

# MATLAB EXPO

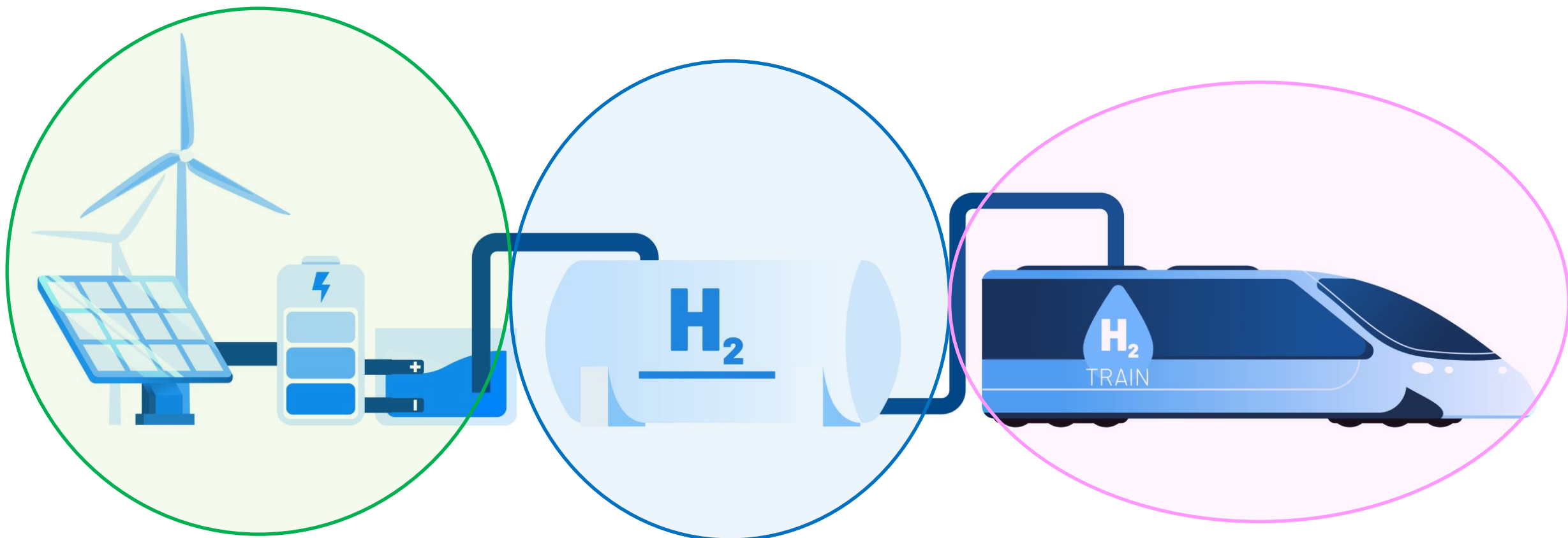
MATLAB/Simulink为绿色氢能产业赋能

宋胜凯



# 为绿色氢能产业赋能——供应链

Enabling Green Hydrogen – Supply chain



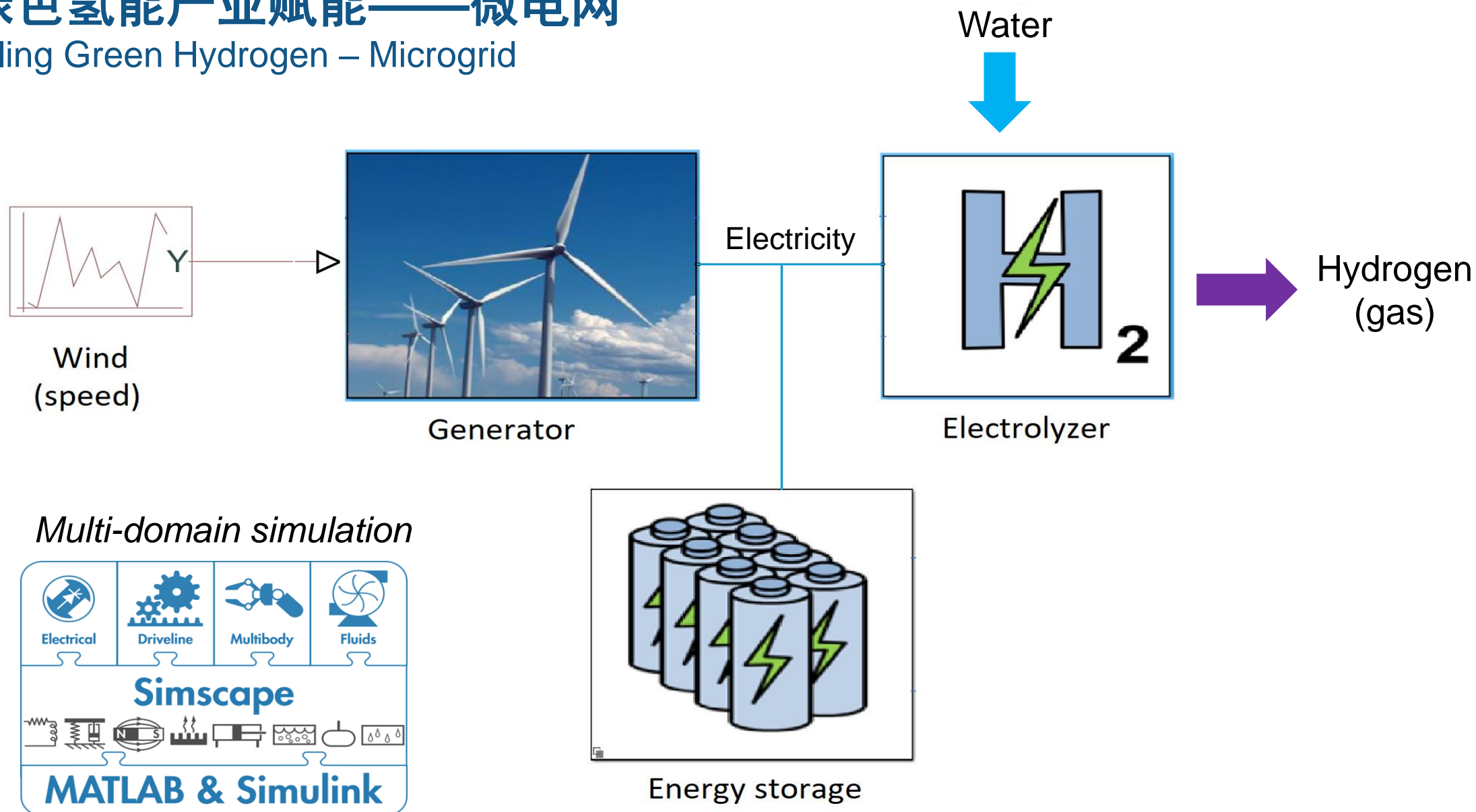
绿氢的生产  
Green Hydrogen  
Production

氢气的输送  
Hydrogen  
Distribution

氢气的利用  
Hydrogen  
Consumption

# 为绿色氢能产业赋能——微电网

Enabling Green Hydrogen – Microgrid



# 为绿色氢能产业赋能——动力/动机

## Enabling Green Hydrogen – Motivation

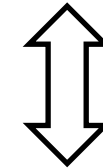
### 优势 Advantages

- 100% 可持续性 sustainable
- 可存储 storable
- 多用途 versatile
- 便携的 transportable

“Green hydrogen: an alternative that reduces emissions and cares for our planet”  
[Iberdrola > Sustainability > Green Hydrogen](#)

### 劣势 Deltas

- 高能耗 high energy consumption
- 安全性 safety (managing H2)
- 高成本 high cost

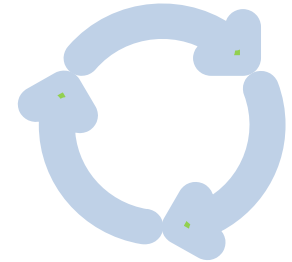


Simulation  
Based  
Engineering

# 为绿色氢能产业赋能——关键点

## Enabling Green Hydrogen – Key takeaways

- 可行性评估 Assert feasibility
  - 经济技术分析 Techno-economic analyses
  - 概念论证 Proven concept
- 保证可持续和可靠的运行 Secure sustainable and robust operation
  - 设计自动化 Design Automation
  - 设计与运行优化 Optimization
- 协作开发 Collaborative Engineering
  - 知识分享与IP保护 Sharing know-how & IP
  - 多应用场景下的产品部署 Deployment



# 阶段一：绿氢的生产

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



# 为绿色氢能产业赋能——挑战

Enabling Green Hydrogen – Challenges

Production  
(Micro-grid)

Unit  
Level

## 组件设计 Component design

- 电解槽 electrolyzer
- 能量存储单元 energy storage
- 电力变换单元 power converter unit
- 发电机 generator

## 资产数字化 Asset digitalization

- 异常检测 anomaly detection
- 寿命预估 lifetime estimation
- 预测开发 prognostics development

System  
Level

## 装备设计 Plant design

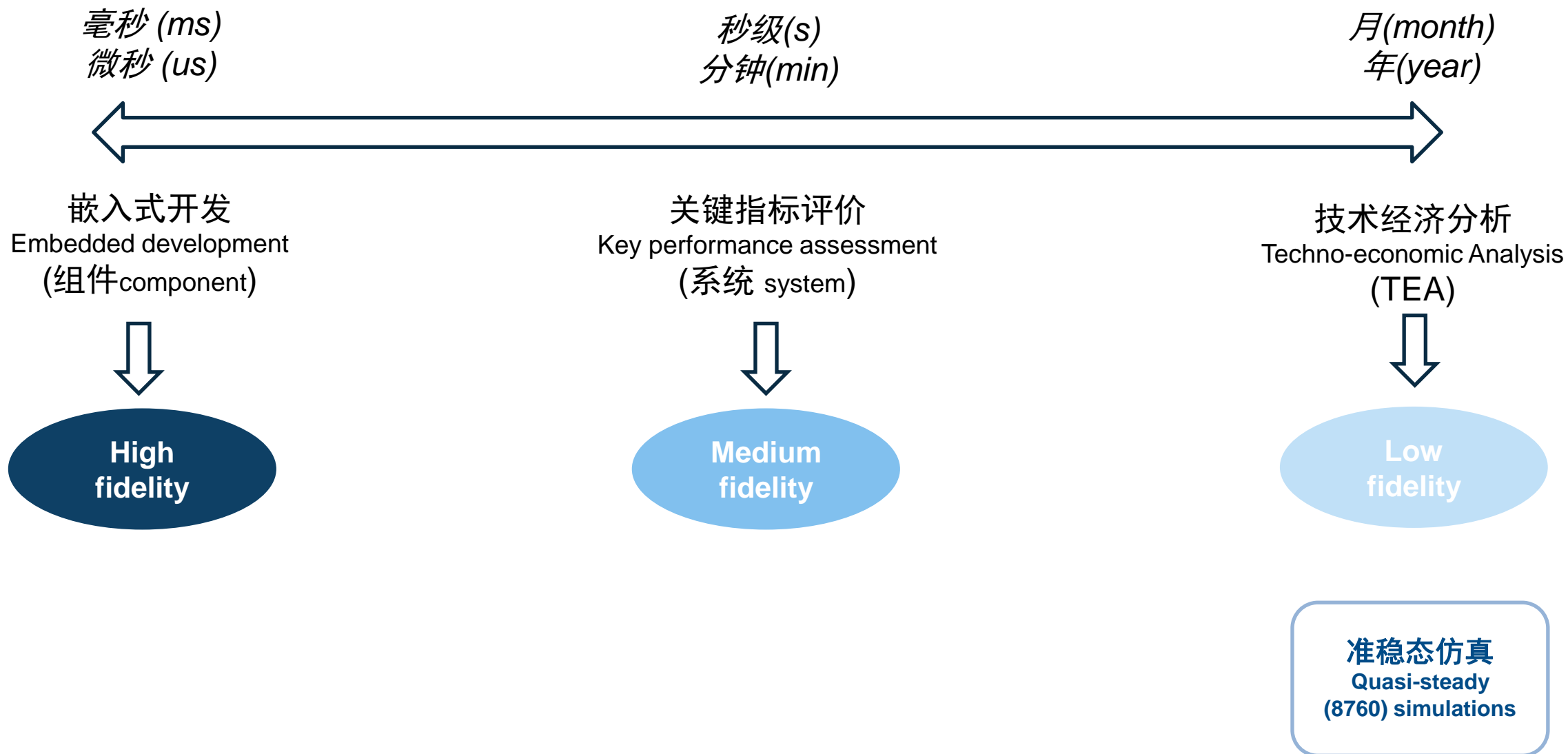
- 概念评估 concept evaluation
- 物理需求 physical requirements
- 能量平衡 energy balance

## 高层算法设计 High-level algorithmic design

- 监管逻辑 supervisory logic
- 设置运行点 setpoint definition

# 为绿色氢能产业赋能——模型保真度

Enabling Green Hydrogen – Model fidelity





# 为绿色氢能产业赋能——技术经济分析TEA（太阳能微网）

Enabling Green Hydrogen – TEA (solar microgrid)

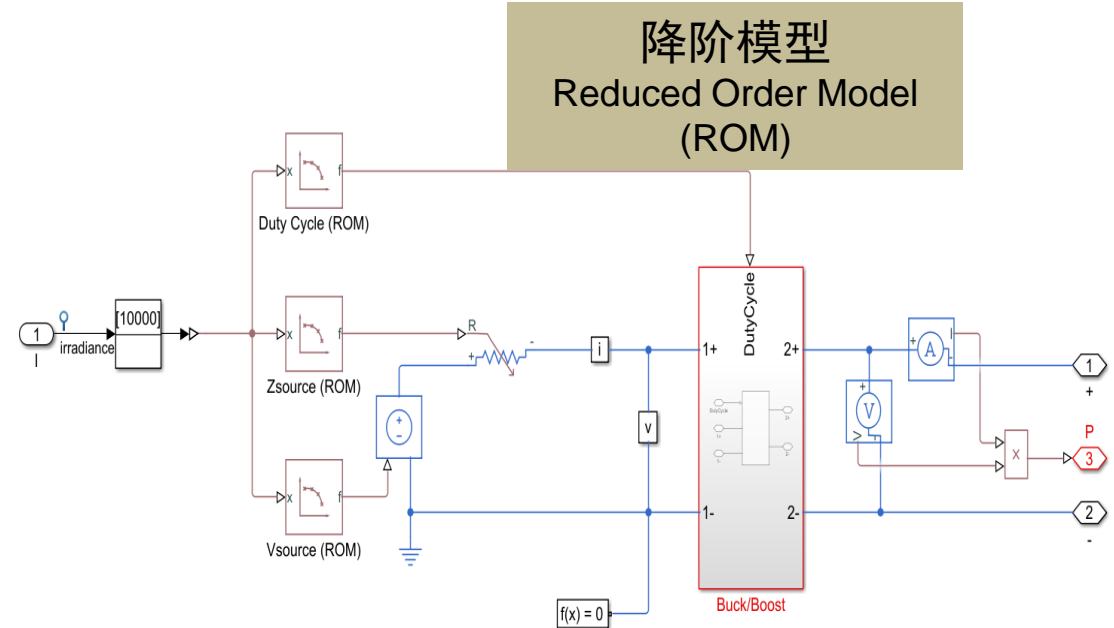
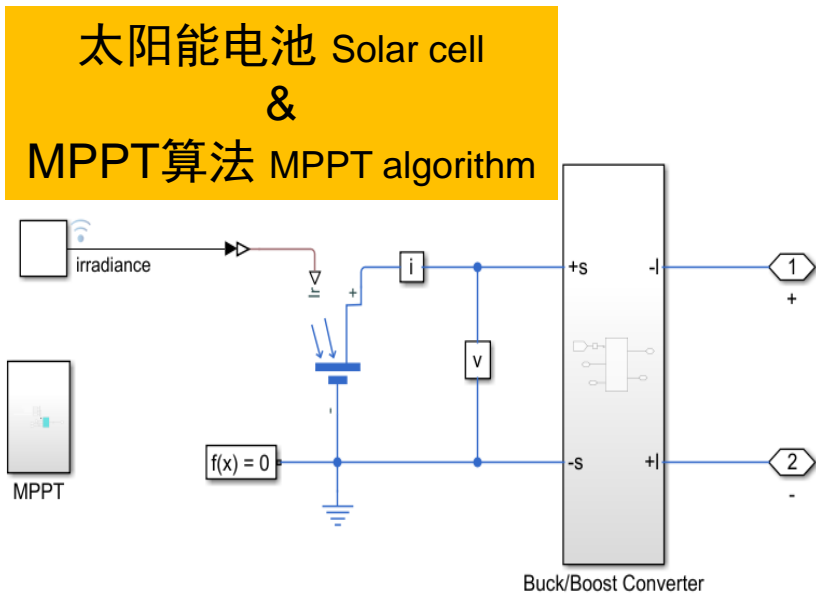
指标评价  
Performance assessment

技术经济分析  
Techno-economic analyses

Medium fidelity

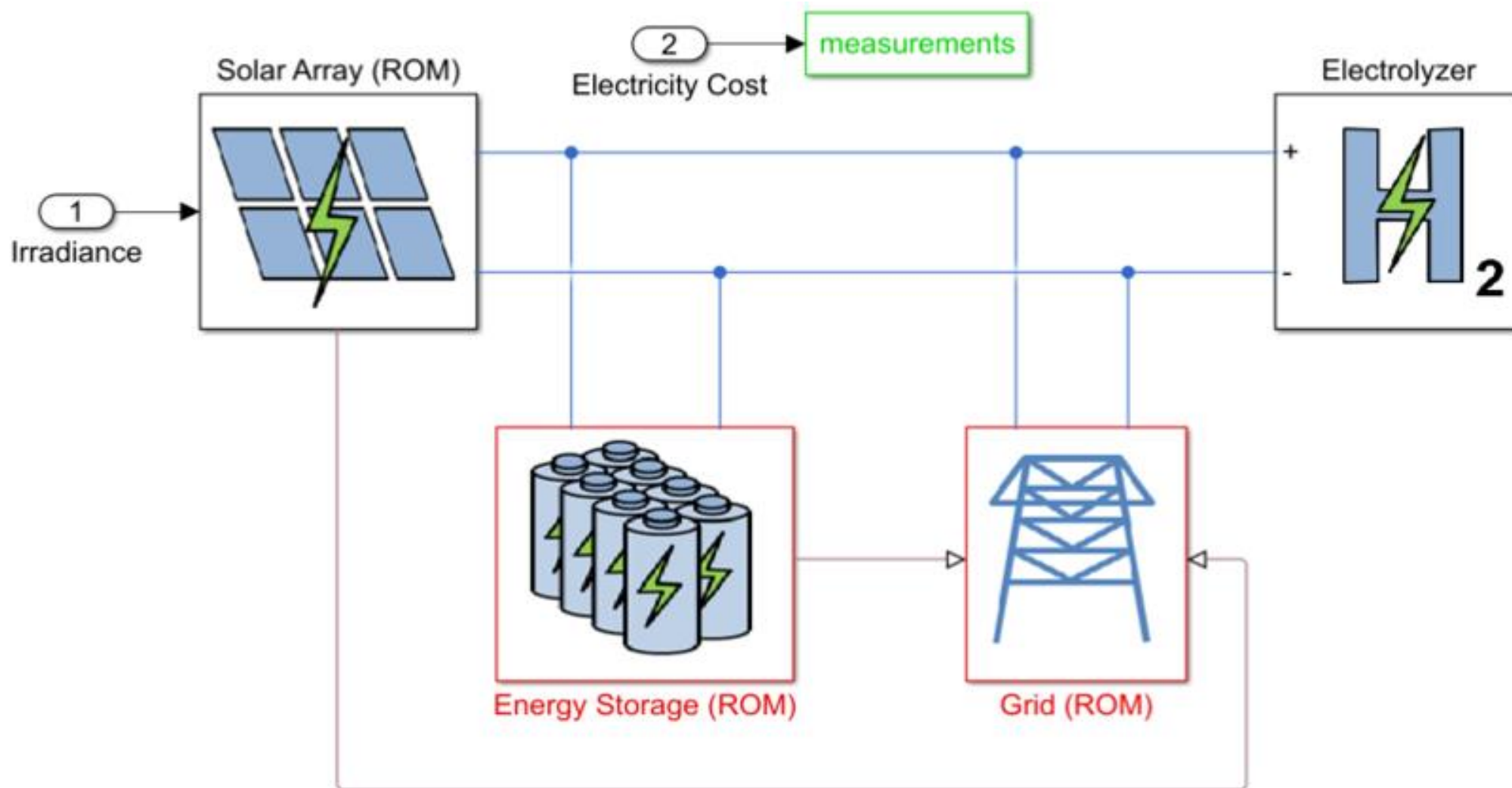


Low fidelity



# 为绿色氢能产业赋能——技术经济分析TEA（太阳能微网）

Enabling Green Hydrogen – TEA (solar microgrid)

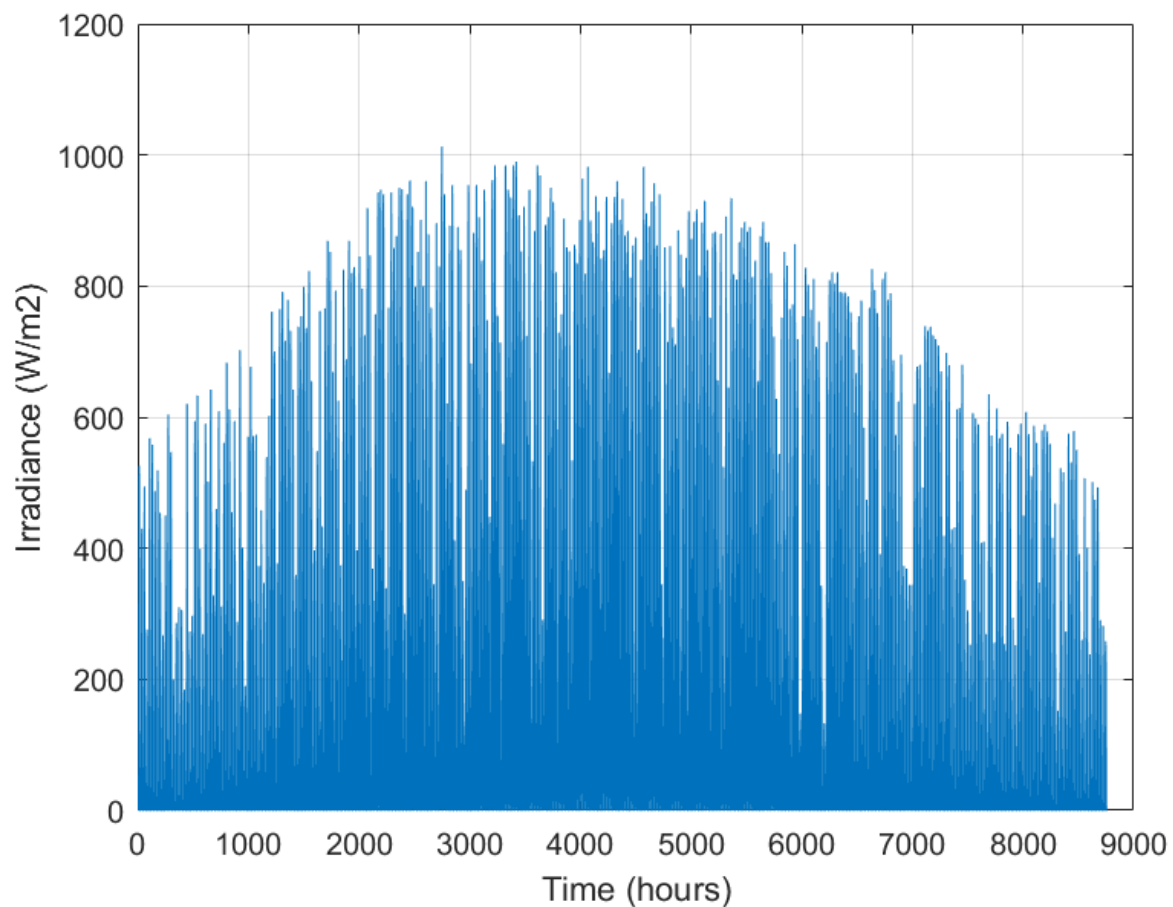


# 为绿色氢能产业赋能——技术经济分析TEA（数据的复用）

Enabling Green Hydrogen – TEA (data re-use)

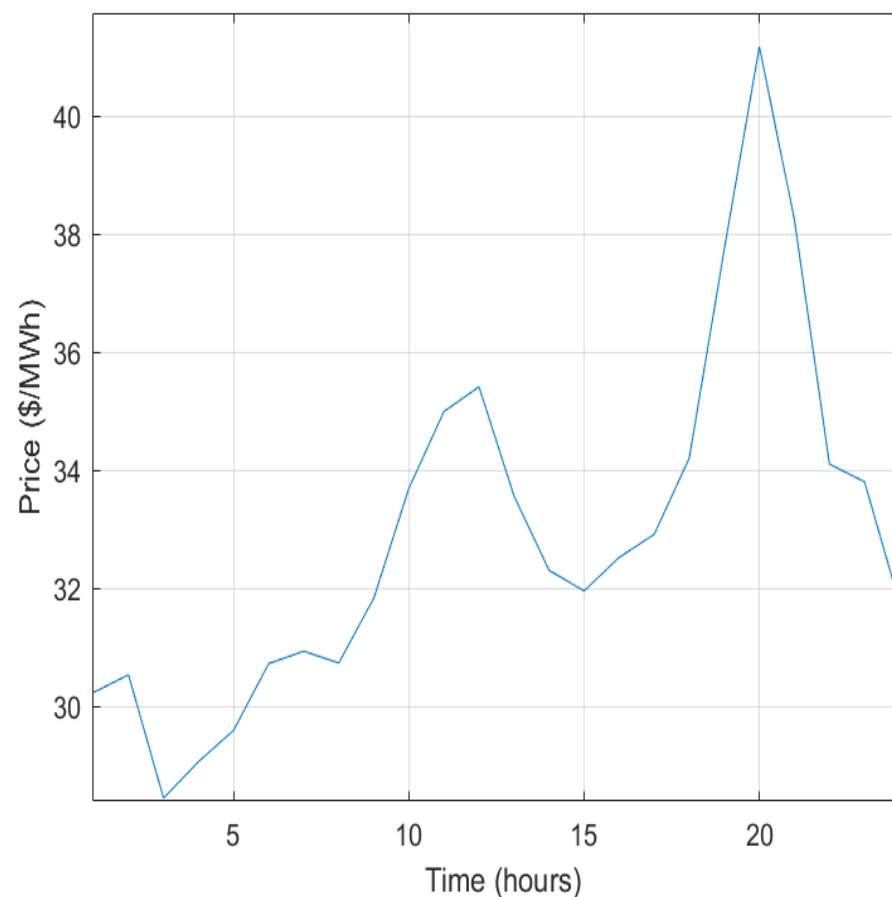
来自NREL的日照强度数据

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



运营商的每日电力价格

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



# 为绿色氢能产业赋能——技术经济分析TEA（产出）

Enabling Green Hydrogen – TEA (outcome)

氢气生产 H<sub>2</sub> production: Highest grid cost & Lowest solar resource

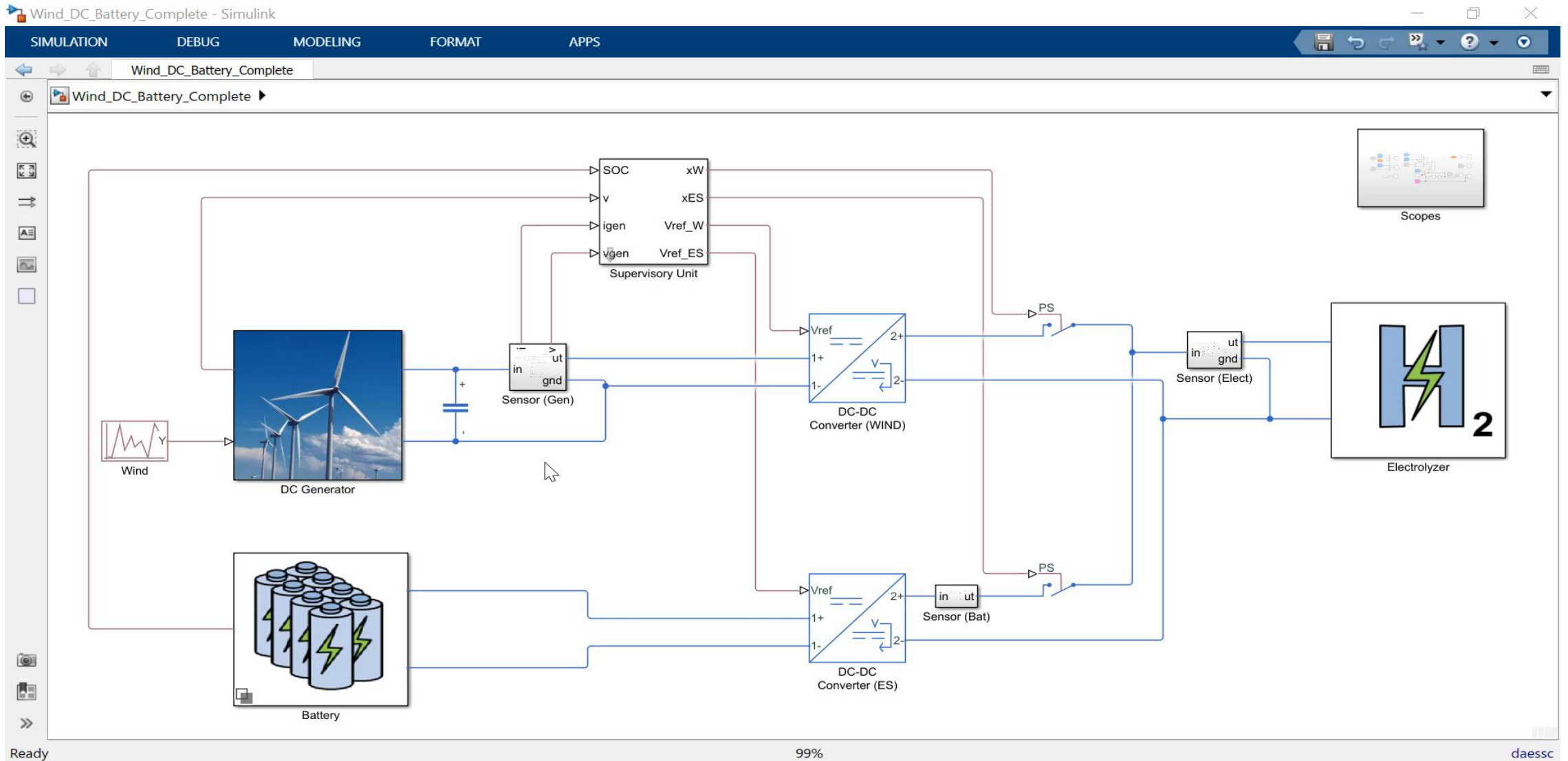
```
Elapsed time is 510.209014 seconds.  
-----  
Lowest grid cost is USD 6761.6456 at Phoenix Sky Harbor Intl AP  
Highest solar resource is 497.1227MWh at Daggett Barstow-Daggett AP  
  
Highest grid cost is USD 13217.5585 at Quillayute State Airport  
lowest solar resource is 291.2997MWh at Quillayute State Airport  
-----
```

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

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

# 为绿色氢能产业赋能——系统效能

## Enabling Green Hydrogen – System performance

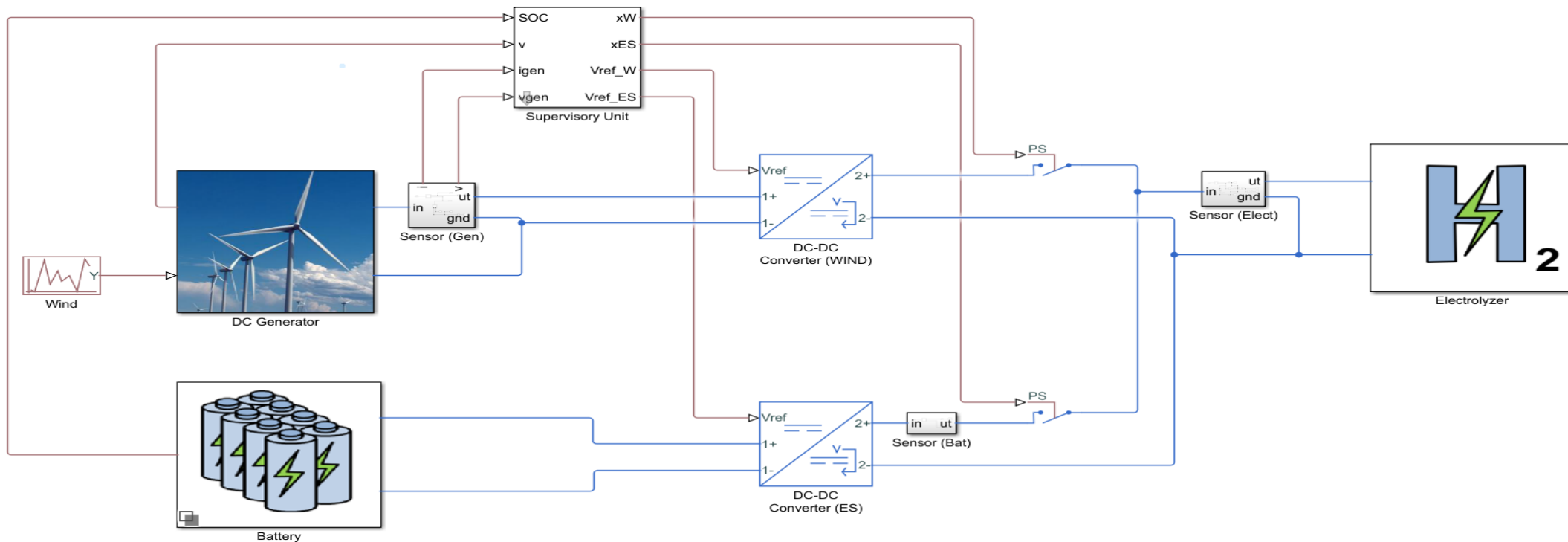


# 为绿色氢能产业赋能——系统效能

## Enabling Green Hydrogen – System performance

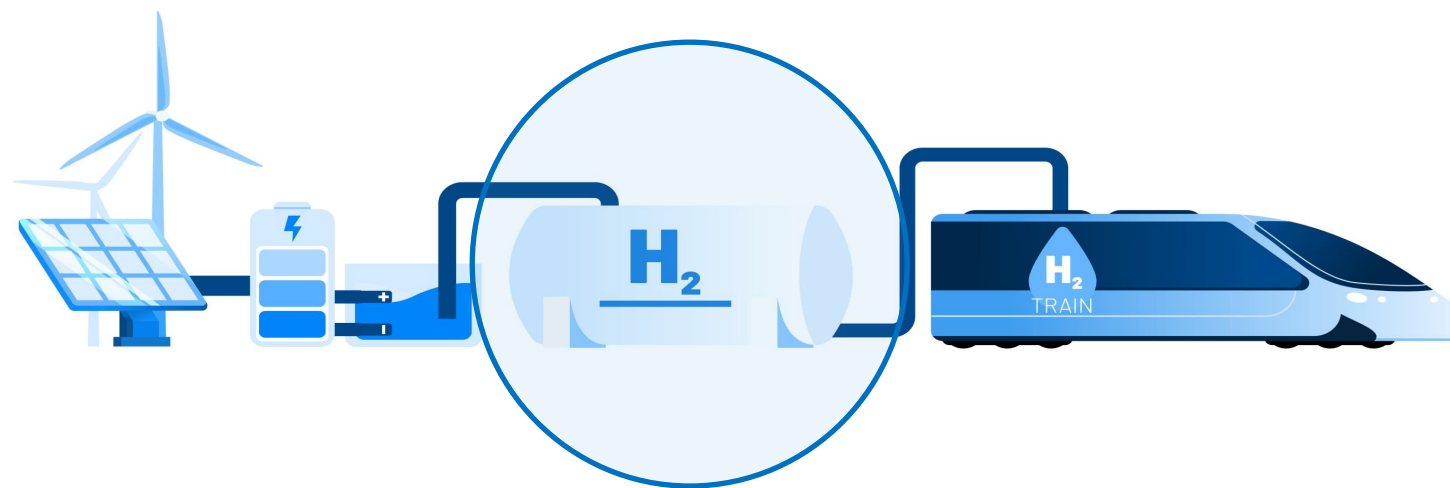
Medium  
fidelity

- 预期的氢气生产与水的消耗 expected H<sub>2</sub> production & water consumption
- 合适的控制策略 suitable control strategy (conditions, use of physical assets)
- 能源存储 energy storage (dimensioning, expected duty regime)
- 运行计划 planning of operations (collect – replace - maintain)



## 阶段二：氢气的输送

Stage 2. Hydrogen Distribution  
(from tank to consumers)



# 为绿色氢能产业赋能——氢气处置和使用上的挑战

Enabling Green Hydrogen – Challenges H2 handling and usage

(Stage 2)

Transfer  
(tank-to-cell)

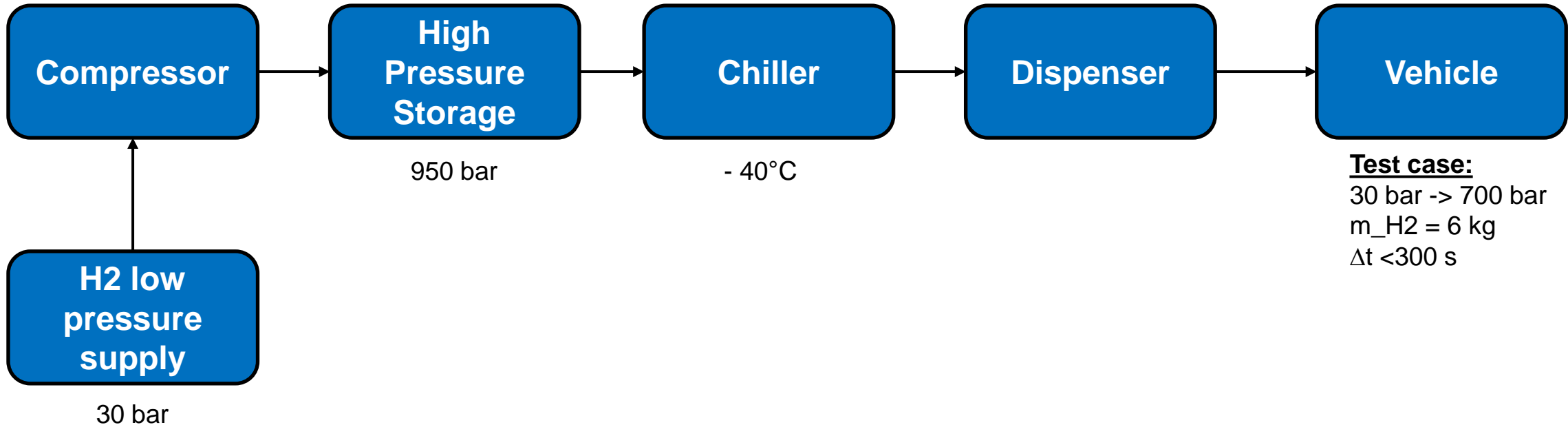
- 最优的组件规格 Optimal components sizing (cooling, storage, compressors)
- 可靠的运行24/7 Reliable 24/7 software operation
- 符合安全规范 Meet critical safety requirements



# 使用Simscape对气体系统建模

Modeling gas systems with Simscape

- 案例分析 Case study: Hydrogen Refueling Station



SIMULATION    DEBUG    MODELING    FORMAT    APPS

Project    New    Open    Save    Print    Library Browser    Model Settings    Property Inspector    Log Signals    Stop Time: 4000    Normal    Step Back    Run    Step Forward    Stop    Data Inspector    Sequence Viewer    Logic Analyzer

FILE    LIBRARY    PREPARE    SIMULATE    REVIEW RESULTS

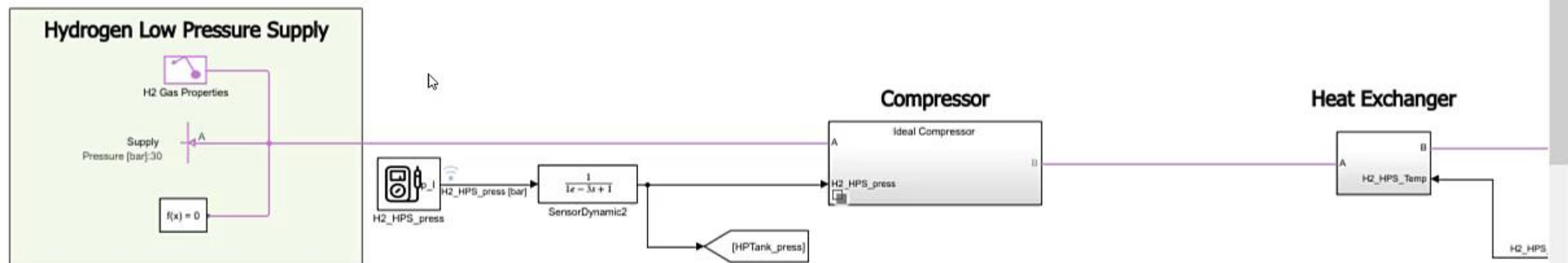
Fast Restart

Ideal Compressor    HydrogenGasTank    Compressor    Ideal Heat Exchanger    Ideal Chiller

HydrogenGasTank

# Hydrogen Gas Refuelling Station

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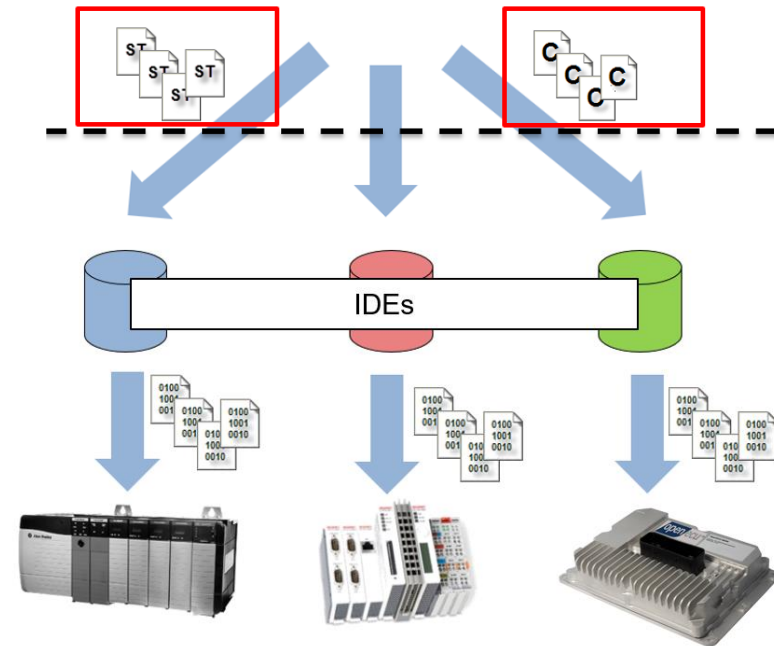
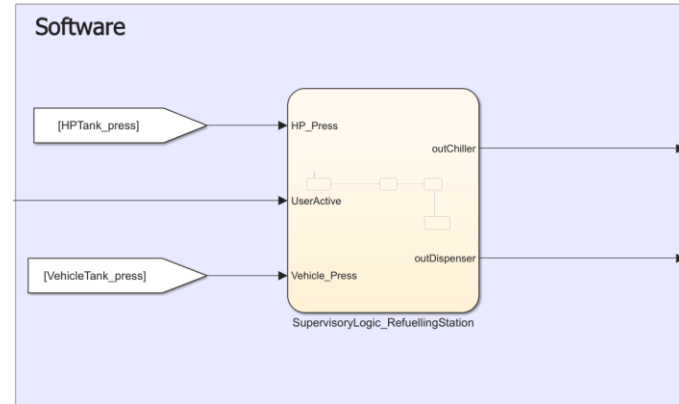


Software

# 构建算法模型并部署到实时控制器

## Algorithm model and deployment on real-time controller

- 从模型到代码的自动生成 Automatic code generation from models
- 减少编程时间和编码错误 Reduced coding time & errors
- 不依赖硬件的源代码 Hardware independent source code
- 单一源的知识表达 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	✓	✓	✓

# 支持认证的工作流为高质量和高安全性提供保障

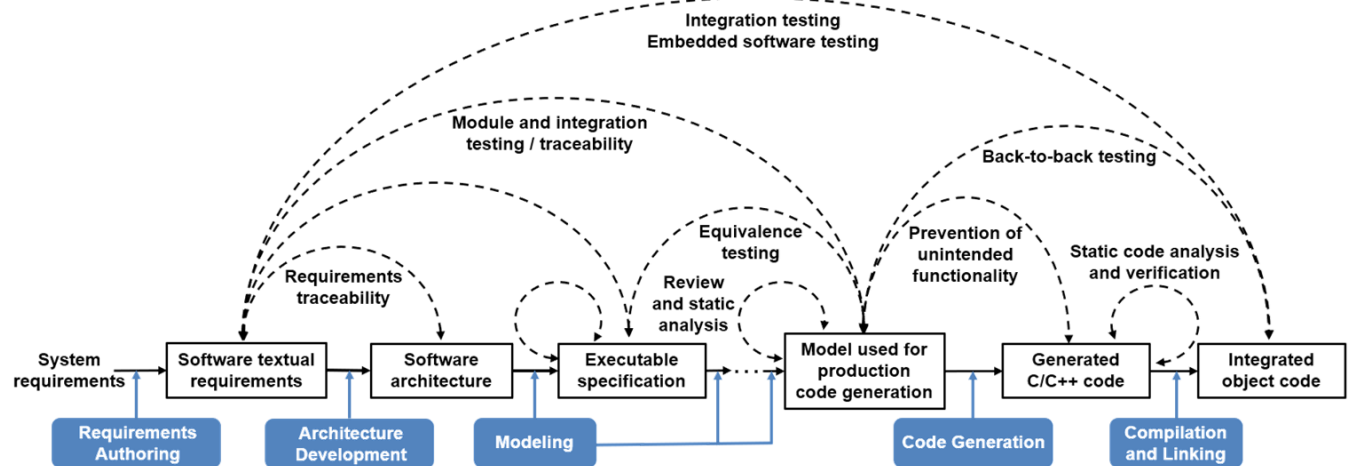
Scalable to certification workflows ensuring highest quality & safety

- 
 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



# 为绿色氢能产业赋能——氢气处置和使用上的挑战

Enabling Green Hydrogen – Challenges H2 handling and usage

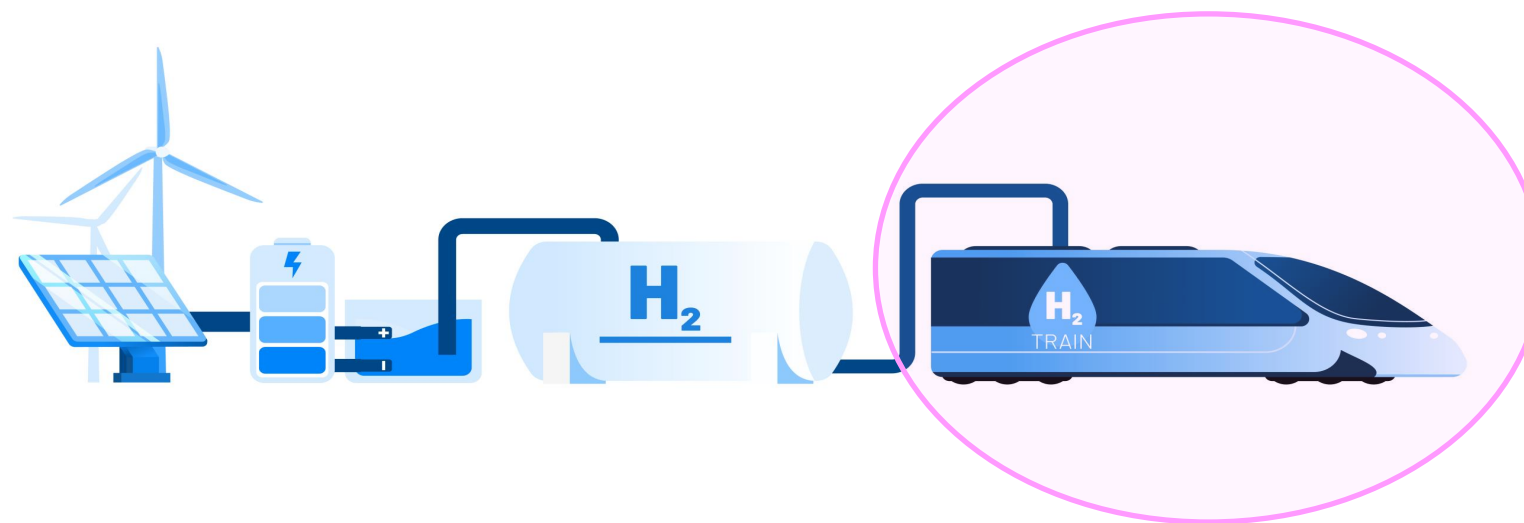
(Stage 2)

Transfer  
(tank-to-cell)

- 最优的组件规格 Optimal components sizing (cooling, storage, compressors)
  - 多域仿真平台  
Multi-domain simulation platform
- 可靠的运行24/7 Reliable 24/7 software operation
  - 借助V&V进行控制逻辑开发  
Develop supervisory logic with state-of-the-art V&V capabilities
- 符合安全规范 Meet critical safety requirements
  - 基于模型设计的认证 workflows  
Model-Based Design streamline certification of your embedded systems

# 阶段三：氢气的利用

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



# 为绿色氢能产业赋能——氢气处置和使用上的挑战

Enabling Green Hydrogen – Challenges H2 handling and usage

(Stage 2)

Transfer  
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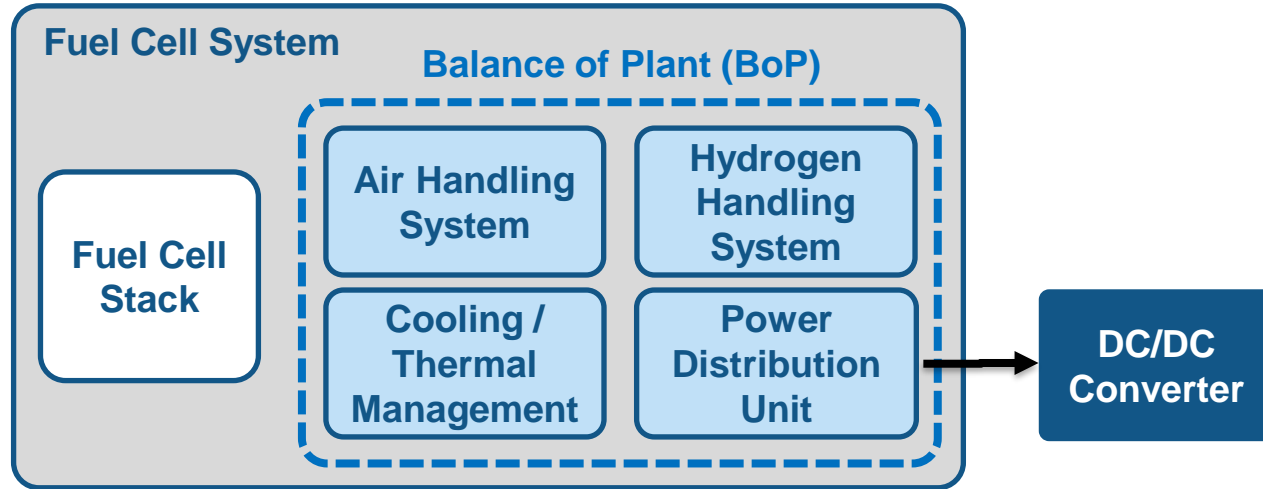
(Stage 3)

Consumption  
(E-mobility)

- 组件级 Vs 系统级仿真 Component-level vs system-level simulation
- 最佳的系统架构 Optimal system architecture (e.g., fuel cell multi-stack, battery)
- 昂贵的硬件原型测试 Expensive physical prototype testing

# 燃料电池系统

## Fuel Cell System in Vehicle





# 使用多领域技术对燃料电池系统进行仿真

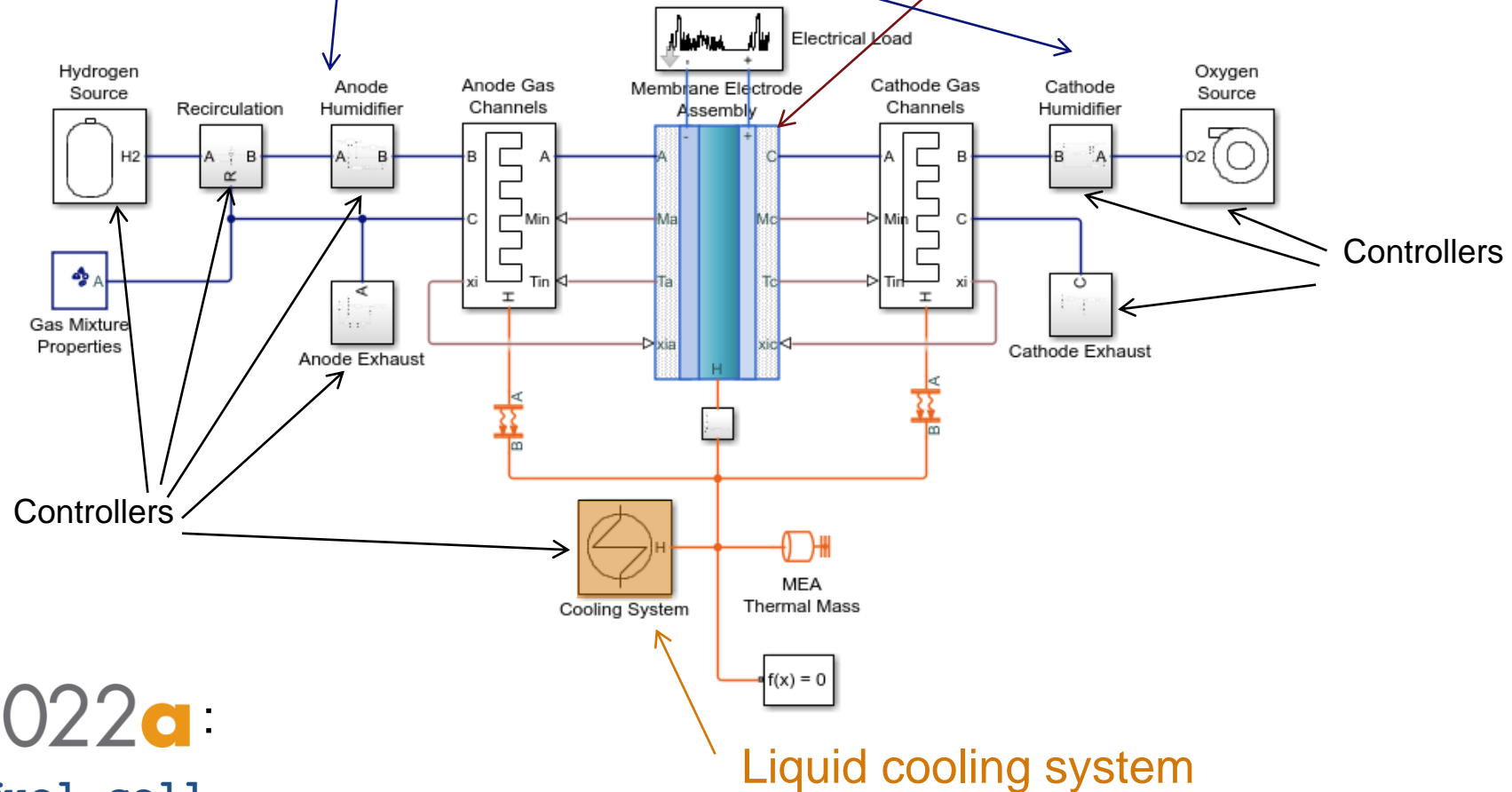
Multiple Domains used to Simulate Fuel Cell Systems....

## 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

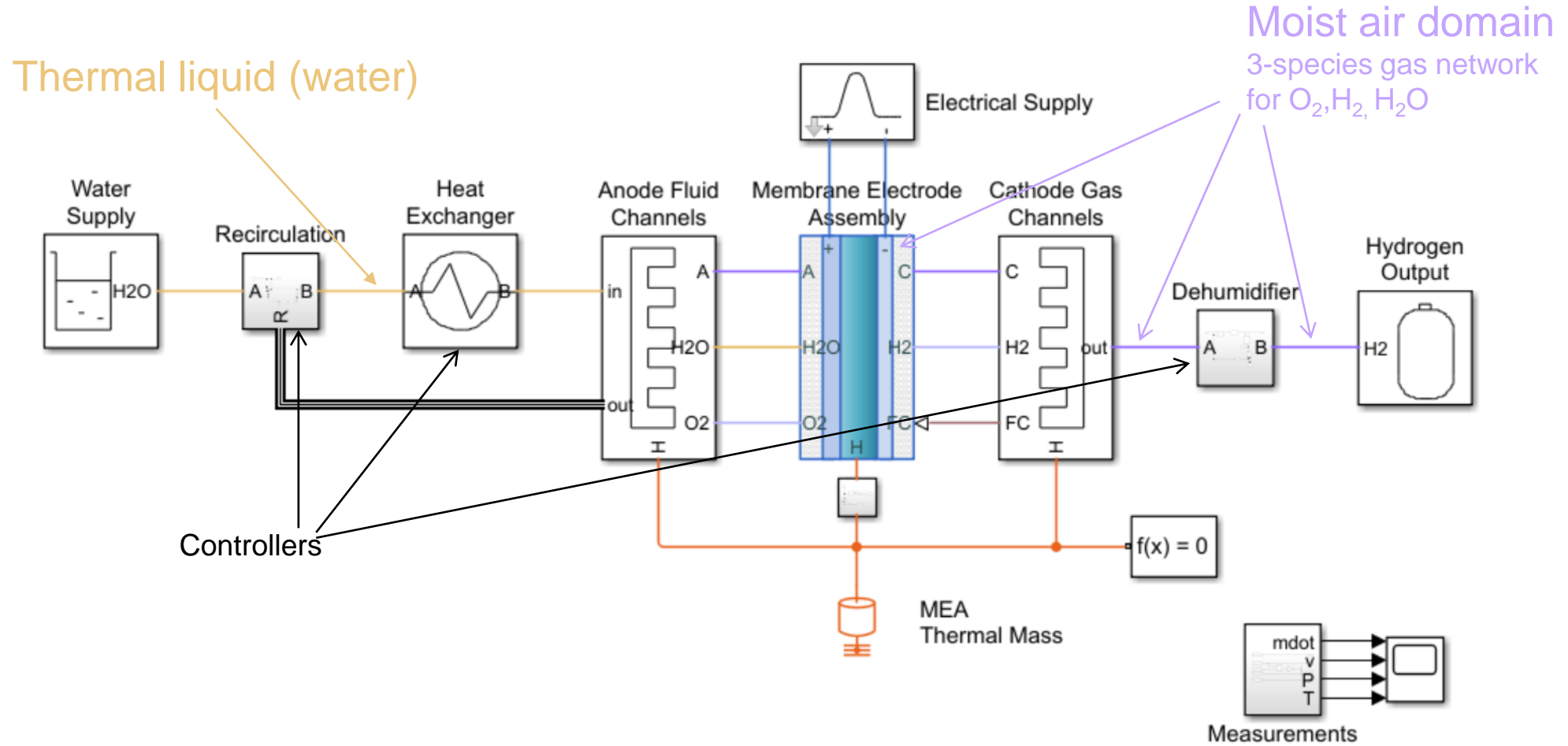


Try it out in **R2022a**:

`>> sscfluids_fuel_cell`

# 对电解槽建模

... and Electrolyzers!



Try it out in **R2022a**:

`>> ssc_electrolyzer`

**SIMULATION**    **DEBUG**    **MODELING**    **FORMAT**    **APPS**

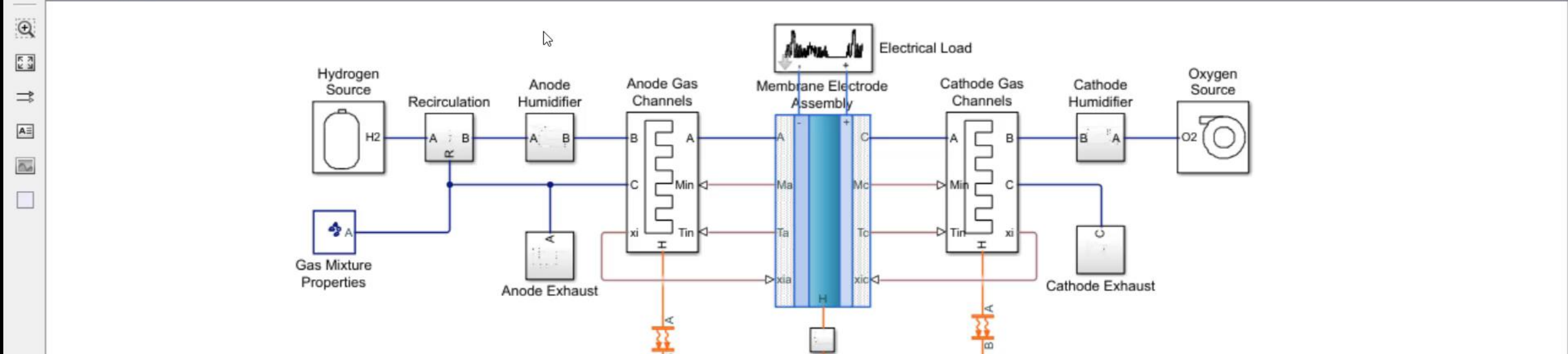
+ Open    + Save    + Print    + Library Browser  
 FILE    LIBRARY

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

sscfuids\_fuel\_cell



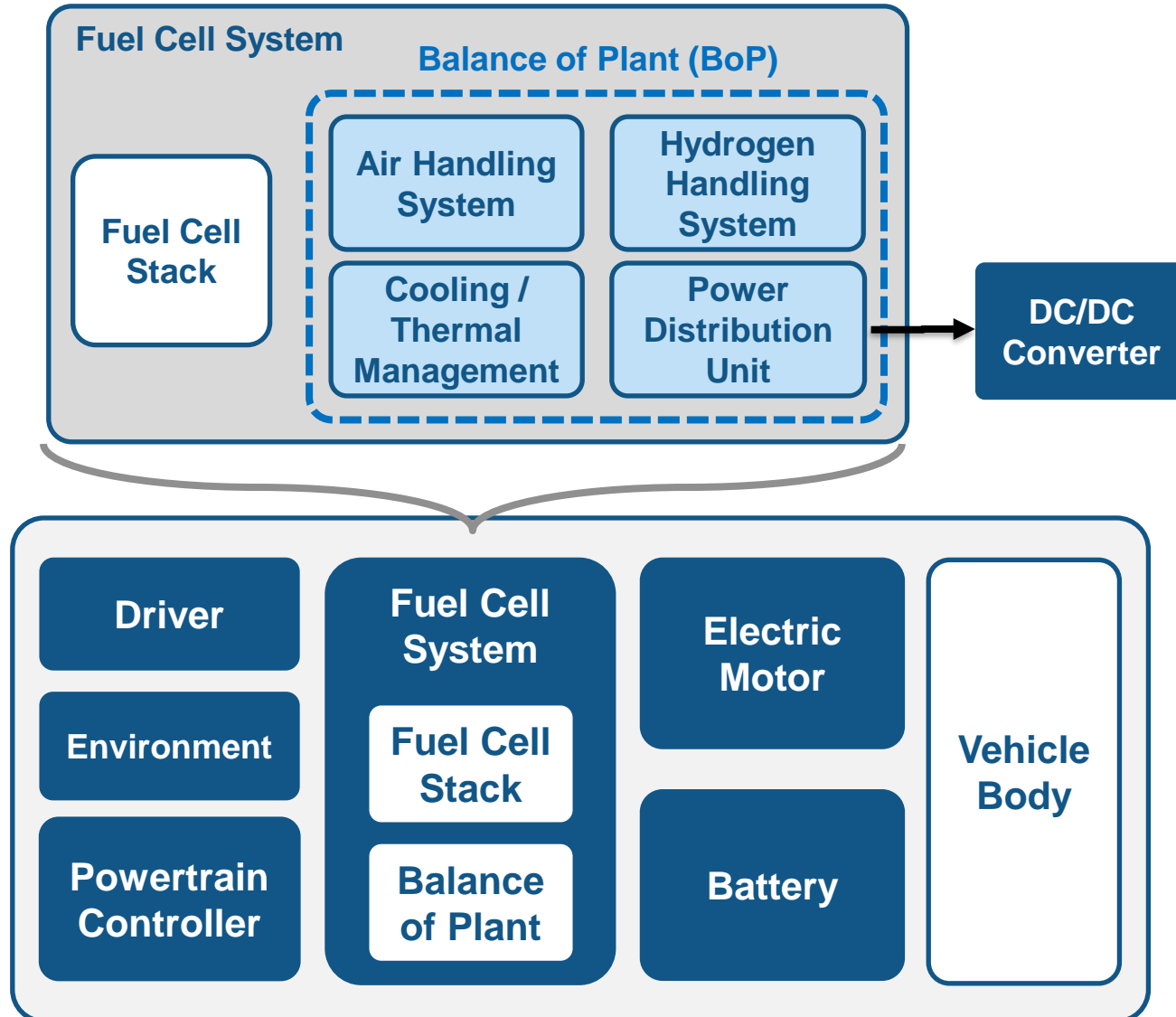
**PEM Fuel Cell System with a Custom Library**

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

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# 燃料电池系统

## Fuel Cell System in Vehicle



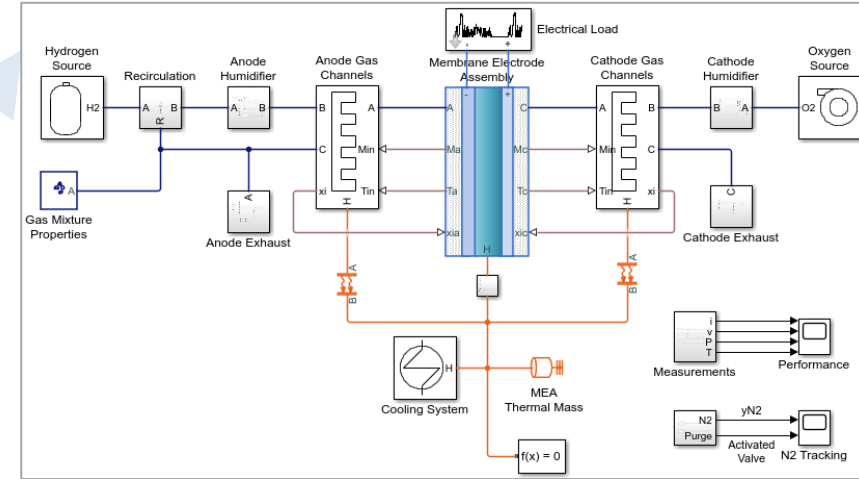
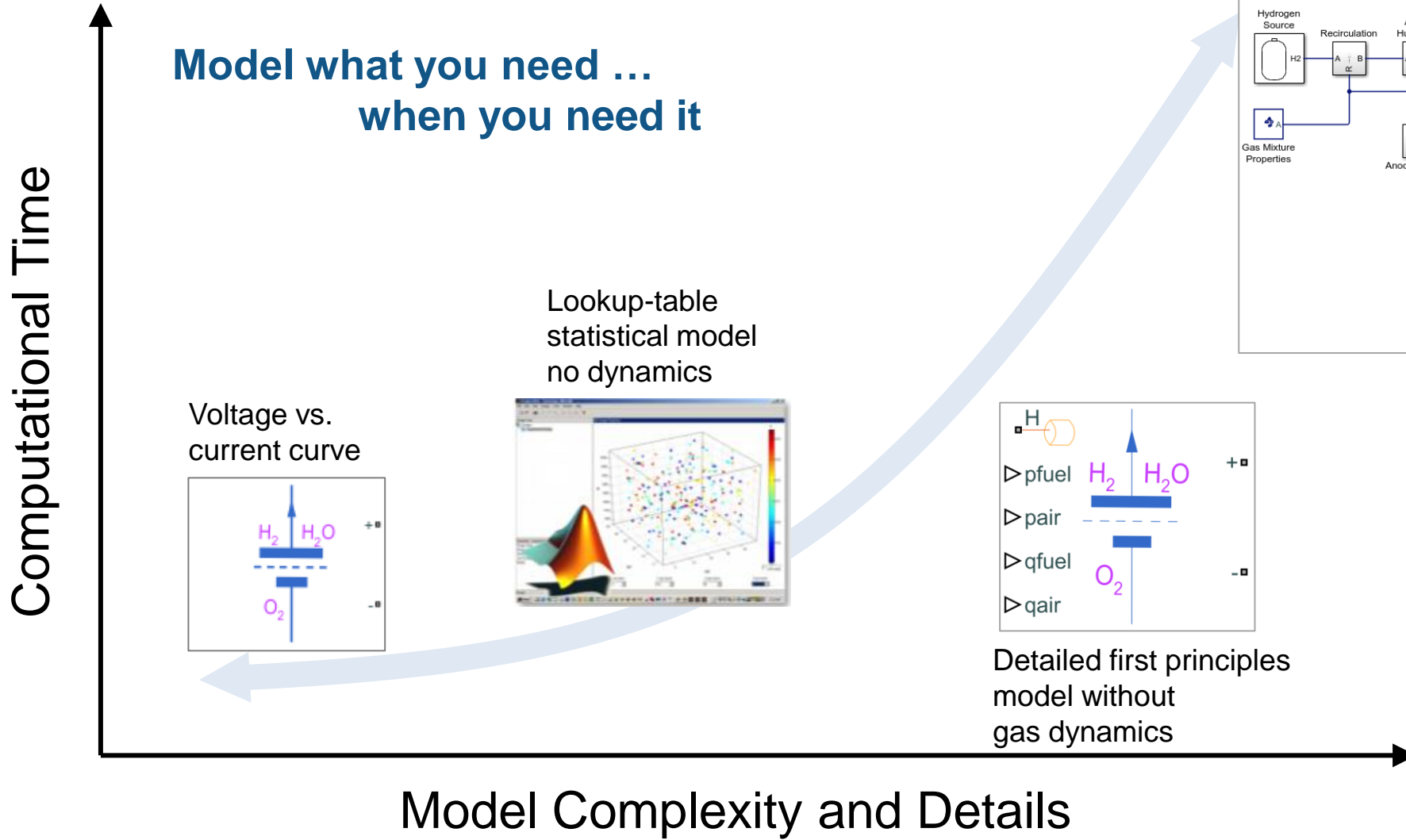
## 车辆上燃料电池系统的运行

### Fuel cell system operation in an FCV

- 确定瞬时能源需求 Determine instantaneous power demand
- 将能源需求转化为电流需求 Convert power demand to current demand
- 在电池和燃料电池间分配电流需求 Distribute current demand between battery and fuel cell
- 将电流需求转换为对氢气/气流的控制 Translate current command to H<sub>2</sub> / Air flow commands

# 选择合适的保真度对燃料电池系统建模

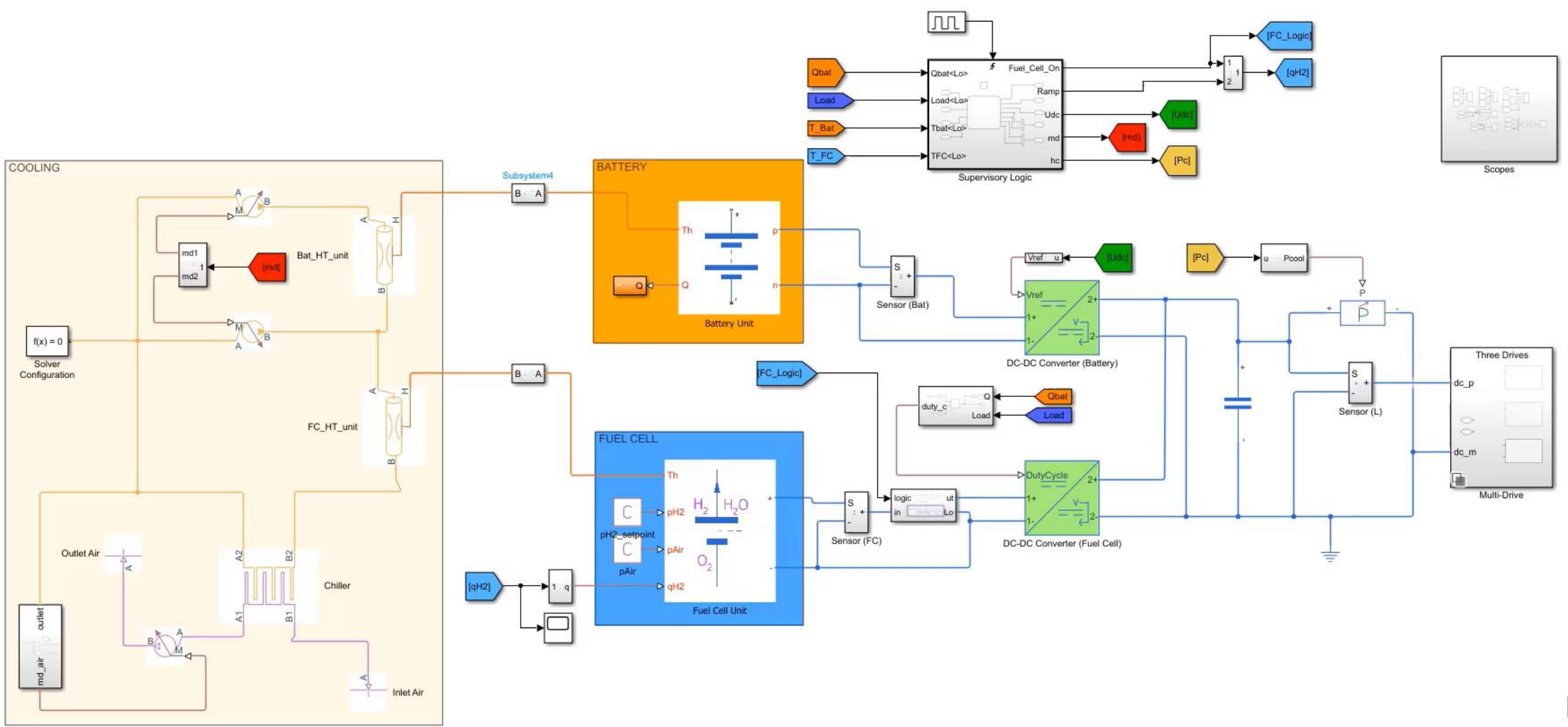
Choose the Appropriate Fidelity Level for Fuel Cell System Modeling



Detailed first principles model with gas dynamics

Dual\_FC\_Battery\_Mobile

Dual\_FC\_Battery\_Mobile



# 系统级的电力推进

## System level electrified propulsion

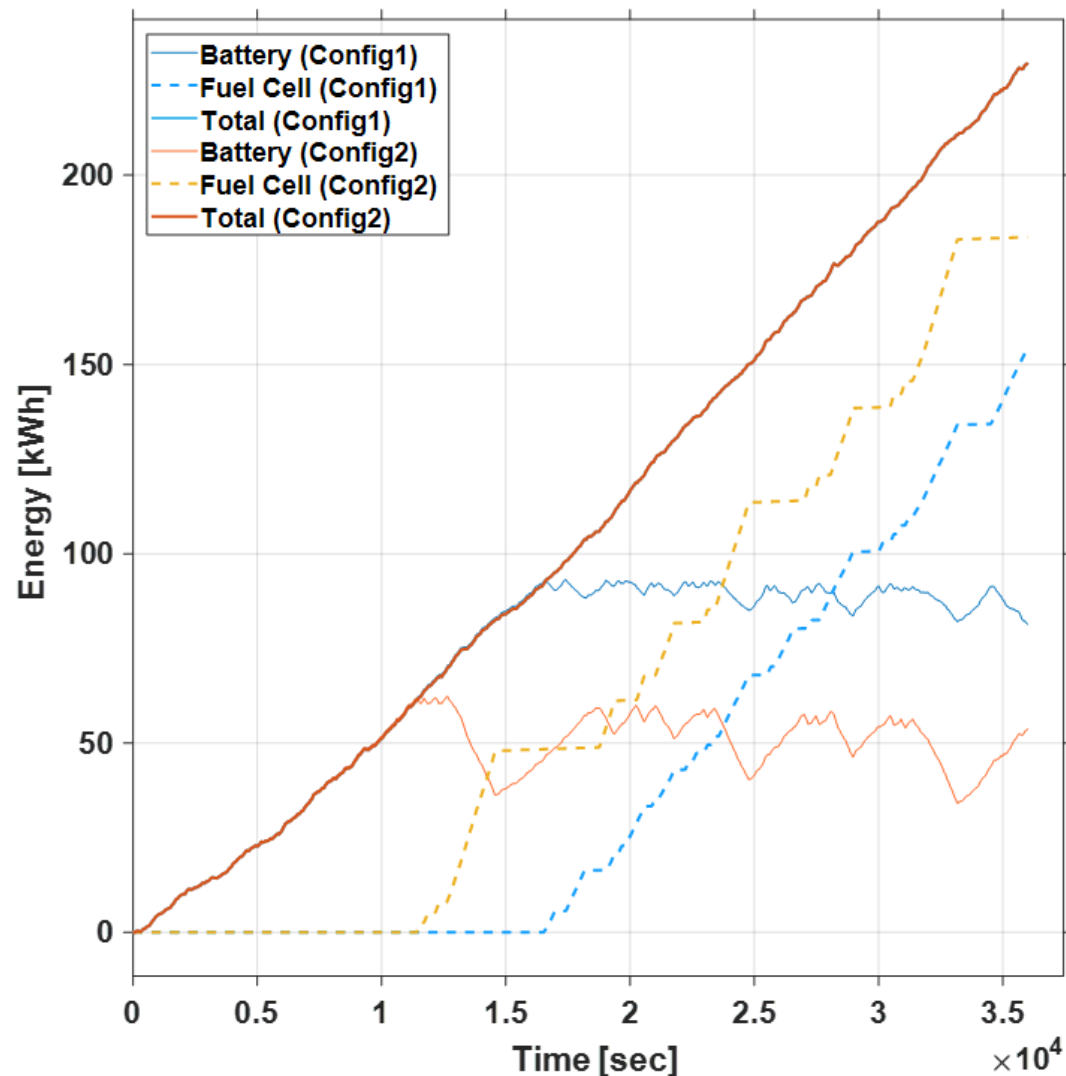
- 探索设计空间 Explore Design Space

— Example:

3 Battery Modules  
2 Fuel Cell Stacks

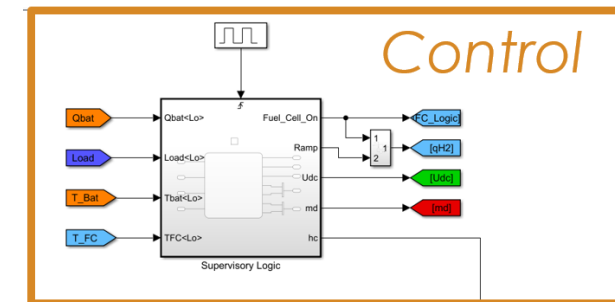
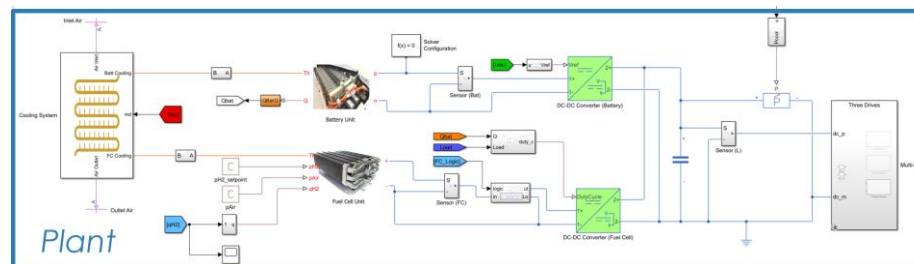
VS

2 Battery Modules  
3 Fuel Cell Stacks



# 硬件在环HIL

## Hardware-in-the-Loop



### Development Computer

The development computer displays a Simulink model of the control system. The model includes blocks for 'ECCO Signal Generator', 'ECCO Inverter', and 'ECCO Motor'. A real-time plot shows a signal oscillating between approximately 10 and 14 over time.

### Target Computer

The target computer is a Speedgoat real-time simulation and testing hardware. It consists of a main processing unit and several peripheral modules, including a power supply and a multi-channel I/O board.

### Device Under Test

The device under test is a power electronics board. It features a large Infineon MOSFET, various capacitors, and other power components. It is connected to a multi-pin connector at the bottom.

Ethernet

Emulated Sensor Signals, Digital Protocols (CAN)

Controller Commands



# 为绿色氢能产业赋能——氢气处置和使用上的挑战

## Enabling Green Hydrogen – Challenges H2 handling and usage

### (Stage 2)

#### Transfer (tank-to-cell)

- 最优的组件规格 Optimal components sizing (cooling, storage, compressors)
  - 多域仿真平台  
Multi-domain simulation platform
- 可靠的运行24/7 Reliable 24/7 software operation
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Develop supervisory logic with state-of-the-art V&V capabilities
- 符合安全规范 Meet critical safety requirements
  - 基于模型设计的认证 workflows  
Model-Based Design streamline certification of your embedded systems

### (Stage 3)

#### Consumption (E-mobility)

- 组件级 Vs 系统级仿真 Component-level vs system-level simulation
  - 灵活的建模和仿真平台  
Flexible modelling and simulation platform
- 最佳的系统架构 Optimal system architecture (e.g., fuel cell multi-stack, battery)
  - 权衡分析与蒙特卡洛仿真  
Trade-off analysis and monte carlo simulations
- 昂贵的硬件原型测试 Expensive physical prototype testing
  - 复用模型进行HIL测试  
Reduce physical prototypes, reuse models for Hardware-in-the-Loop tests

# 来自用户的实例——Nuvera燃料电池

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**. “



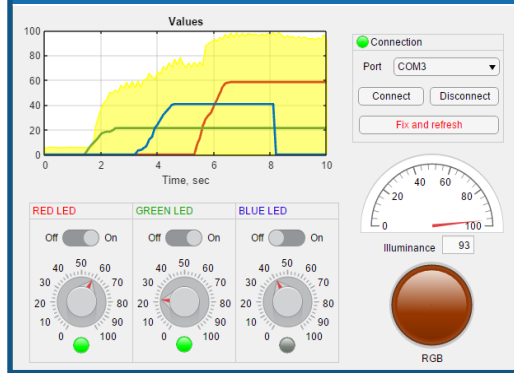
# 协作开发——IP保护，部署与成果分享

Collaborative Engineering– IP Protection, Deployment & Sharing

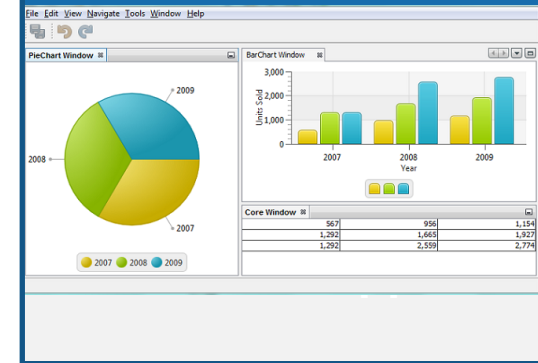
## IP protection

-  Ref\_Model.slxp
-  MATLABscript.p
-  Cell.sscp

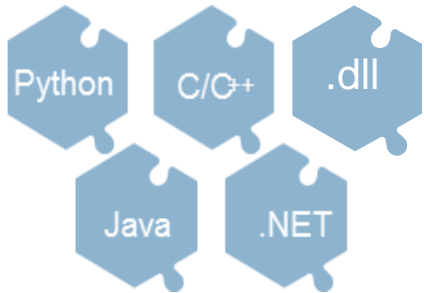
## Standalone Apps



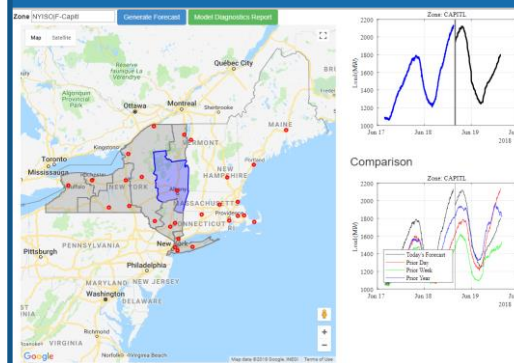
## Web Apps



## Shared Libraries



## Service APIs

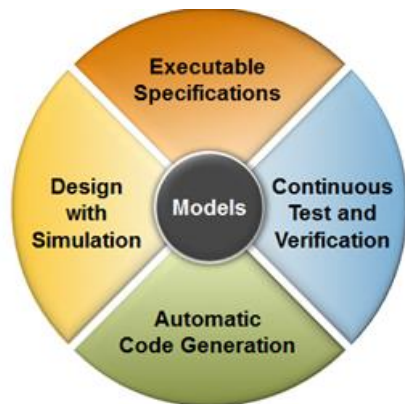
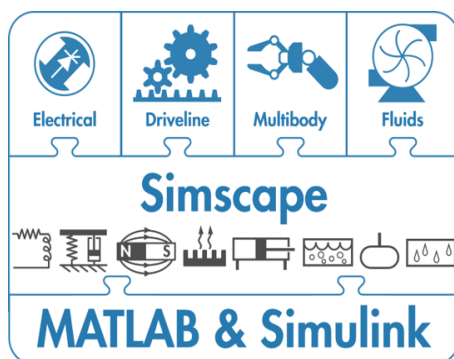


## Standalone FMUs

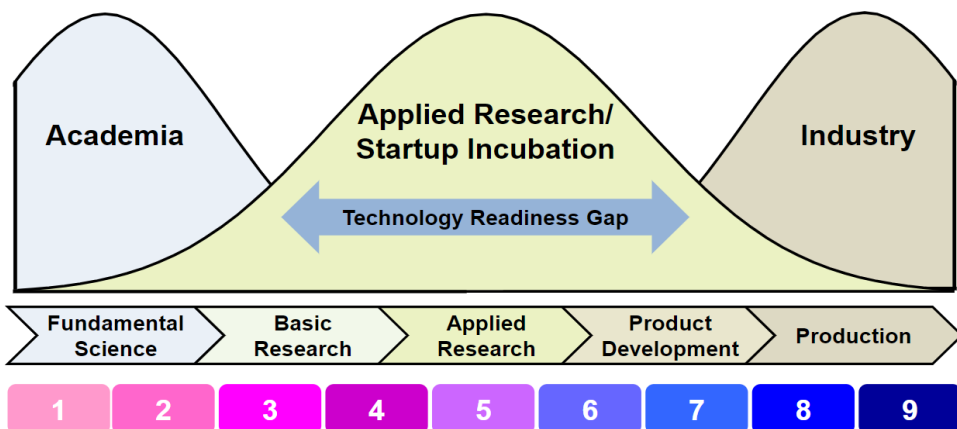


# 为绿色氢能产业赋能——总结

## Enabling Green Hydrogen – Conclusions



- 可行性评估 Assert feasibility
  - 经济技术分析 Techno-economic analyses
  - 概念论证 Proven concept
  
- 保证可持续和可靠的运行 Secure sustainable and robust operation
  - 设计自动化 Design Automation
  - 设计与运行优化 Optimization
  
- 协作开发 Collaborative Engineering
  - 知识分享与IP保护 Sharing know-how & IP
  - 多应用场景下的产品部署 Deployment



# 更多的资料

## 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)

# MATLAB EXPO

谢谢！

