IES
Integrated Energy Systems

LWRS
LIGHT WATER REACTOR SUSTAINABILITY

HYBRID Overview

FORCE Workshop
March 17, 2022
INL/MIS-22-66355 Rev:00

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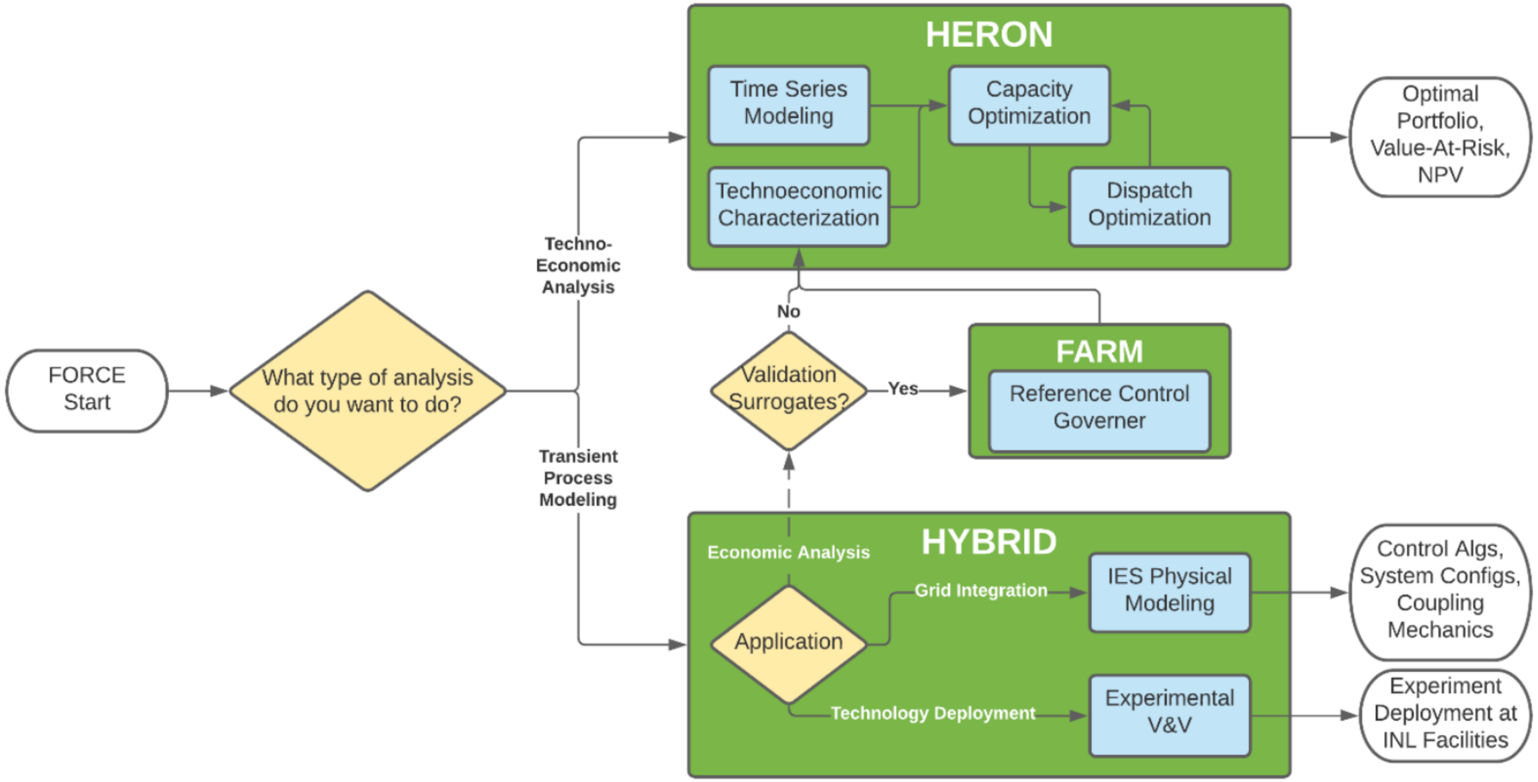
Prepared by: Dr. Konor Frick

FORCE

Capabilities

- Portfolio optimization
- Dispatch optimization
- Process model simulation
- Control simulation
- Economic analysis
- Supervisory control
- Stochastic analysis
- Workflow automation
- Validation and verification
- Digital twinning



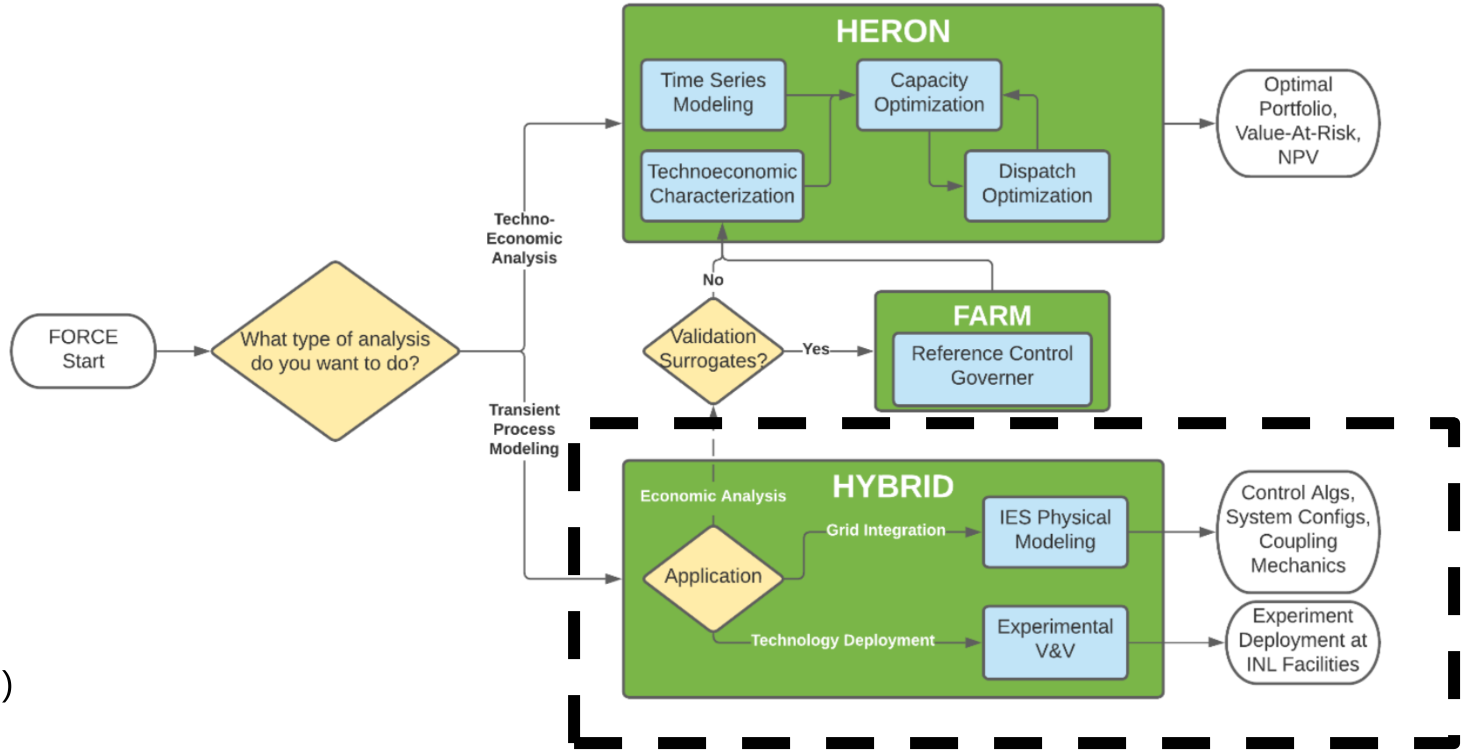
FORCE

HERON

- Portfolio optimization
- Dispatch optimization
- Stochastic analysis
- Workflow automation
- Economic analysis
    - Multiyear, Multi-history

HYBRID

- Process model simulation
    - Steady state
    - Transient
- Control simulation
- Economic analysis
    - (Component-level daily/weekly optimization)
- Supervisory control (system-level)
- Validation and verification
- Digital twinning

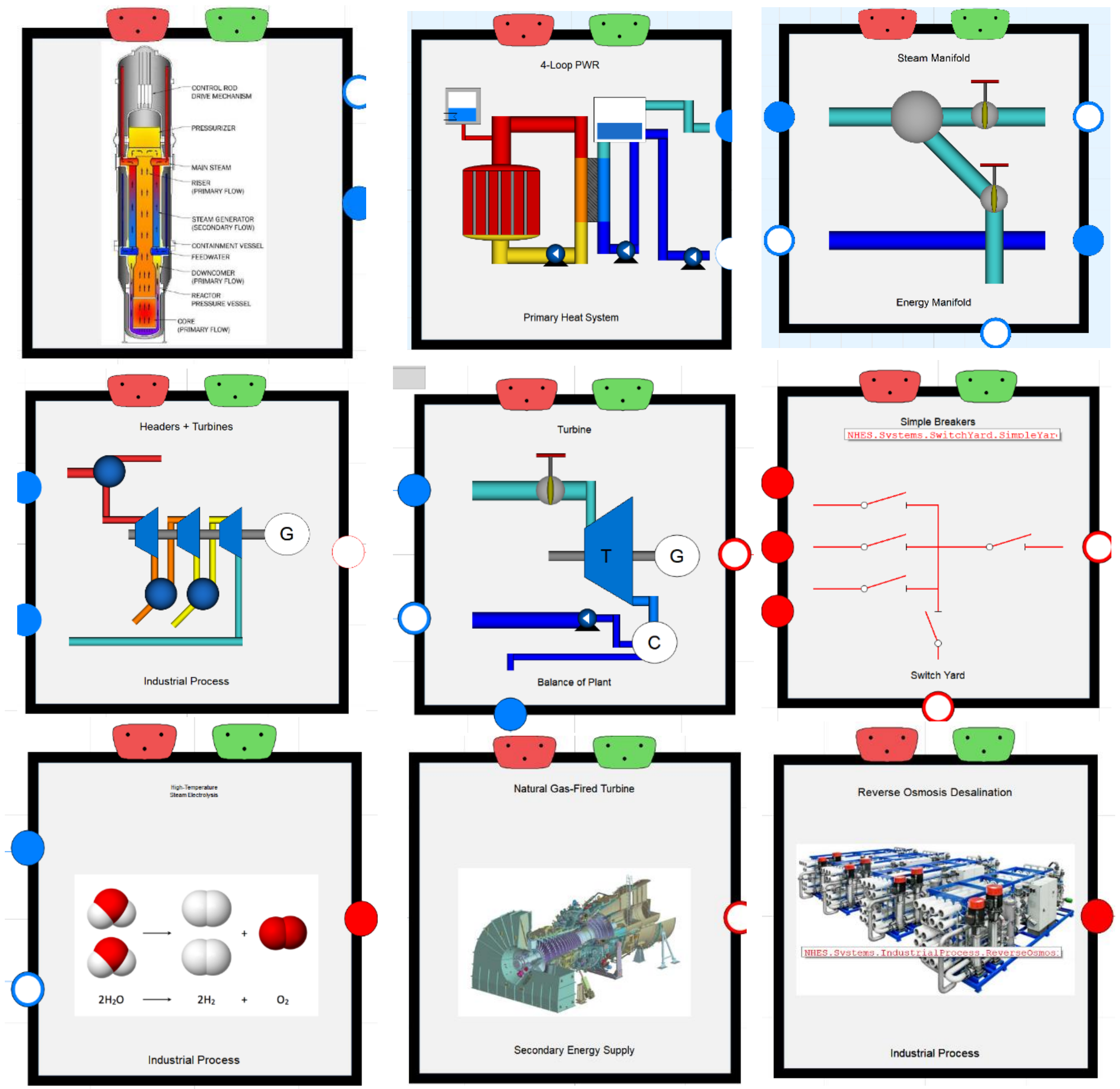


HYBRID – What is it?

- HYBRID is a collection of physical models written in the Modelica language and Aspen HYSYS to characterize:
  - Ramp speed
  - Thermal and electrical integration of different processes
  - Creation of novel control schemes
  - Off-demand system dynamics
  - Safety limitations based on control systems
  - Costing functions

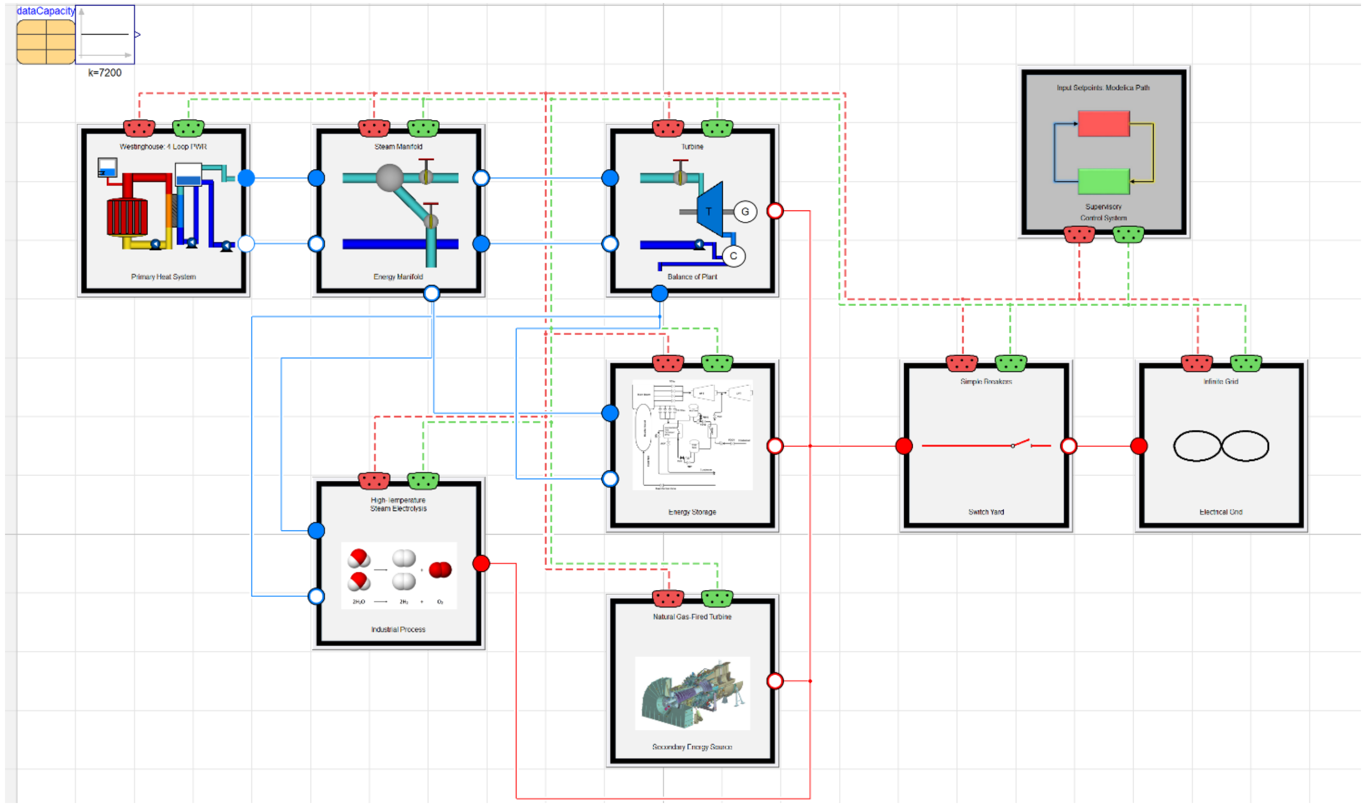
- Adaptable
  - Object-oriented, with standardized connections
  - The FMI/FMU standard can be used to accomplish external collaboration without necessitating the transfer of sensitive proprietary data or the recoding of models
  - Components can be “hot swapped” within code
    - Modelica was originally developed as the automotive industry’s language of choice for quick interchangeability: drive shafts, engines, transmissions, electronics, etc.

- It was developed using the commercial platform Dymola from Dassault Systems.



Design Capability

- Physical models are based around process systems
  - A few coupled subsystems (nuclear plant + gas turbine + thermal storage + grid + ancillary process)
  - Not a regional grid area consisting of hundreds of power plants with regional transmission lines
- Figures of merit
  - Demand missed
  - System stability
    - System pressure, temperature, thermal gradients, valve positioning, etc.
  - Control strategy effects on each subsystem

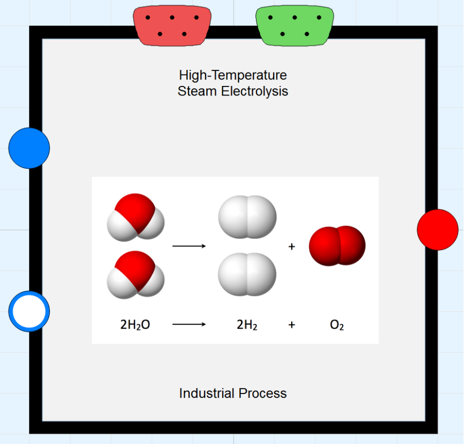


Interconnectability

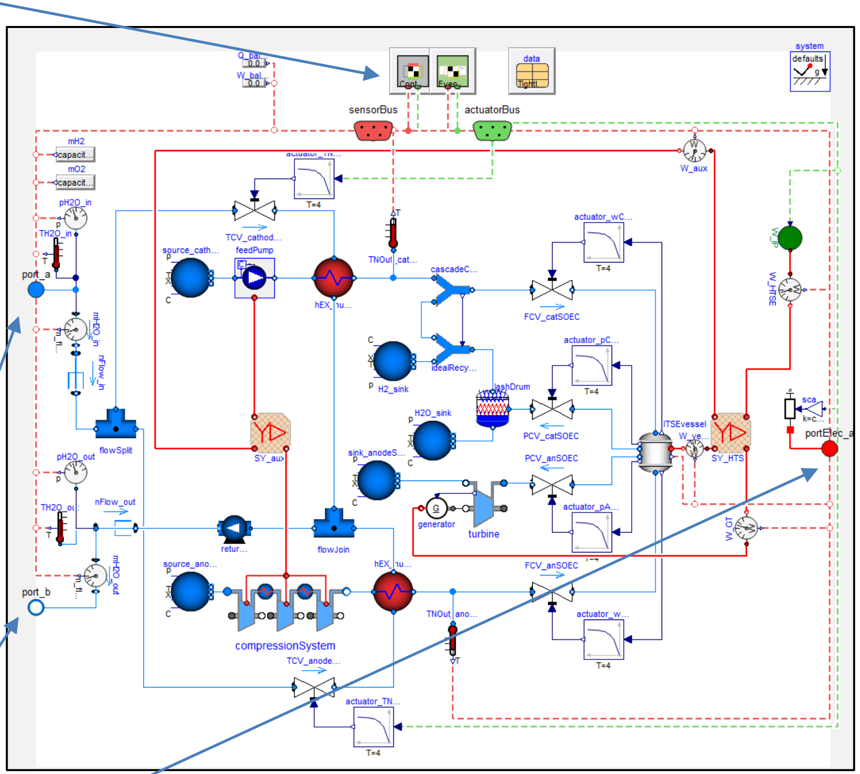
- Creation of dynamic process models capable of modeling full plant dynamics under normal operating conditions within an object-oriented platform capable of quickly coupling with other dynamic process models within the same platform, or via FMI/FMUs.

- Models are configured using interchangeable base classes for ease of use and the adaptability of models into different configurations.

- Can be exported in the FMI/FMU standard to allow robust interoperability with industry.



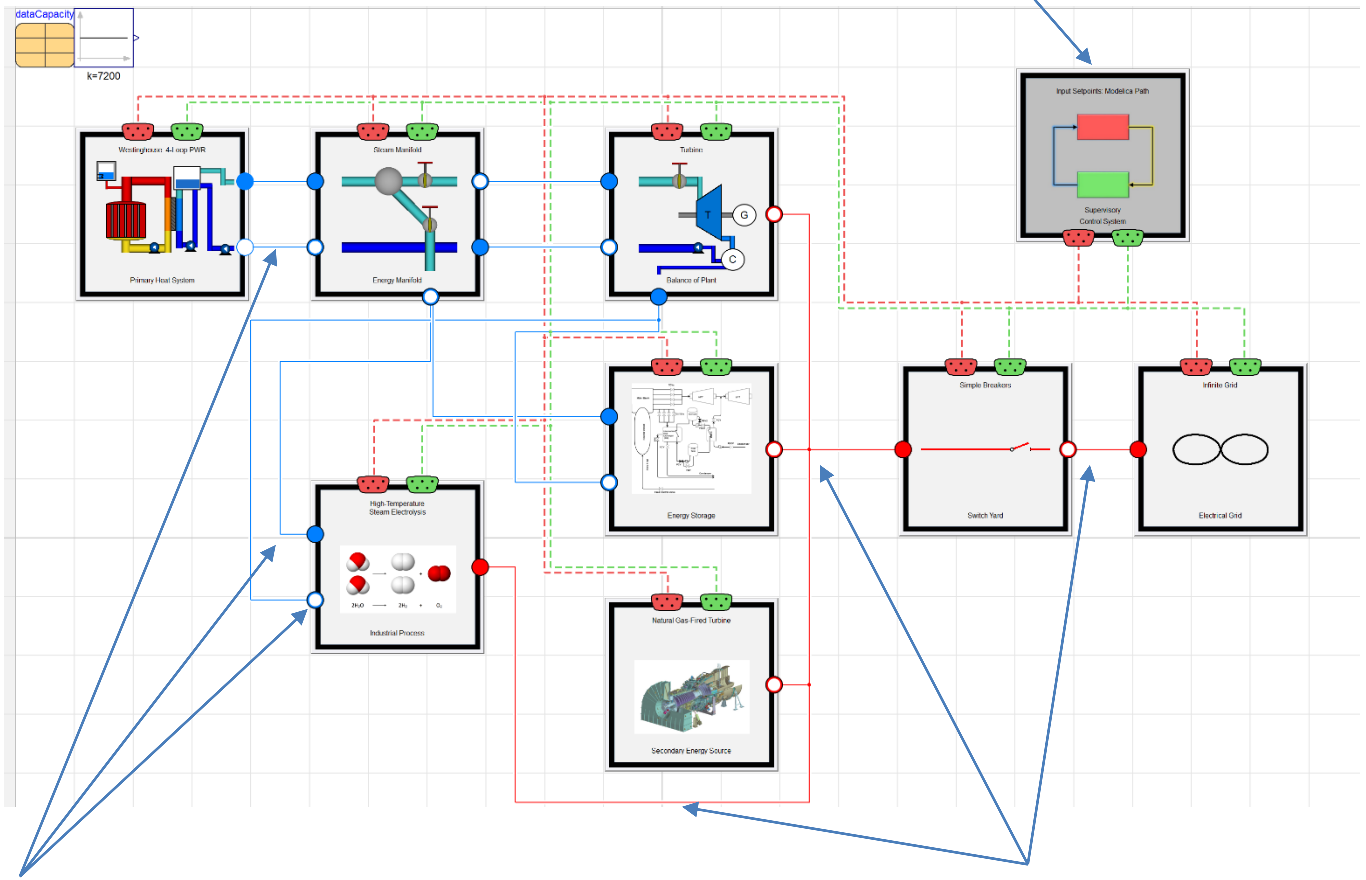
Interchangeable control system



Connection points

Inputs

- System sizing
  - Values taken from FORCE technoeconomic optimization workflow
  - Size Parameter available in top level of each system
- Thermal and electrical demands for each subsystem through time.
  - This can be input manually
  - Can also be automatically coupled with the HERON workflow to provide dispatch points for each subsystem.
- Desired control strategies
  - Each subsystem has its own control strategy
- Coupling methodologies
  - Supervisory control
  - Minimum electrical and heat rates for each subsystem



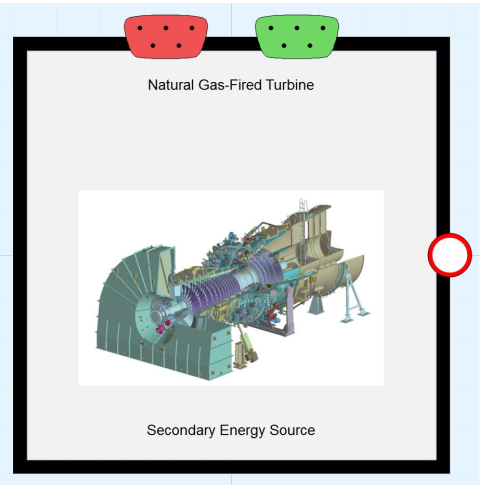
Supervisory Control

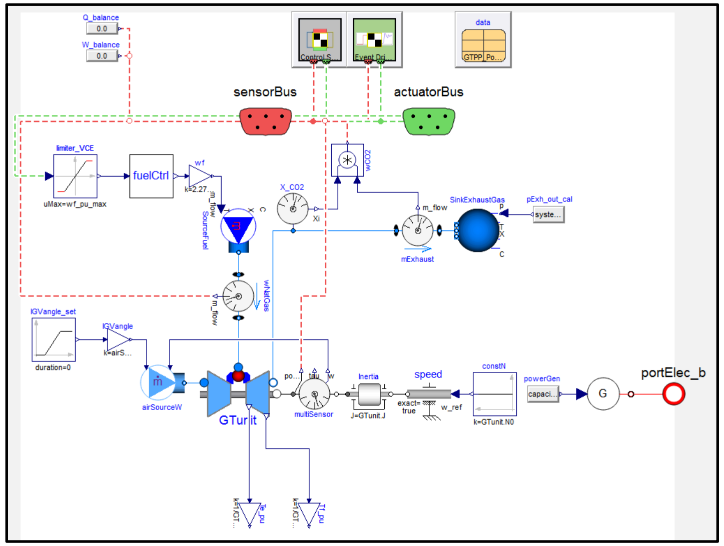
Example Thermal Coupling Points

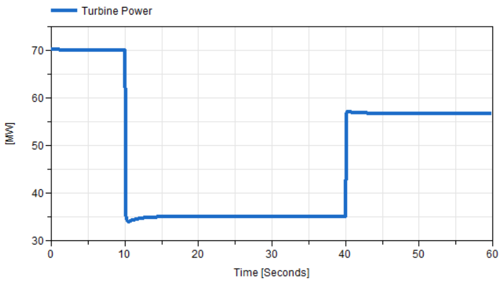
Example Electrical Coupling Points

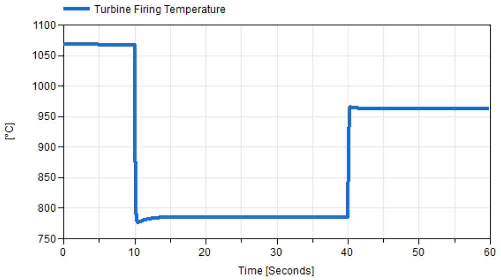
Key Outputs

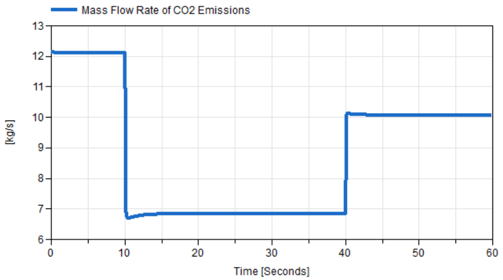
- Transient results of processes
- Coupling and interaction phenomena
- Missed demand
- Ramp limitations based on underlying system physics (phase change, thermal time constants, valve opening speeds)
- Test platform for novel control strategies

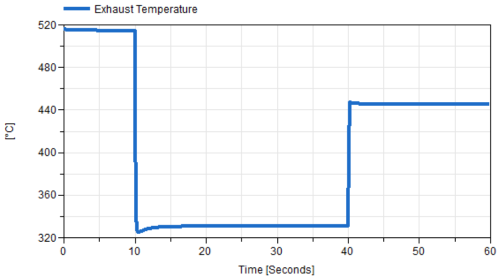










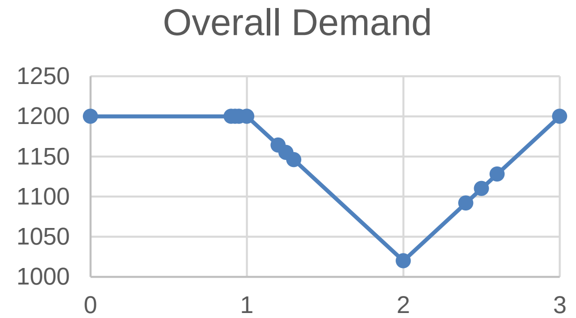


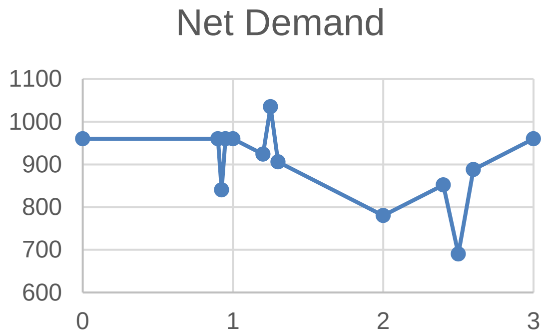
Example: Multi-Component Integrated Energy System

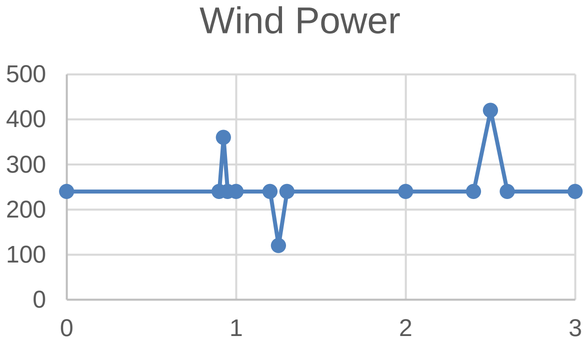
- Multi-component integrated energy system
- Power source = pressurized-water reactor
- Ancillary process = hydrogen production
- Energy storage = thermal energy storage
- Secondary energy source = natural gas-fired turbine

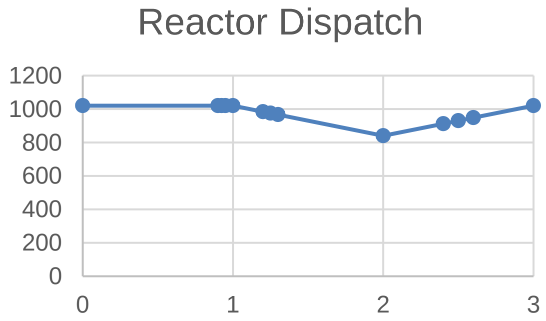
Case

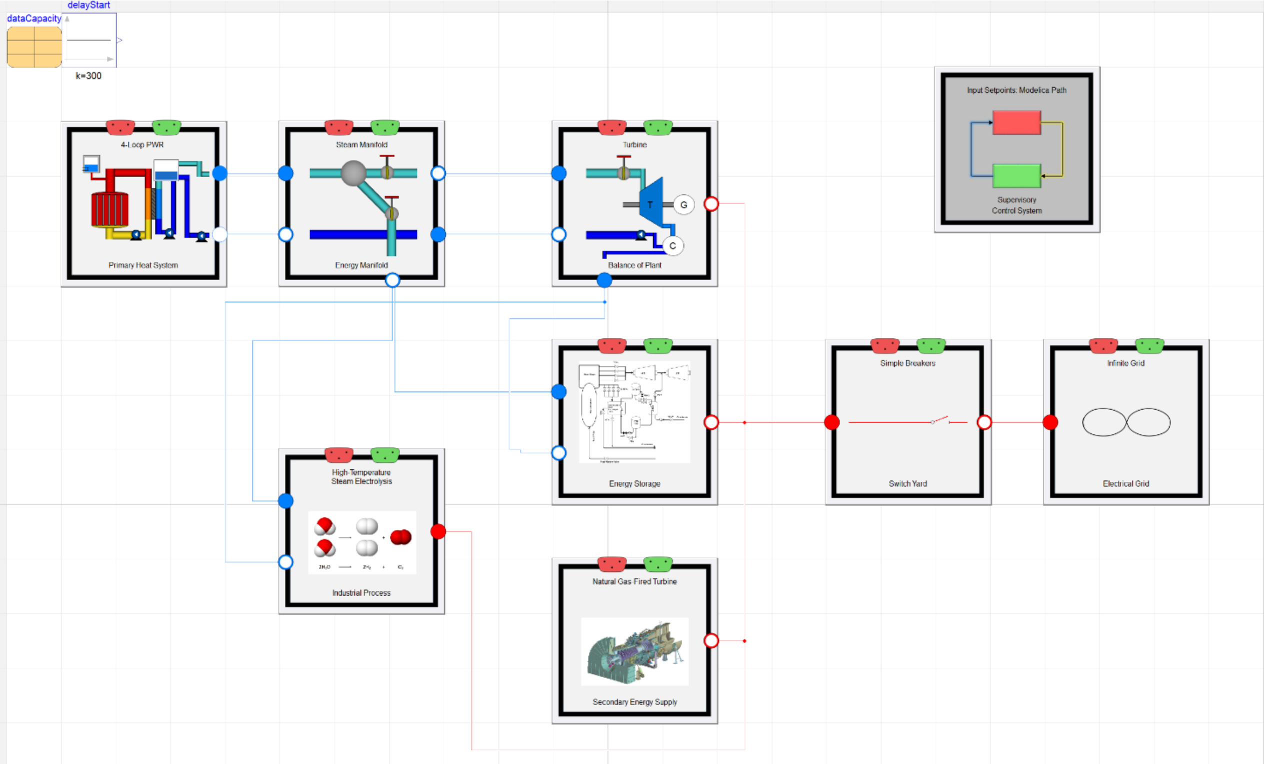
- Operating in a microgrid with wind power
- Total microgrid power needs = 1200 MWe

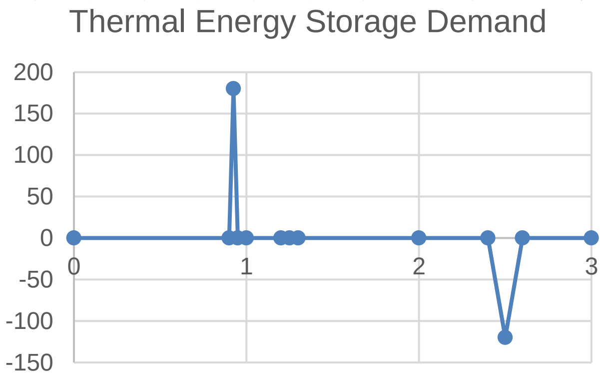


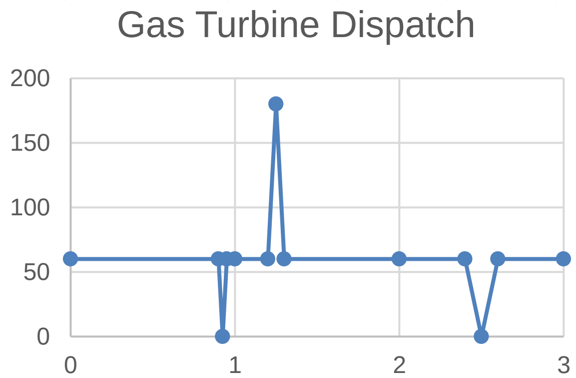












Current Status of the HYBRID Repository

- Opensource on GitHub
    - https://github.com/idaholab/HYBRID

- In use by university partners
    - North Carolina State, Toledo, Michigan

- Automatic regression system implemented using the RAVEN-based ROOK system

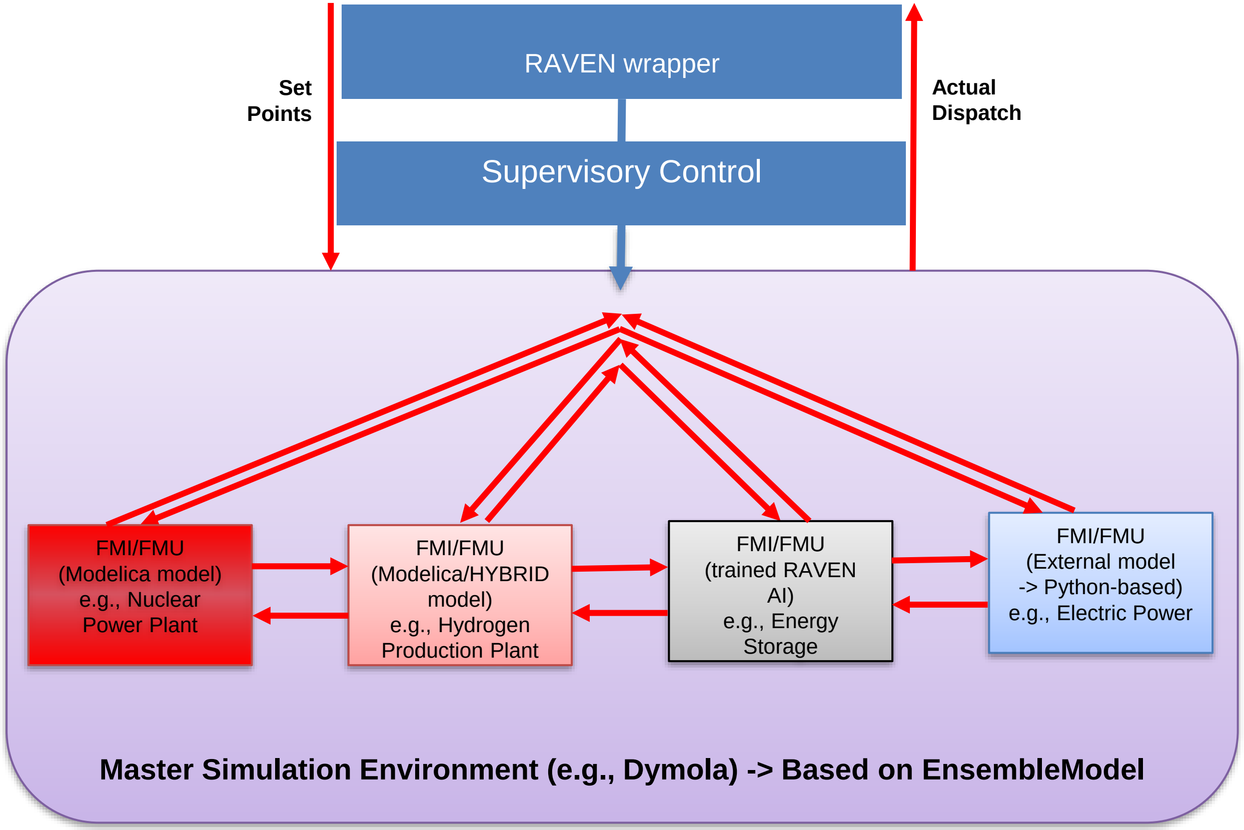
- Recent additions
    - Concrete energy storage
    - Phase change material energy storage
    - High-fidelity balance of plant
    - Compressed air energy storage
    - High-temperature gas-cooled reactor

Subsystems within the HYBRID Repository

Identifier	Category	Description	Specific Example
1	Primary heat system (PHS)	Provides base load heat and power	Nuclear reactor
2	Energy manifold (EM)	Distributes thermal energy between subsystems	Steam distribution
3	Balance of plant (BOP)	Serves as the primary electricity supply from energy not used in other subsystems	Turbine and condenser
4	Industrial process (IP)	Generates high-value product(s) using heat from the energy manifold/secondary energy supply and electricity from the switch yard	Steam electrolysis, gas to liquids, or reverse osmosis desalination
5	Energy storage (ES)	Serves as an energy buffer to increase overall system robustness	Batteries, two-tank sensible heat storage, thermocline packed bed, concrete, phase change material
6	Secondary energy source (SES)	Delivers small amounts of topping heat required by industrial processes or rapid dynamics in grid demand that cannot be met by the remainder of the system	Gas turbine, hydrogen turbine
7	Switch yard (SY)	Distributes electricity between subsystems, including the grid	Electricity distribution
8	Electrical grid (EG)	Sets the behavior of the grid connected to the NHES	Large grid behavior (not influenced by NHES)
9	Control system center (CS)	Provides proper system control, test scenarios, etc.	Control/supervisory systems and event drivers

Extensible Plug-and-Play Approach

- The individual Modelica models can be exported using the FMI/FMU standard and then reconnected within an FMI importing environment.
- Using a standardized templating system, interconnection of external models with Modelica models can be accomplished while preserving internal physics and protecting proprietary information.
- Through the use of FMI/FMUs, trained RAVEN AI can be interconnected with existing physical Modelica models.



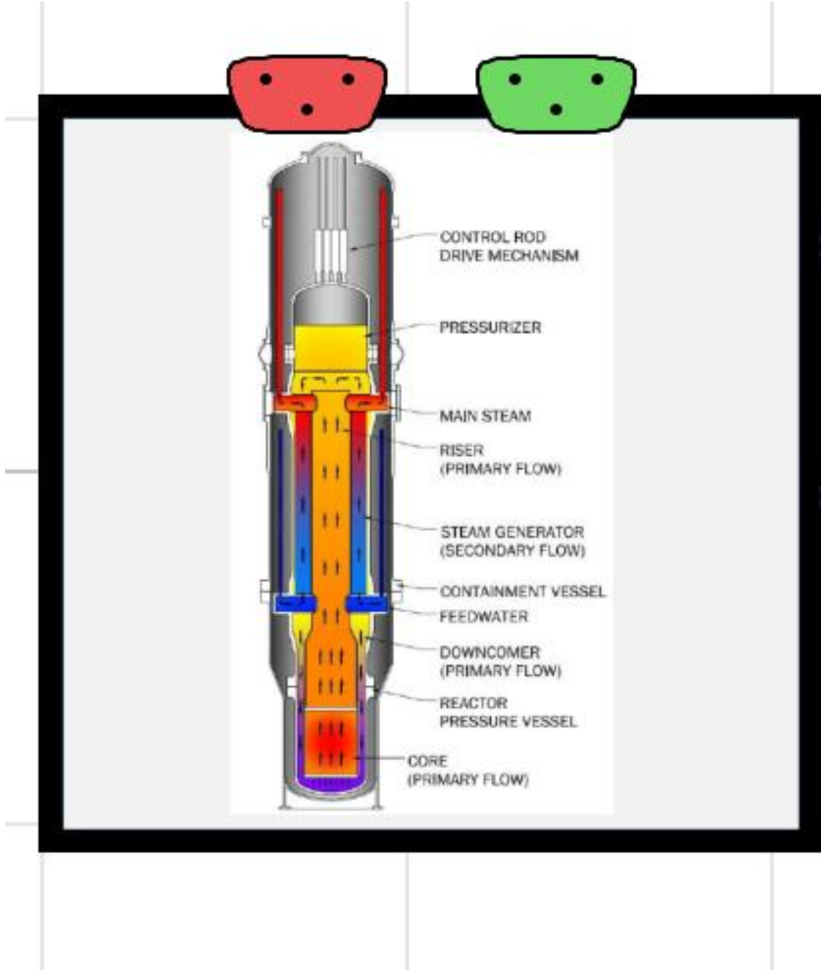
Future HYBRID Training

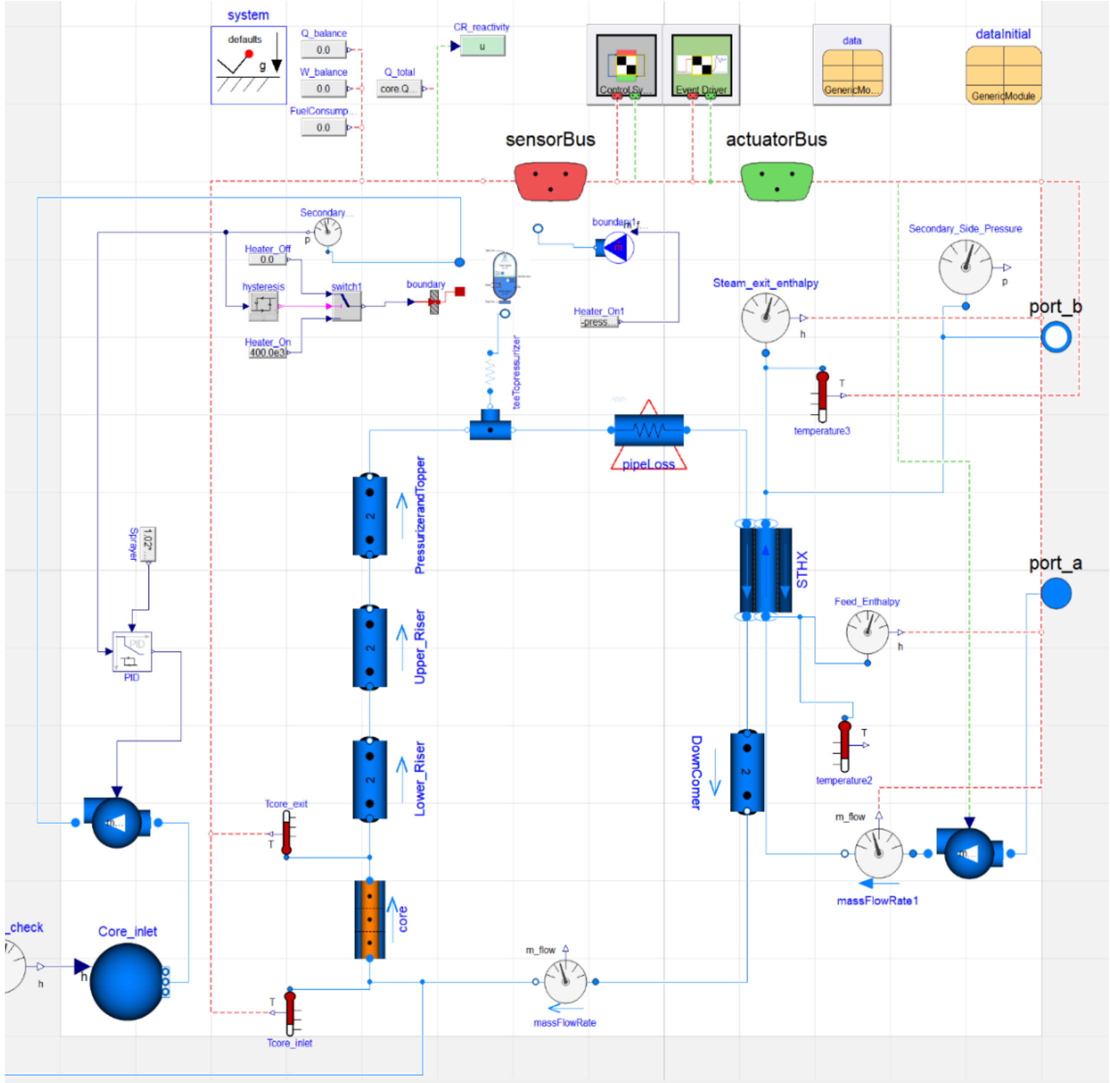
- Full Day on HYBRID Transient Modeling Capabilities March 24th
  - Three Modules
    - Introduction to Modelica and HYBRID
      - Basics of Modelica
      - How to use the GUI
      - HYBRID Repository Tour
    - Model Development
      - Building a model
      - Modifying existing models
      - How to implement control schemes
    - HYBRID For Analysts
      - Navigating HYBRID
      - How to connect existing models and use for analysis
      - FMI/FMU

Thank you for your attention

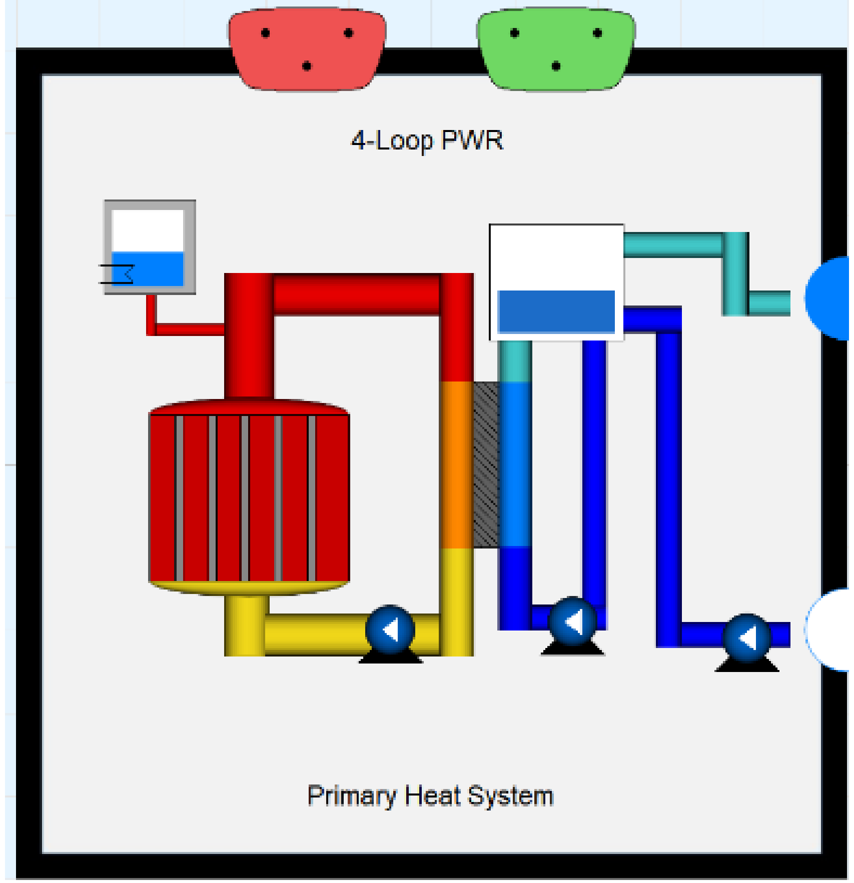
In-Depth Models

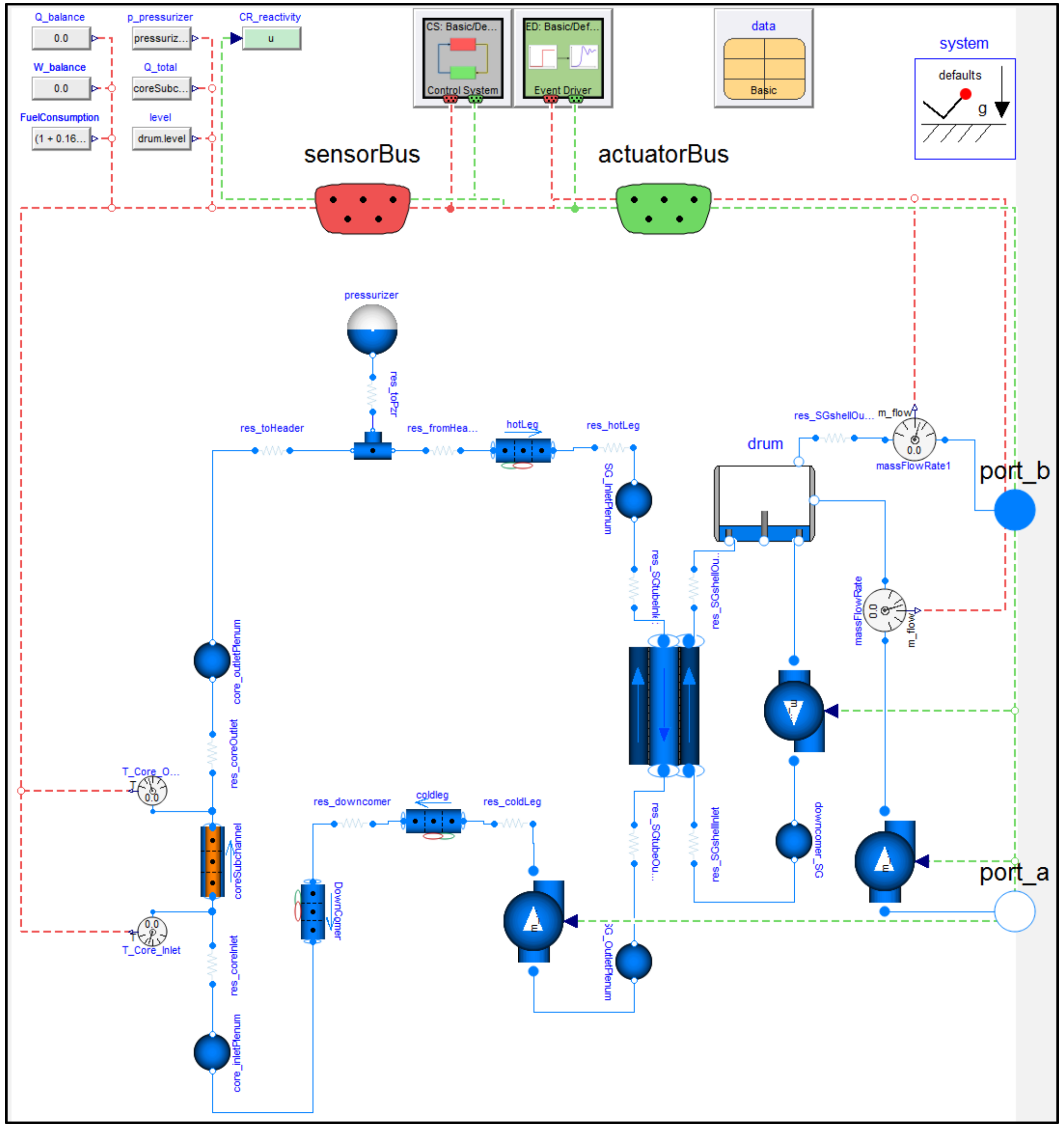
Transient NuScale-style Model in the Modelica Language



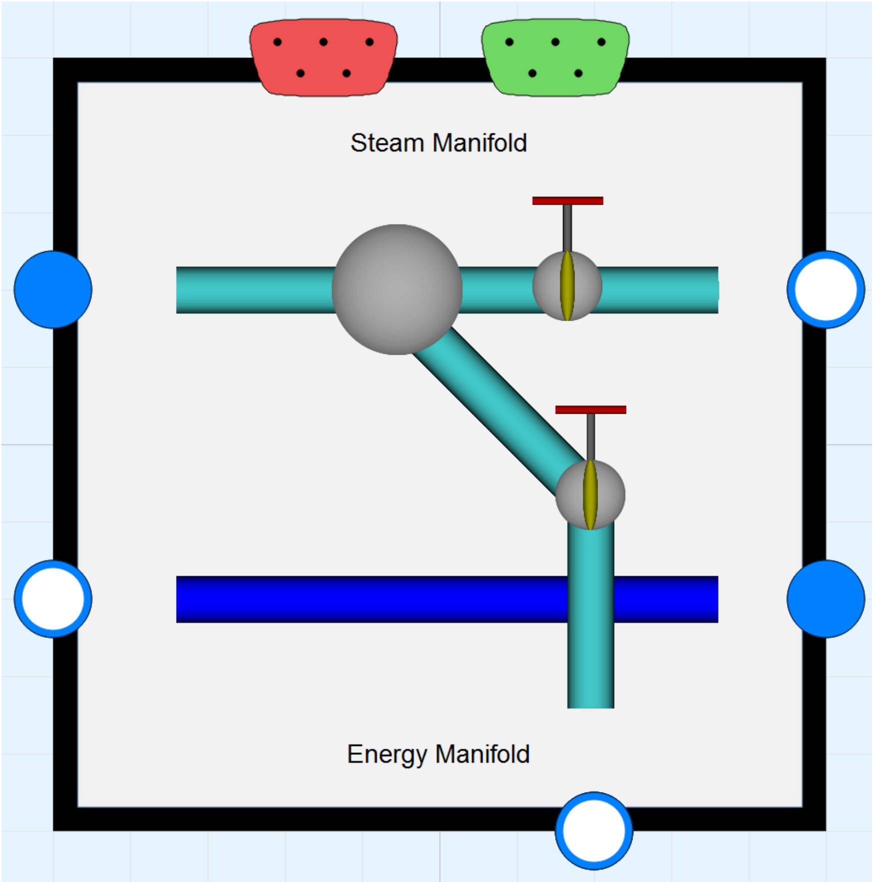


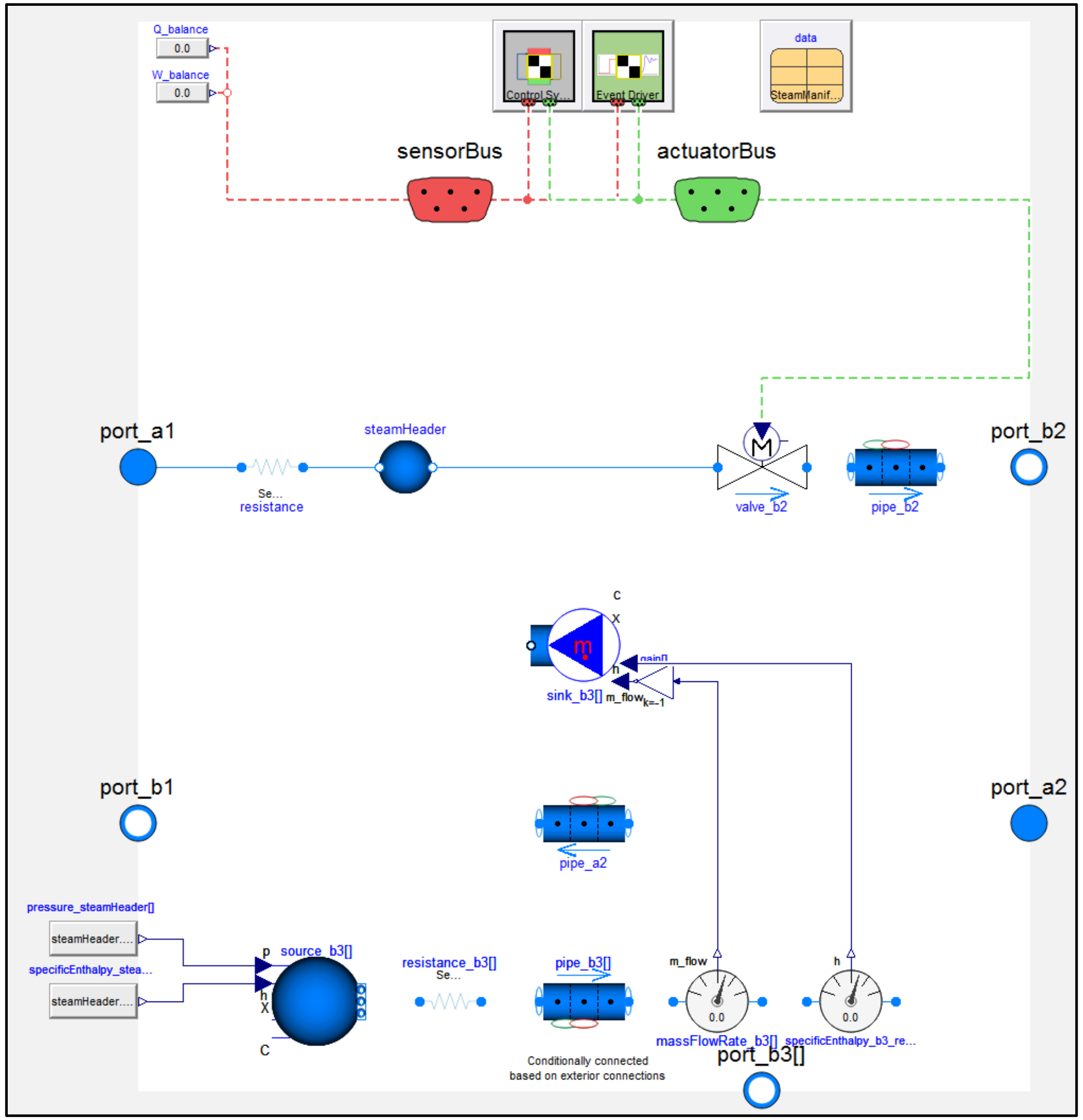
PHS – Westinghouse (WH) Style: 4-Loop PWR



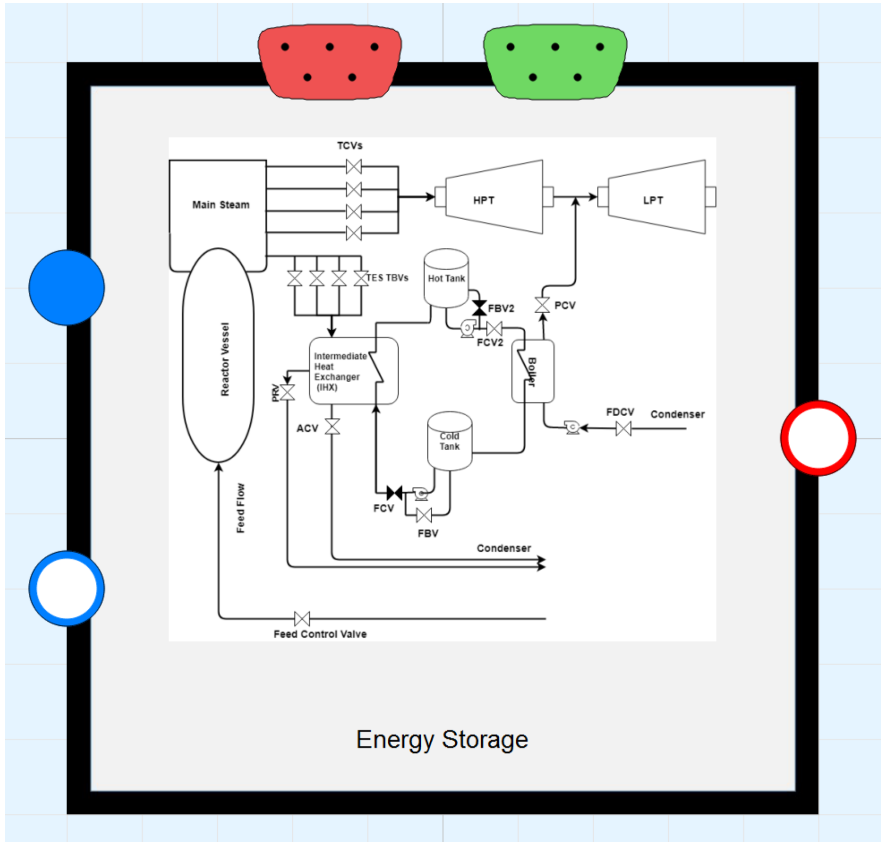


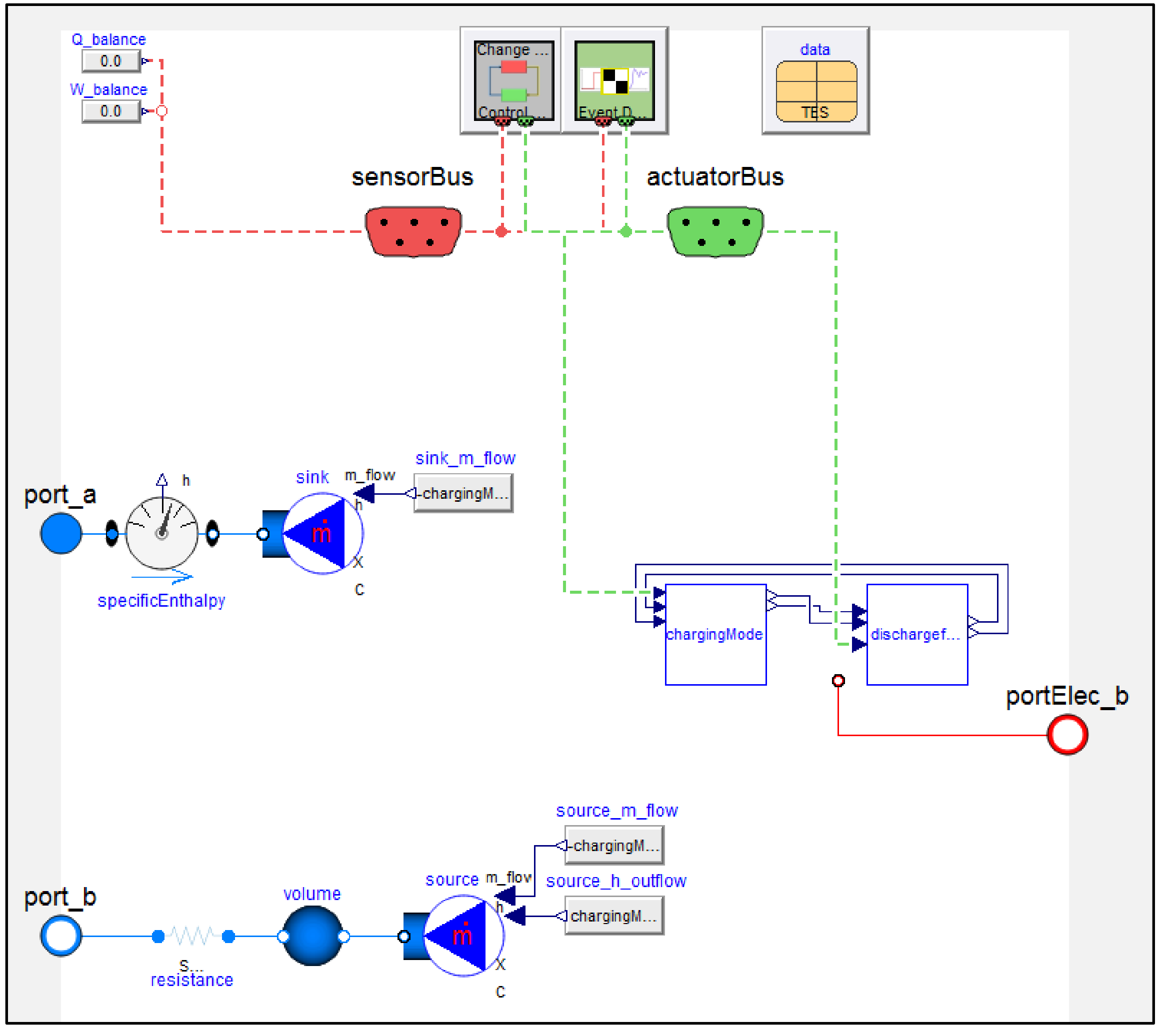
Energy Manifold



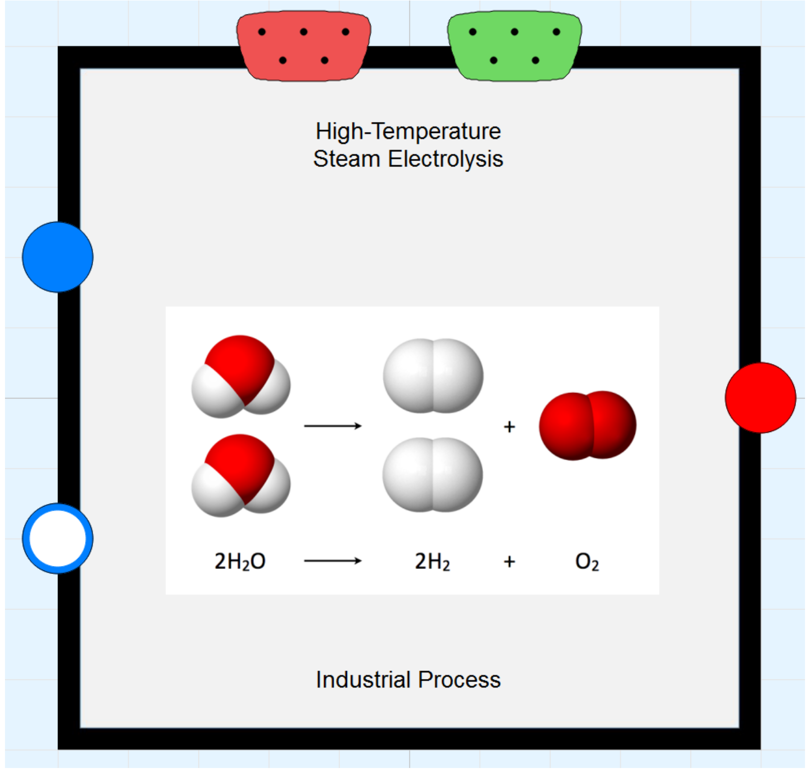


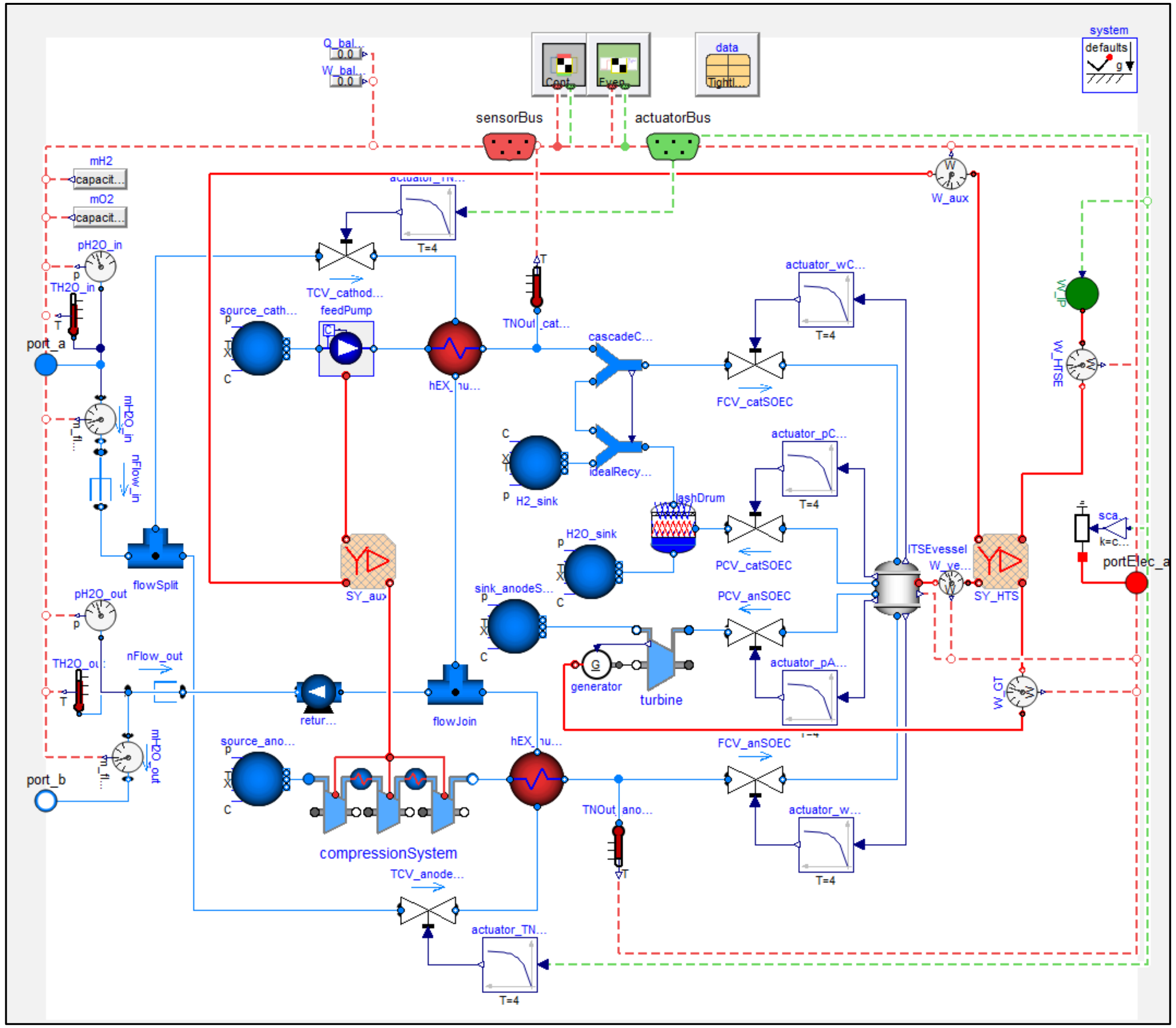
ES – Sensible Thermal Energy Storage (TES)



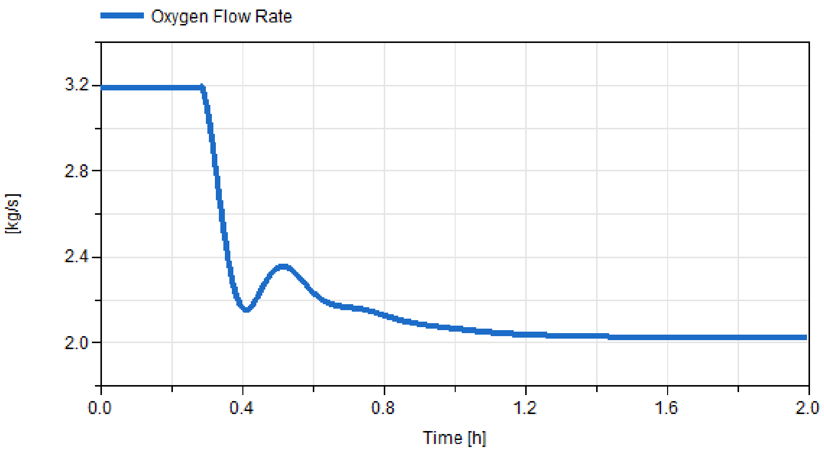


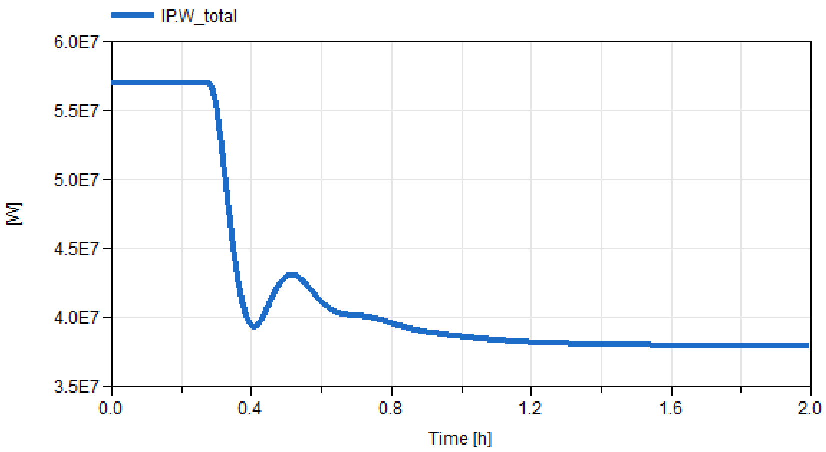
High-Temperature Steam Electrolysis (HTSE)

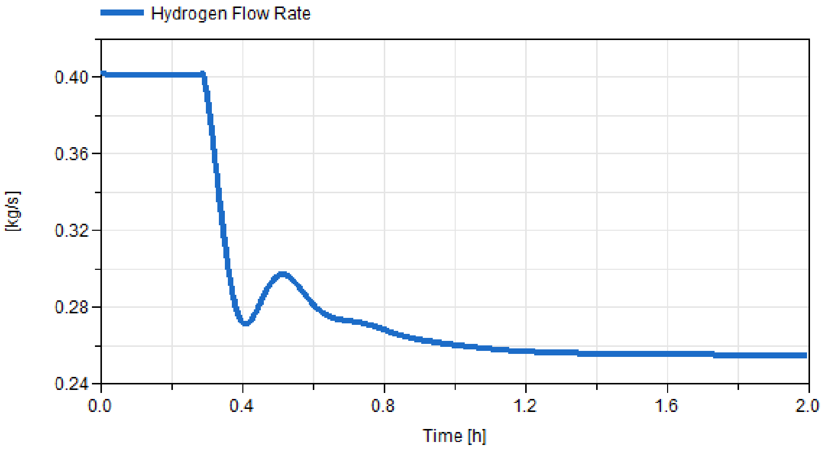


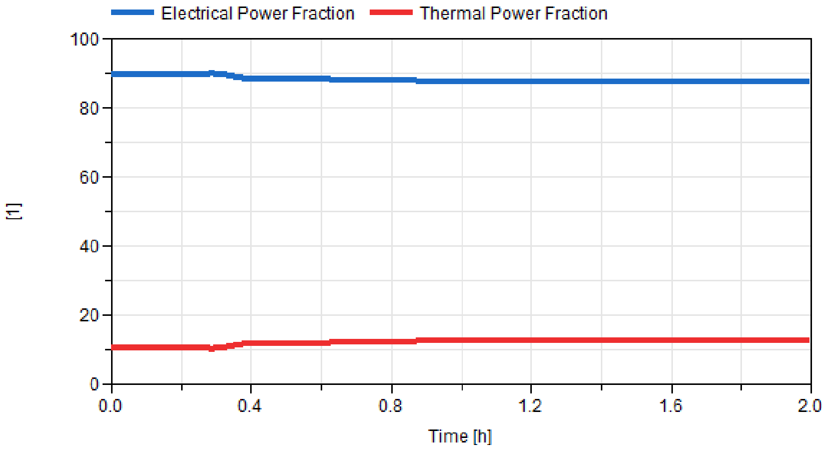


HTSE 2-Hour Simulation

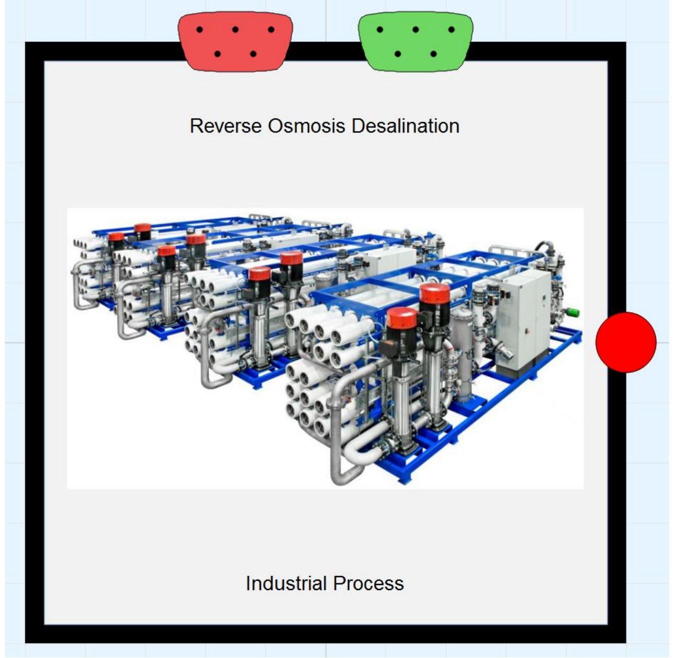


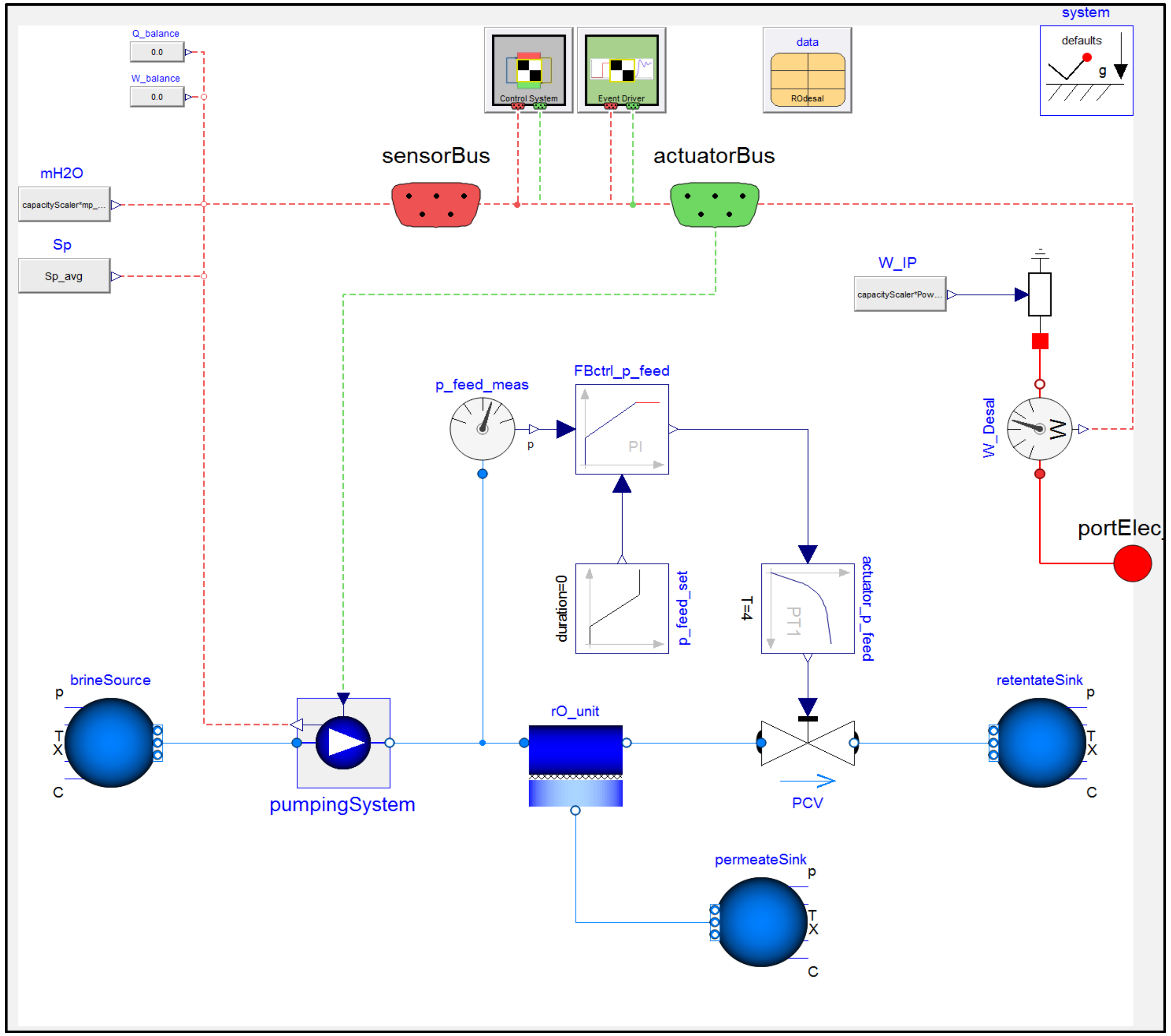




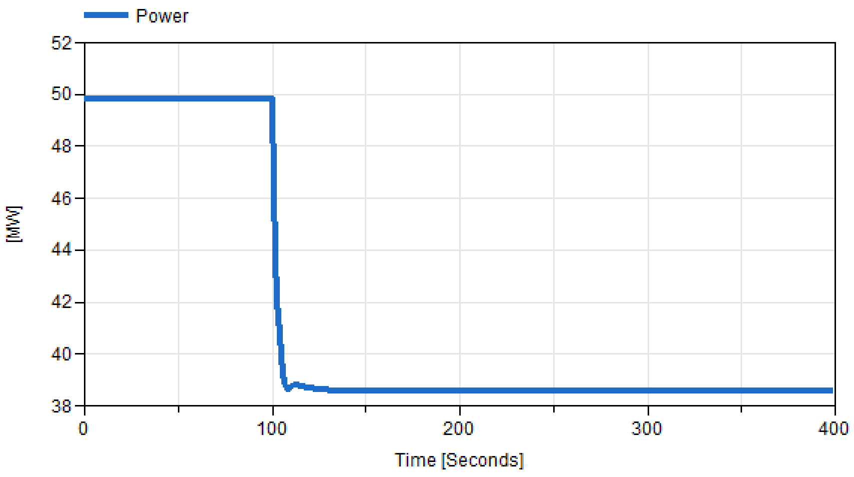


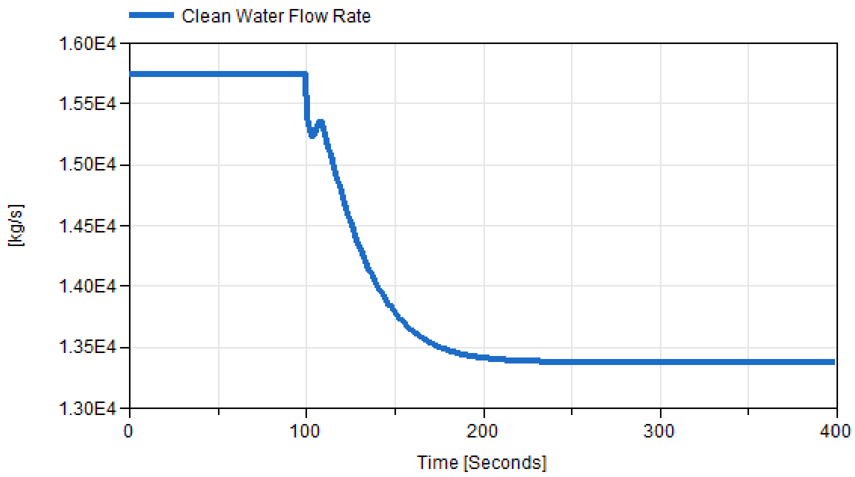
Reverse Osmosis Desalination

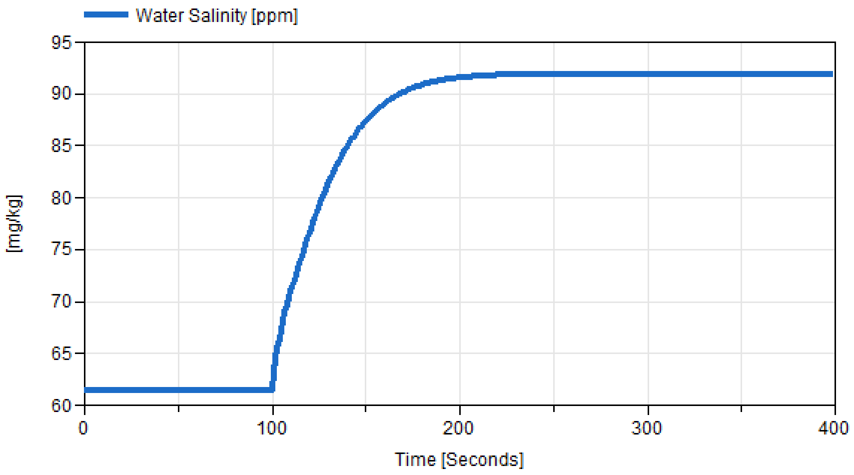


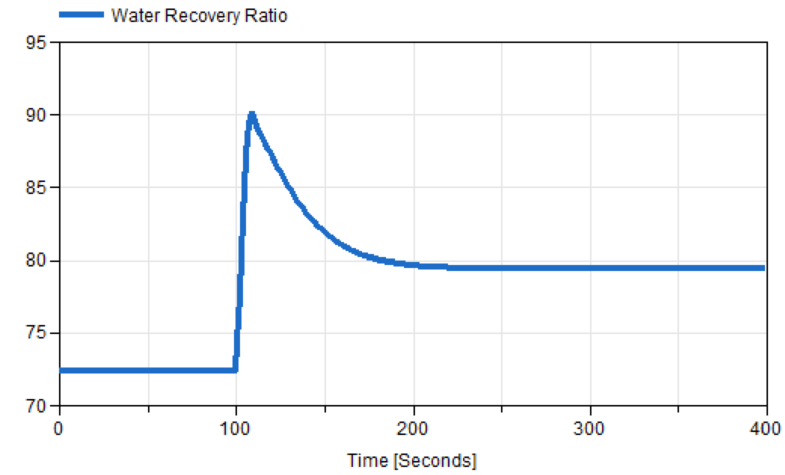


Reverse Osmosis 400-Second Run

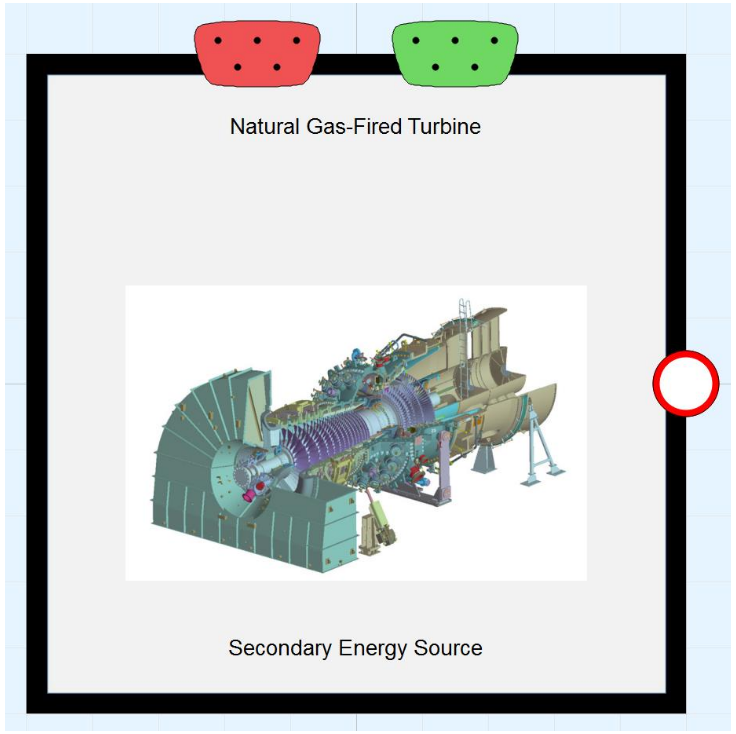


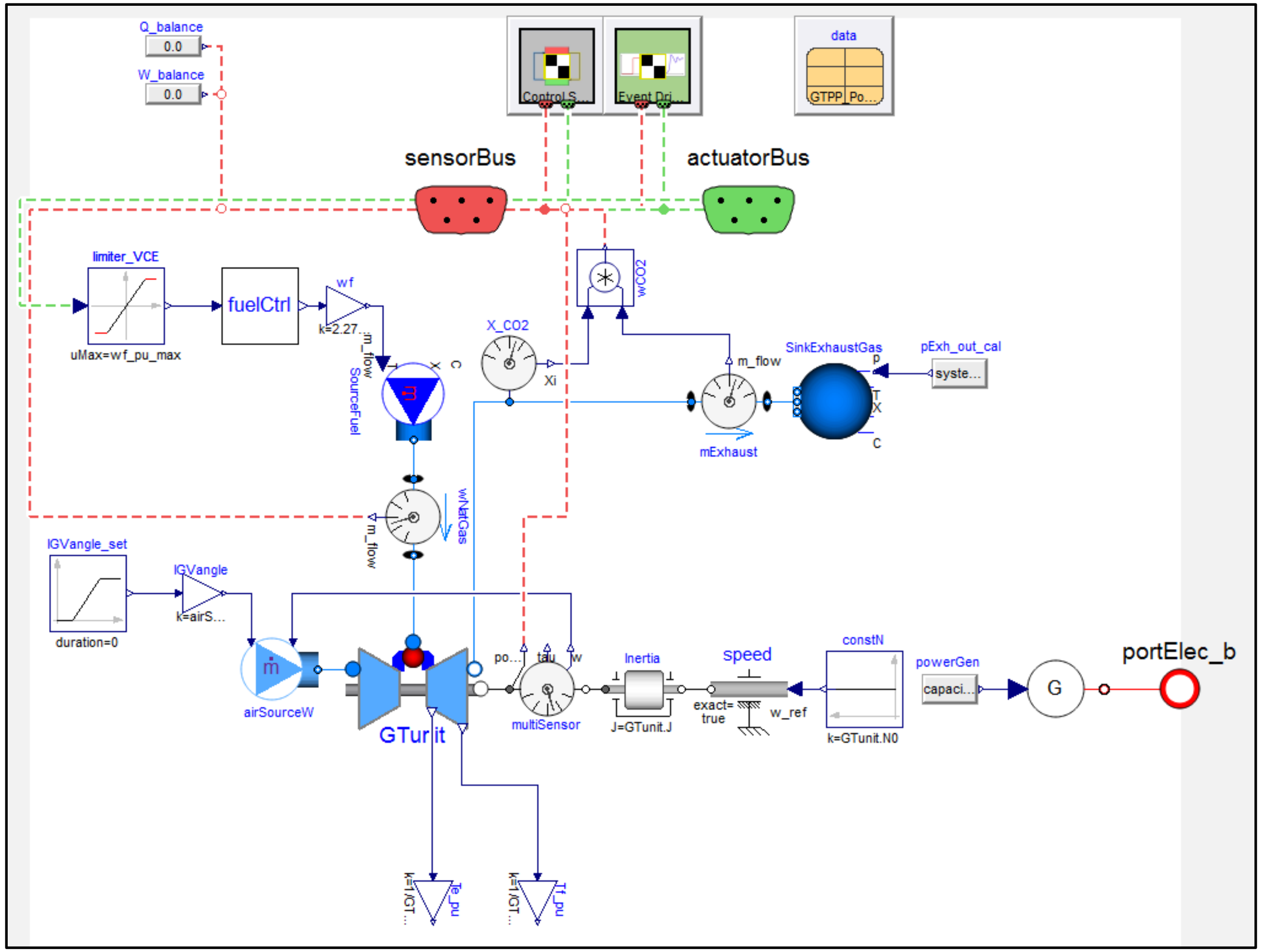




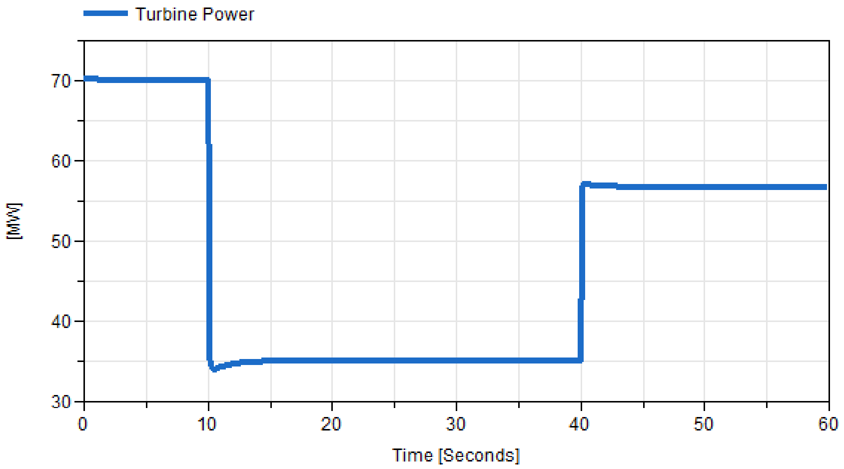


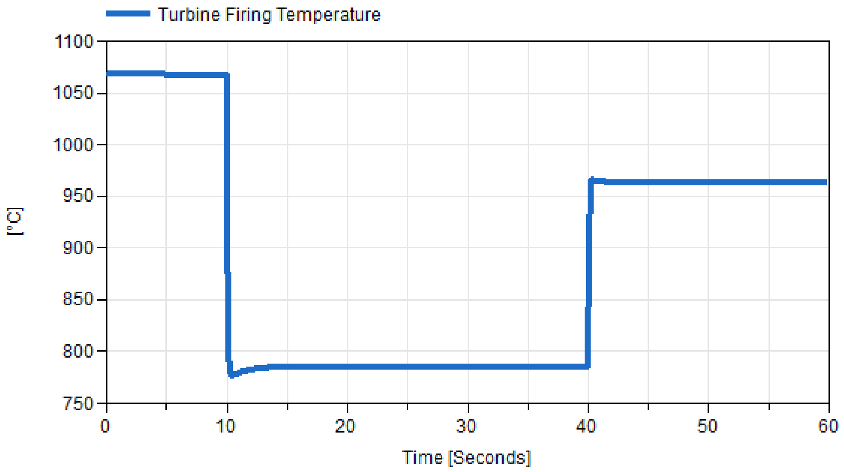
Natural Gas-Fired Turbine

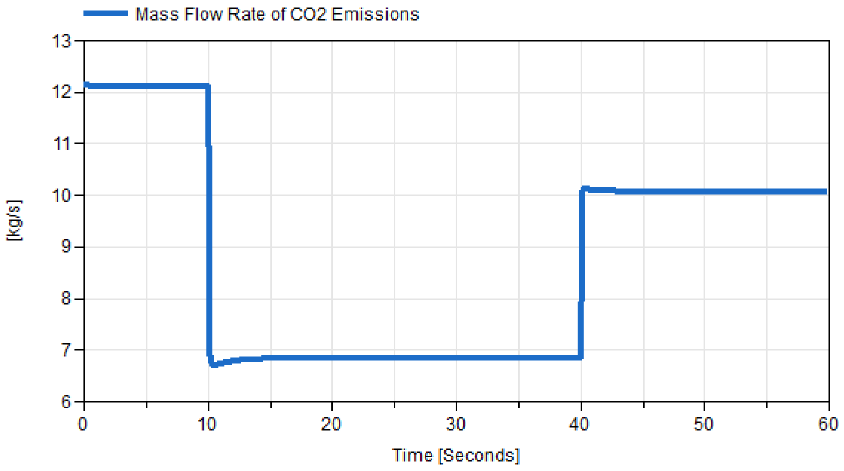


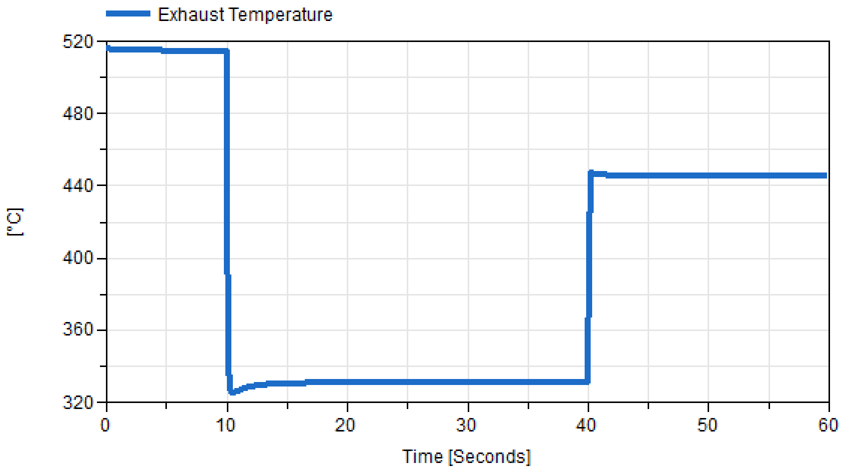


60-Second Dynamics









Simulation Capabilities/Limitations

Subsystem		**Simulation** (All simulation times using Dymola 2018. New CPU numbers have not been run with Dymola 2020.)			
Category	Model	Settling time (min)	Stop time (s) [interval length (s)]	CPU time (s)	CPU time/ stop time
PHS	SMR – NuScale Style	<15	100 [1]	--	--
	WH-style 4-Loop PWR	<60	10,000 [1]	33.31	0.0033
EM	Steam manifold	<60	100 [1]	0.623	0.0032
BOP	Ideal steam turbine	<60	100 [1]	0.06	0.0006
IP	HTSE	<45	3,600 [1]	11.48	0.0032
	RO desalination	<30	400 [1]	6.66	0.0166
ES	Battery	<60	100 [1]	0.006	0.00006
	Sensible TES	5–10	93,600 [1]	57.07	0.00061
SES	GTPP	1–5	600 [1]	0.067	0.00011
IES	FY17 example: WH + HTSE + Battery + GTPP	–	352,800 [10]	5,886	0.0167
	FY18 example: WH PWR + HTSE + Battery + GTPP	–	86,400 [10]	213	0.0025

Available Literature on Models

- Literature:

1) https://www.osti.gov/biblio/1569288-status-report-nuscale-module-developed-modelica-framework. -- Frick, Konor L. Status Report on the NuScale Module Developed in the Modelica Framework. United States: N. p., 2019. Web. doi:10.2172/1569288.
2) https://www.osti.gov/biblio/1333156-status-component-models-developed-modelica-framework-high-temperature-steam-electrolysis-plant-gas-turbine-power-plant -- Suk Kim, Jong, McKellar, Michael, Bragg-Sitton, Shannon M., and Boardman, Richard D. Status on the Component Models Developed in the Modelica Framework: High-Temperature Steam Electrolysis Plant & Gas Turbine Power Plant. United States: N. p., 2016. Web. doi:10.2172/1333156.
3) https://www.osti.gov/biblio/1468648-status-report-component-models-developed-modelica-framework-reverse-osmosis-desalination-plant-thermal-energy-storage --Kim, Jong Suk, and Frick, Konor. Status Report on the Component Models Developed in the Modelica Framework: Reverse Osmosis Desalination Plant & Thermal Energy Storage. United States: N. p., 2018. Web. doi:10.2172/1468648.
4) https://www.osti.gov/biblio/1333156-status-component-models-developed-modelica-framework-high-temperature-steam-electrolysis-plant-gas-turbine-power-plant -- Suk Kim, Jong, McKellar, Michael, Bragg-Sitton, Shannon M., and Boardman, Richard D. Status on the Component Models Developed in the Modelica Framework: High-Temperature Steam Electrolysis Plant & Gas Turbine Power Plant. United States: N. p., 2016. Web. doi:10.2172/1333156
5) https://www.osti.gov/biblio/1557660-design-operation-sensible-heat-peaking-unit-small-modular-reactors -- Frick, Konor, Doster, Joseph Michael, and Bragg-Sitton, Shannon. Design and Operation of a Sensible Heat Peaking Unit for Small Modular Reactors. United States: N. p., 2018. Web. doi:10.1080/00295450.2018.1491181.
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7) https://www.osti.gov/biblio/1562960-dynamic-performance-analysis-high-temperature-steam-electrolysis-plant-integrated-within-nuclear-renewable-hybrid-energy-systems -- Kim, Jong Suk, Boardman, Richard D., and Bragg-Sitton, Shannon M. Dynamic performance analysis of a high-temperature steam electrolysis plant integrated within nuclear-renewable hybrid energy systems. United Kingdom: N. p., 2018. Web. doi:10.1016/j.apenergy.2018.07.060.
8) https://www.osti.gov/biblio/1357452-modeling-control-dynamic-performance-analysis-reverse-osmosis-desalination-plant-integrated-within-hybrid-energy-systems. Kim, Jong Suk, Chen, Jun, and Garcia, Humberto E. Modeling, control, and dynamic performance analysis of a reverse osmosis desalination plant integrated within hybrid energy systems. United States: N. p., 2016. Web. doi:10.1016/j.energy.2016.05.050.