INL/MIS-22-66313

IES
Integrated Energy Systems

FORCE – Transient Physical Modeling Workshop

Hybrid Overview

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Session Agenda

1. Introduction to Modelica (15 min)
   a) Why Modelica
   b) Modelica features
   c) IDEs, Dymola
2. Basic model creation overview (15 min)
   a) Classes, equations, and algorithms
   b) Workflow overview
3. Hybrid repository (30 min)
   a) What is Hybrid?
   b) Models overview
   c) Navigating Hybrid & TRANSFORM

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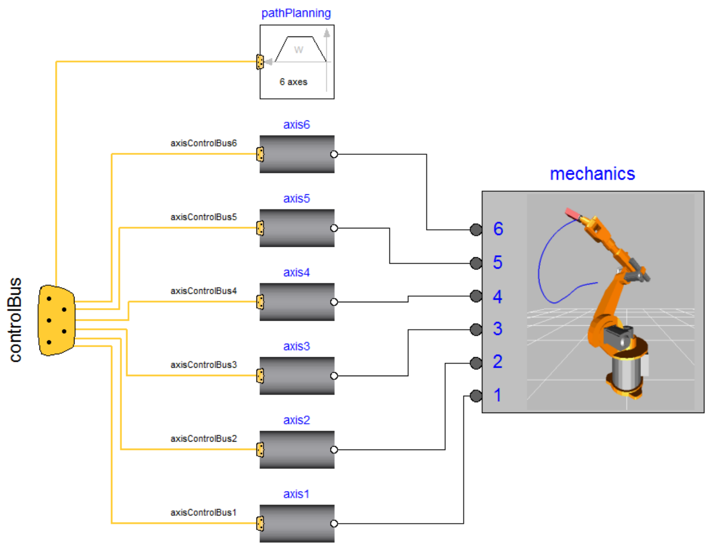
Why Modelica?

- Rapid Development
  - Fidelity level controlled by user
  - Fast feedback from development environment
- Collaborative
  - Model repositories can be open-source like Hybrid with standardized connections
  - FMI/FMU allows for “black-box” sharing
- Flexible, Adaptable
  - Modeling across multiple physical domains
  - Models modifiable for existing and new users

Modelica Features

Equation Based (acausal)

- Order of computations is not decided at modeling time
- Equations do not specify input/outputs
  - $x + y = z^x + yz$
- Solutions direction adapts to data flow



Built for Dynamic Problems

- Time integration handled by solver
  - $der(v) = a + bx(t)$

Example from the Modelica Standard Library

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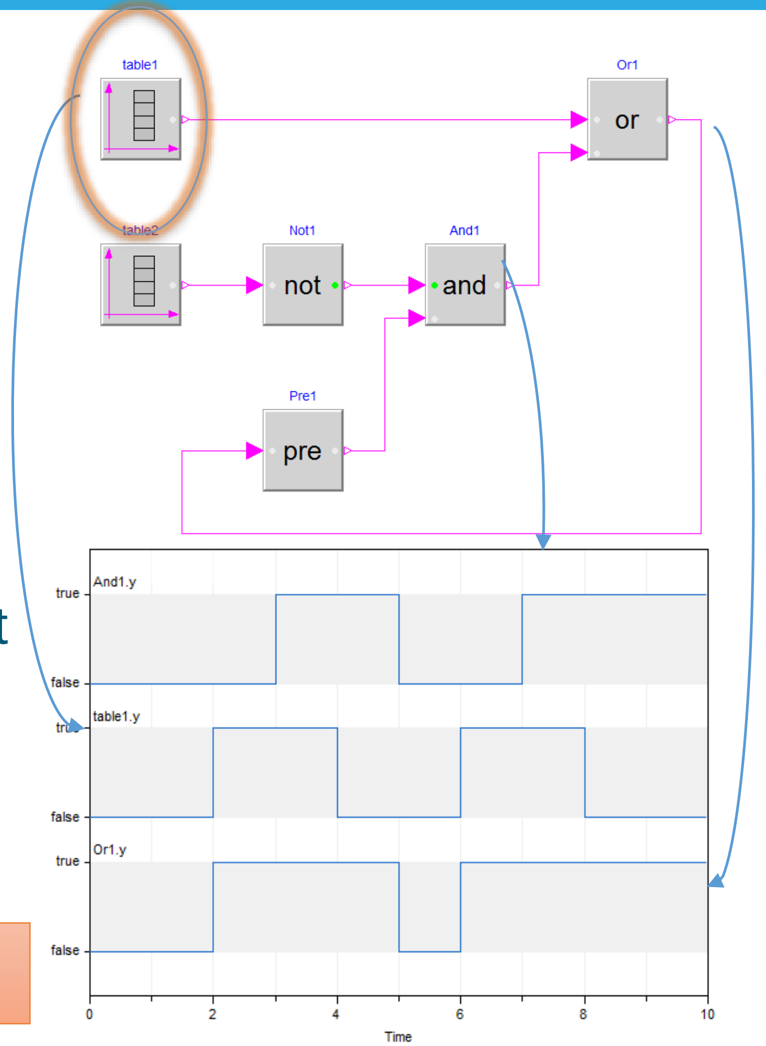
Dynamic Simulation

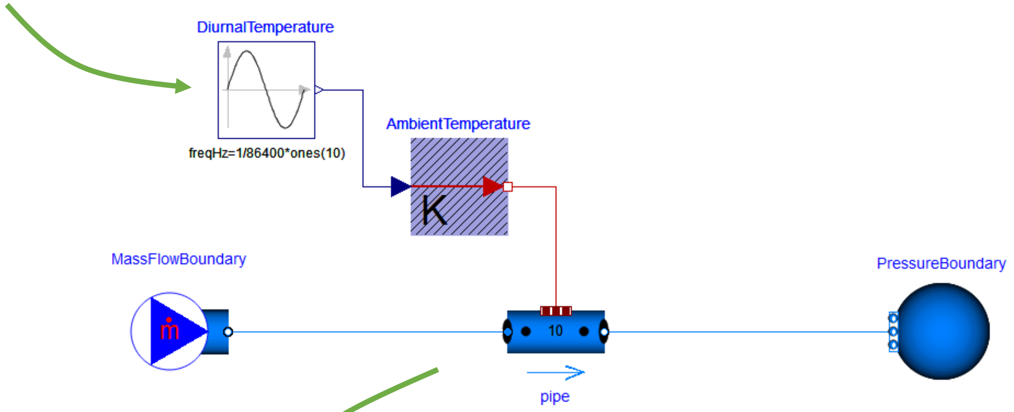
- Time dependent aspects of a system
- Concerned with concepts of:
  - States: Attributes described at a point in time
  - Events: Occurrences that trigger a state transition
  - Transitions: A change in the state of an object
  - Actions: Instantaneous operation that results due to an event
  - Activities: Ongoing operations upon the state of an object



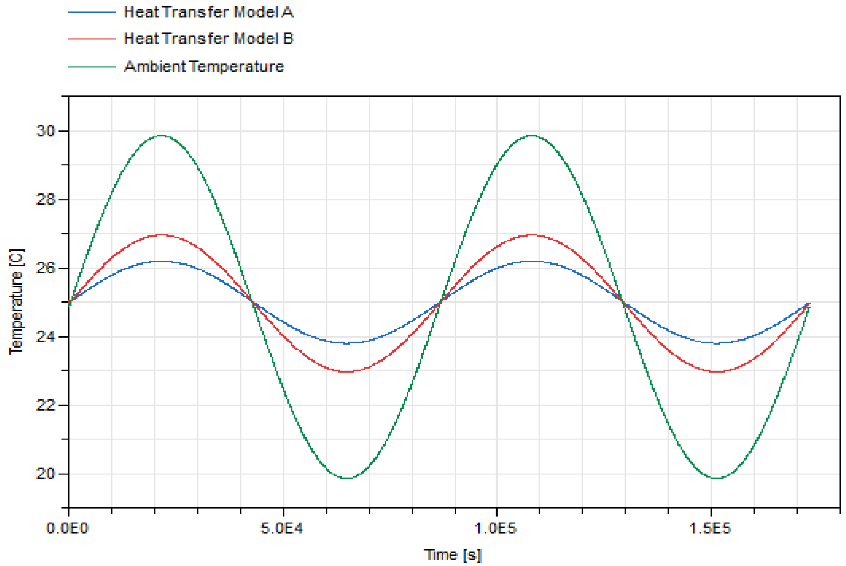
Example of a dynamic problem

Replaceable Modeling

A pipe subjected to cyclic ambient temperature



Simulate



Double click on the component of interest and change the fluid or heat transfer correlation

Fluid Media

Water using the IF97 standard, explicit in p and h. Recommended for most applications

- Moist air without condensation
- Simple flue gas for over0stochiometric O2-fuel ratios
- Simplest flue gas for over-and understochiometric combustion of hydrocarbons
- Simple natural gas mix with 6 components
- Same as SimpleNaturalGas but with fixed composition
- 1,2-Propylene glycol, 47% mixture with water
- Essotherm thermal oil
- Incompressible medium properties based on tables
- Medium model for R134a and p,h as states
- Water: Steam as ideal gas from NASA source

Heat Transfer Correlation

Seban-Shimazaki: Liquid metal correlation for flow in circular tubes and uniform wall tem

- <Remove modifier>
- IdealHeatTransfer: Ideal heat transfer without thermal resistance
- ConstantHeatTransfer: Constant heat transfer coefficient
- LocalPipeFlowHeatTransfer: Laminar an...nvection in pipes, local coefficients
- Lyon-Martinelli: Liquid metal correlati...n circular tubes and constant heat flux
- Seban-Shimazaki: Liquid metal correla...ar tubes and uniform wall temperature
- FFTF: Liquid metal rod bundle; 20 <= Pe <= 1000
- Borishanskii et al.: Liquid metal rod bundle; 1.1 <= P/D <= 1.5, Pe <= 2000
- Graber-Rieger: Liquid metal rod bundle; 1.25 <= P/D <= 1.95, 150 <= Pe <= 3000
- modifiedSchad: Liquid metal rod bundle; 1.05 <= P/D <= 1.15, Pe <= 1000

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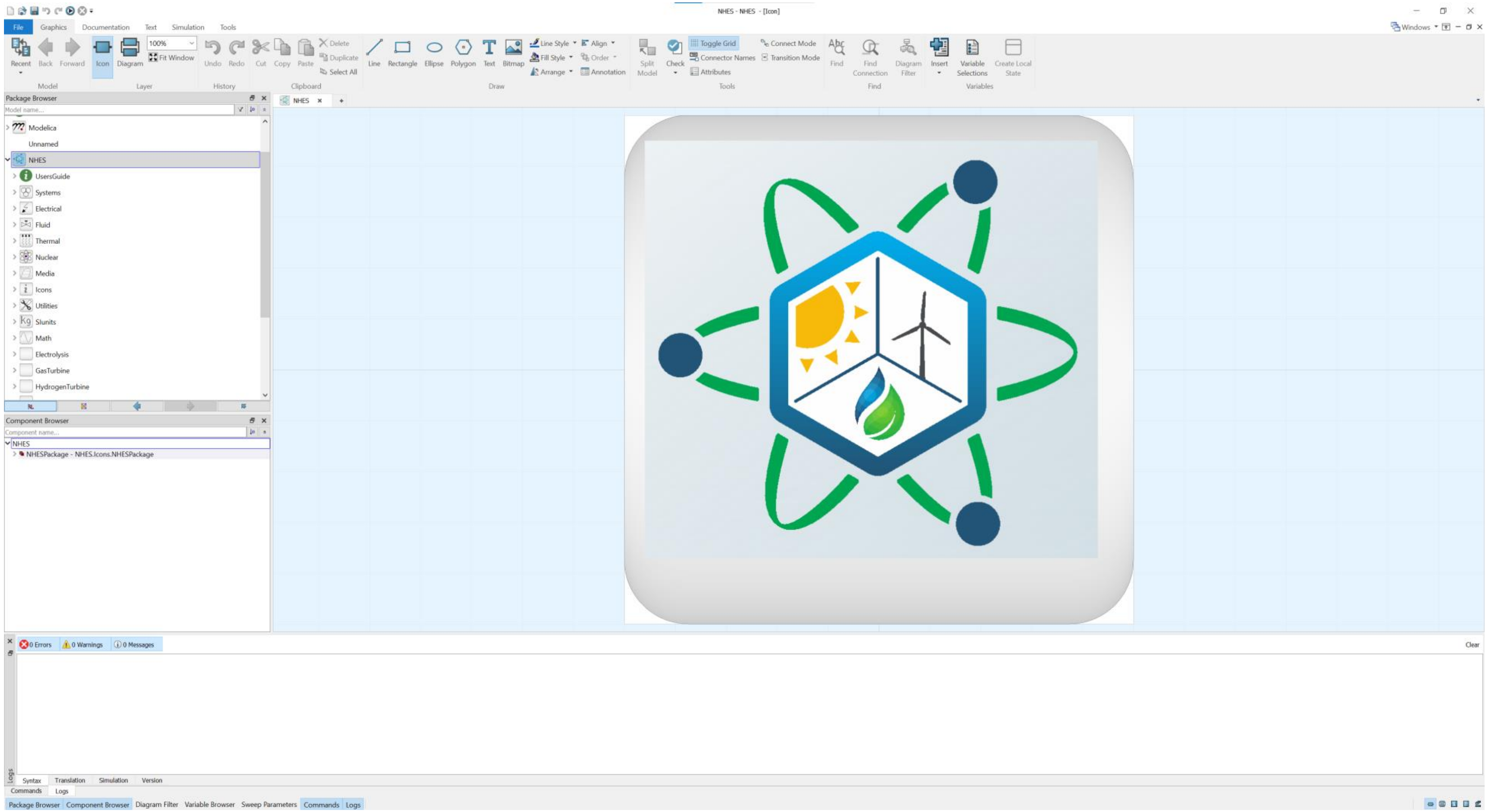
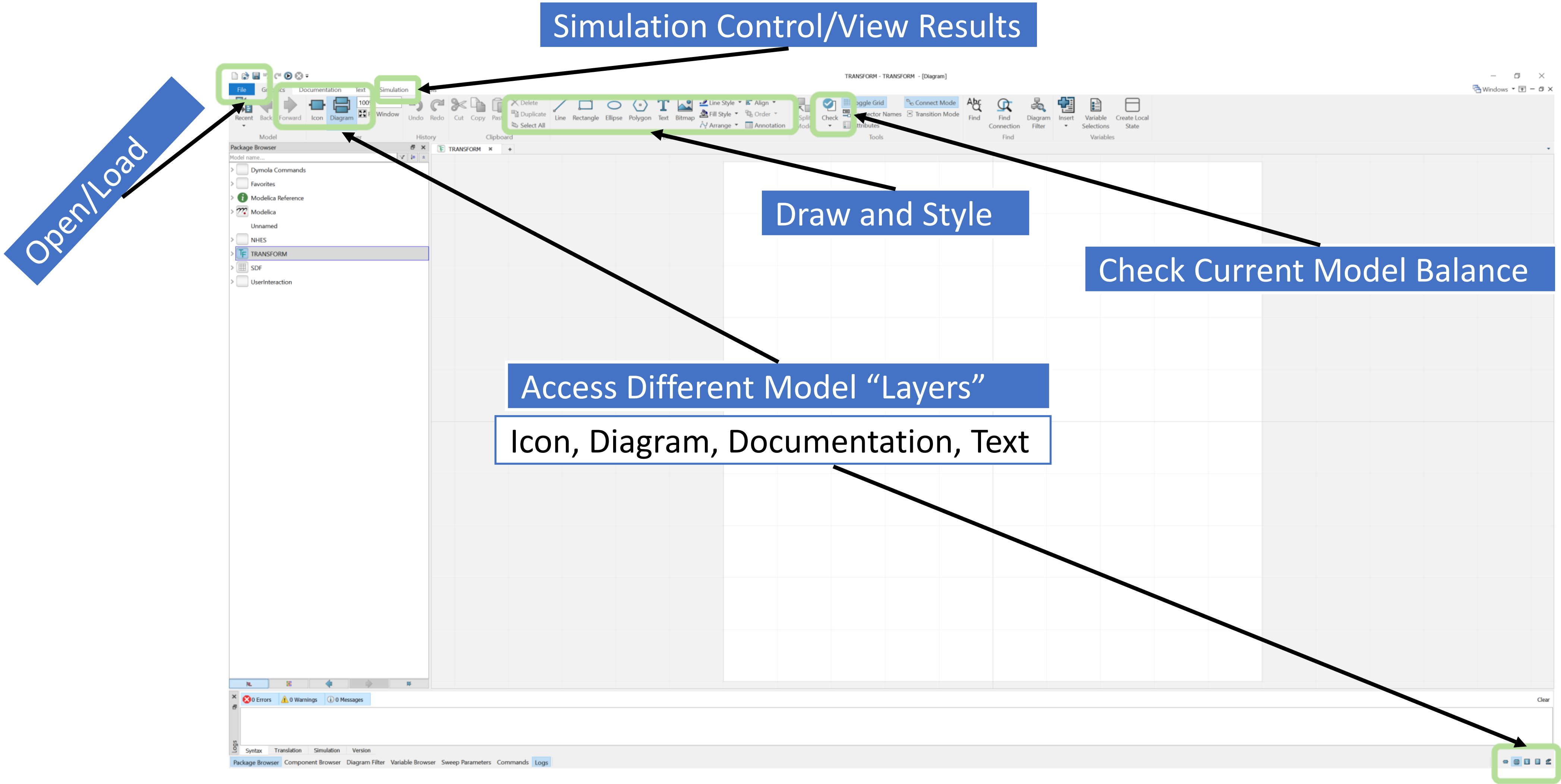
Integrated Development Environments

- Several IDE exist, such as:
  - OpenModelica, open source
  - Dymola, Dassault Systemes
  - Modelon Impact, Modelon
- At INL, we use Dymola
  - IES program maintains multiple server licenses
- IDE provides convenient GUI for model development

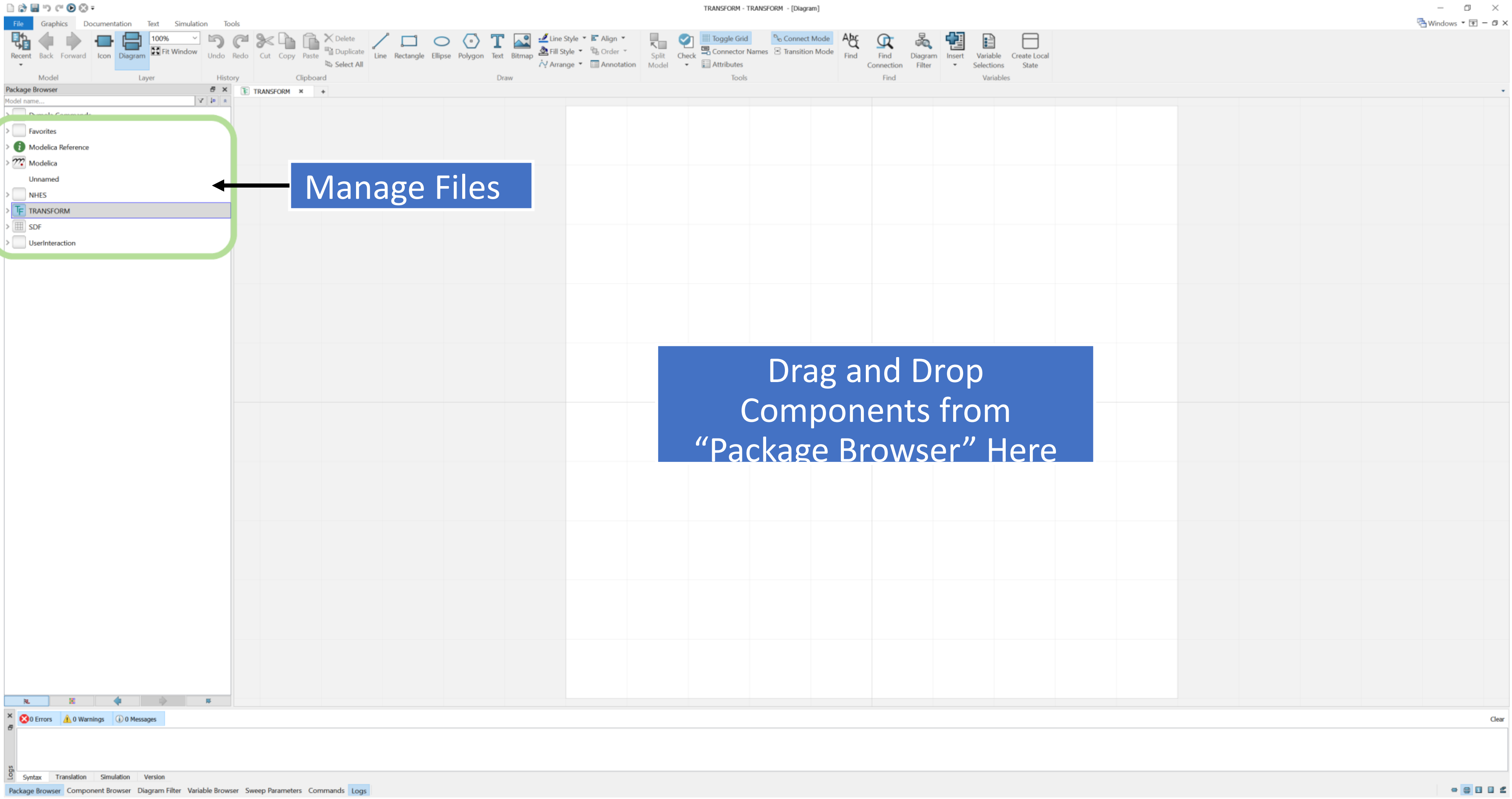
Dymola Introduction



IDE – Navigating the GUI



IDE – Navigating the GUI



Manage Files

Drag and Drop Components from "Package Browser" Here

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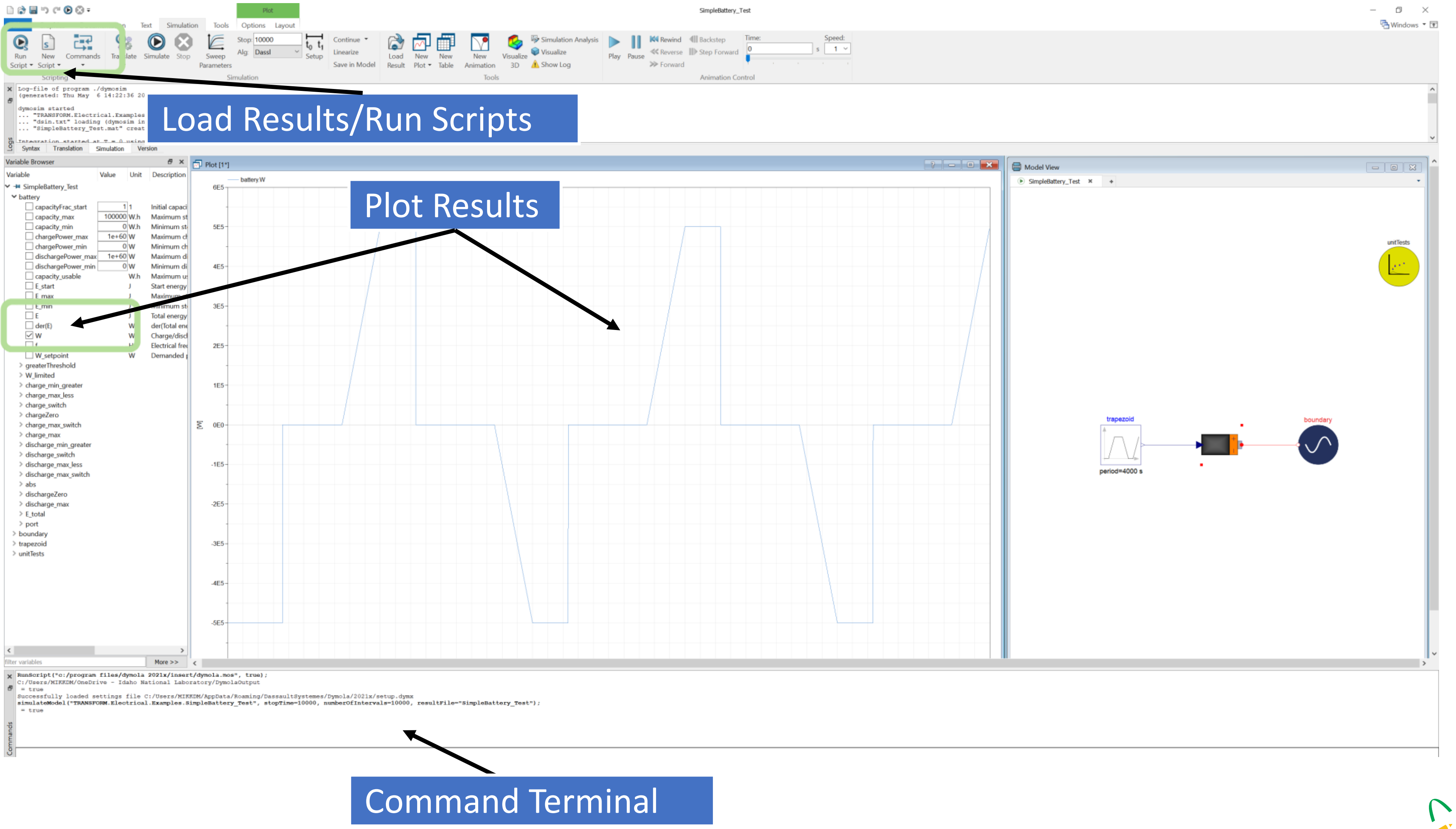
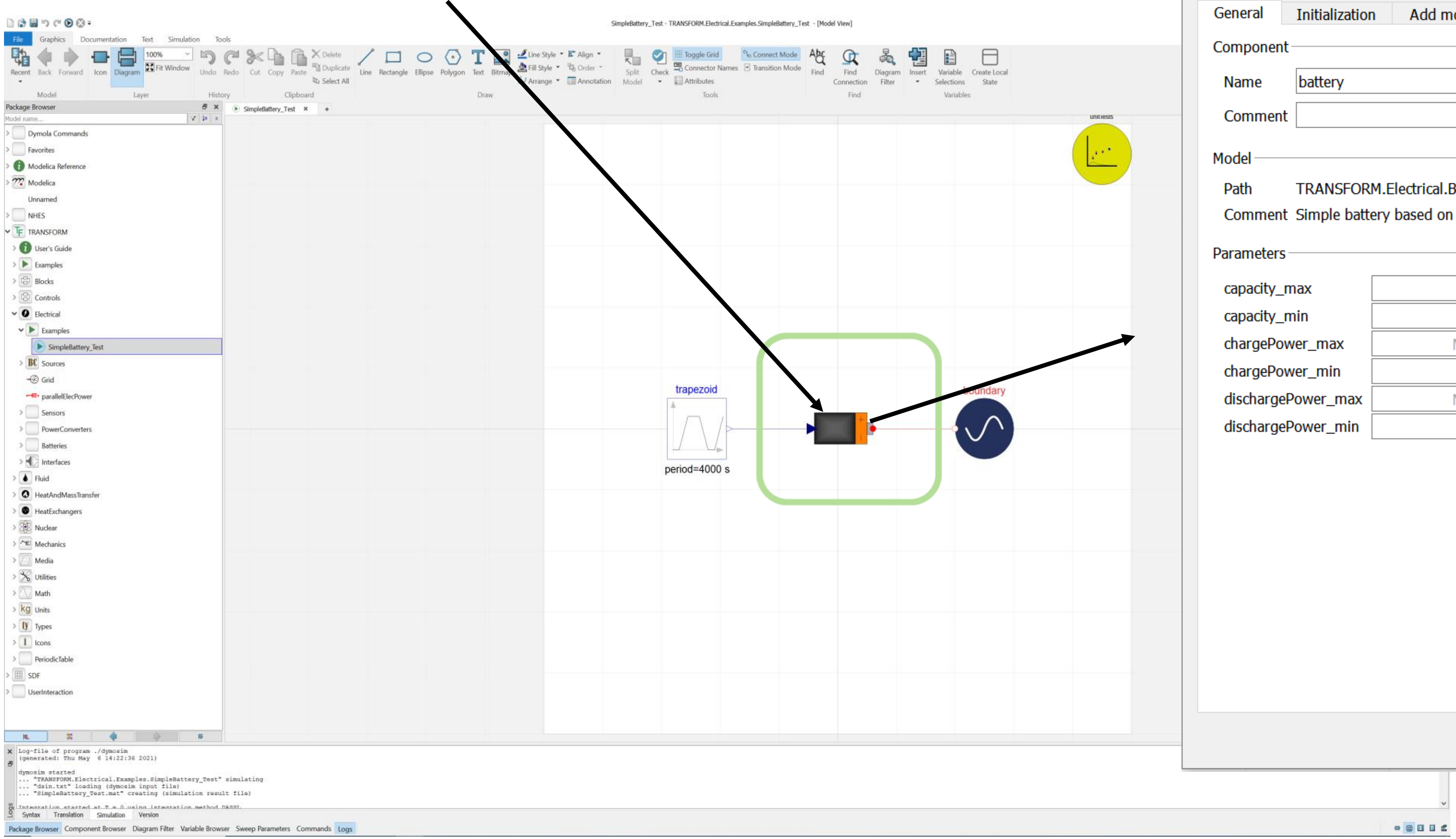
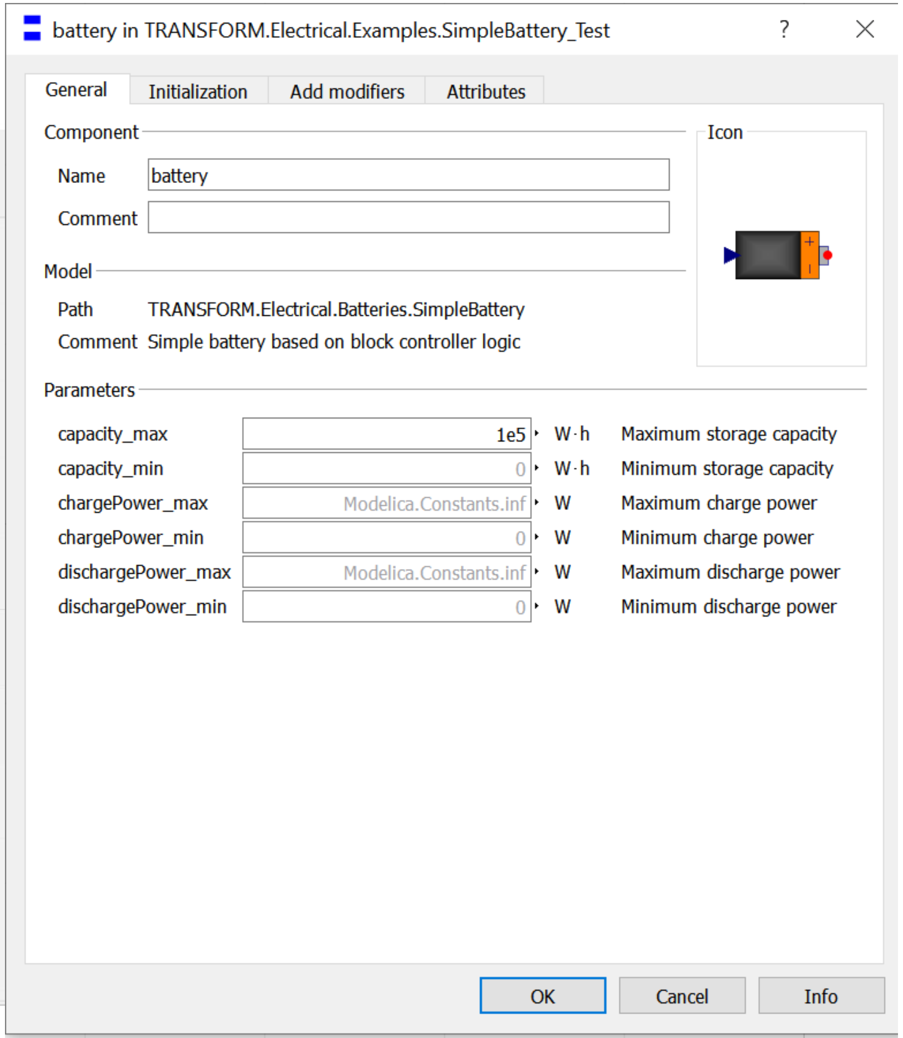
IDE – Navigating the GUI



IDE – Parameter GUI

Double click component to access parameter GUI





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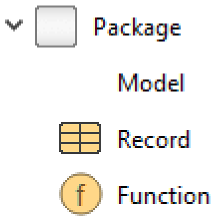
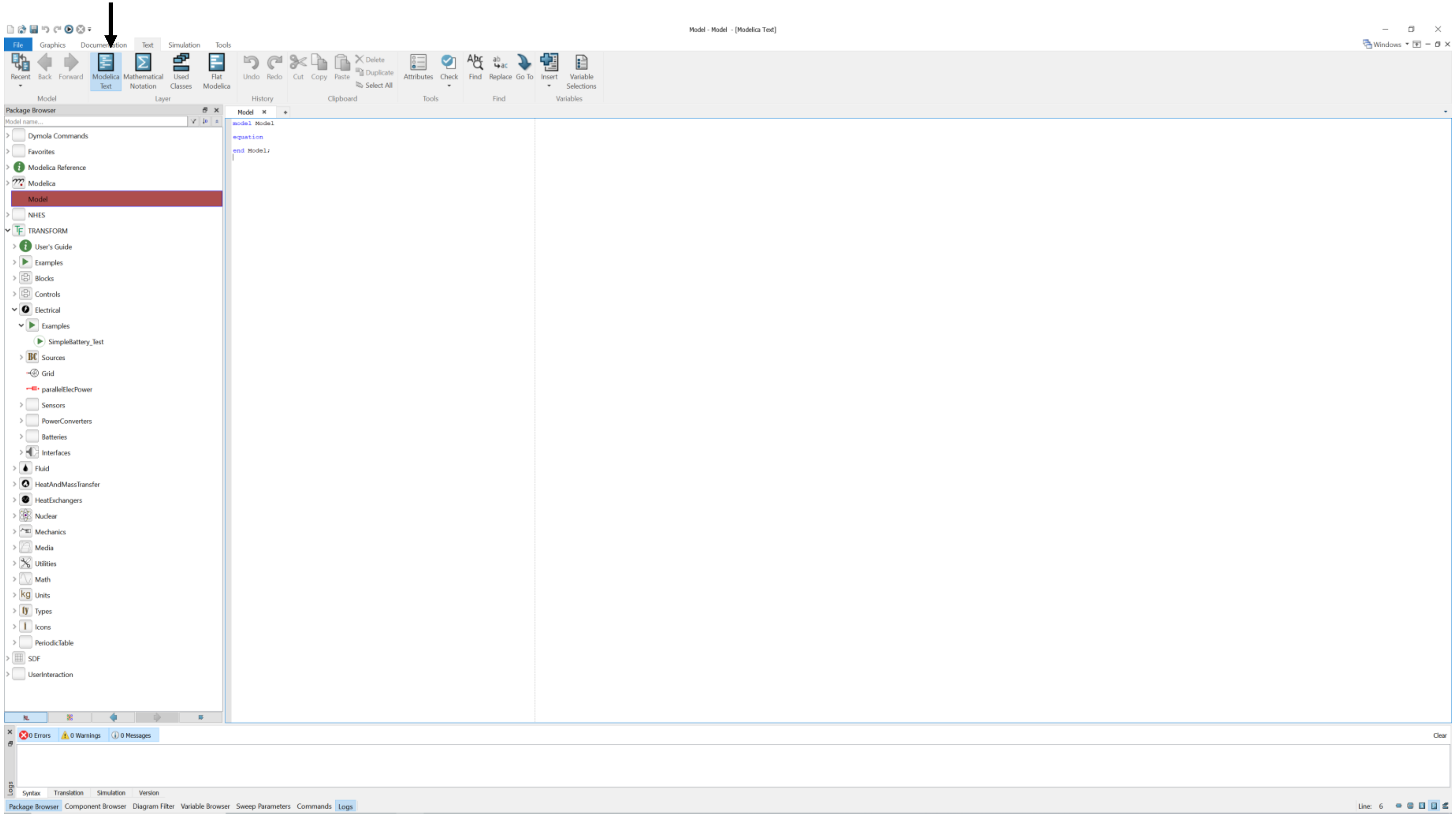
Model Creation – Common Classes

- Difference between
  - Package
    - Analogous to folder or directory
  - Model
    - Principle method for creating systems
    - Location of “equation” section
  - Function
    - Behaves similar to traditional programming languages (e.g., Matlab)
    - *Imperative* – used only for special cases
    - Location of “algorithm” section
  - Record
    - Used to define common types that are reused in various locations
    - For example, common input parameters to multiple models



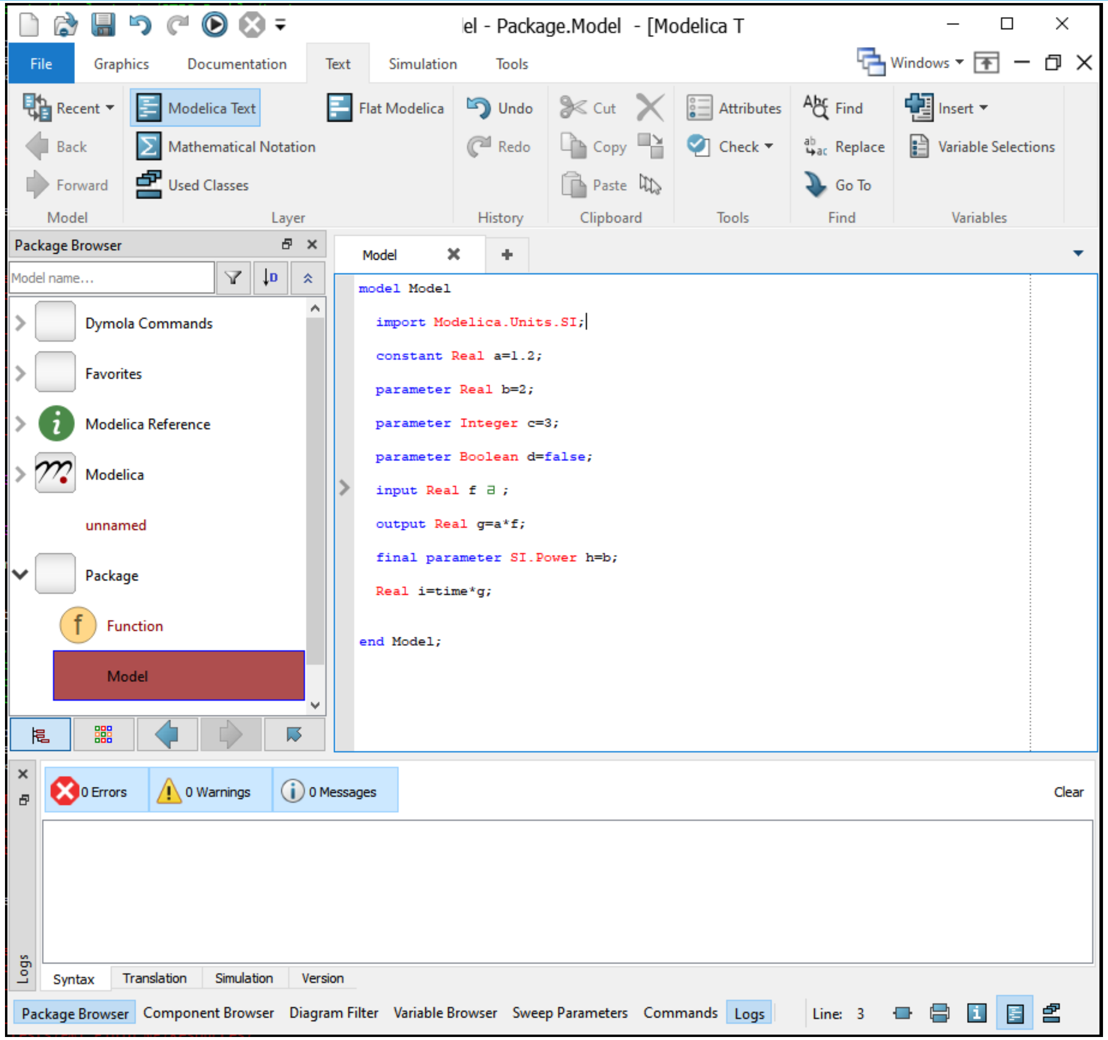
Model Creation: Working in the Text Editor

Click here to change to text editor



Model Creation: Variable Classes and Types

- Classes
  - Constant
  - Parameter
    - Normal and “final”
  - Input
  - Output
  - Unspecified
- Types
  - Real
    - Can define types for units
  - Boolean
  - Integer
- Annotations
  - GUI/translation related



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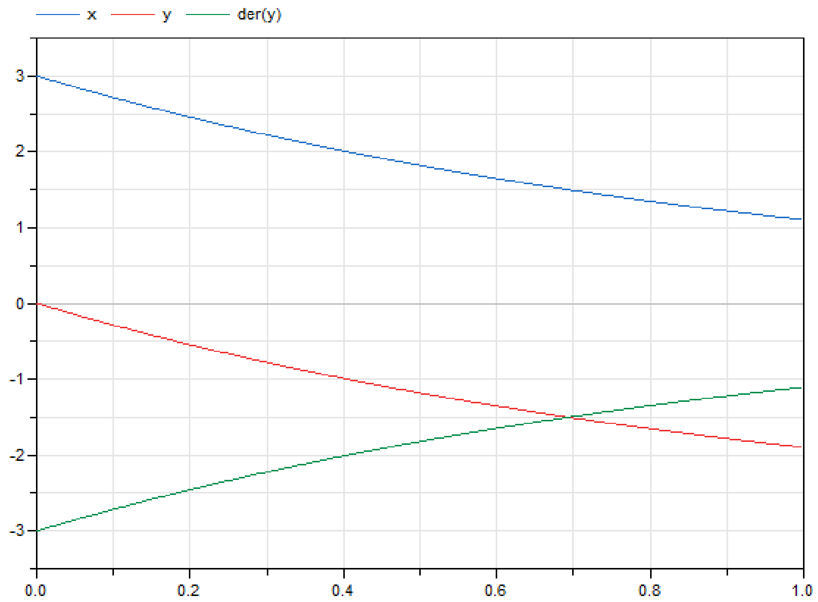
Model Creation: Equation and Algorithm Section

- Equation:
  - Can be used in “model” class
  - Acausal (engineering type equation)
  - Allows translator/solver freedom to manipulate equations
  - Workhorse section for Modelica… default use this over algorithm/functions
- Algorithm
  - Can be used in “model” and “function” classes
  - Causal
  - Limits on what the translator can do with equations
  - Can increase solution time/reduce model robustness

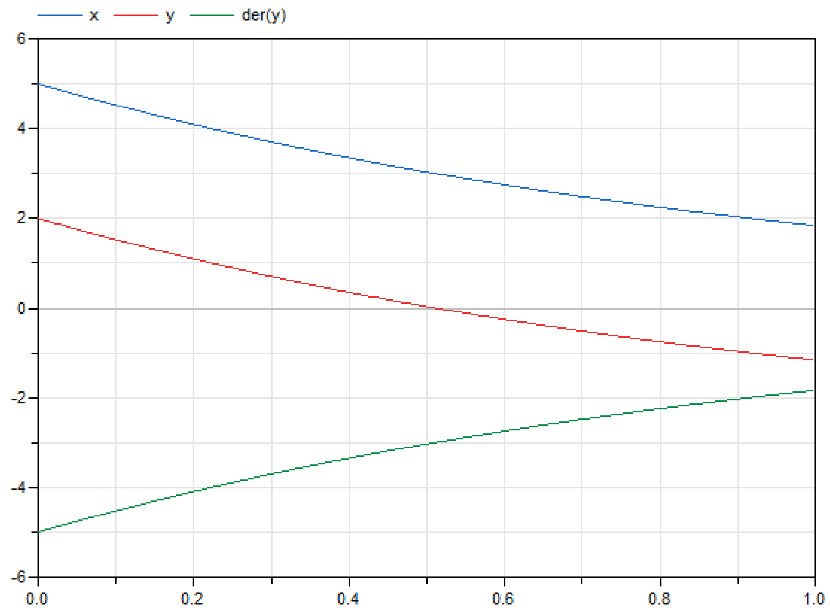
```
model Demo

  Real x;
  Real y;

algorithm
  x := y+3;

equation

  der(y) = -x;

end Demo;
```



Model Creation: der(), start, and initial equation

- der()
  - Built-in operator for specifying the derivative of the variable
  - “time” is the built-in/associated variable
- start
  - Allows the user to define the initial value
  - Can have a soft (guess) or fixed start value
- initial equation
  - Each variable with a derivative should have a start value
  - Default start value is 0 or der() = 0
  - These sections cause “fixed” start values
  - Can have der() = 0 be defined

```
model Demo

  Real x(start=2,fixed=false); //false is default
  Real y;

algorithm
  x := y+3;

initial equation
  y = 2;

equation

  der(y) = -x;

end Demo;
```

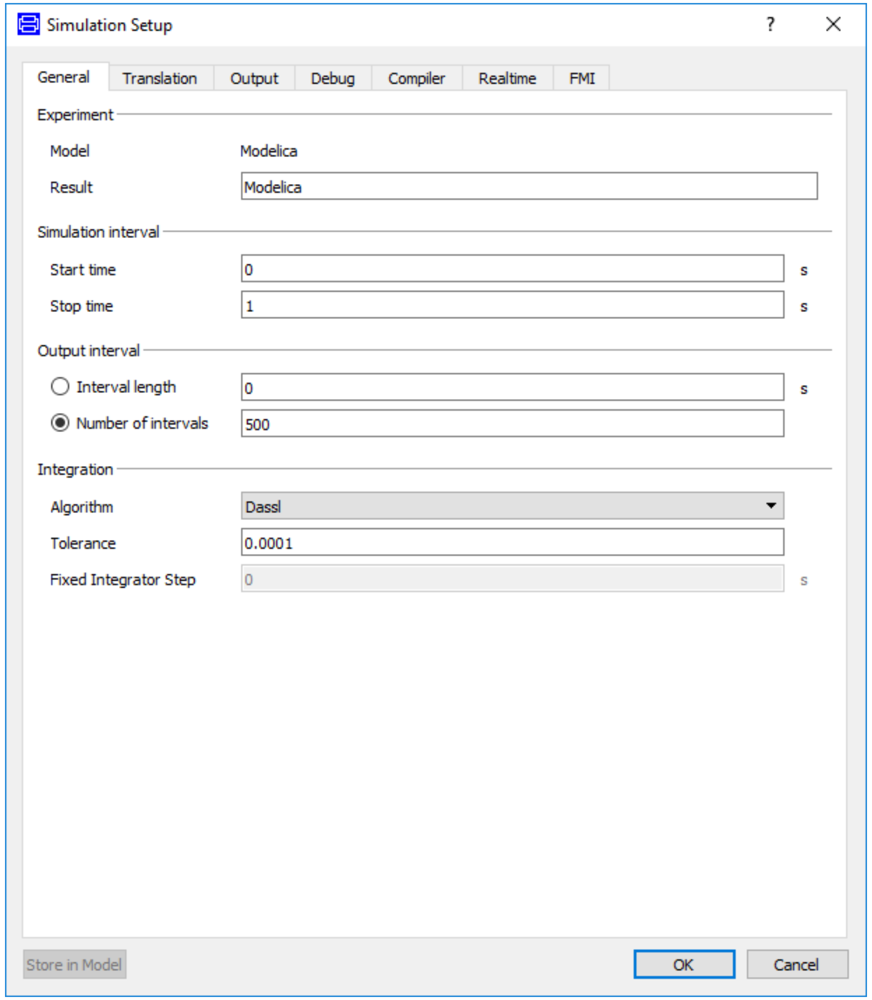


Workflow – Current Working Directory

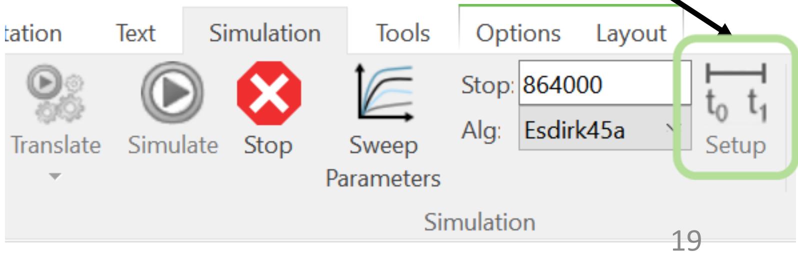
- Current working directory
  - Upon simulation, all files are generated in the current working directory
  - Typically, a dedicated working directory for results (i.e., /Documents/Dymola)
- Open vs. load
  - Open: Changes the current working directory to the location of the file opened
  - Load: Adds the file to the path… keeps the current working directory unchanged

Workflow – Simulation Settings

- Variety of options
  - Start/Stop, intervals, solver, global tolerance
  - Translation/debug flags
  - Change compiler
  - Realtime and model export (FMI) options



Click here to control simulation settings



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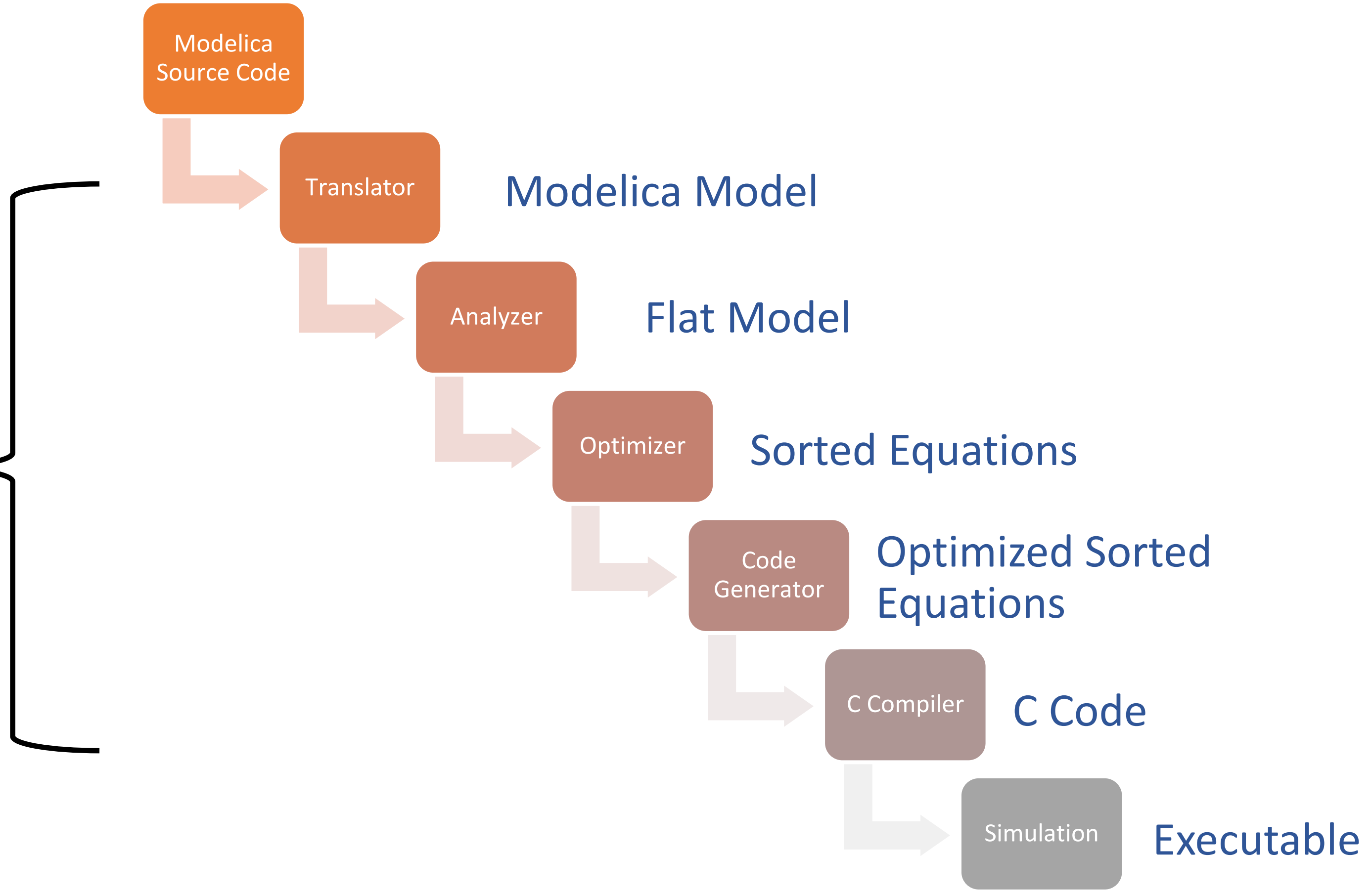
Workflow – What Happens When You Push “Simulate”?

Much of this is the focus of the IDE



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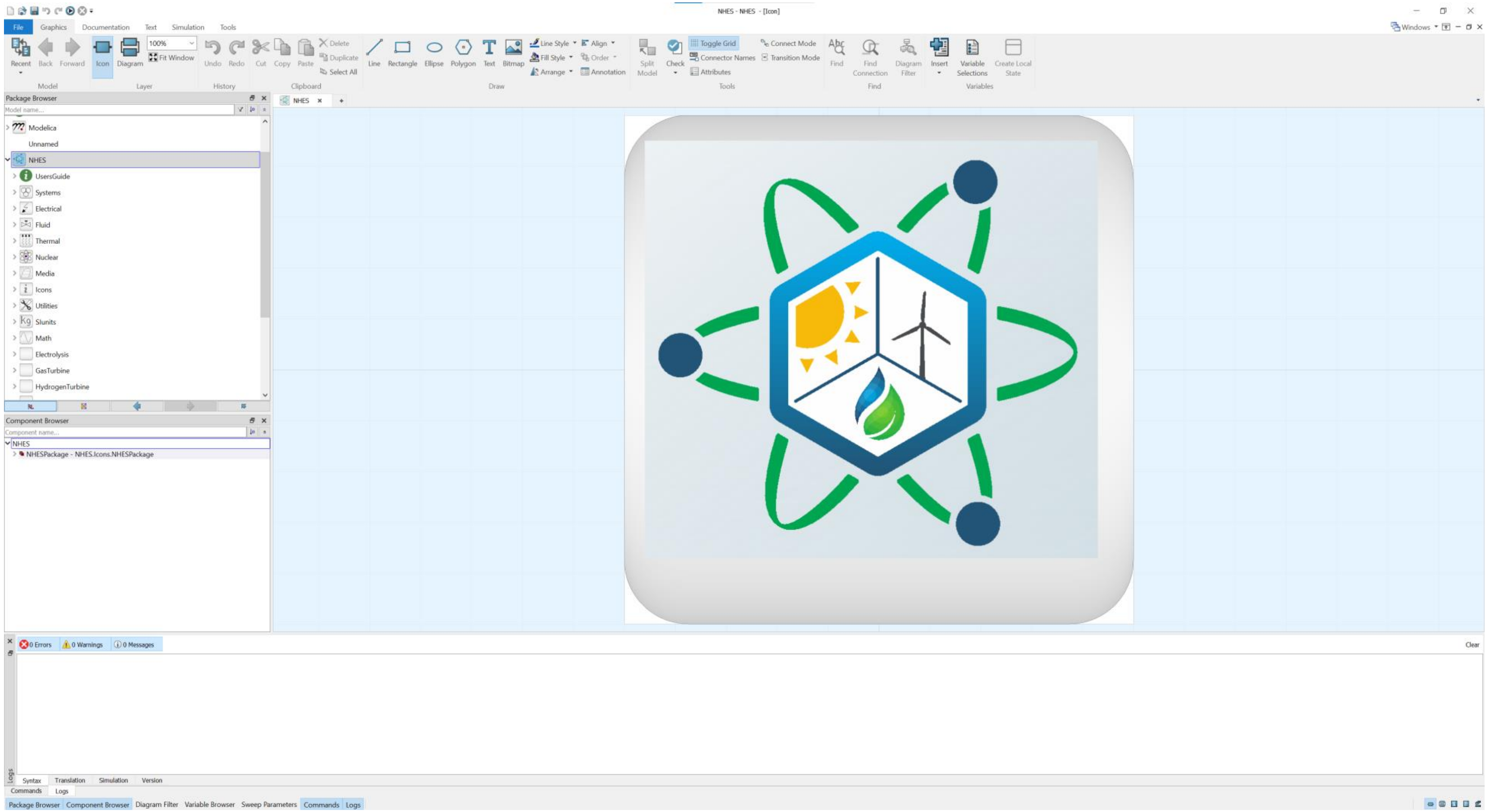
Hybrid Repository



Hybrid – What Is It?

- Hybrid is a collection of dynamic physical models written in the Modelica language to characterize:
  - Ramp speed
  - Thermal and electrical integration of different processes
  - Creation of novel control schemes
  - Off-design system dynamics
  - Safety limitations based on control systems

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

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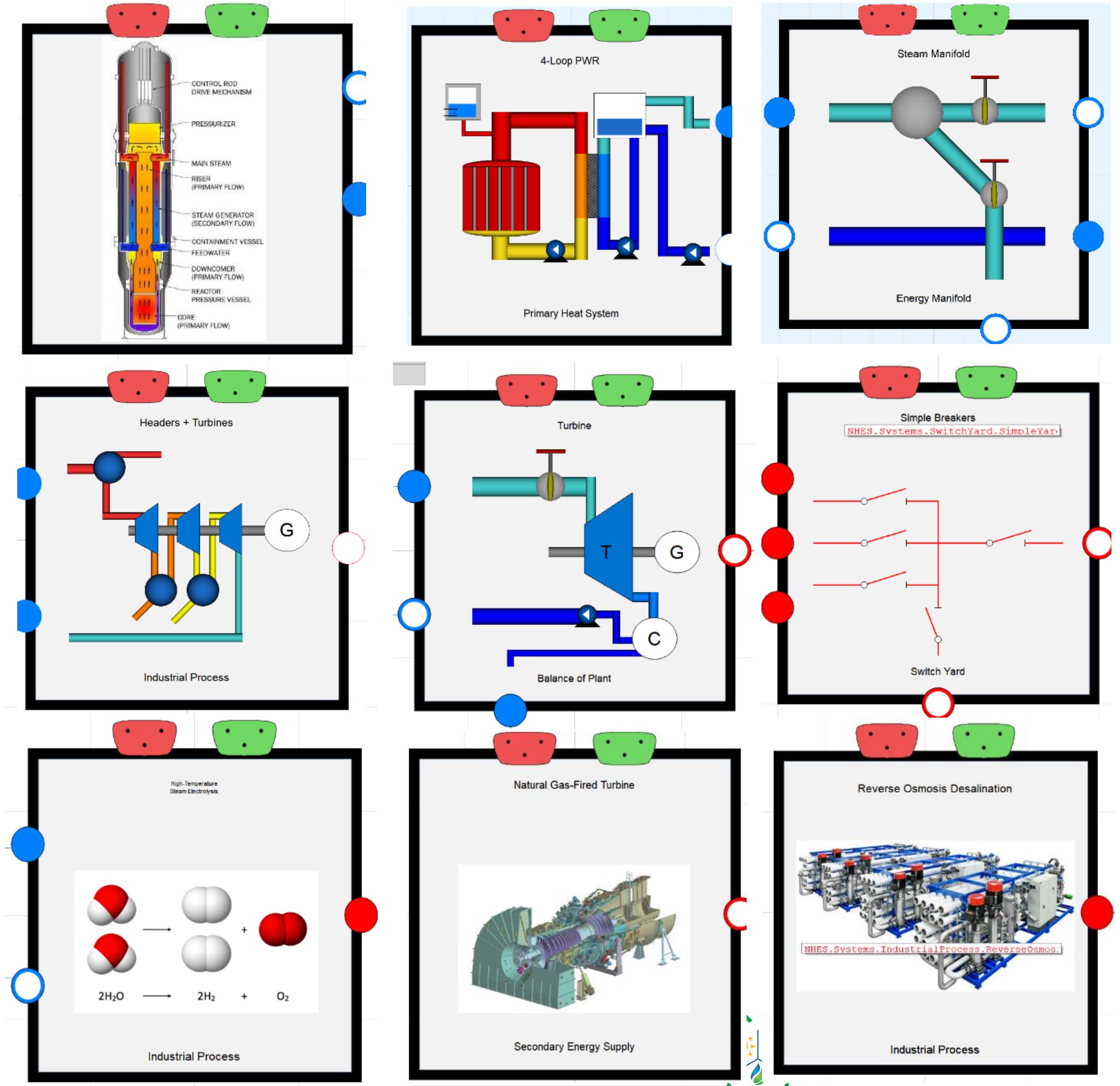
Hybrid – What Is It?

- Hybrid evaluates the feasibility of systems developed within FORCE and provides constraint data necessary for broader system evaluations
  - An ideal intermediary for determining:
    - Integration design
    - Control methods
    - Ramp rate feasibility
    - Determination of off-design behaviors



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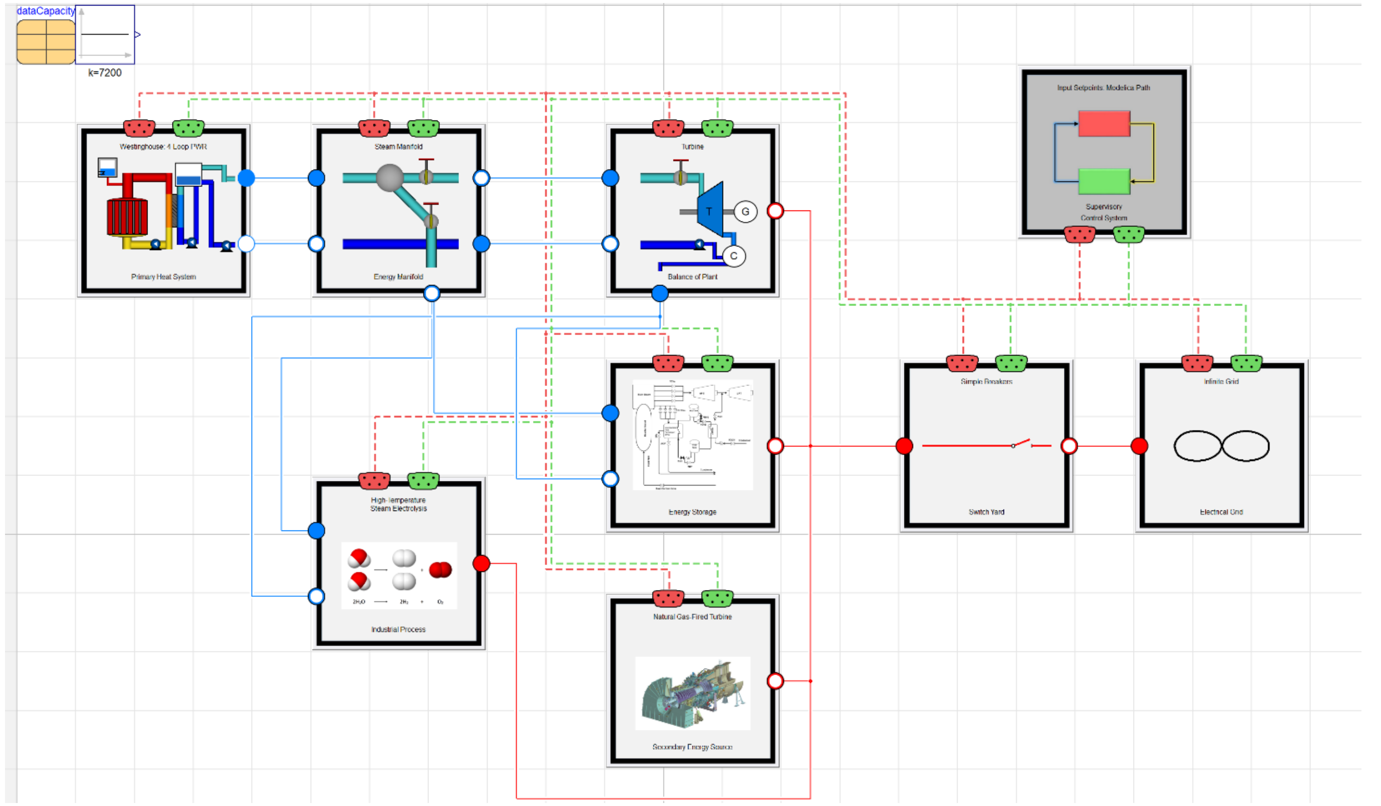
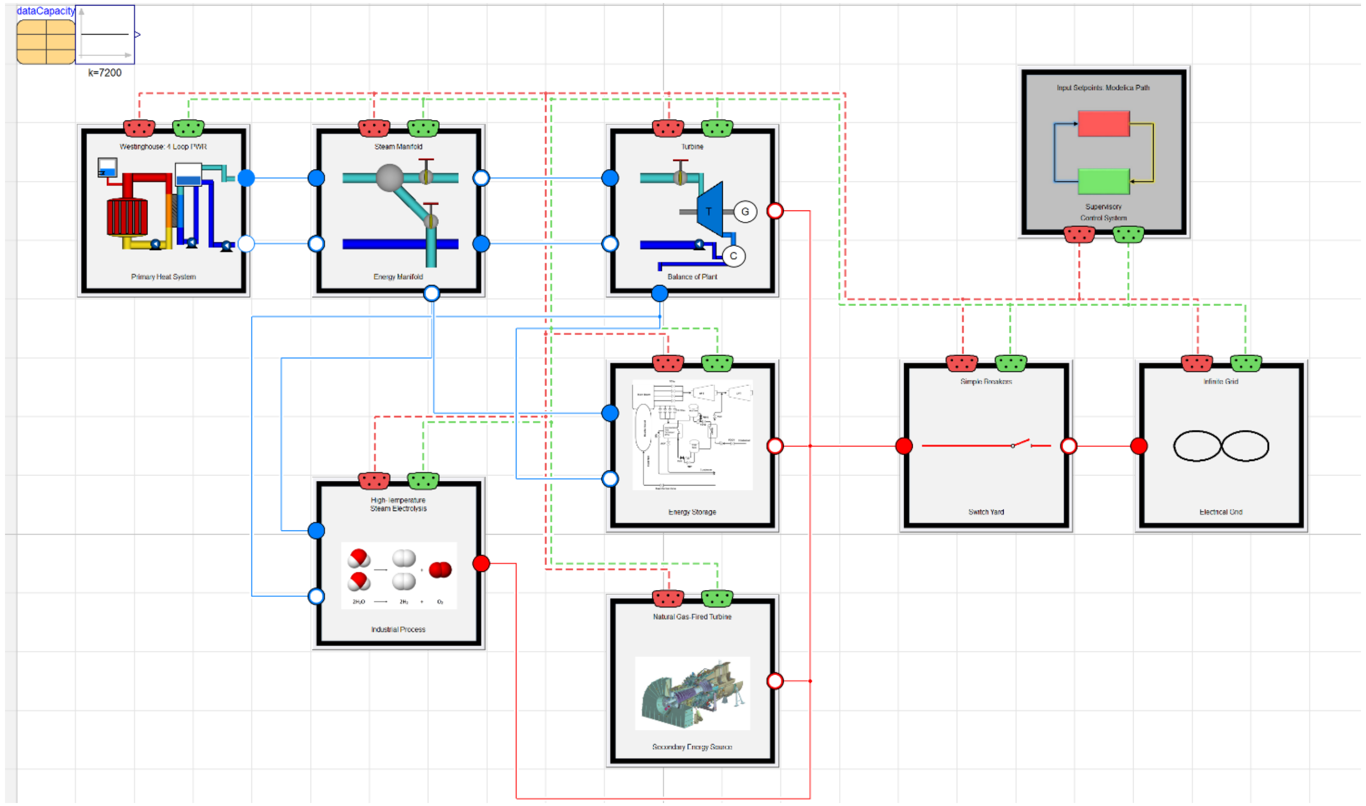
Design Capability

- Physical models are focused on process system bases
  - A few coupled subsystems (nuclear plant + gas turbine + thermal storage + grid + ancillary process)
  - Focus within Hybrid has been single energy park systems



Design Capability

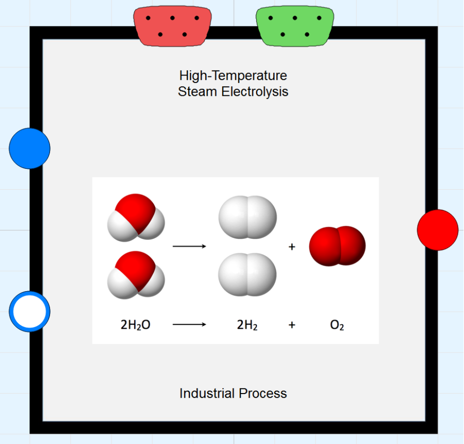
- Figures of merit
    - Demand missed
    - System stability
        - System pressure, temperature, thermal gradients, valve positioning, etc.
    - Control strategy effects on each subsystem.

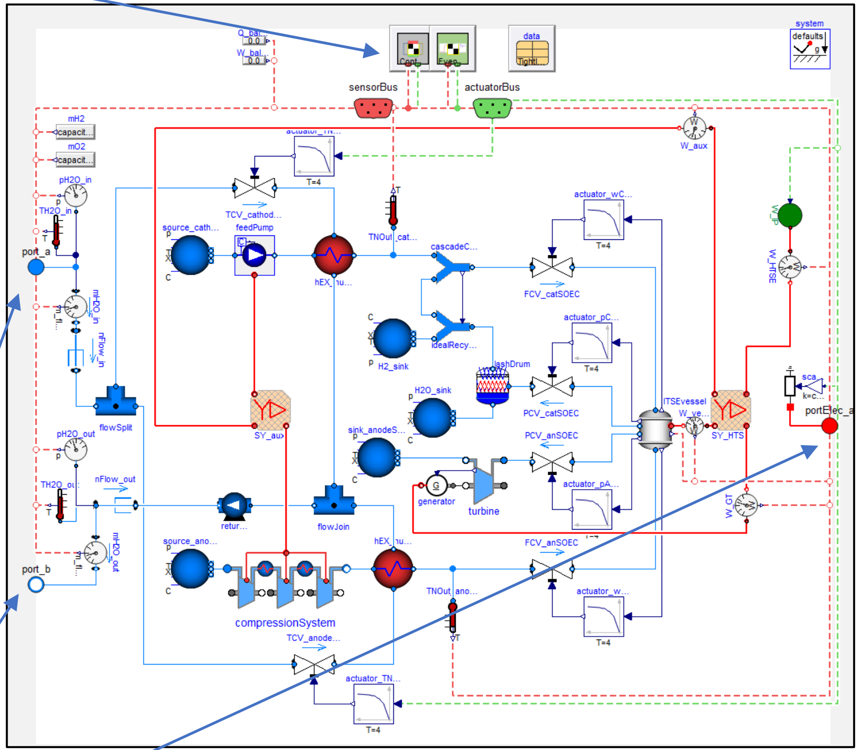


Interconnectability

- Create self-contained process models
- These models calculate on- and off-design behavior
- Coupling occurs with other Modelica models or process models built via FMI/FMU

Interchangeable Control System





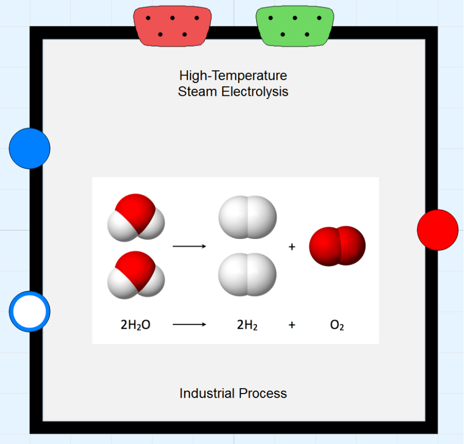
Connection points

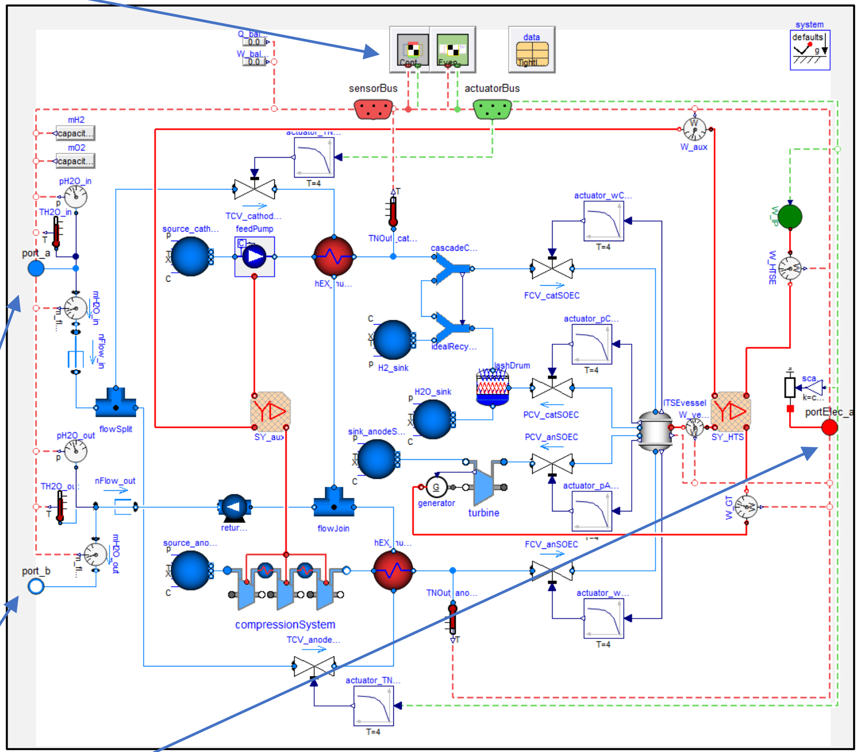
Interconnectability

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

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

Interchangeable Control System

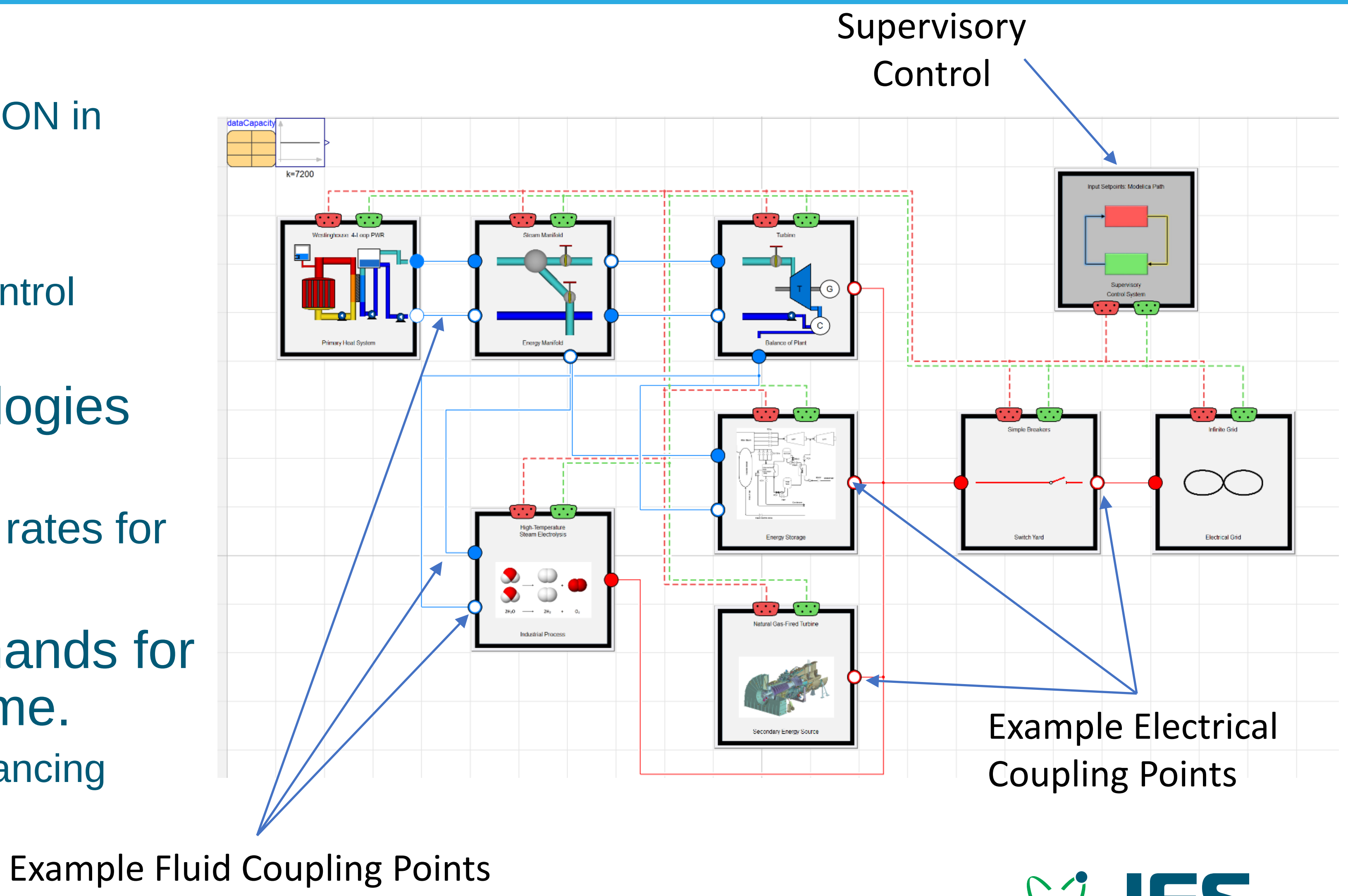




Connection points

Where FORCE Interacts?

- Inputs are system sizing
  - Values taken from RAVEN/HERON in optimization workflow
- Control strategies desired
  - Each subsystem has its own control strategy
- Planned coupling methodologies
  - Supervisory control
  - Minimum electrical and heat rates for each subsystem
- Thermal and electrical demands for each subsystem through time.
  - Total demand an input from balancing authority routine

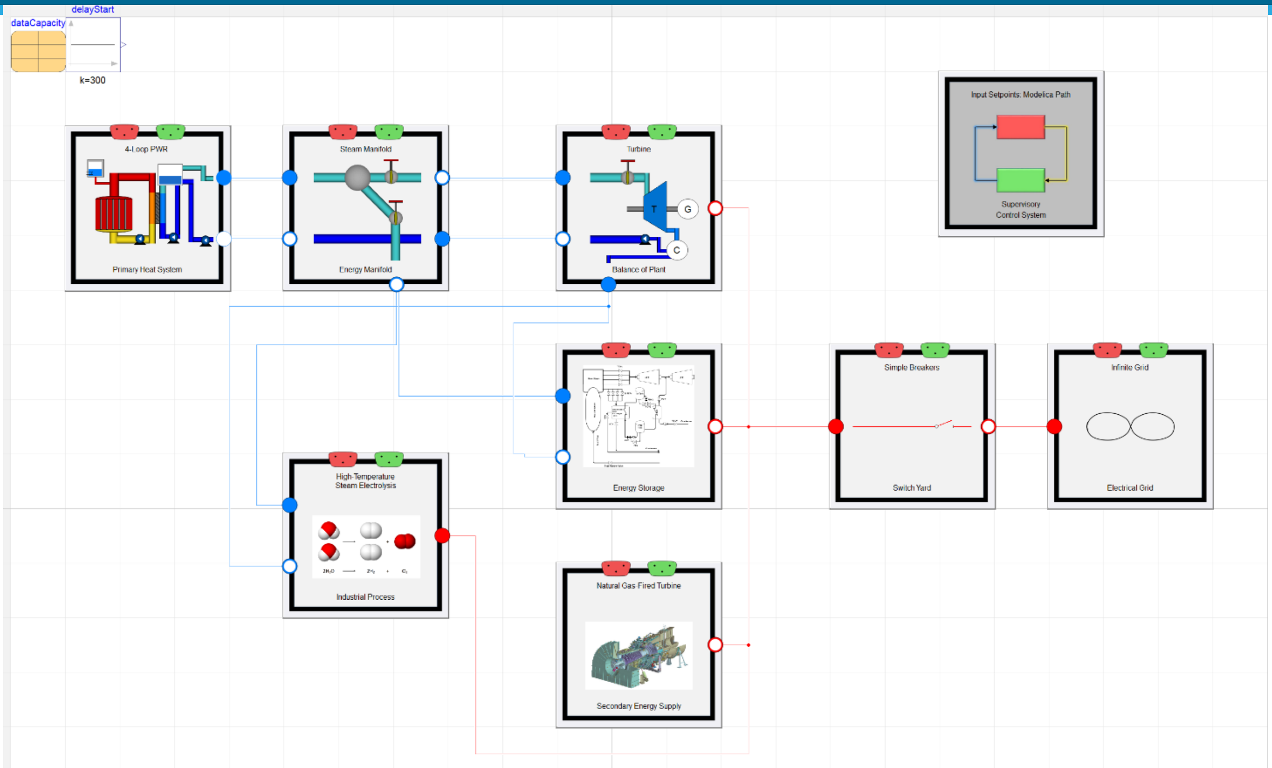


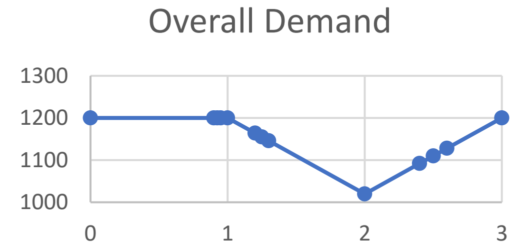
Example – Multi-Component Integrated Energy System

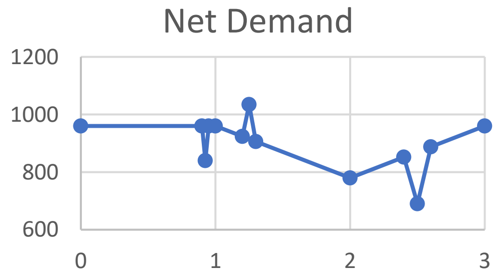
- Multi-component Integrated Energy System.
- Power Source = Pressurized Water Reactor
- Ancillary Process = Hydrogen Production
- Energy Storage = Thermal Energy Storage
- Secondary Energy Source = Natural Gas Fired Turbine

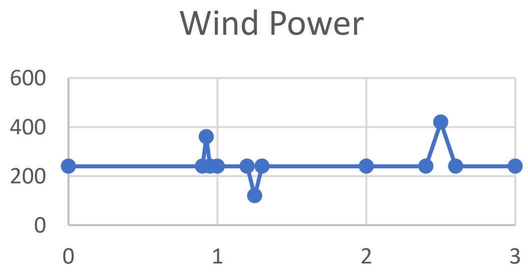
Case

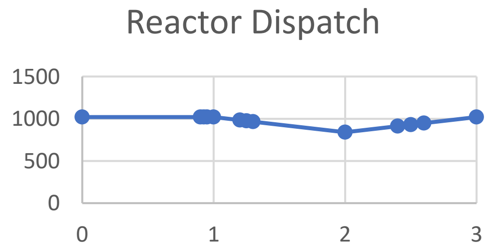
- Consider we are operating in a Microgrid with Wind Power.
- Total Microgrid Power Needs = 1200MWe

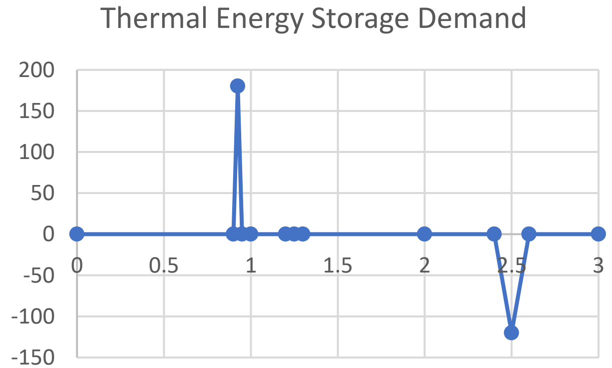


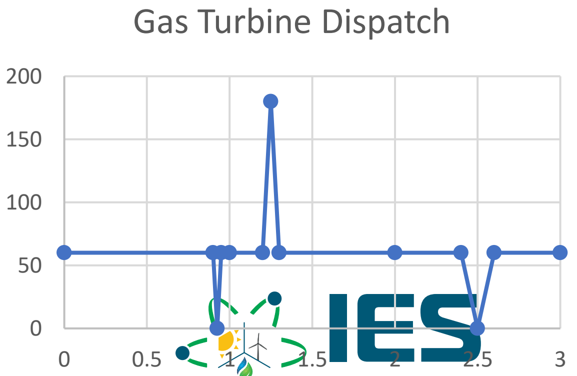




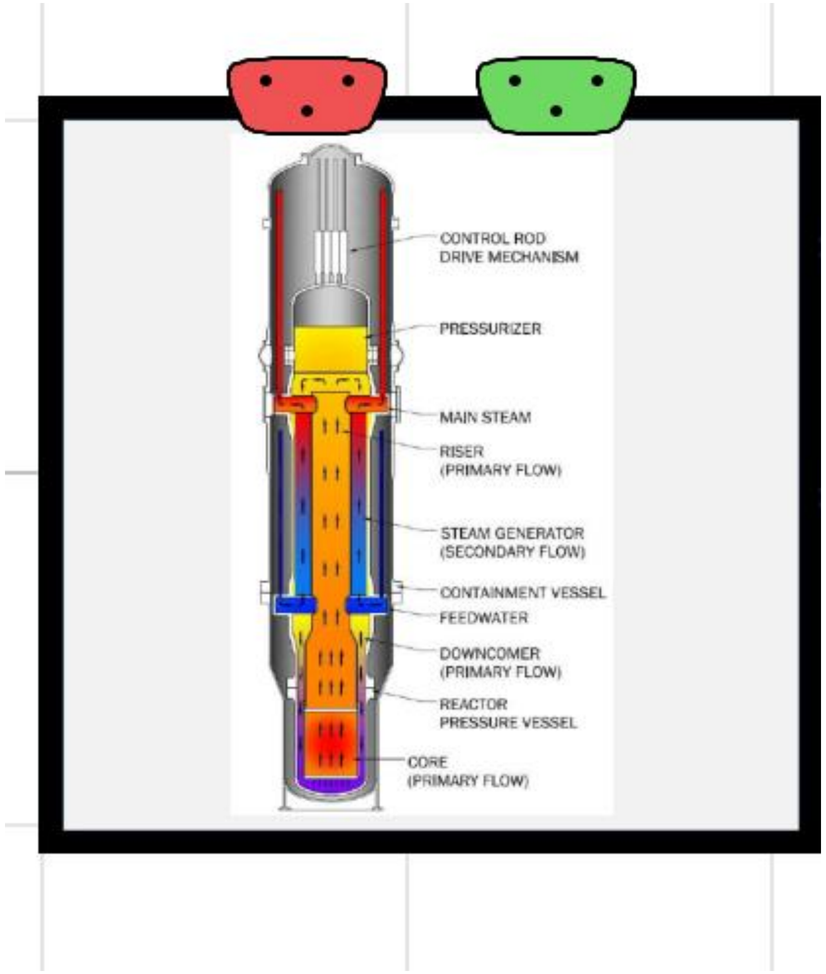


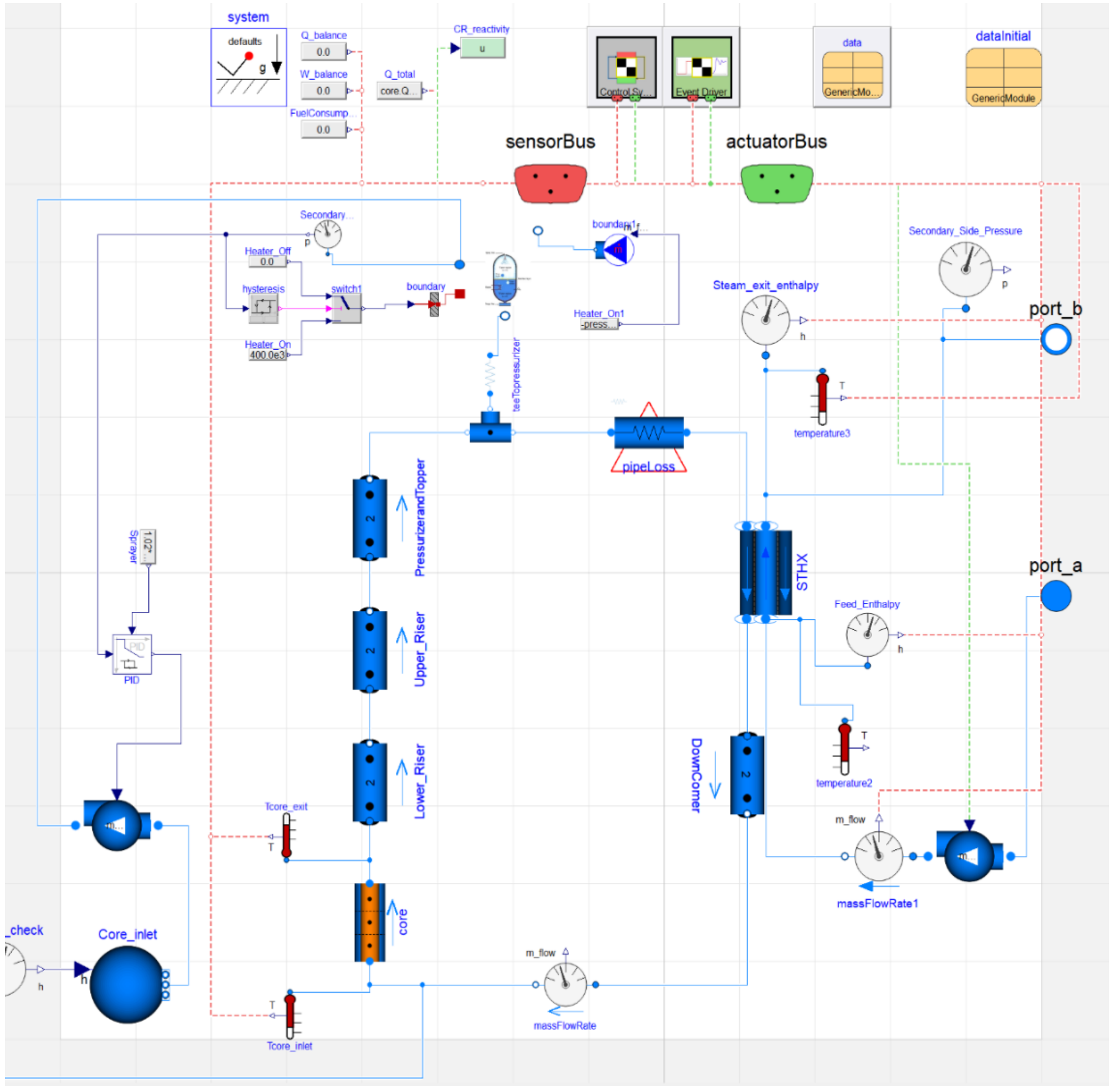






Transient NuScale-style Model





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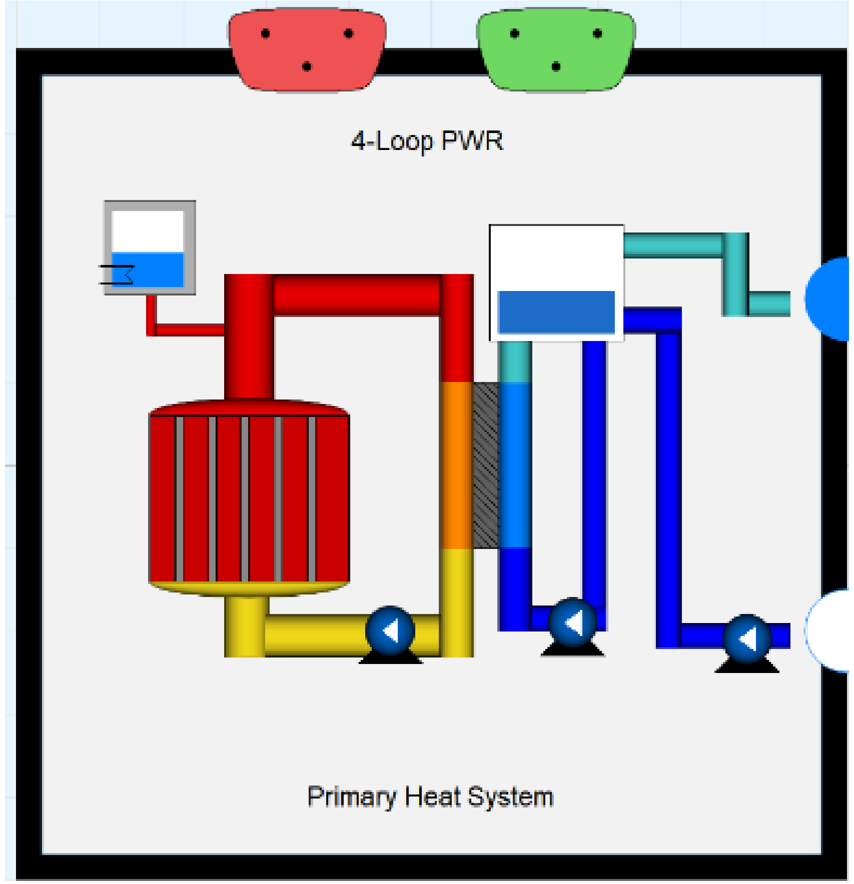
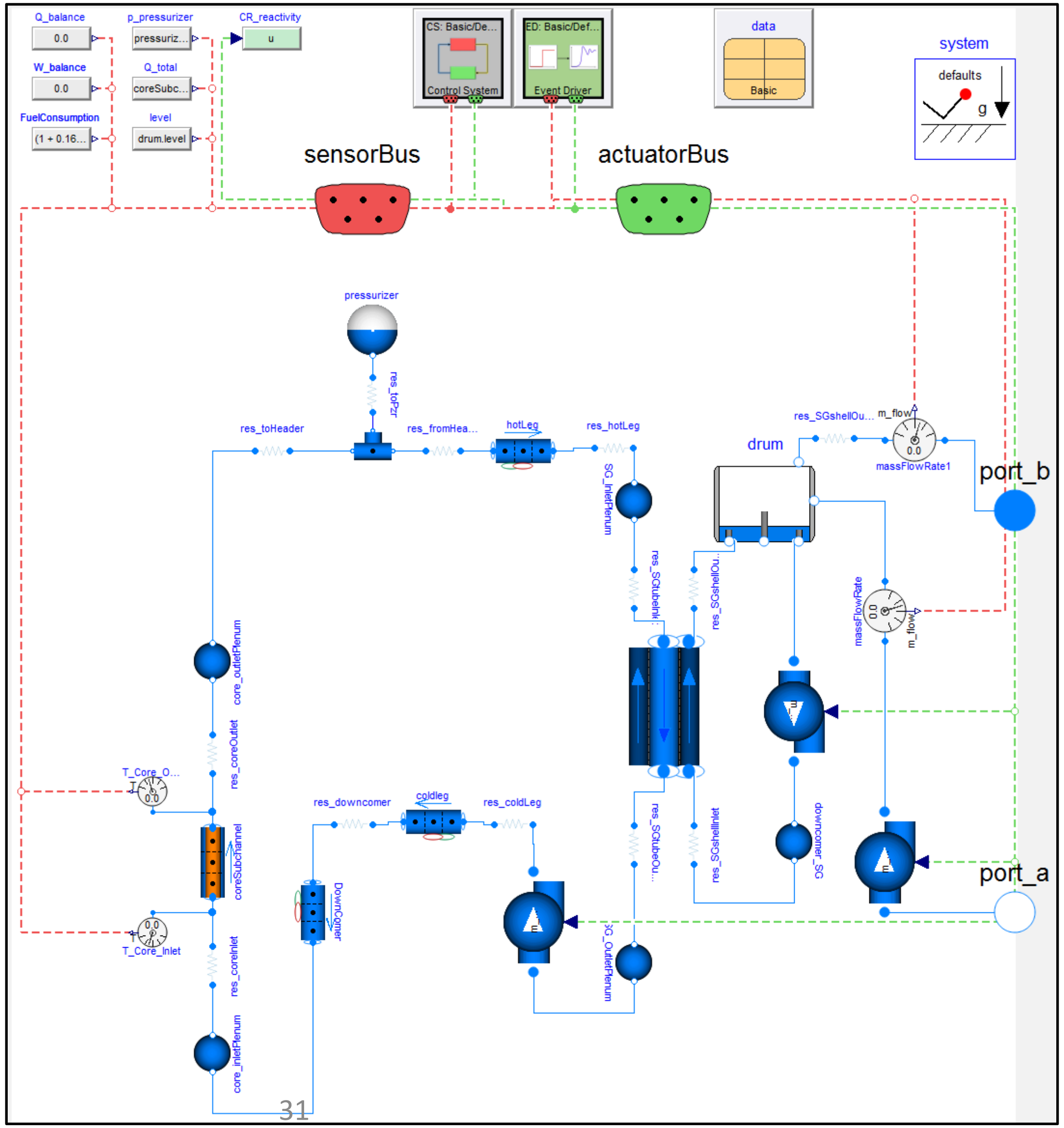
PHS– Westinghouse (WH) Style: 4-Loop (PWR)





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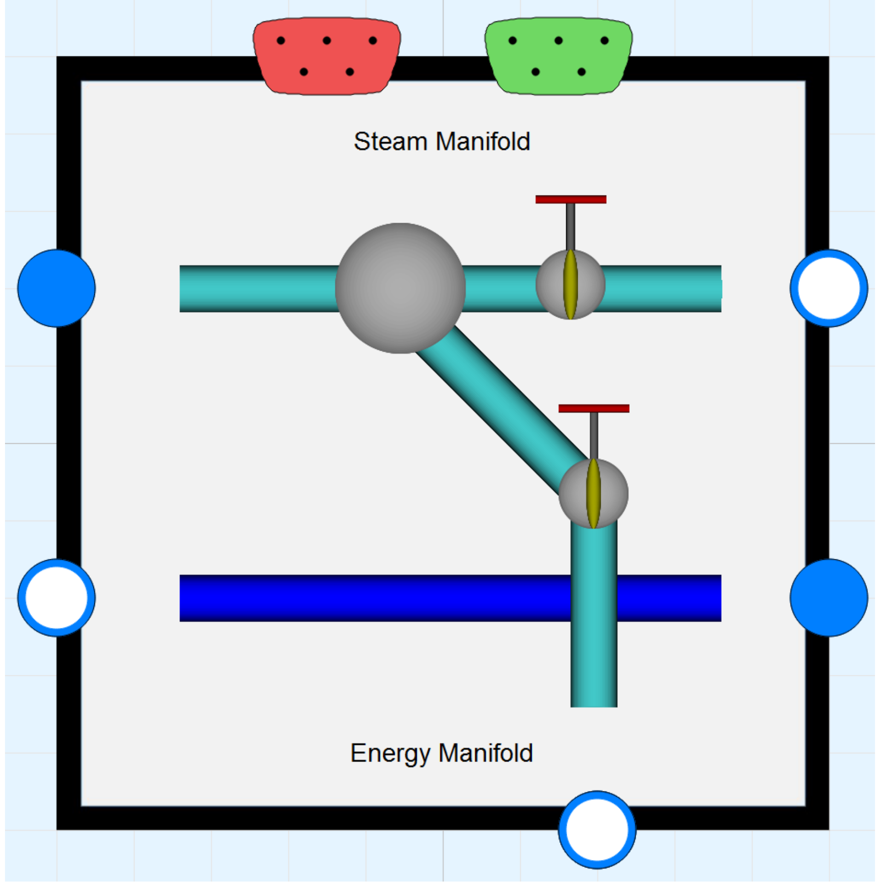
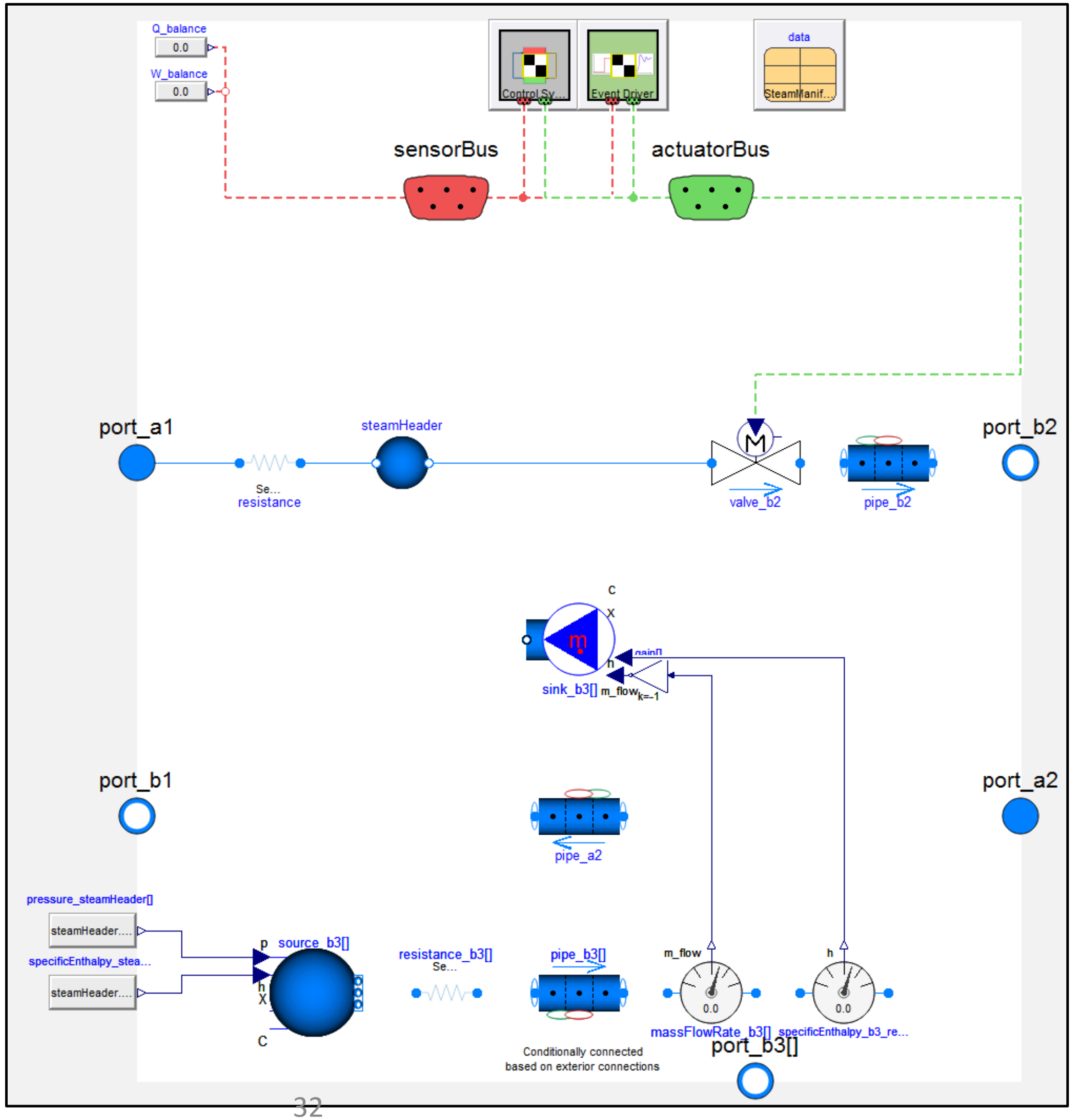
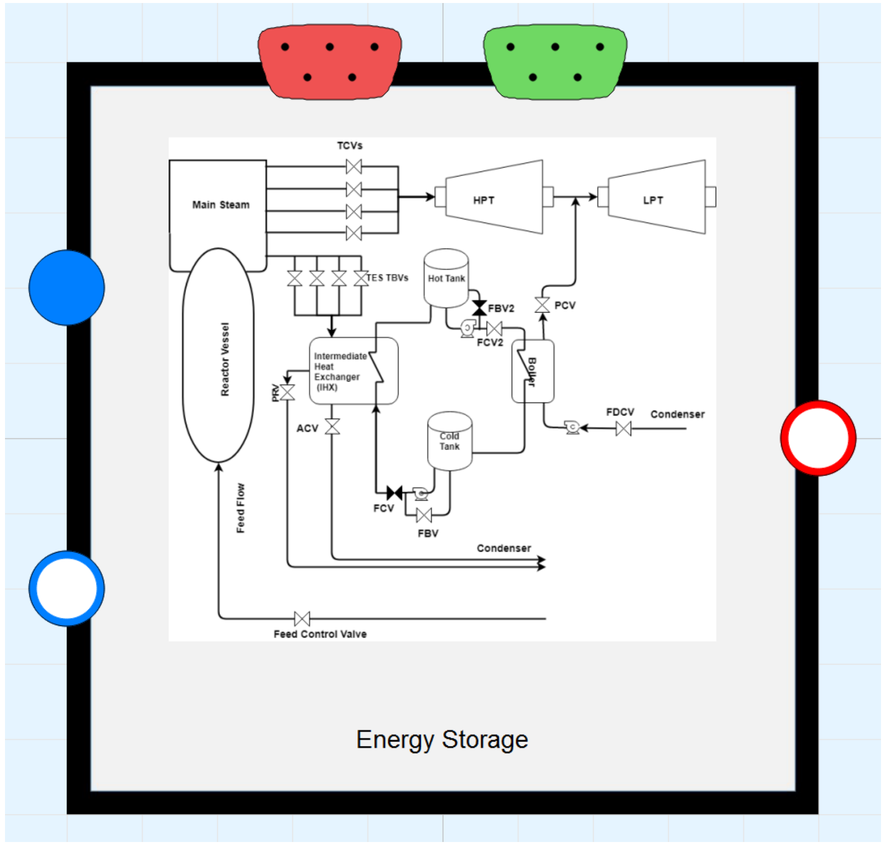
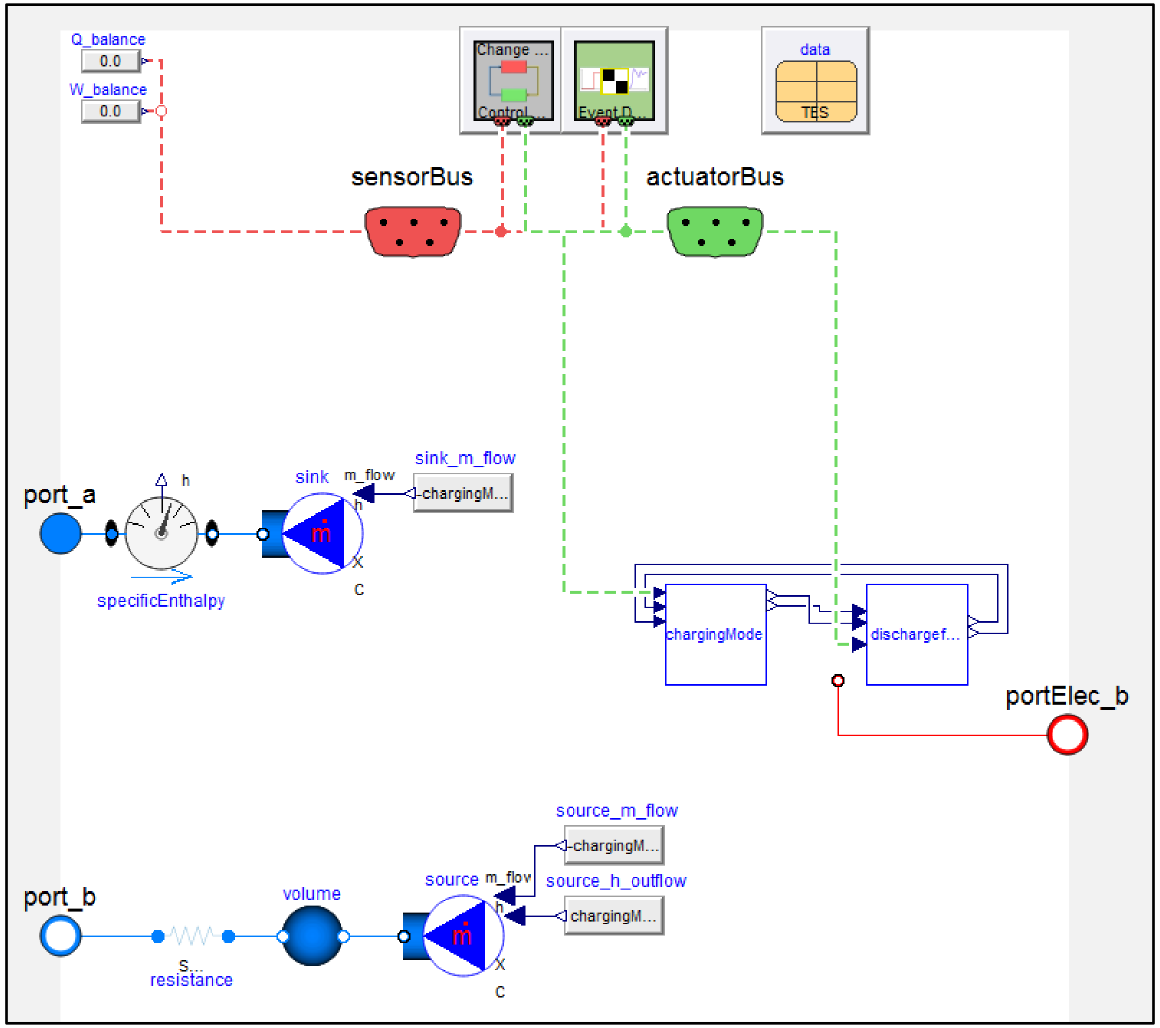
Energy Manifold





ES – Sensible Thermal Energy Storage (TES)





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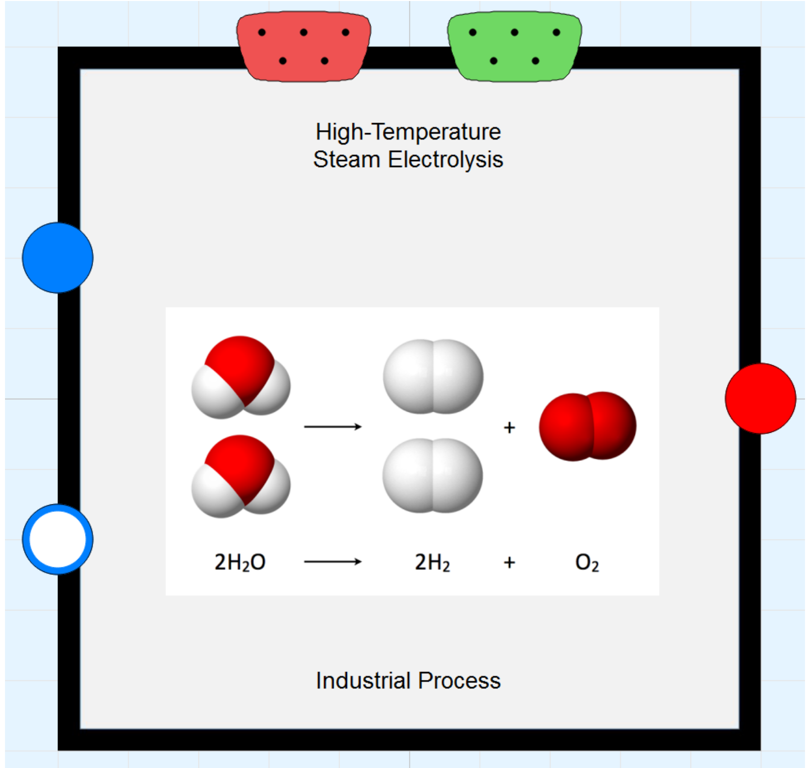
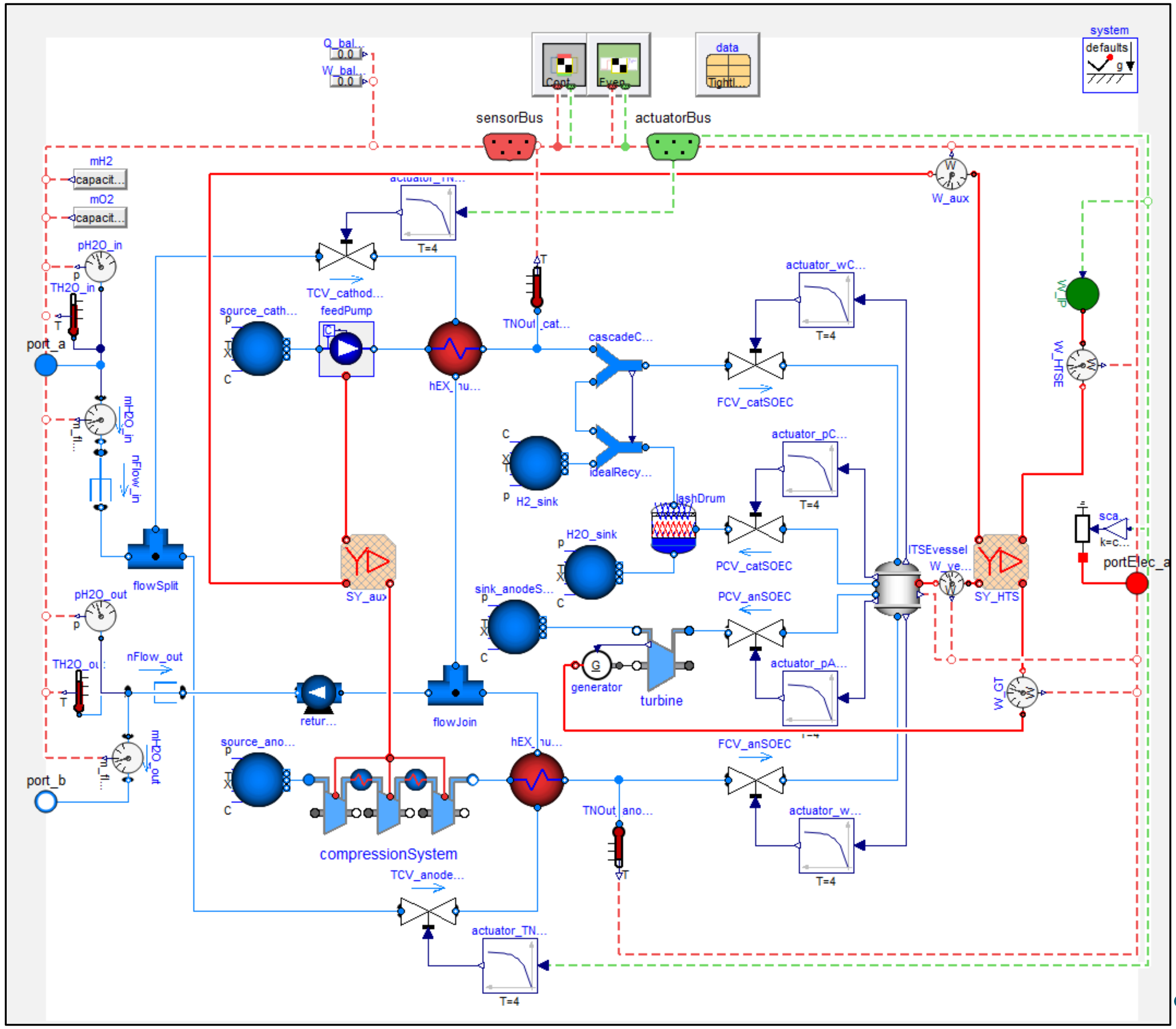
High-Temperature Steam Electrolysis (HTSE)





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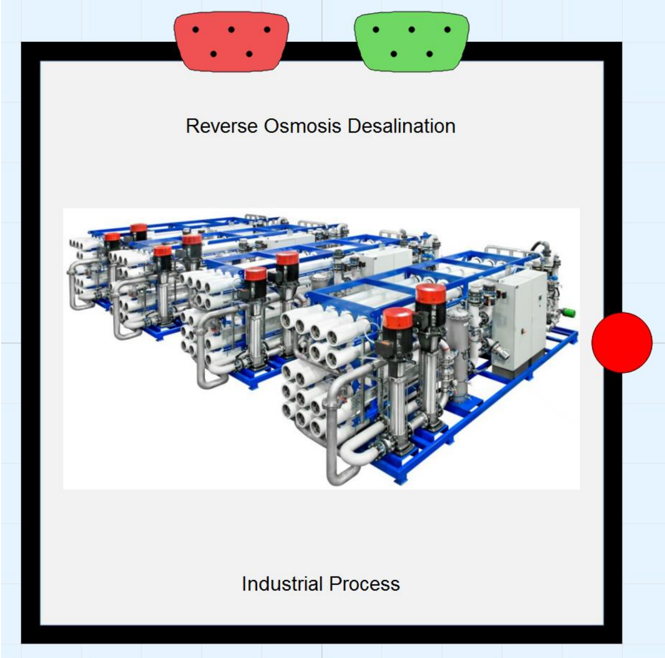
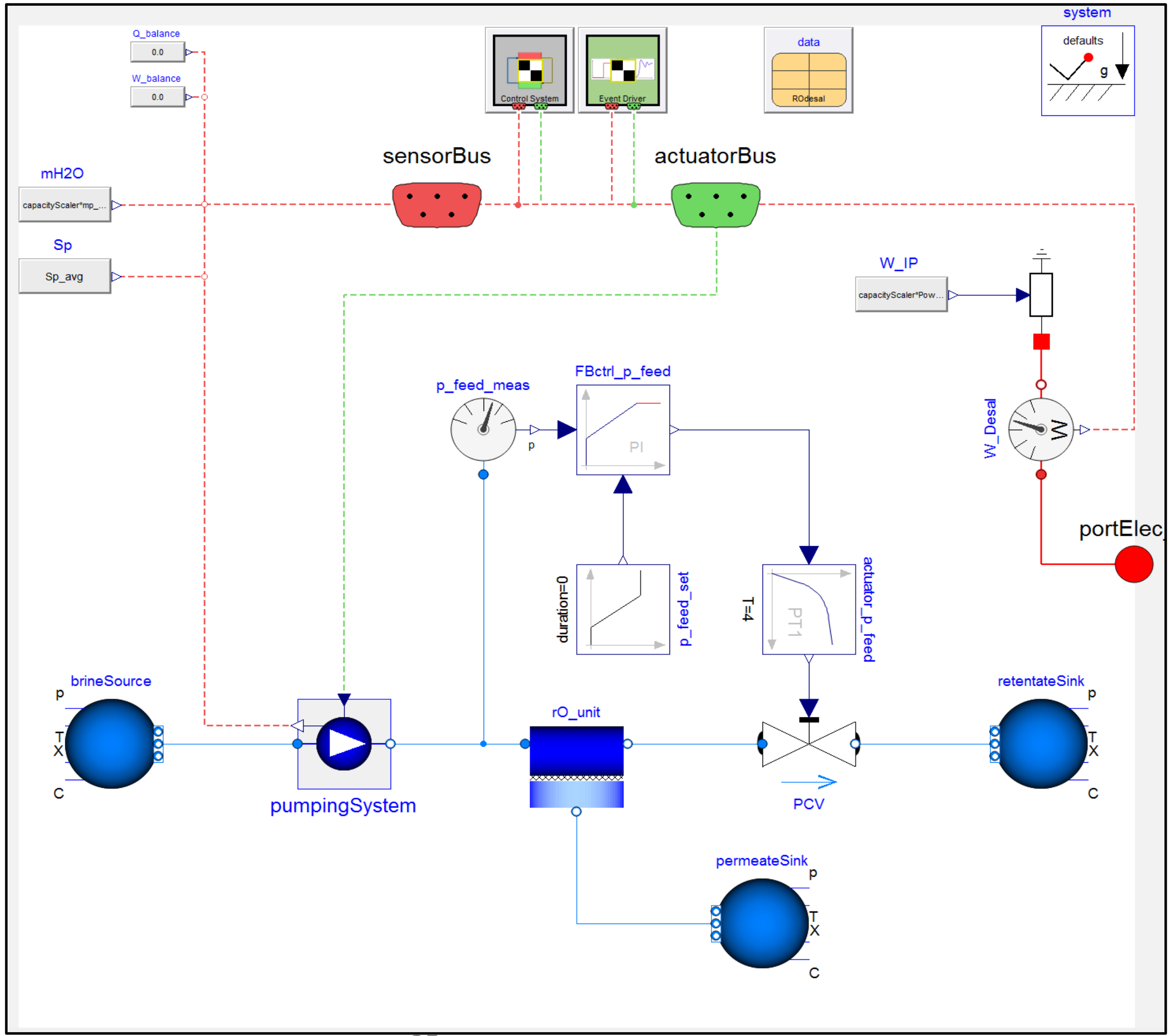
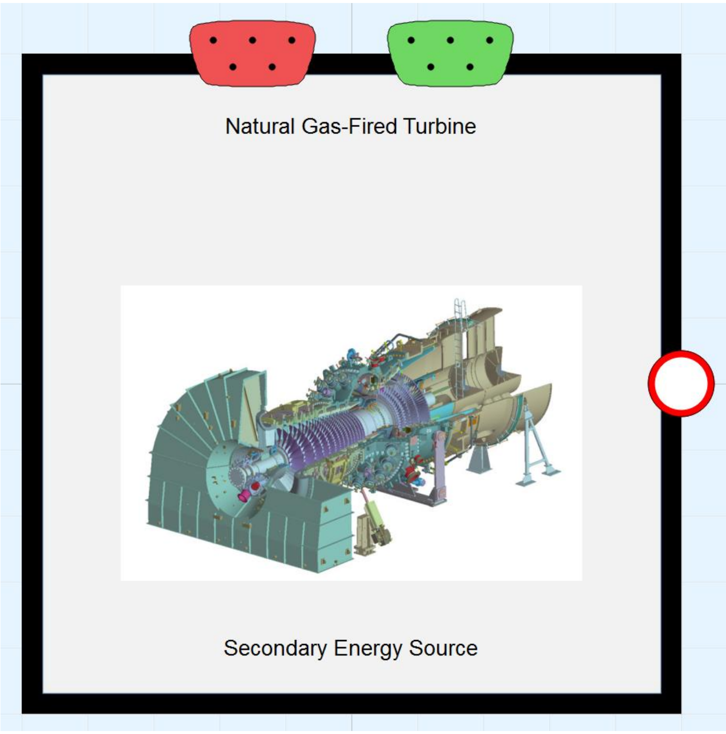
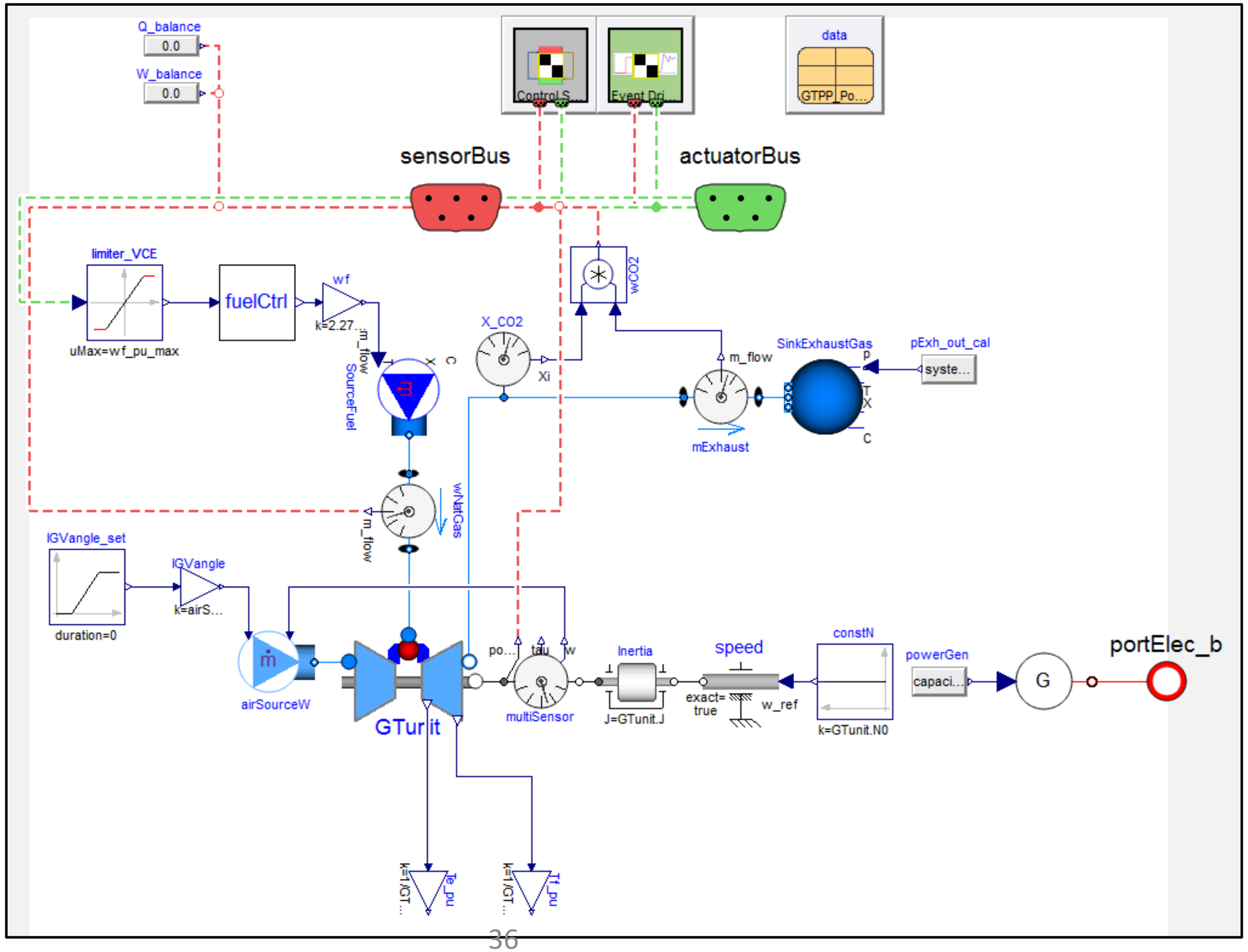
Reverse Osmosis (RO) Desalination





Natural Gas Fired Turbine





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 ROOK
- Recent additions
  - Packed-bed thermocline energy storage
  - Concrete energy storage
  - Phase change material energy storage
  - High-fidelity balance of plant
  - High temperature gas reactor
  - Brayton power cycle

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 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 energy manifold/secondary energy supply and electricity from switch yard	Steam electrolysis, gas to liquids, or reverse osmosis desalination
5	Energy storage (ES)	Serves as 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 IES	Large grid behavior (not influenced by IES)
9	Control system center (CS)	Provides proper system control, test scenarios, etc.	Control/supervisory systems and event drivers

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Hybrid Expansion

- Development of concurrent model structures
  - Modelica transient models
  - Aspen HYSYS steady-state models
  - Reduced order models based on Modelica transient modeling
  - Subsystem costing information
- Full FORCE vertical integration
- Continued expansion of modeling capabilities

Questions?

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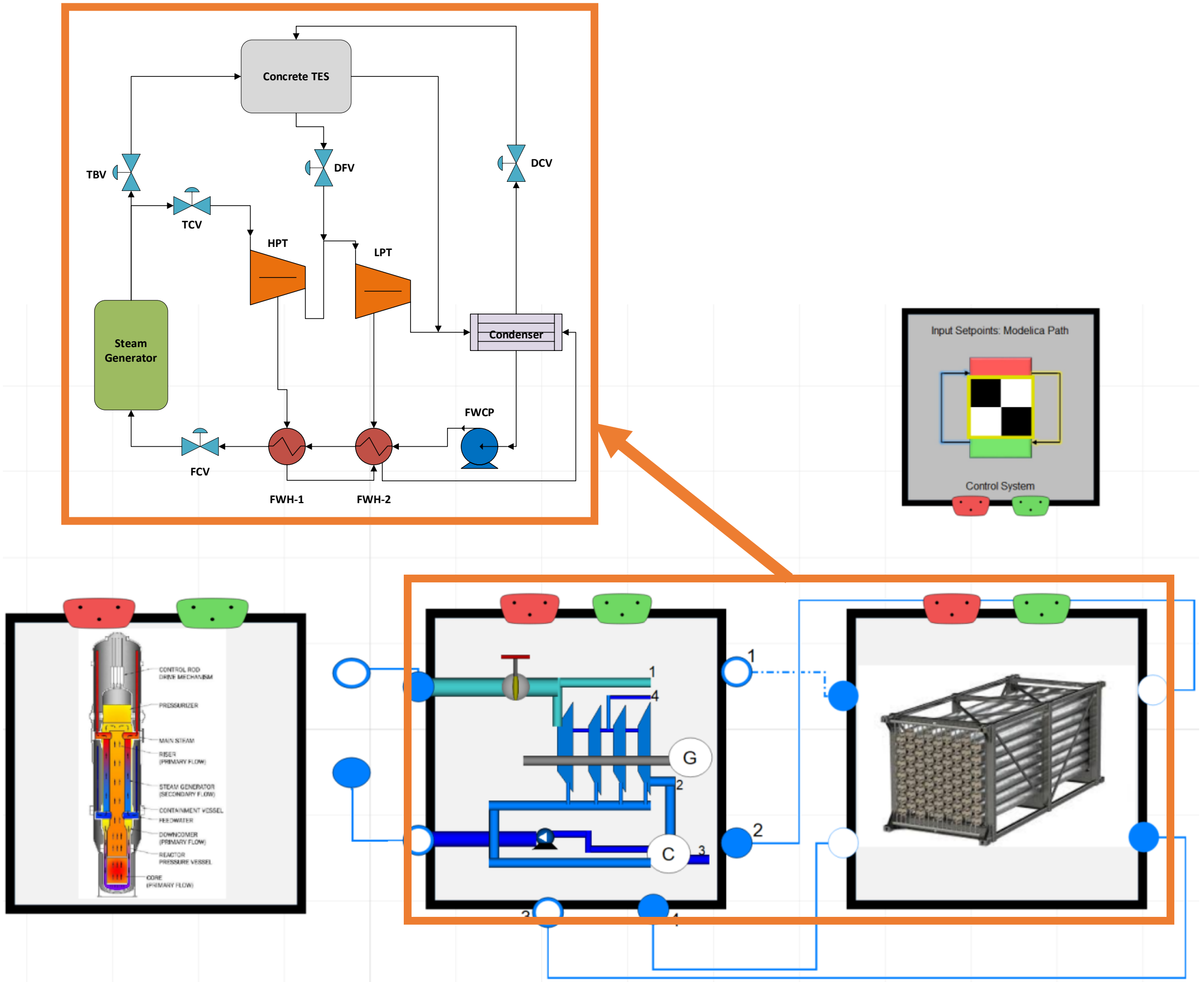
Energy Arbitrage IES

- NuScale-style SMR
- High-fidelity balance of plant
- Integrated-concrete thermal-energy storage system (dual network model)
- Week-long-scaled dispatchable demand profile calculated and input



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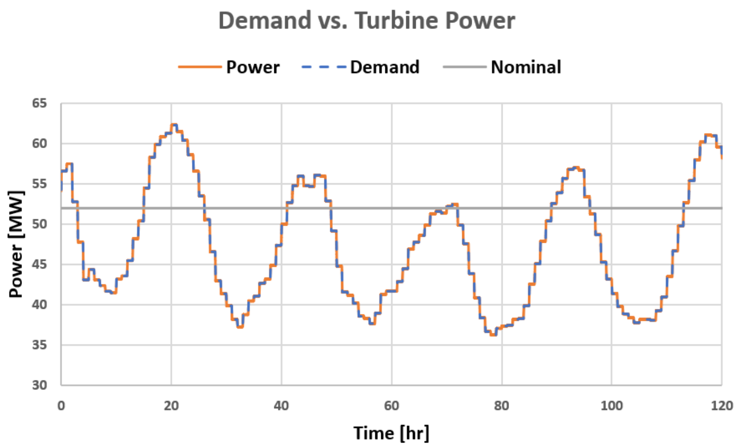

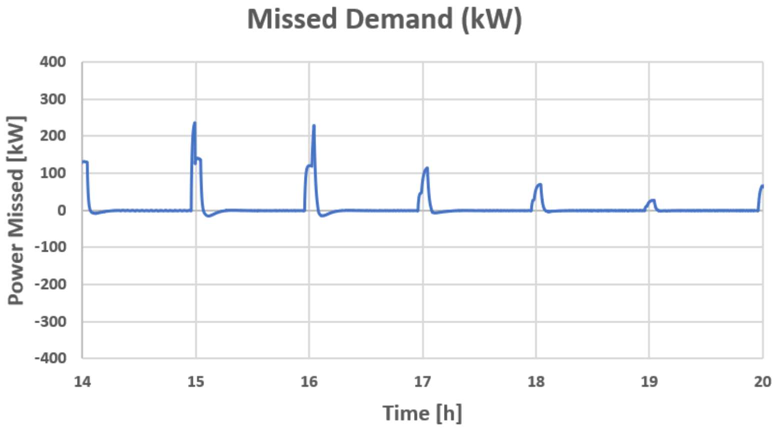

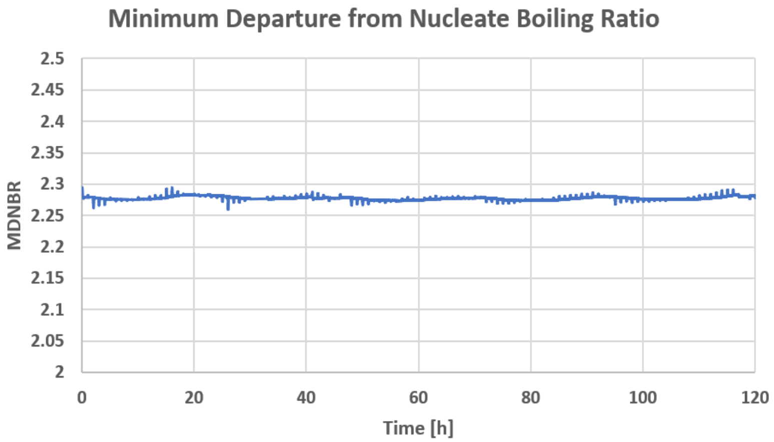

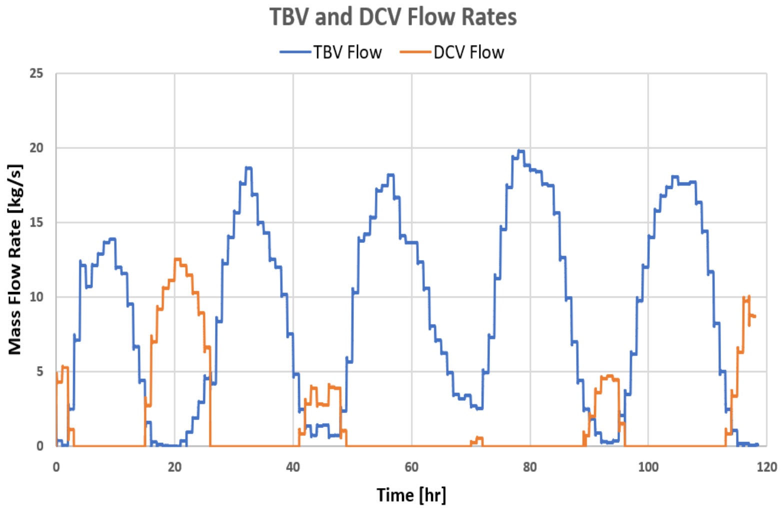

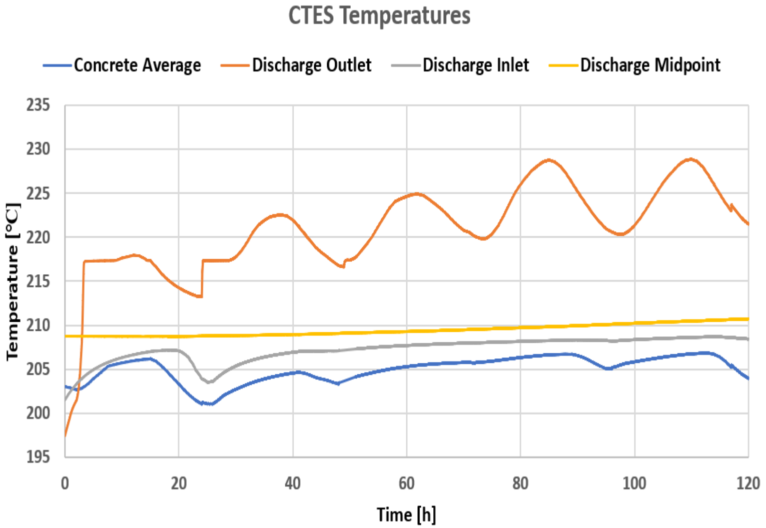

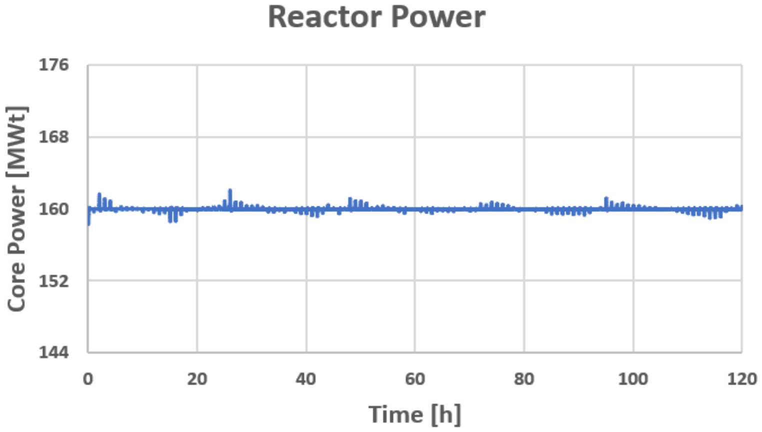

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Available Literature on Models

- 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.
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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.
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