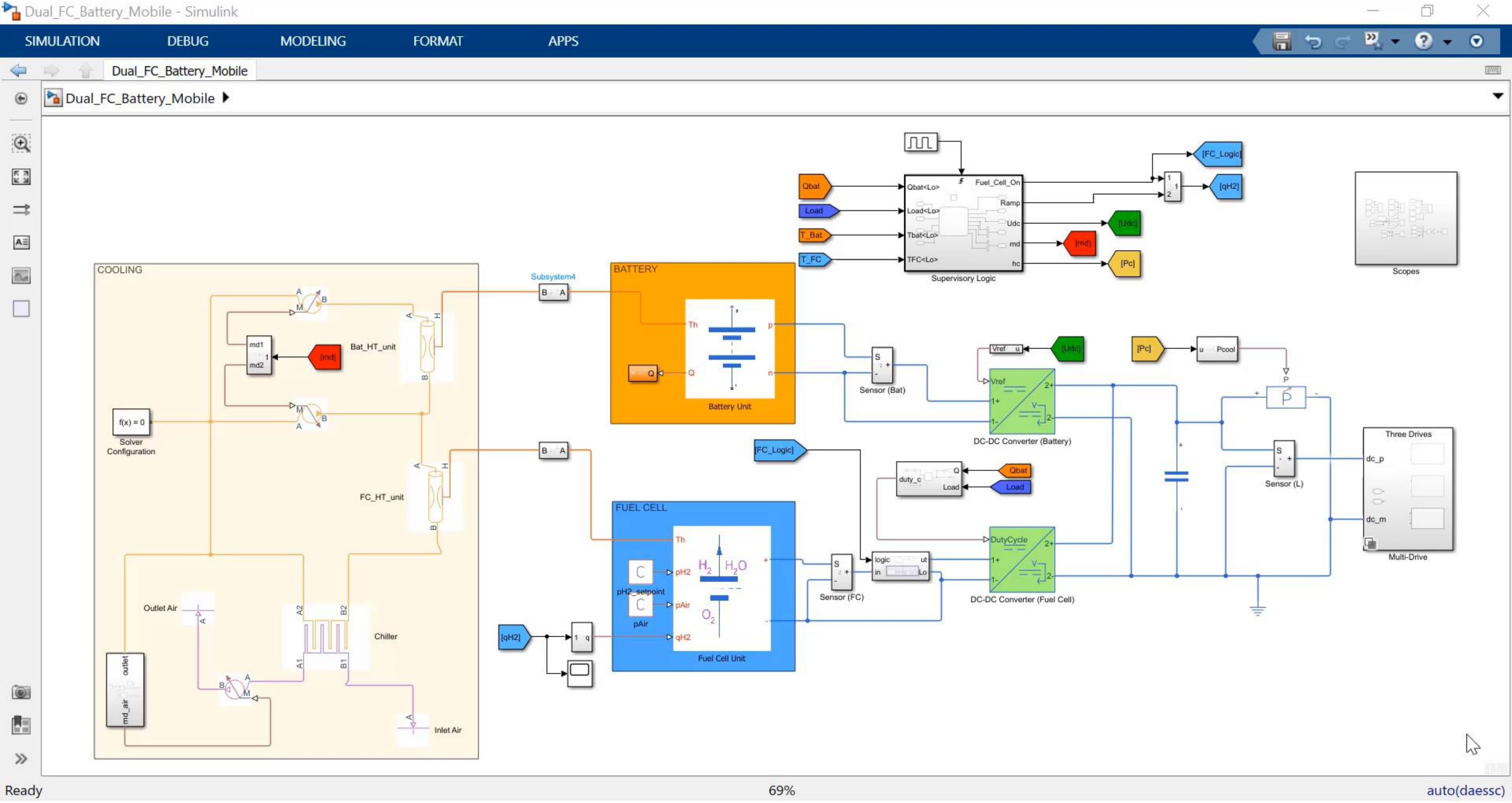


Dual_FC_Battery_Mobile - Simulink
SIMULATION
DEBUG
MODELING
FORMAT
APPS
Dual_FC_Battery_Mobile
COOLING
Bat_HT_unit
md1
md2
[md]
f(x) = 0
Solver Configuration
FC_HT_unit
Outlet Air
Chiller
Inlet Air
Subsystem4
BATTERY
Battery Unit
Sensor (Bat)
Qbat
Load
T_Bat
T_FC
Qbat<Lo>
Load<Lo>
Tbat<Lo>
TFC<Lo>
Fuel_Cell_On
Ramp
Udc
md
hc
Supervisory Logic
[FC_Logic]
[qH2]
[Udc]
[md]
[Pc]
Scopes
Vref
DC-DC Converter (Battery)
Pcool
Three Drives
dc_p
dc_m
Multi-Drive
Sensor (L)
duty_c
DutyCycle
DC-DC Converter (Fuel Cell)
logic
Sensor (FC)
FUEL CELL
pH2_setpoint
pAir
pH2
qH2
Fuel Cell Unit
Ready
69%
auto(daessc)

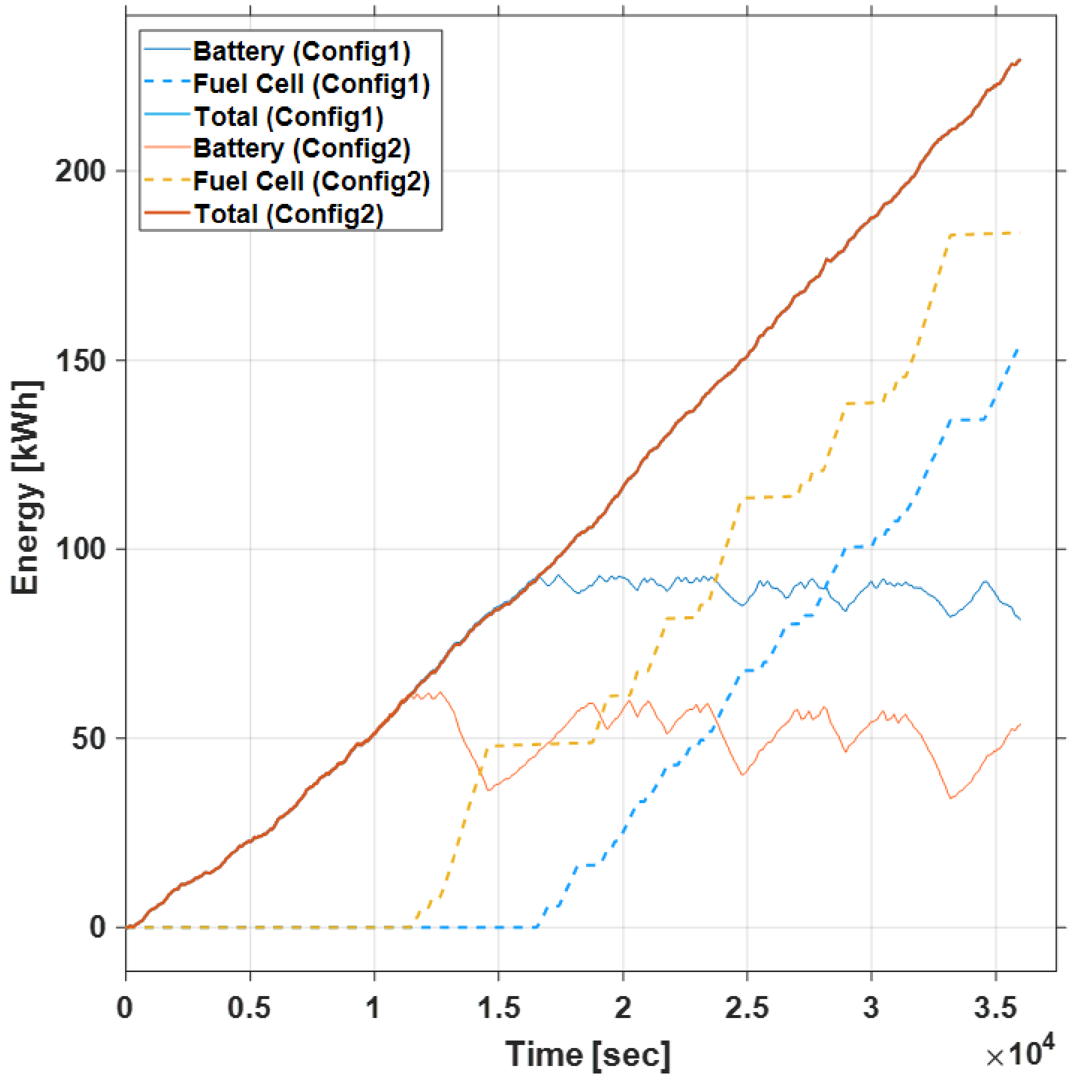
System level electrified propulsion unit

- Explore Design Space
  - Example:

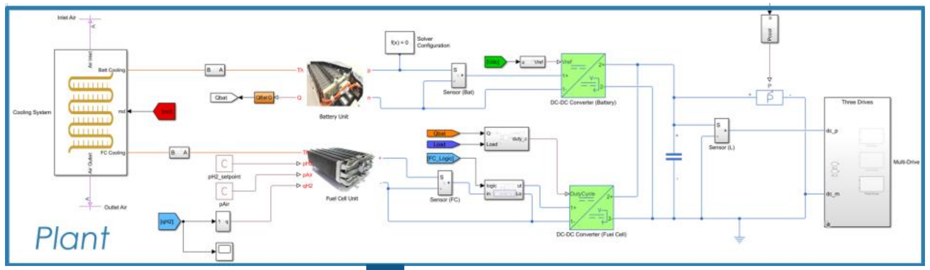
3 Battery Modules
2 Fuel Cell Stacks

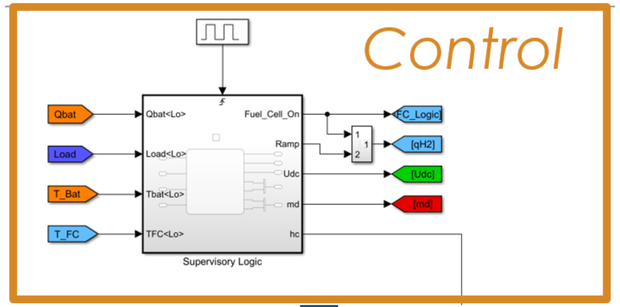
VS

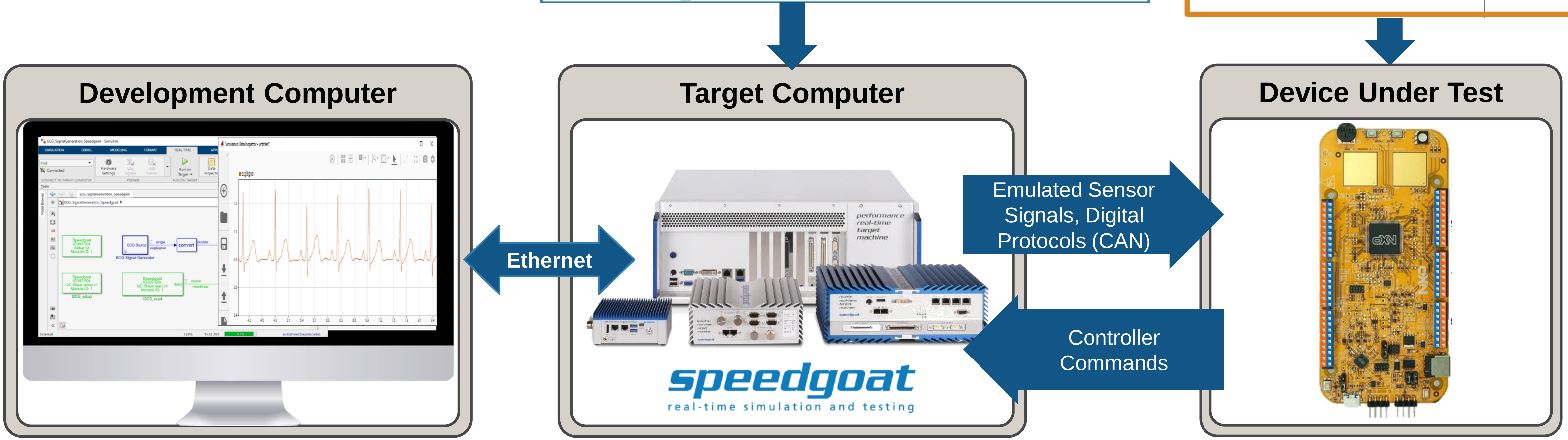
2 Battery Modules
3 Fuel Cell Stacks



Hardware-in-the-Loop







If you want to know more, register to tomorrow' webinar (19th of May 2022):
[Hardware-In-Loop Testing of Balance of Plant Controller of Fuel Cell System]
Simulink Real-Time + Speedgoat in action!

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Enabling Green Hydrogen – Challenges H2 handling and usage

(Stage 2)

Transfer (tank-to-cell)

- Optimal components sizing (cooling, storage, compressors)
  - ➢ Leverage multi-domain simulation platform
- Reliable 24/7 software operation
  - ➢ Develop supervisory logic with state-of-the-art V&V capabilities
- Meet critical safety requirements
  - ➢ Model-Based Design streamline certification of your embedded systems

(Stage 3)

Consumption (E-mobility)

- Component-level vs system-level simulation
  - ➢ Flexible modelling and simulation platform
- Optimal system architecture (e.g., fuel cell multi-stack, battery)
  - ➢ Perform trade-off analysis and monte carlo simulations
- Expensive physical prototype testing
  - ➢ Reduce physical prototypes, reuse models for Hardware-in-the-Loop tests

User testimonial – Nuvera Cells

Hydrogen Is the New Diesel:
Electrifying Heavy-Duty Vehicles
with Nuvera Fuel Cells
Video

*“ Using **modeling** and **real-time simulation** enables Nuvera’s engineers to iterate on their design **quickly** and allows for experimentation without putting a real engine **at risk**. “*

Collaborative Engineering– IP Protection, Deployment & Sharing

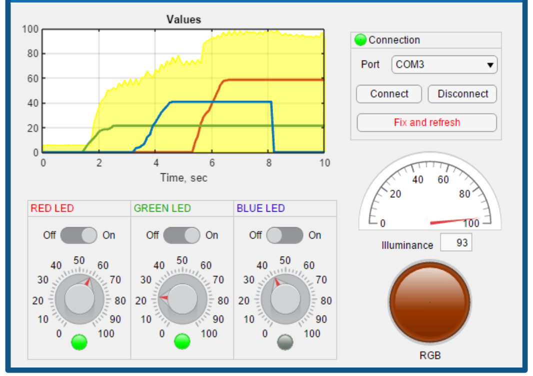
IP protection

Ref_Model.slxp

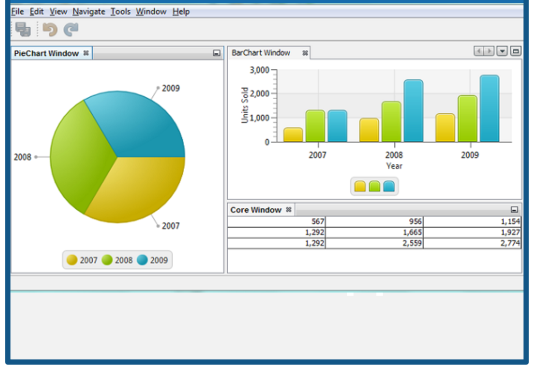
MATLABscript.p

Cell.sscp

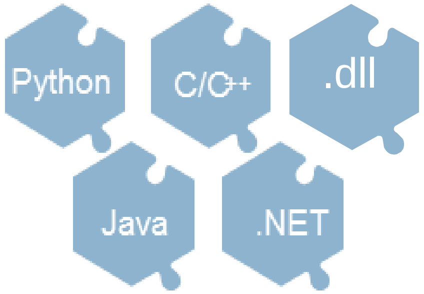
Standalone Apps



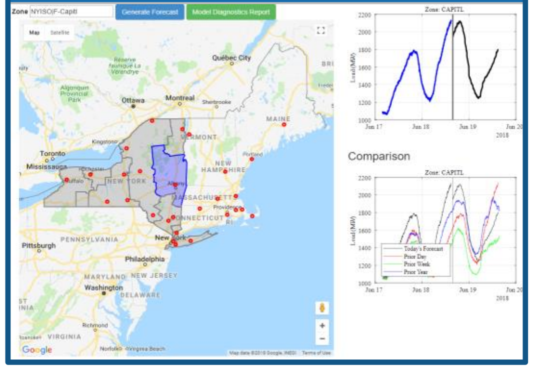
Web Apps



Shared Libraries



Service APIs



Standalone FMUs

fmi FUNCTIONAL MOCK-UP INTERFACE

Click on the boxes to learn more!

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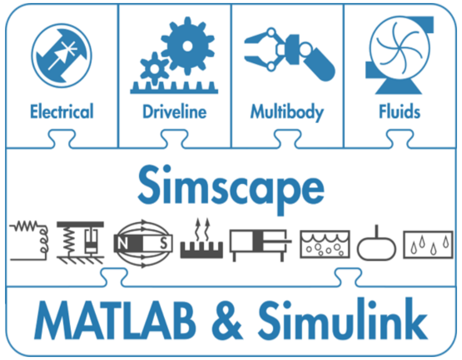
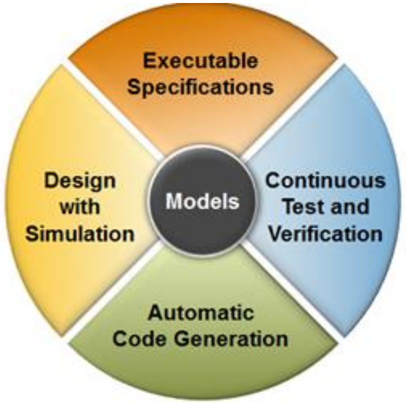
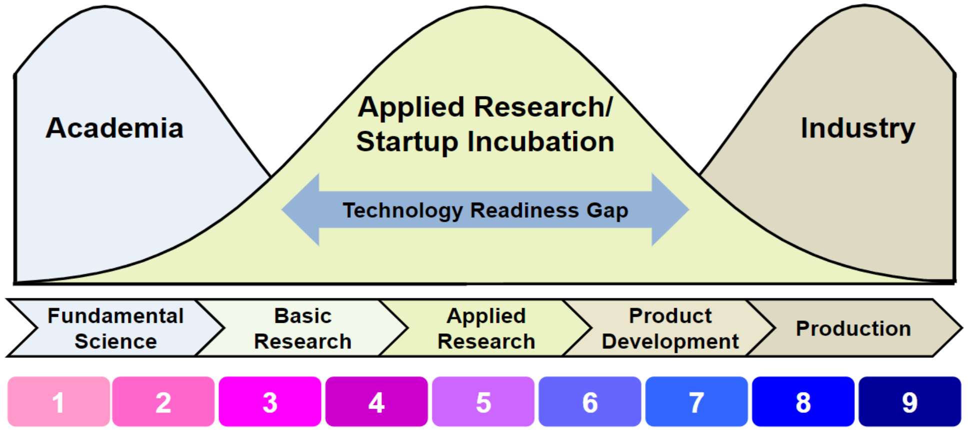
Enabling Green Hydrogen - Conclusions







- Assert feasibility
  - techno-economic analyses
  - concept evaluation
- Secure sustainable and robust operation
  - design automation
  - optimization
- Collaborative Engineering
  - sharing know-how
  - deployment

Call to Action

- Developing Hydrogen Production and Fuel Cell Applications with MATLAB and Simulink
  - In-depth videos & resources
  - Customer references
- Additional resources
  - MATLAB and Simulink for the Utilities and Energy Industry
  - MATLAB and Simulink for Electric Vehicle Development
  - MATLAB and Simulink for Developing Power Generation and Transmission Equipment
  - MATLAB and Simulink for Verification, Validation and Test
- Shipping examples
  - PEM Fuel Cell System (2022a)
  - PEM Electrolysis System (2022a)

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Thank you!
Any questions?

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