Cyber-Physical Reformer Development at NETL

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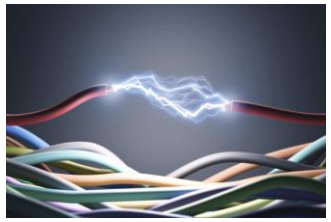
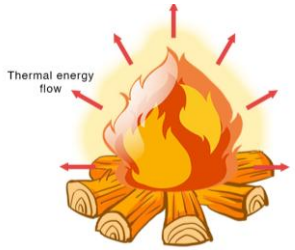
Motivation

The Need for Integrated Energy Systems (IES) for Efficiency – Flexibility – Resilience

- Leveraging the synergies among different energy technologies, IES can achieve greater efficiency, higher flexibility, and better CO_2 removal concurrently



Electrical

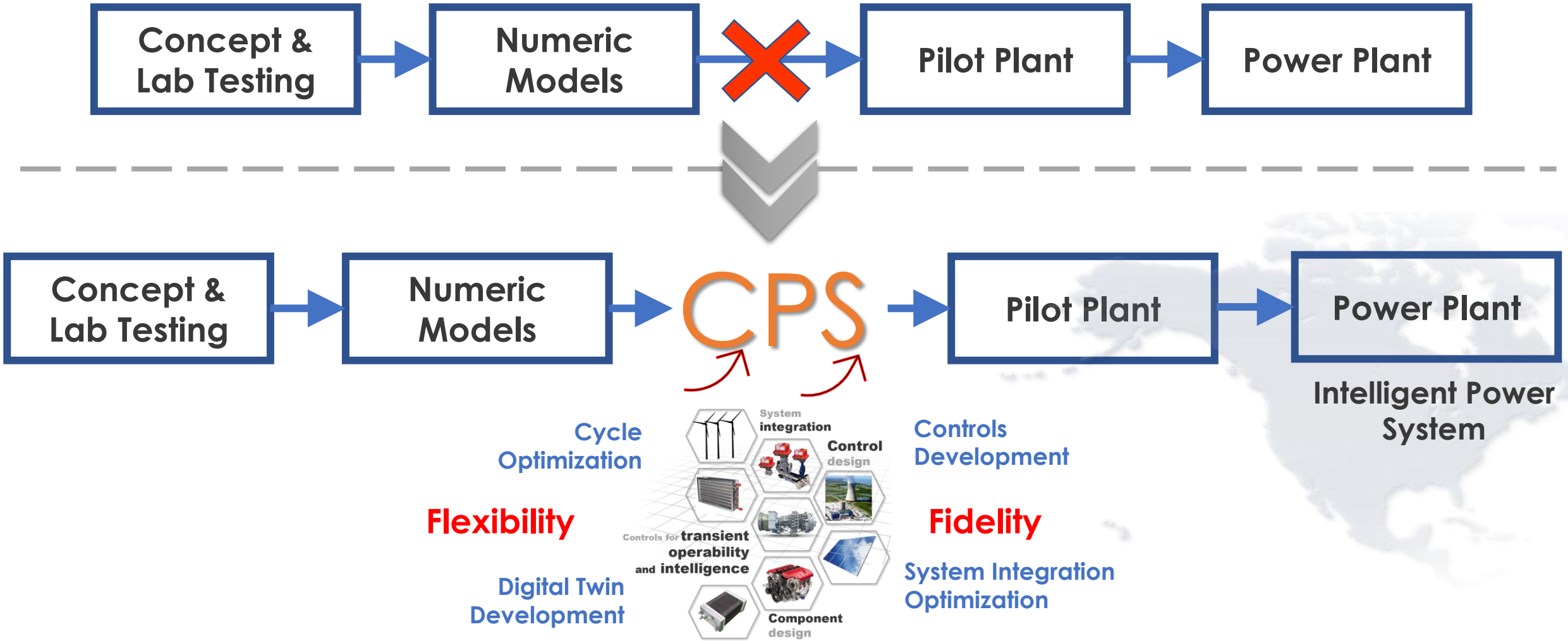


Thermal

Chemical

Motivation

The Need for Cyber-Physical Simulation (CPS) to Accelerate Technology Development

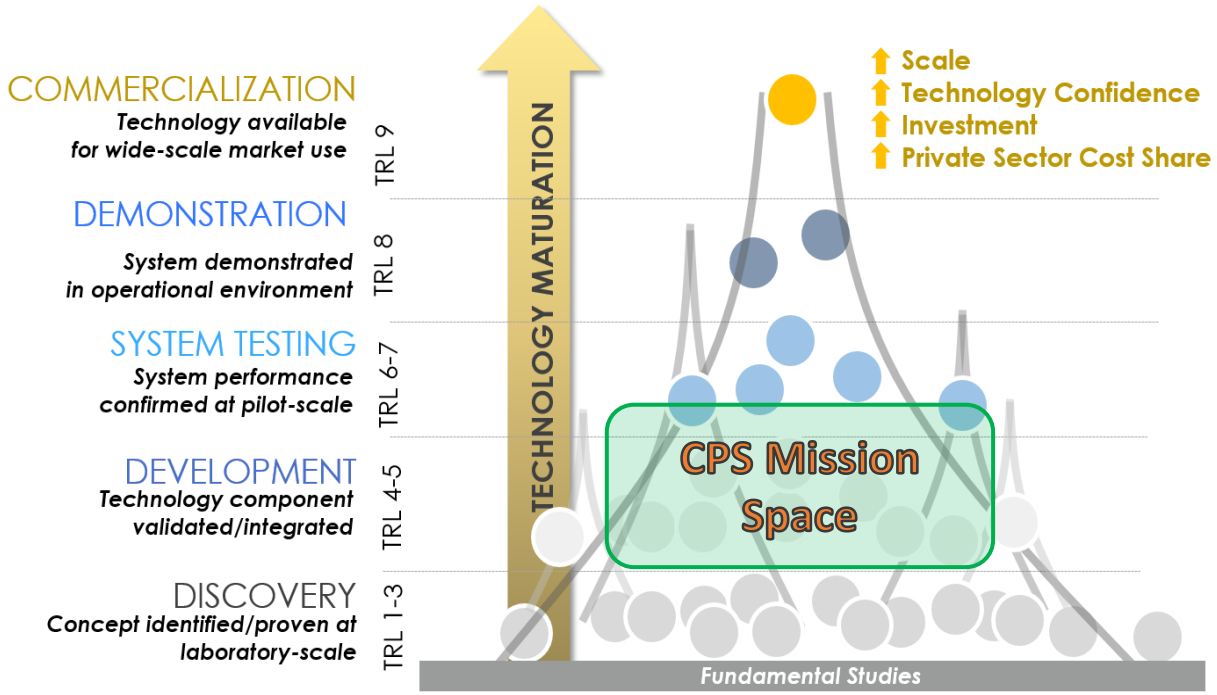


Cyber-Physical Simulation (CPS)

A Paradigm Change in Energy Technology Development

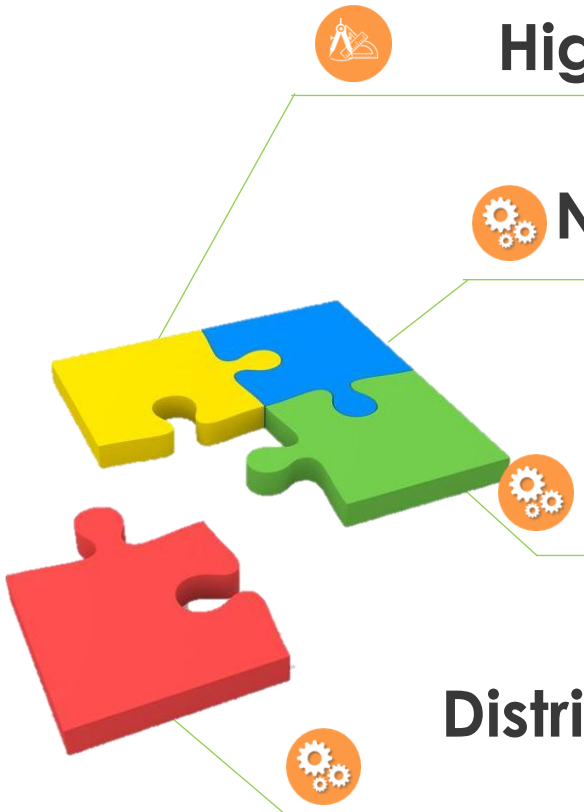
CPS approach enables:

- Emulating expensive/pre-mature components
- Emulating the actual system at high fidelity and low cost
- Identifying system integration and dynamic operability issues
- Developing control strategies
- De-risking pilot testing



Motivation: ARPA-E Integrate

Lower the cost and emissions associated with electricity generation by leveraging thermo-economic synergies between engines and SOFCs



High efficiency >70%

NG and fuel flexibility

Low emission

Distributed energy system, 100 kW – 2 MW

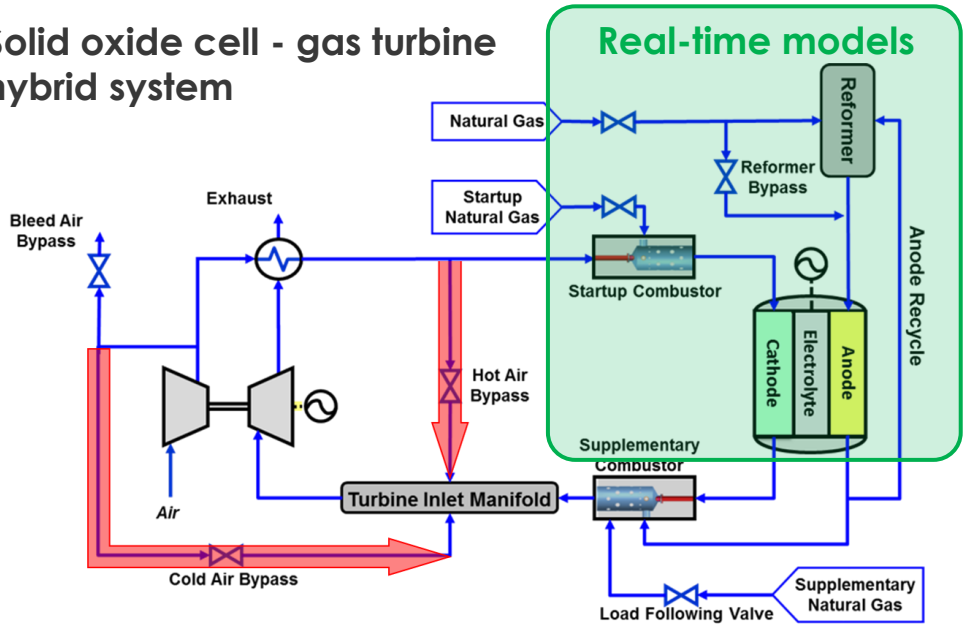
(Targets are from ARPA-E FOA-001797 in 2017)

- **Cost-effective** (<$1.8/W) conversion of fossil and renewable fuels to electric power will continue to be of critical economic importance
- **High efficiency** (>70%) and low emissions (CO_2 and NO_x) conversion processes will help to mitigate the environmental impact of fuel use
- **Fuel flexibility** afforded by SOFC-based systems can help to facilitate and accelerate a transition from fossil to renewable fuels
- Core **100 kW** NG-fueled system technology being demonstrated in Phase II is the first step toward a number of potential applications

Success Stories: Hybrid Performance Project (Hyper) at NETL

NATIONAL ENERGY TECHNOLOGY LABORATORY

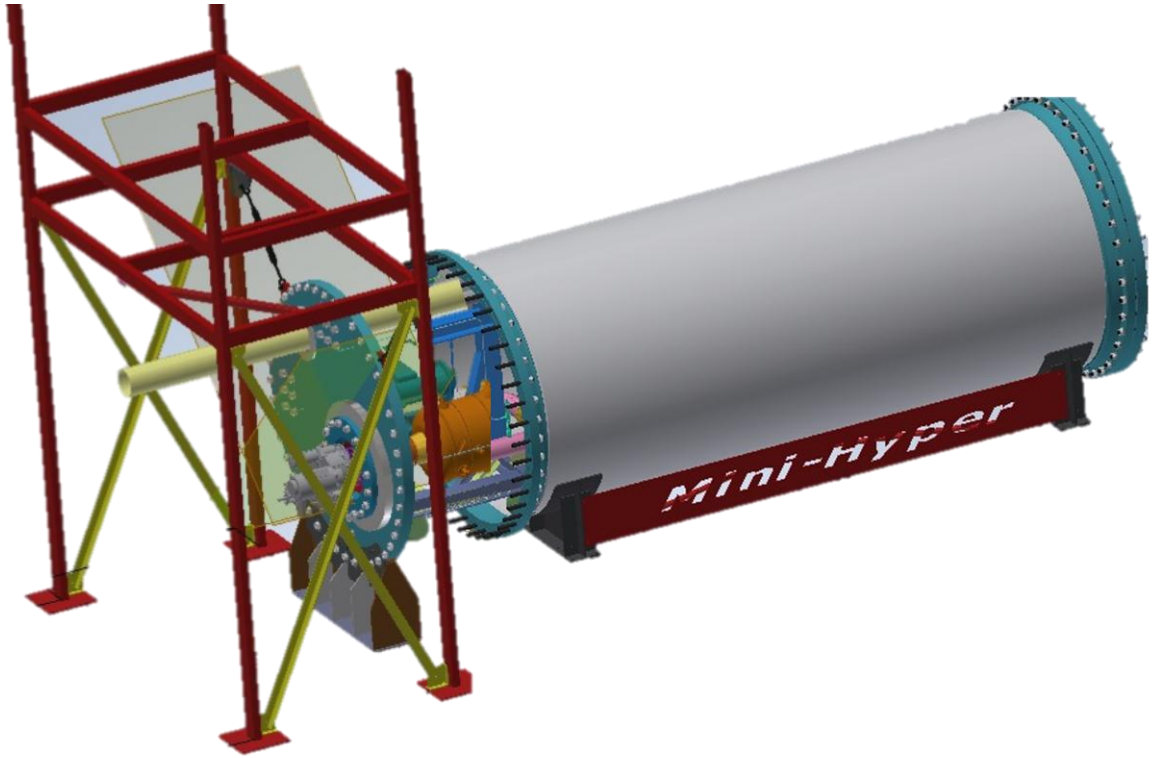
Solid oxide cell - gas turbine hybrid system



- Cycle analyses (part-load and off-design)
- System integration (dynamic operability)
- Advanced controls
- Geographically distributed co-simulation
- Co-design

CPS Reformer

ARPA-E Cyber Physical Reformer (Mini-Hyper) - The automated pressurized SOFC/GT facility



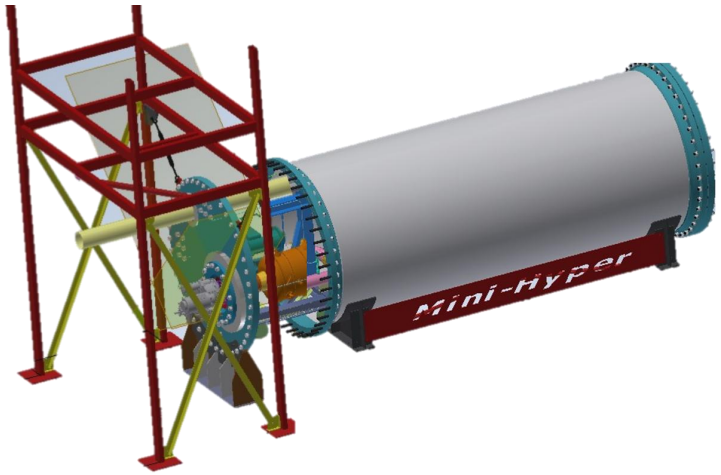
What the CPS Reformer can offer:

- A 20 kW SOFC-GT hybrid system
- Pressurized test chamber
- Compact design
- ASME design standard
- Maximum flexibility
- Penetrations at one side flange
- Capable of operating with a real SOFC and a cyber-physical fuel reformer
- Maximum research capability and component testing

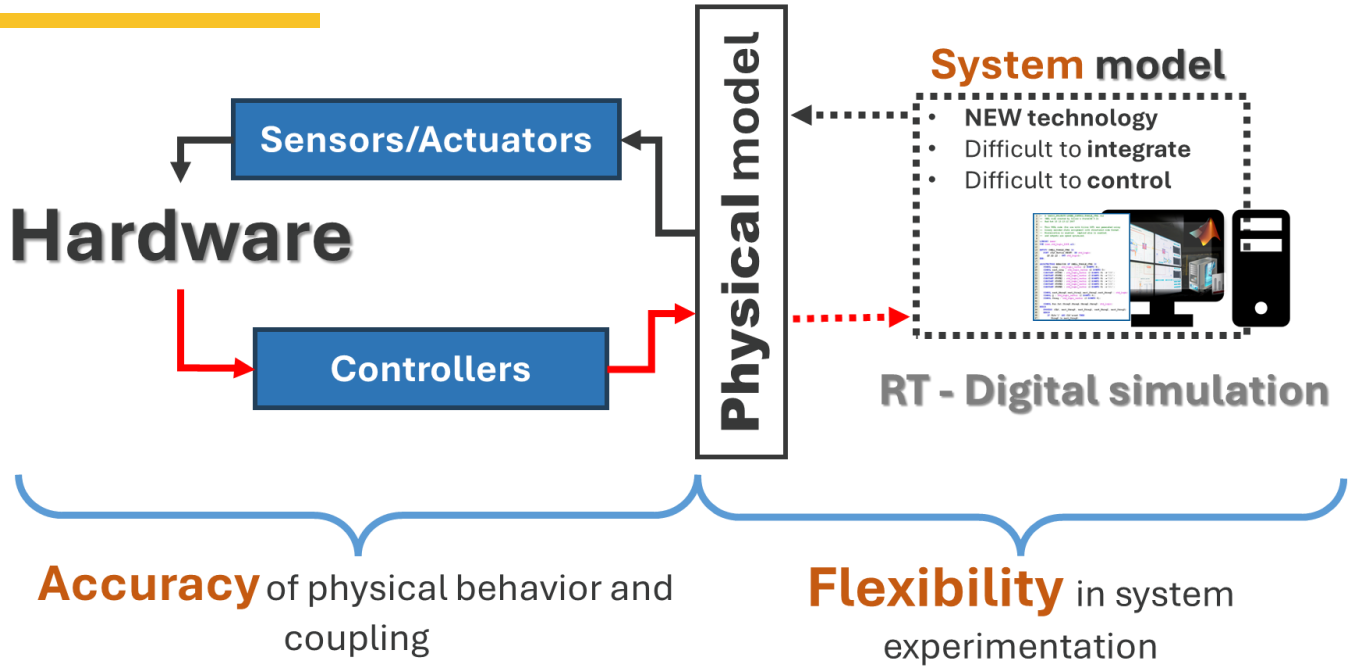
CPS Reformer

Addressing the potential design challenge using CPS

CPS Reformer



ARPA-E Cyber Physical Reformer (**Mini-Hyper**) - The **automated pressurized SOFC/GT** facility



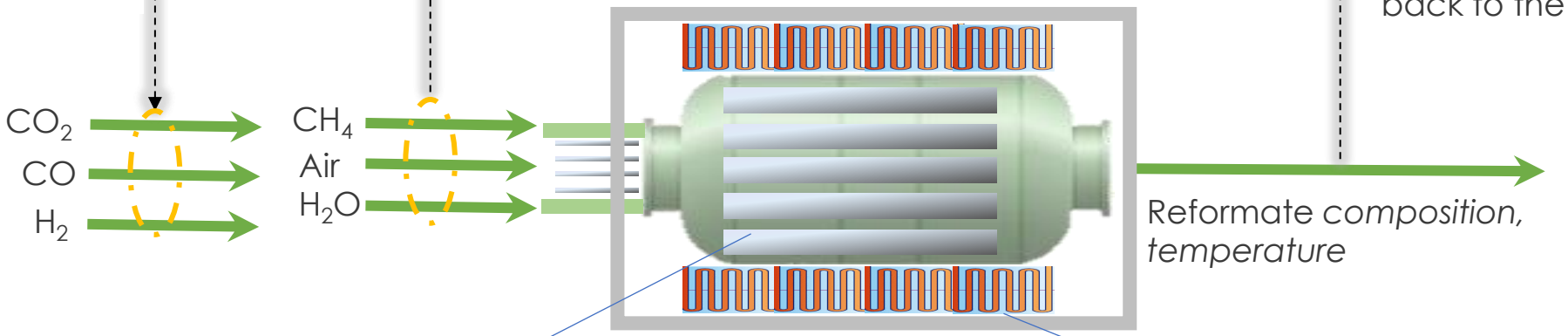
CPS Reformer

Recycle:
Bottle gases can be used to simulate gas recirculation, which is controlled by the model outputs

Real-Time Reformer Model

Process inputs:
Initial inlet measurements can be sent to the model

Feedback:
Reformate composition, temperature, and pressure could be sent back to the model

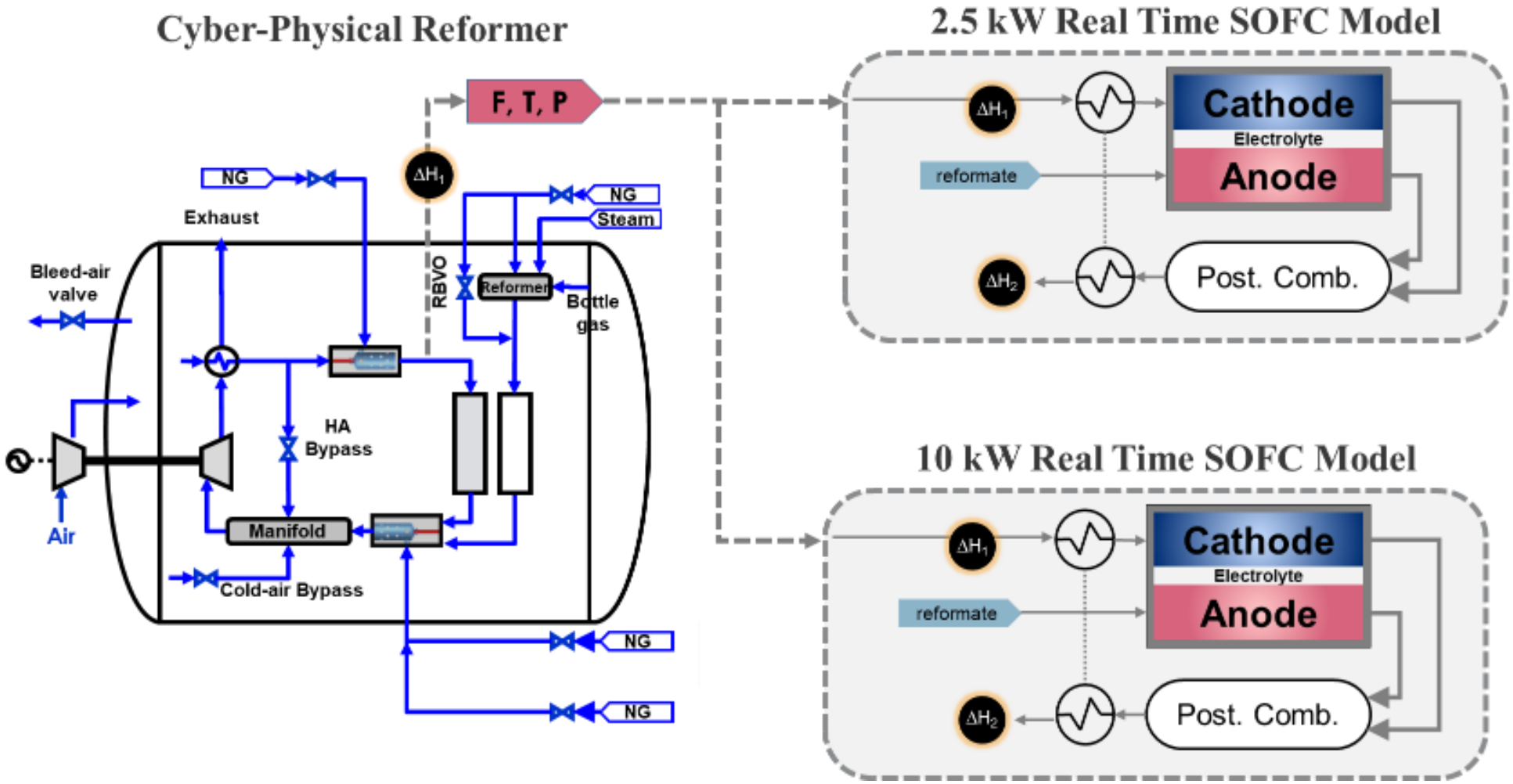


Pyrochlore Reforming System

Catalyst will work on:
1. Any fuel (pyrochlore)
2. Any type of reforming reaction: steam methane reforming and autothermal

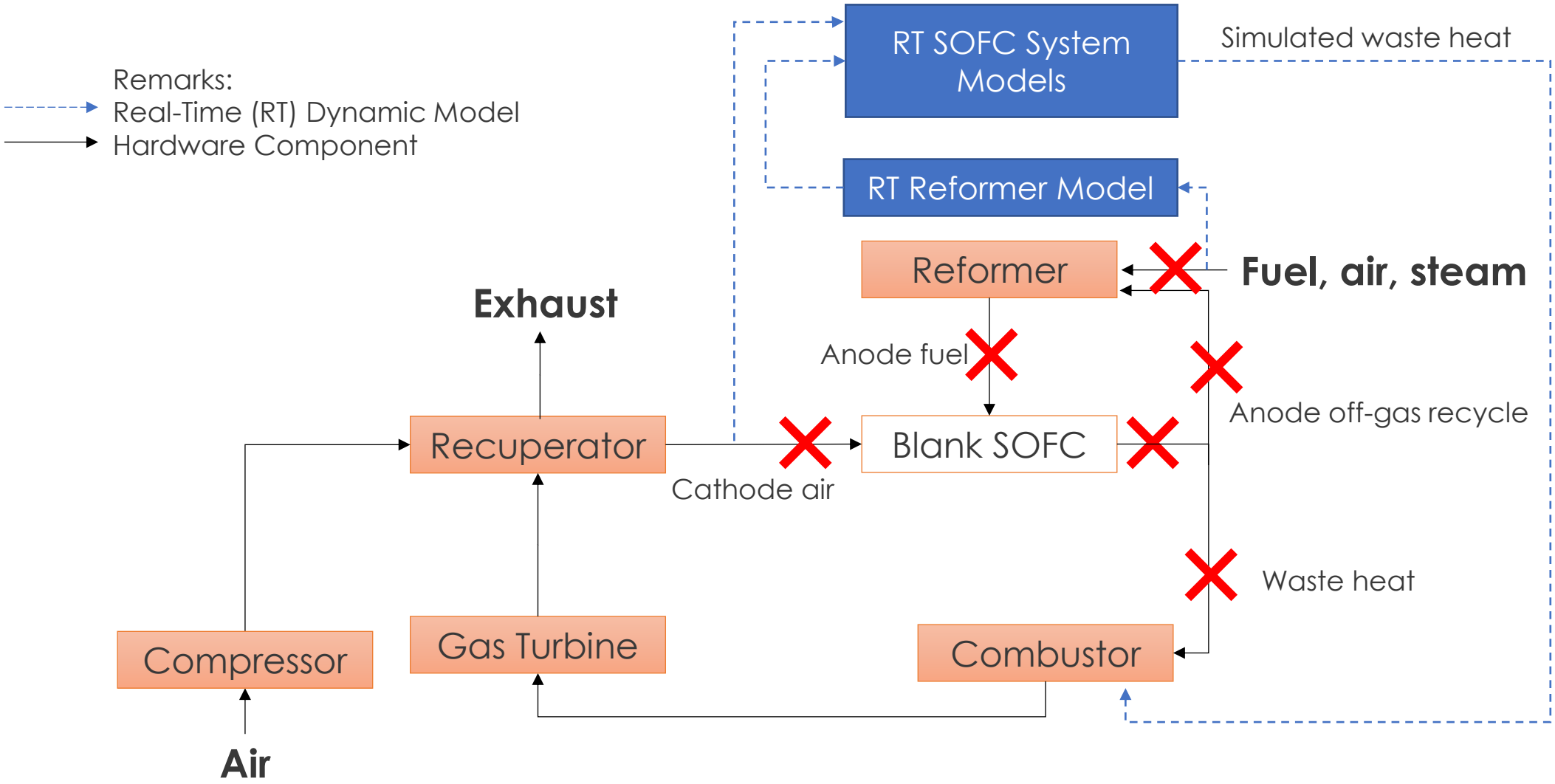
Heat source:
External heating is used to:
1. Simulate different reforming temperature
2. Aim targeted reformate composition
3. Simulate thermal integration of the reformer

CPS SOFC


Cyber-Physical Reformer
F, T, P
ΔH1
NG
Exhaust
NG
Steam
Bleed-air valve
RBVO
Reformer
Bottle gas
HA Bypass
Air
Manifold
Cold-air Bypass
NG
NG
2.5 kW Real Time SOFC Model
ΔH1
reformate
Cathode
Electrolyte
Anode
ΔH2
Post. Comb.
10 kW Real Time SOFC Model
ΔH1
reformate
Cathode
Electrolyte
Anode
ΔH2
Post. Comb.

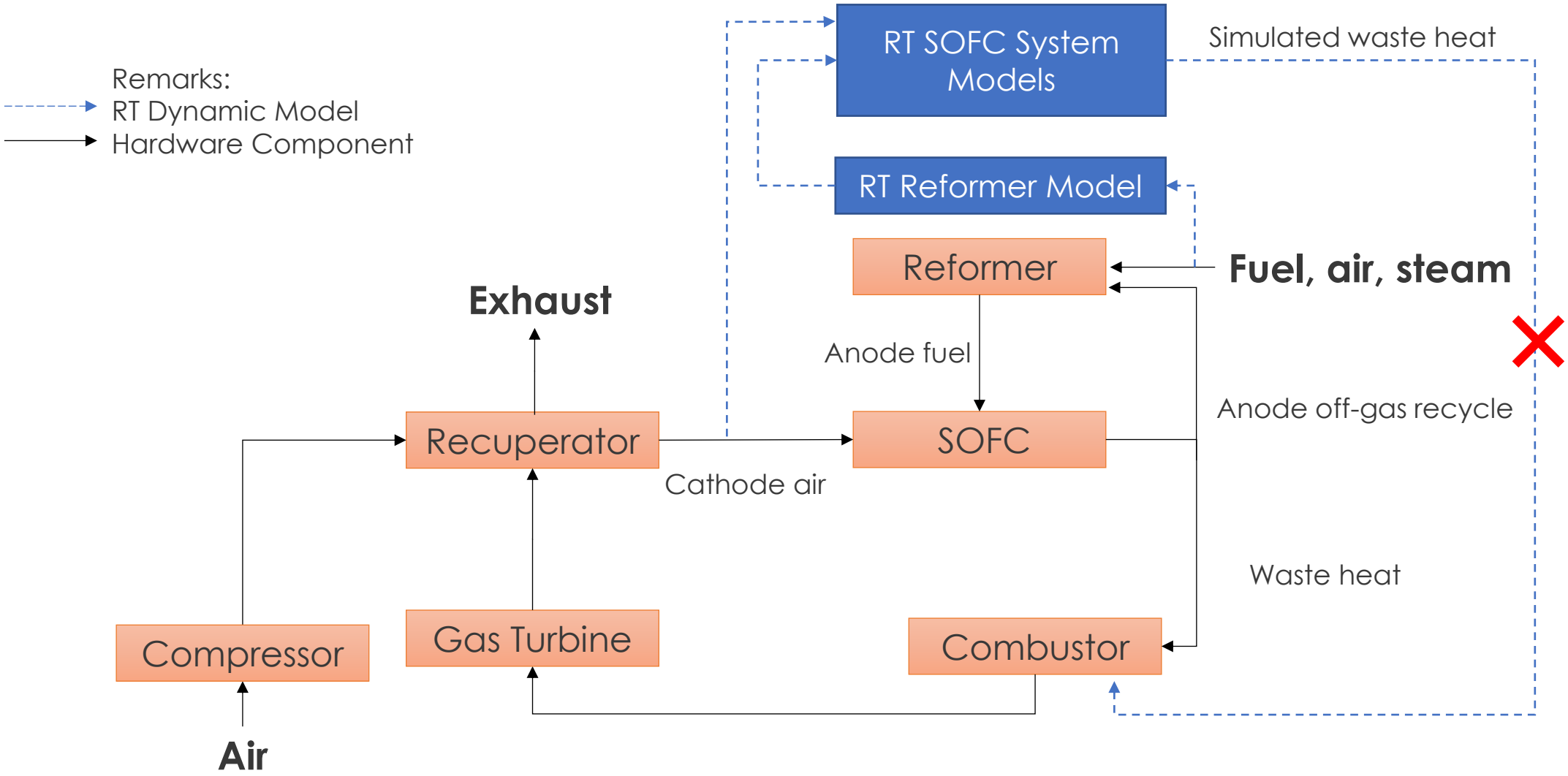
Embedded Digital Twins in CPS

A Paradigm Change in Energy Technology Development



The Role of Digital Twins in CPS

A Paradigm Change in Energy Technology Development



Acknowledgments

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