INL/MIS-23-71698

IES
Integrated Energy Systems

FORCE – Transient Physical Modeling Workshop

HYBRID Overview

April 4, 2023

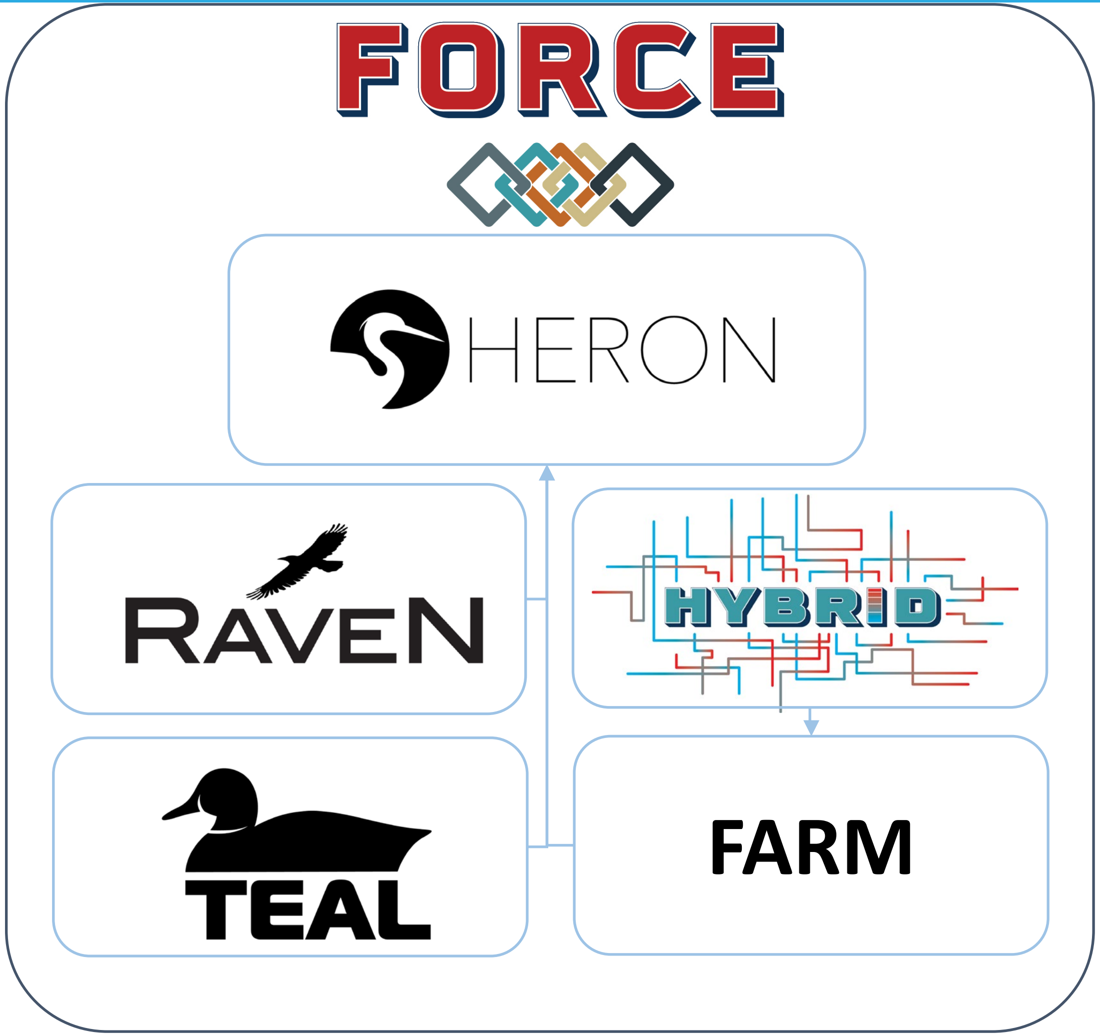
Presented by:
Dr. Daniel Mikkelson

Session Agenda

1. HYBRID and FORCE (15 min)
   a) How HYBRID fits
   b) What is HYBRID
   c) What is in HYBRID
2. Features of Modelica (15 min)
   a) Inherent advantages
   b) Replaceable modeling
3. How Models are Constructed (30 min)
   a) Model integration
   b) Parameterizing and information passing
   c) Initialization and RAVEN interface

How HYBRID Fits Within FORCE

- INL tools enable IES modeling analysis
  - *Physical process, integration modeling*
  - Long-term technoeconomic analysis
  - Capacity, dispatch optimization
  - *Stochastic analysis, multiple commodities*
  - *Energy storage, varied markets*
  - *Real-time optimization*



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HYBRID – What Is It?

- The HYBRID repository is a collection of physical models written to characterize:
  - Thermal and electrical integration of different processes
  - Ramp speed
  - Evaluation of novel control schemes
  - Off-design system states
  - Dispatch feasibility
  - Safety limit approaches, considering control system effects

  - https://github.com/idaholab/HYBRID

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New HYBRID Structure

Modelica Dynamic Models
Primary Heat Systems
Energy Manifold
Balance of Plant
Industrial Process
Energy Storage
Secondary Energy Source
Primary Heat Switch Yard
Electrical Grid
Control System Center
Experimental Systems

Steady-State	Transient	ROMs	Cost Information
Tech 1	Tech 1	Tech 1	Tech 1
Tech 2	Tech 2	Tech 2	Tech 2
Tech 3	Tech 3	Tech 3	Tech 3
Tech 4	Tech 4	Tech 4	Tech 4
…	…	…	…
Aspen, Mathcad, Excel, etc.	*non-Modelica or "Save-total" Modelica*	*Trained on other models*	*HERON-readable format*

V&V Matrix (1/4)

Subsystem Name	V&V	Example Type	ROM generated	Steady-state model	Published documents	Reference documents	Nominal Conditions, Notable Limitations
4-loop PWR	Face	Integrated			INL/EXT-19-55395	Systems Summary of a Westinghouse PWR Nuclear Power Plant 1984 "PWR Description", Jacopo Buongiorno	3400 MWt, Steam: 1750 kg/s, 69 bar, 285°C
Small modular IPWR	Data: steady state	Integrated			INL/CON-16-39032	https://aris.iaea.org/PDF/NuScale.pdf doi: 10.1016/j.desal.2014.02.023	160 MWt, Steam: 35 bar, 300°C, 75 kg/s
Small modular natural circulation IPWR	Data: Steady state	Integrated			INL/EXT-19-55520 doi: 10.1080/00295450.2020.1781497 doi: 10.1016/j.apenergy.2022.118800 INL/RPT-22-69214	NuScale Standard Plant Design Certification Application	200 MWt, Steam: 35 bar, 310°C, 84 kg/s
HTGR	Data: Transient	Integrated			doi: 10.2172/1890160 INL/RPT-22-68222 INL/RPT-22-66941 INL/RPT-22-69214	doi: 10.1016/j.nucengdes.2017.11.041	130 MWt, Steam: 140 bar, 540°C, 50 kg/s
SFR	Physics	Individual			INL/RPT-22-68222		BOP under construction

V&V Matrix (2/4)

Subsystem Name	V&V	Example Type	ROM generated	Steady-state model	Published documents	Reference documents	Nominal Conditions, Notable Limitations
Solid Media TES	Face	Integrated			doi: 10.1016/j.est.2022.104387 doi: 10.1016/j.apenergy.2022.118800 INL/EXT-21-61985	doi: 10.1063/1.4984432	Nominally concrete, requires steam
2-tank TES	Face	Integrated			INL/EXT-18-45505 INL/RPT-22-66941 INL/RPT-22-69214		Molten salt
Thermocline TES	Physics, some data	Integrated			INL/EXT-20-59195 INL/EXT-21-64408 INL/EXT-21-61985		Thermal oil
Latent heat TES	Physics, some data	Individual			INL/EXT-21-61985		
Battery storage	Physics	Integrated	X		INL/MIS-20-60624		
Compressed air	Physics	Individual			INL/RPT-22-66941		Single-mode operation

V&V Matrix (3/4)

Subsystem Name	V&V	Example Type	ROM generated	Steady-state model	Published documents	Reference documents	Nominal Conditions, Notable Limitations
Reverse osmosis desalination	Data: steady-state	Integrated			INL/EXT-18-45505 INL/EXT-15-36451		
High temperature steam electrolysis	Data: steady-state	Integrated			INL/EXT-16-40305 INL/EXT-19-55395	doi: 10.1016/j.jpowsour.2006.12.081 doi: 10.1016/j.ijhydene.2012.12.086 doi: 10.2172/1513461	
HTSE 'experimental'	Face	Individual			INL/EXT-22-02188		
Single-stage balance of plant	Face	Integrated			Many		
Two-stage balance of plant	Face	Integrated			INL/RPT-22-69214		
Stage-by-stage balance of plant	Physics	Integrated			doi: 10.1016/j.apenergy.2022.118800		

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V&V Matrix (4/4)

Subsystem Name	V&V	Example Type	ROM generated	Steady-state model	Published documents	Reference documents	Nominal Conditions, Notable Limitations
TEDS loop	Physics, some data	Individual, Integrated			INL/EXT-20-59195 INL/EXT-21-64408		
MAGNET loop	Physics	Individual, Integrated			INL/EXT-22-02188		
Subsystem Name	V&V	Example Type	ROM generated	Steady-state model	Published documents	Reference documents	Nominal Conditions, Notable Limitations
Steam manifold	Physics	Integrated			Many		
Switchyard	Physics	Integrated			Many		
Electric grid	Physics	Integrated			Many		
Natural gas turbine	Face	Integrated	X		INL/EXT-16-40305		

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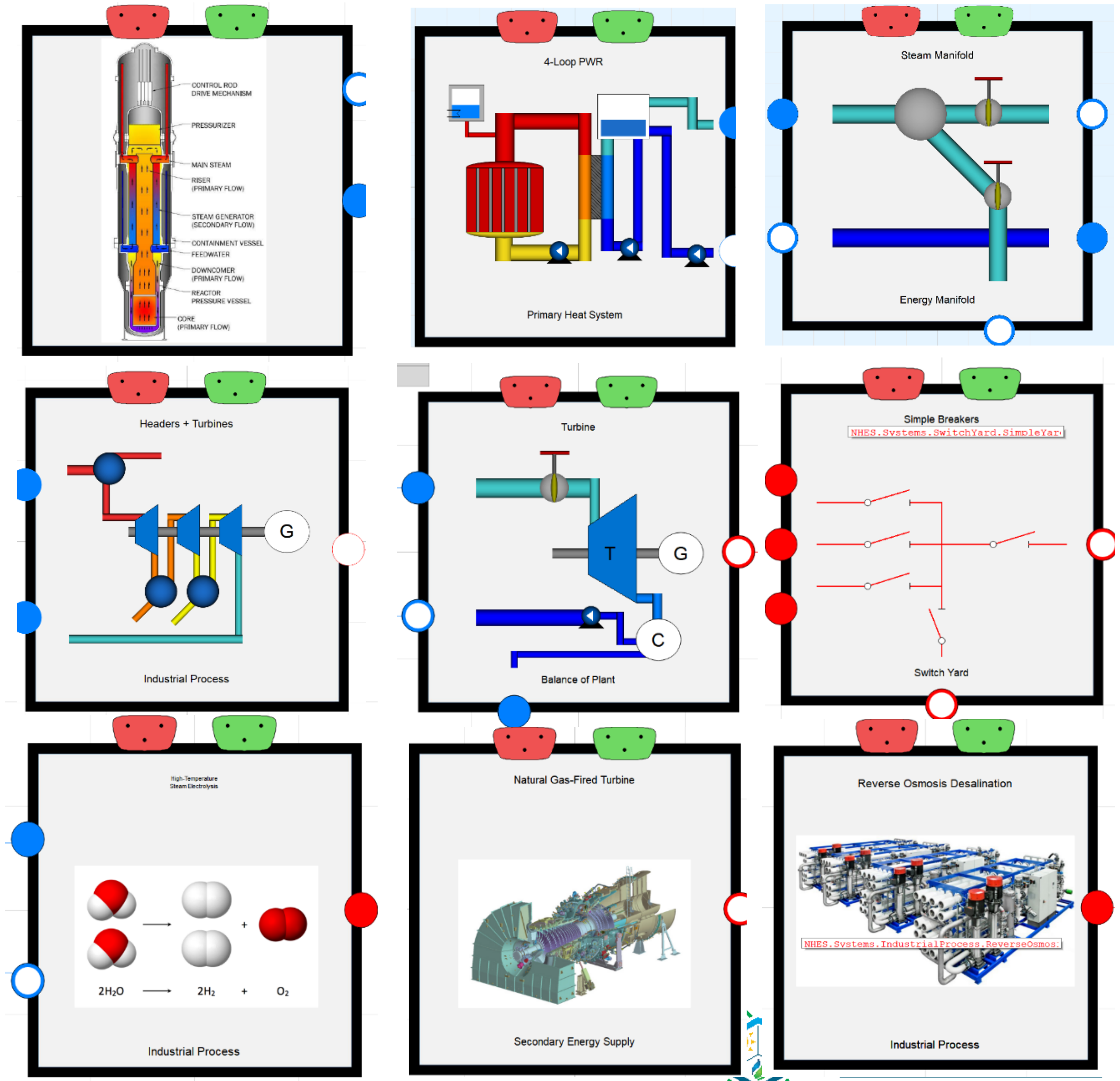
HYBRID Dynamic Modeling

- 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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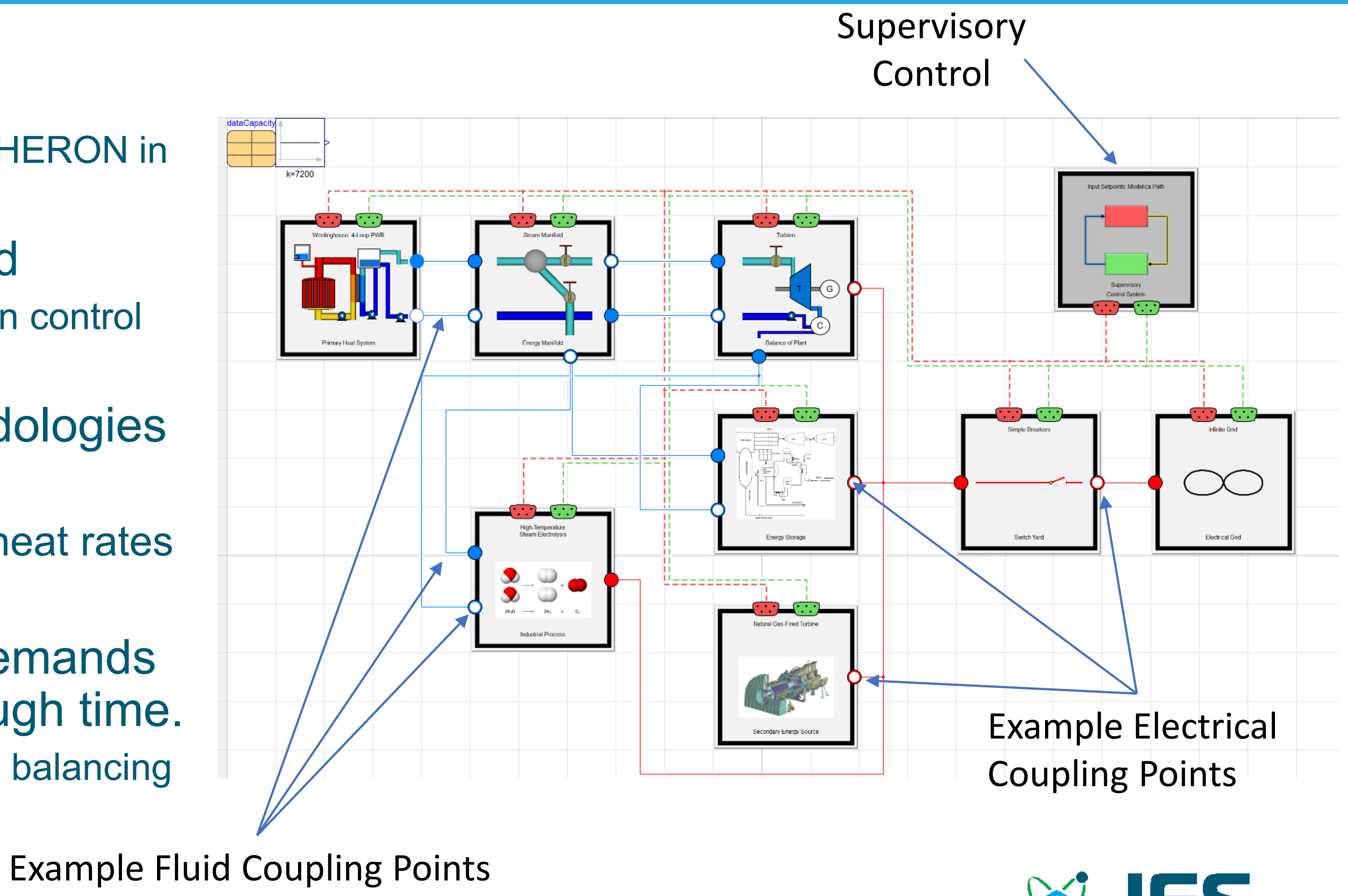
Where FORCE Interacts?

- 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



Why Modelica?

- Rapid Development
  - Fidelity level controlled by user
  - Fast feedback from development environment

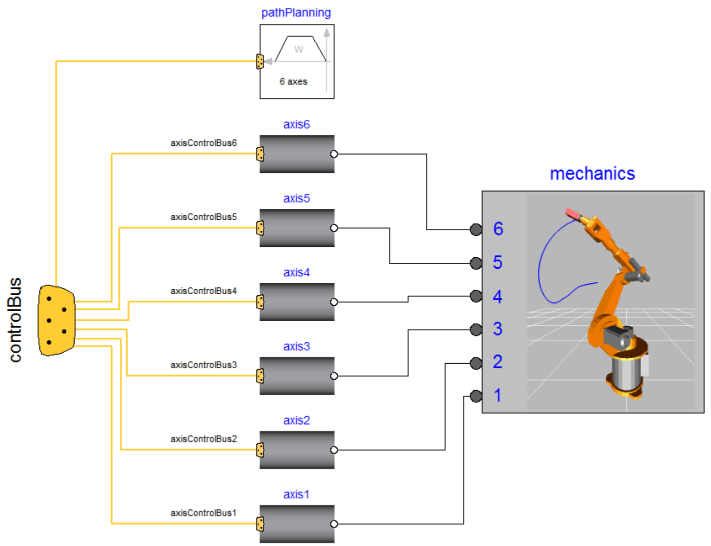
- Collaborative
  - Model repositories can be open-source like HYBRID with standardized connections
  - FMI/FMU allows for “black-box” sharing

- 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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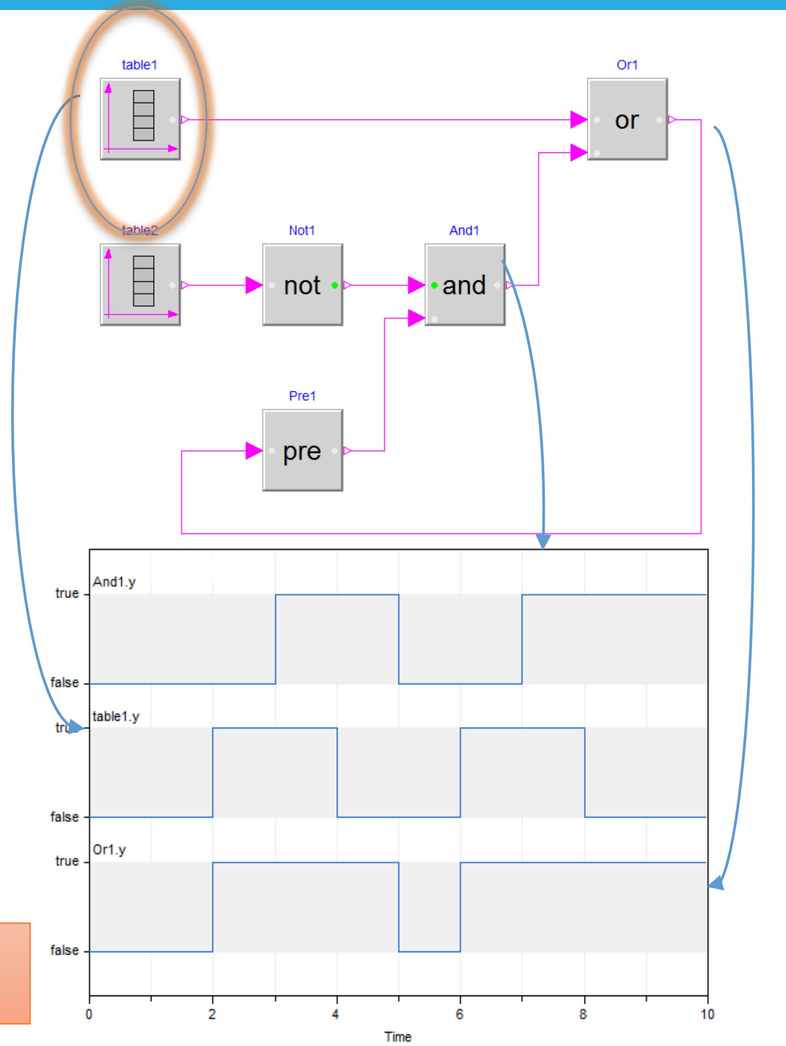
Dynamic Simulation

- 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

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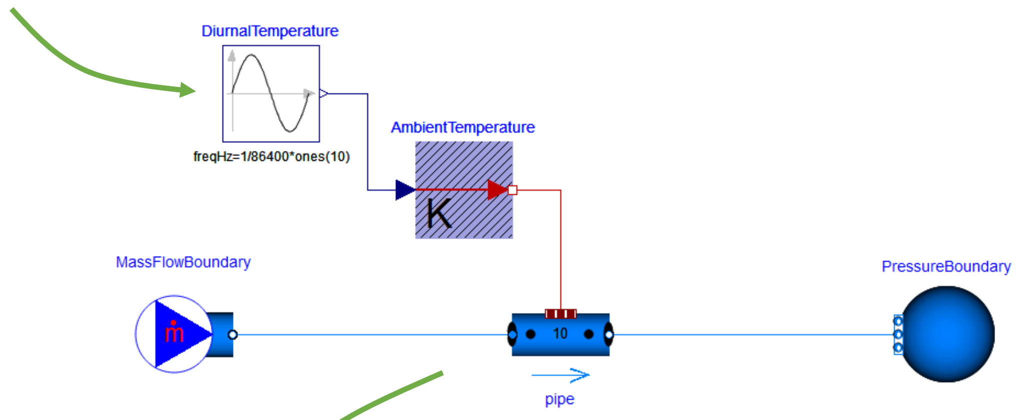
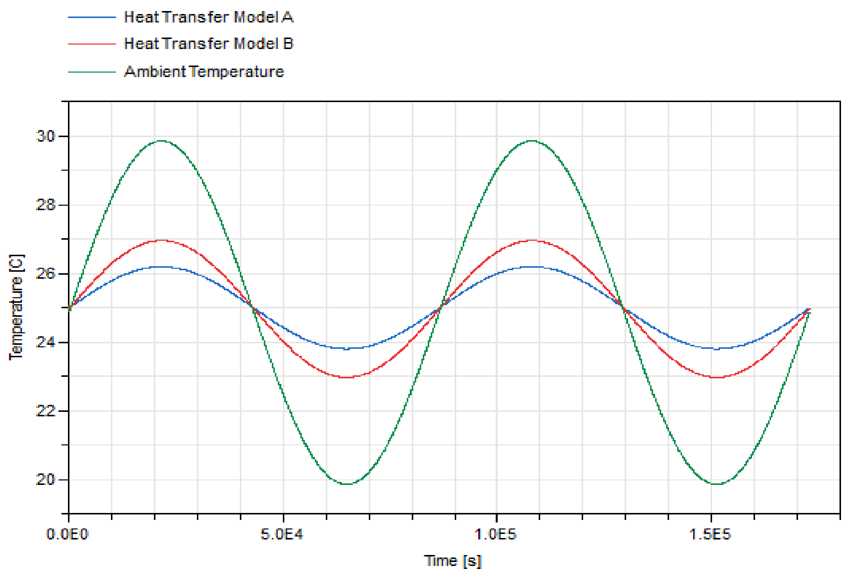
Replaceable Modeling

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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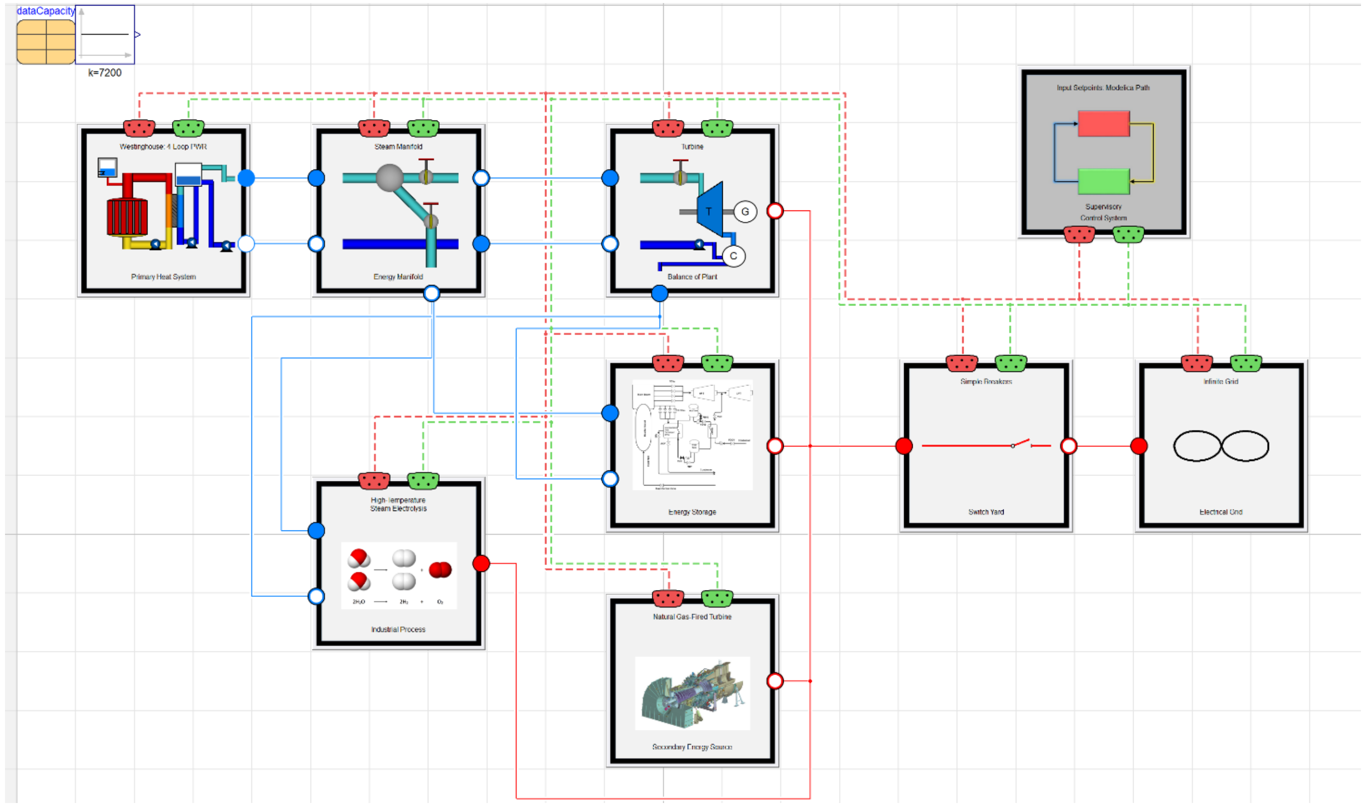
Design Capability

- 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



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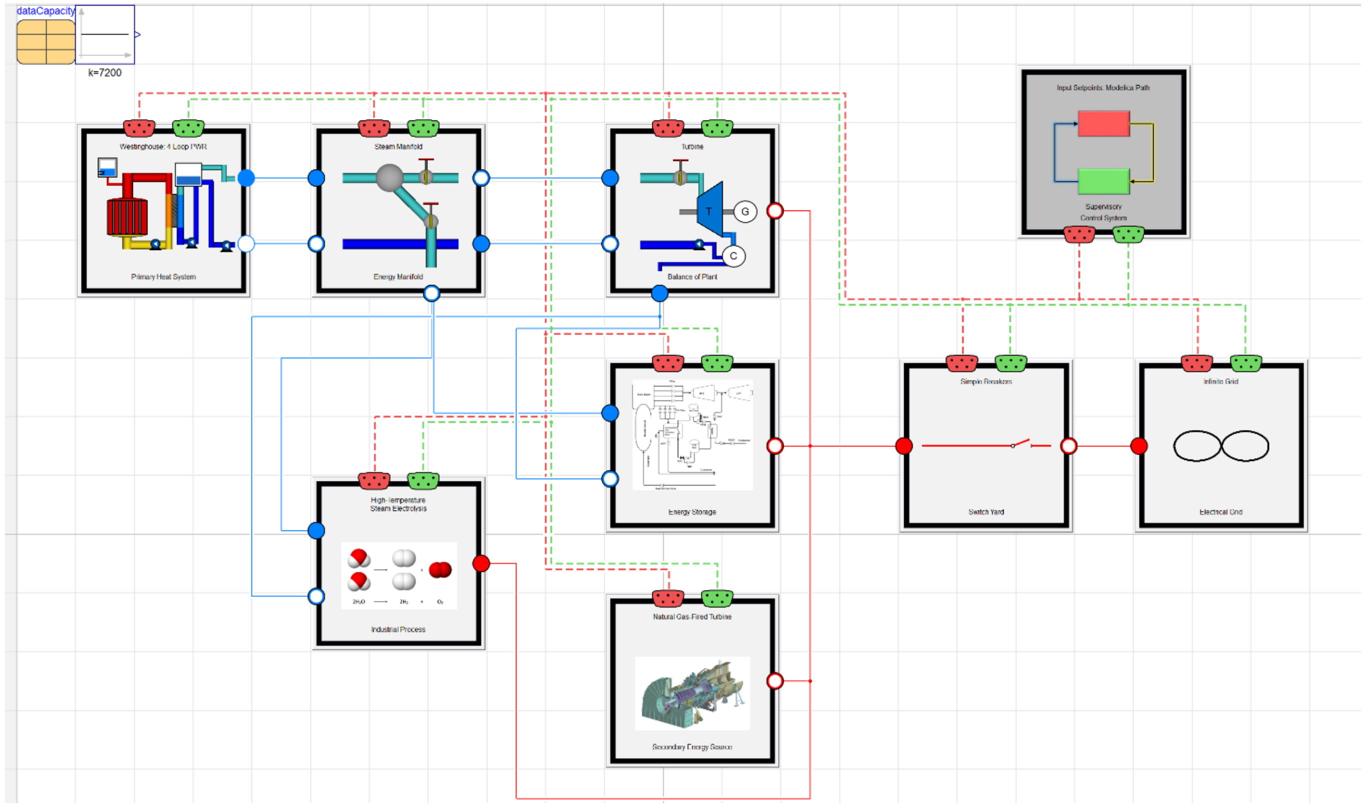
Design Capability

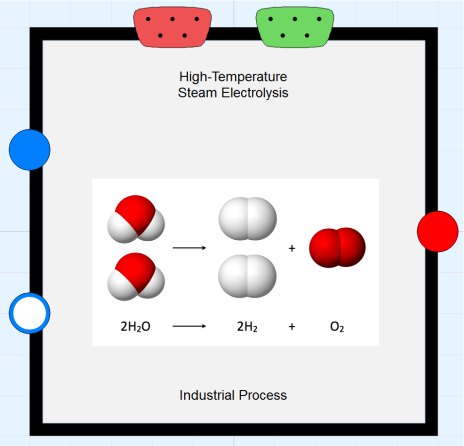
- Figures of merit
  - Demand missed
  - System stability
    - System pressure, temperature, thermal gradients, valve positioning, etc.
  - Control strategy effects on each subsystem
  - Carbon accounting

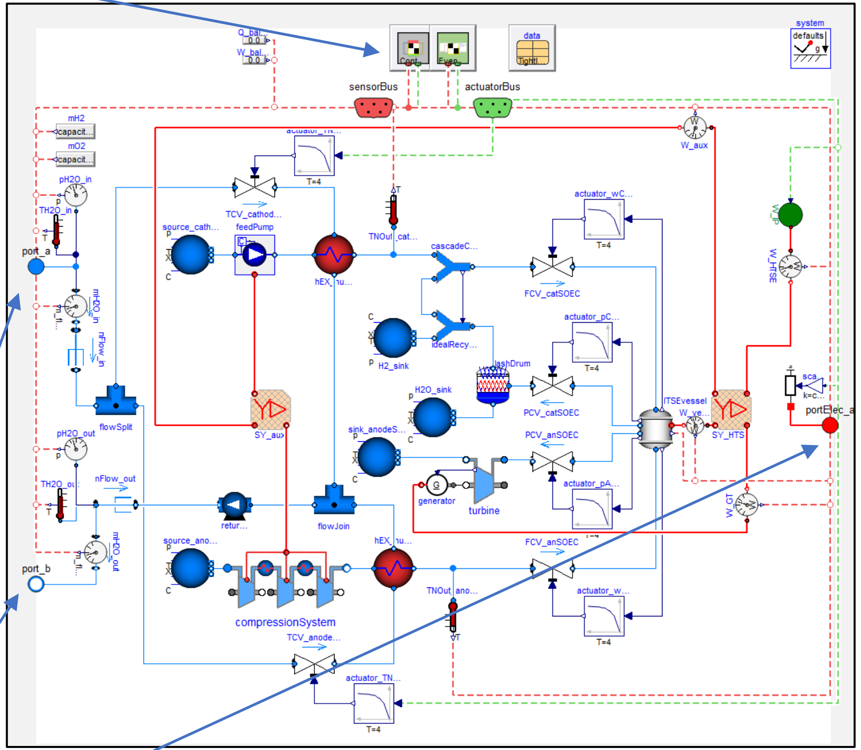


Interconnectability

- 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



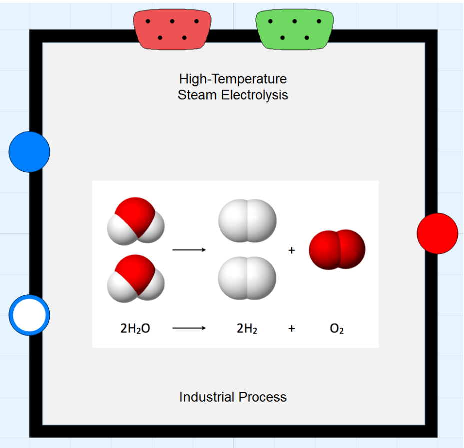


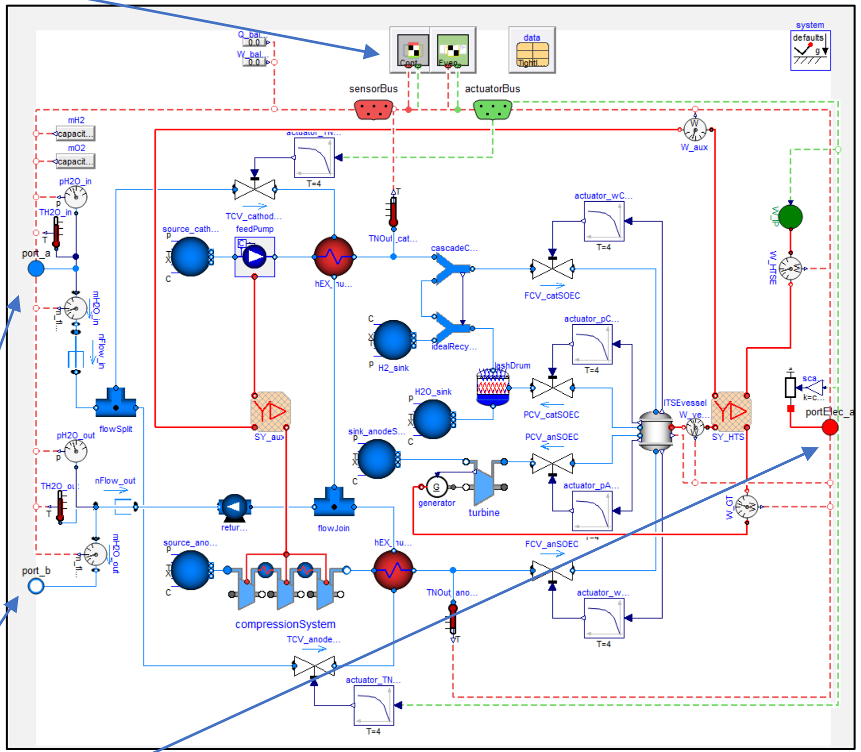
Connection points

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

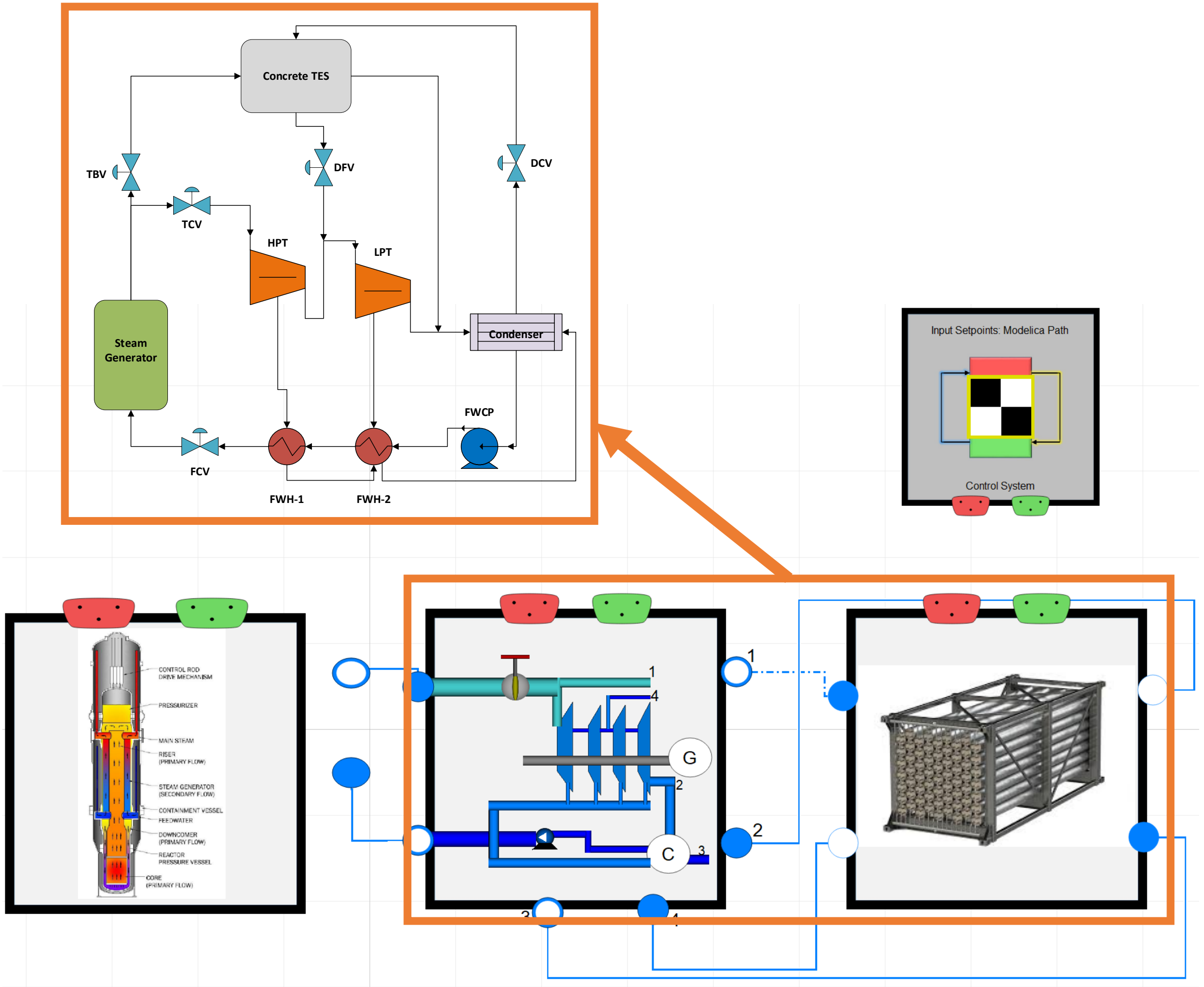




Connection points

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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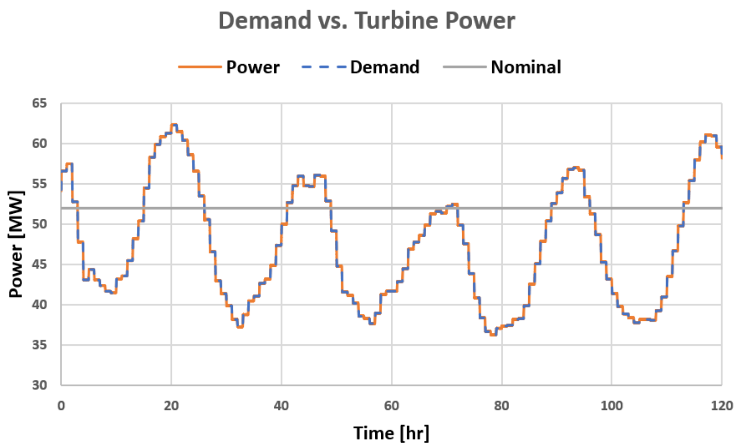
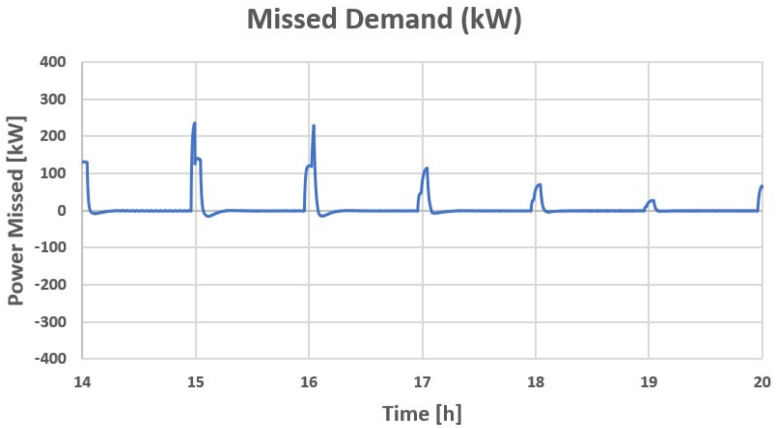
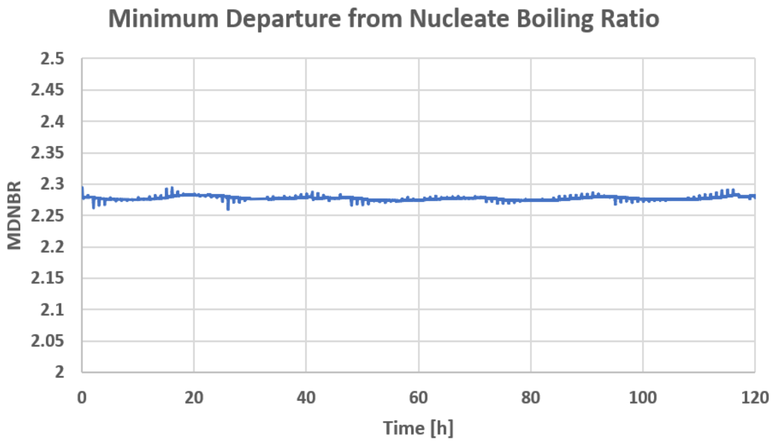
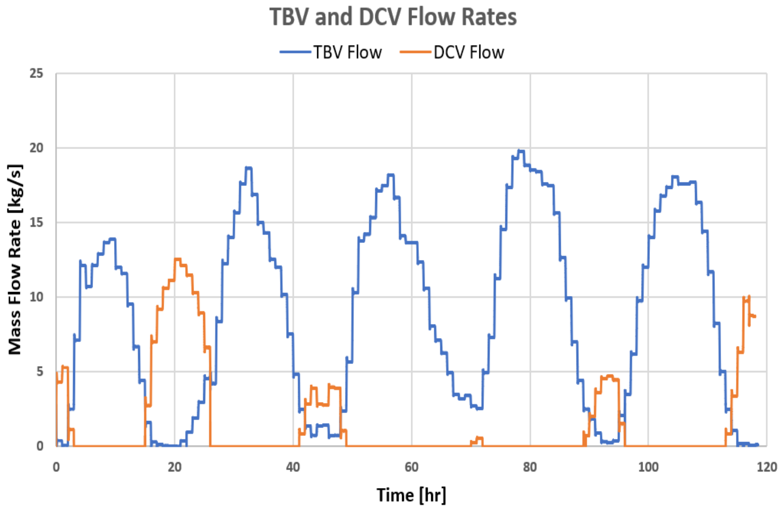
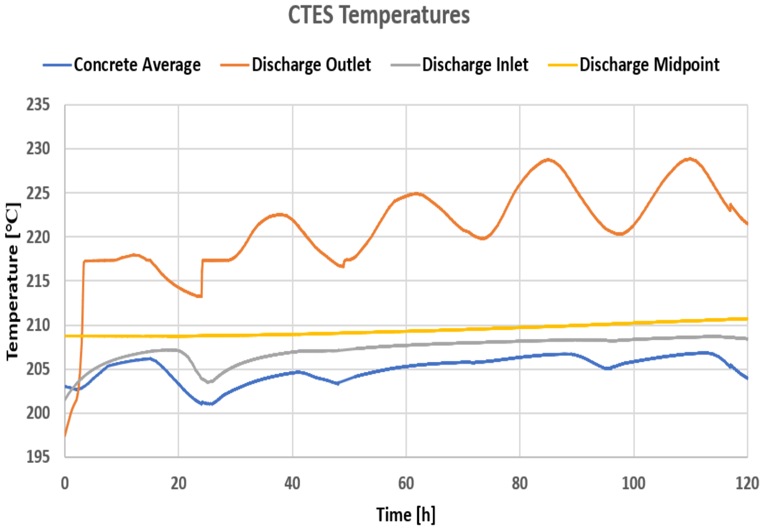
Energy Arbitrage IES

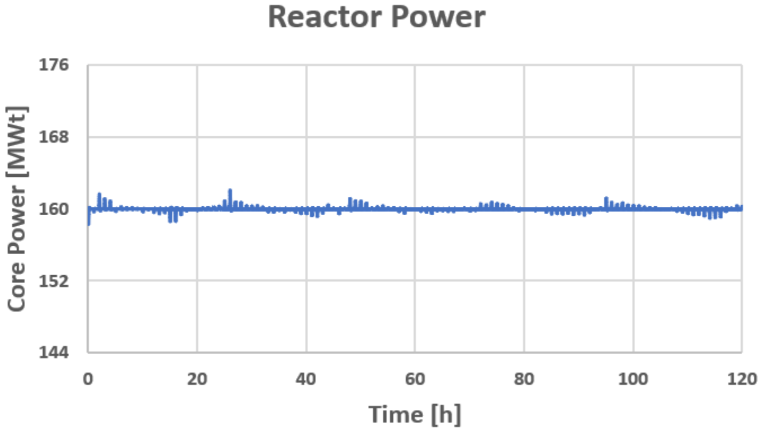












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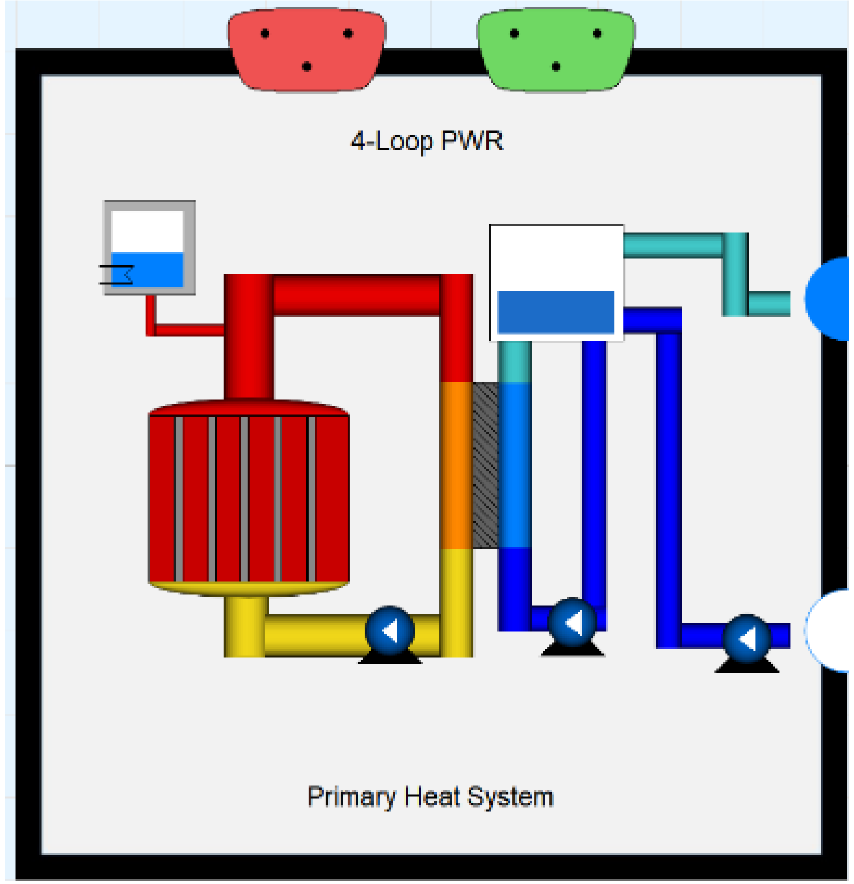
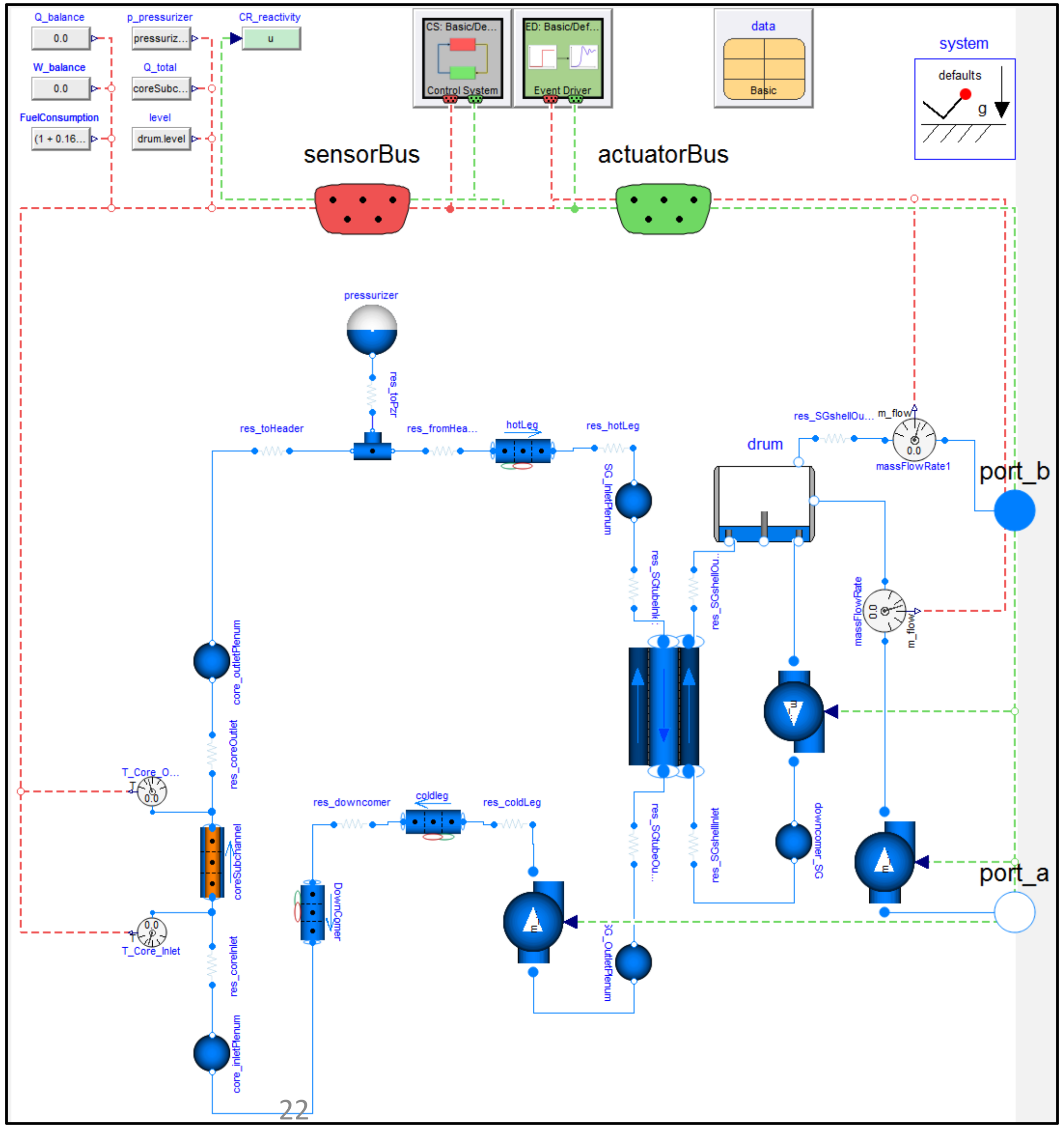
PHS– Westinghouse (WH) Style: 4-Loop (PWR)





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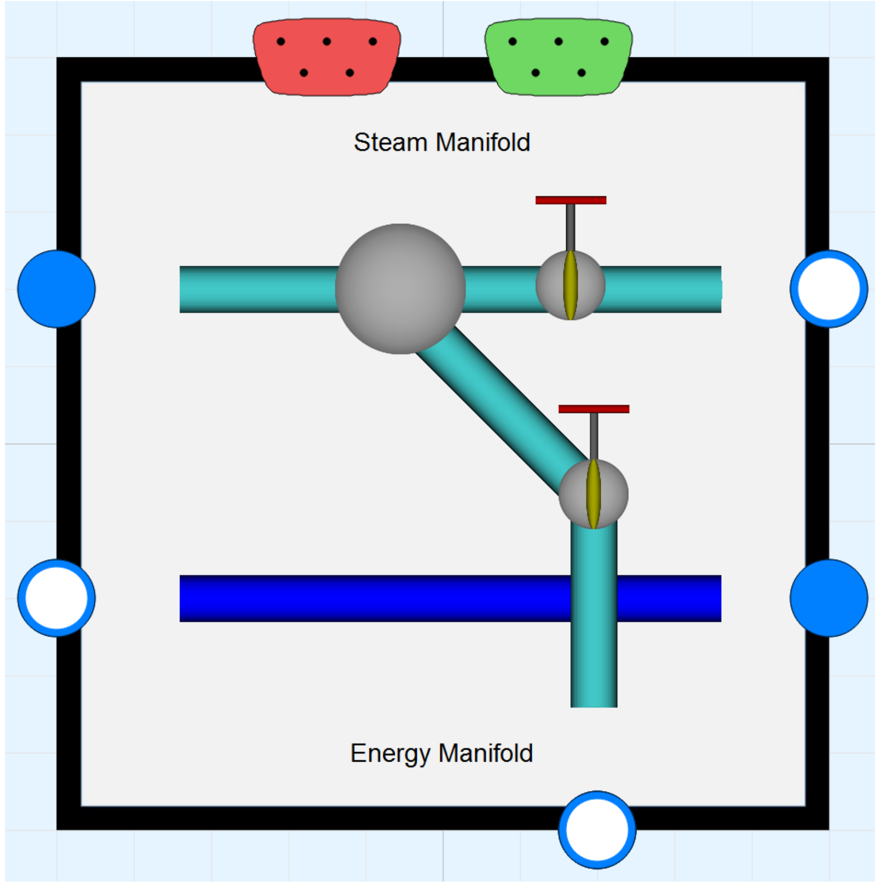
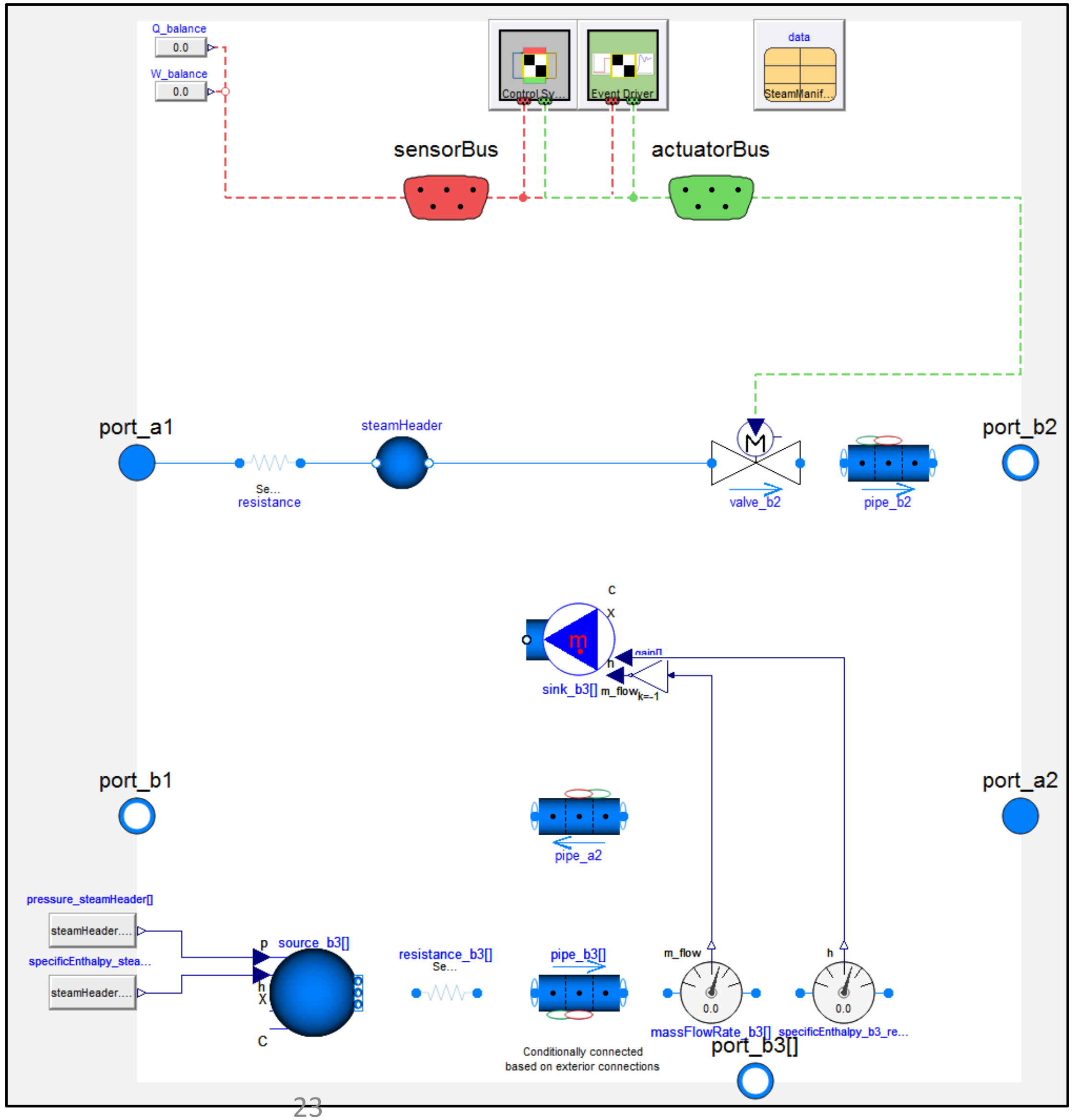
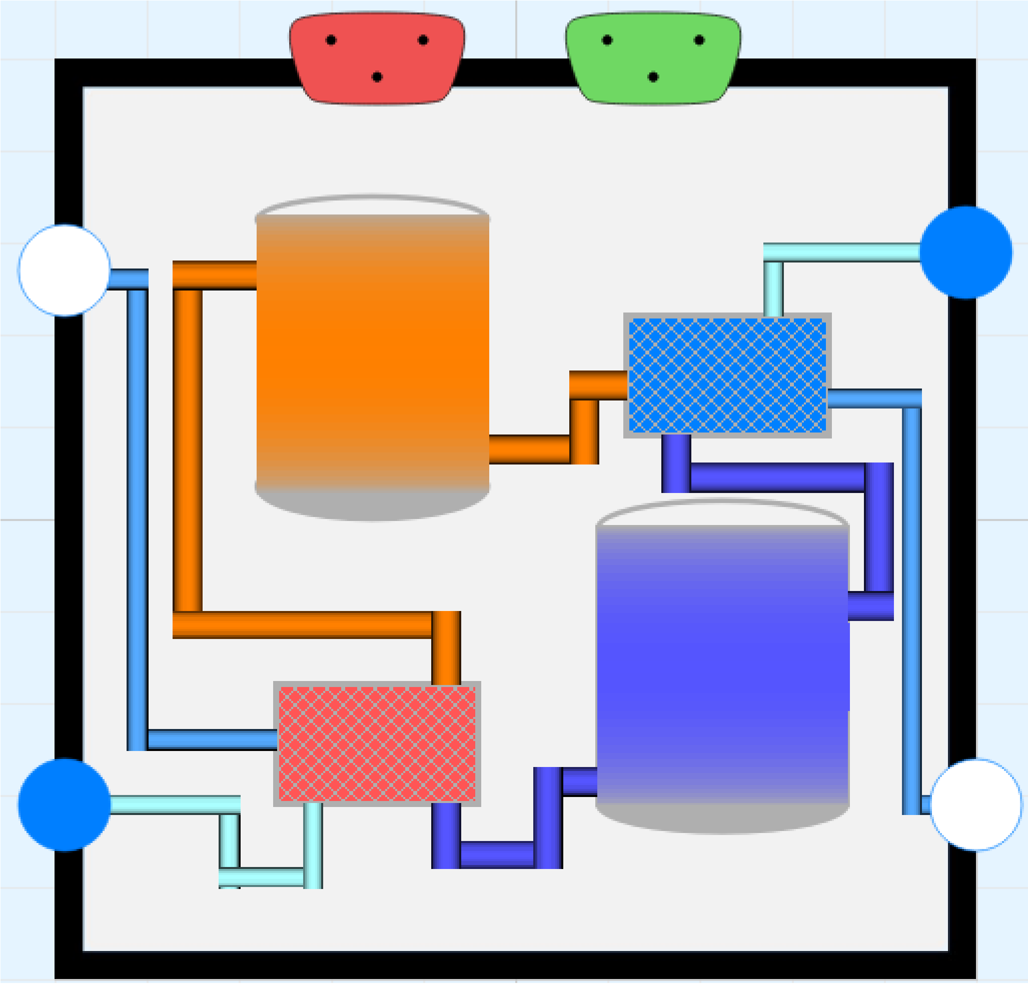
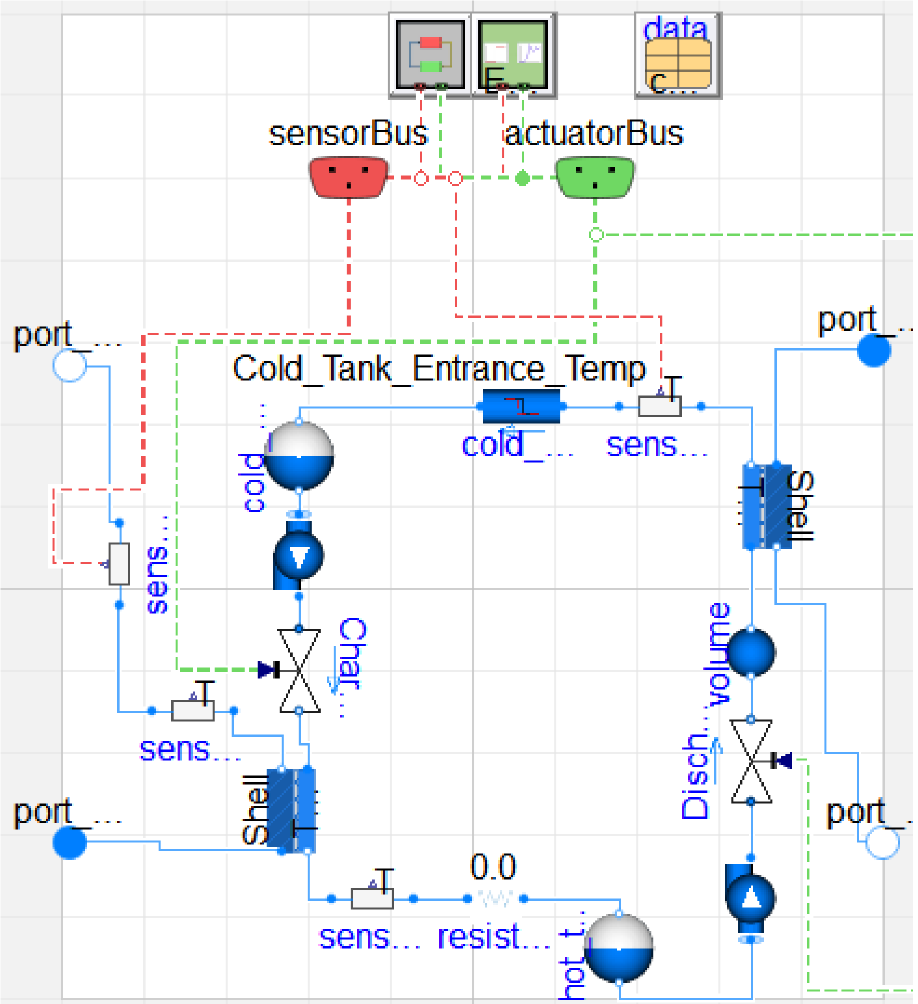
Energy Manifold



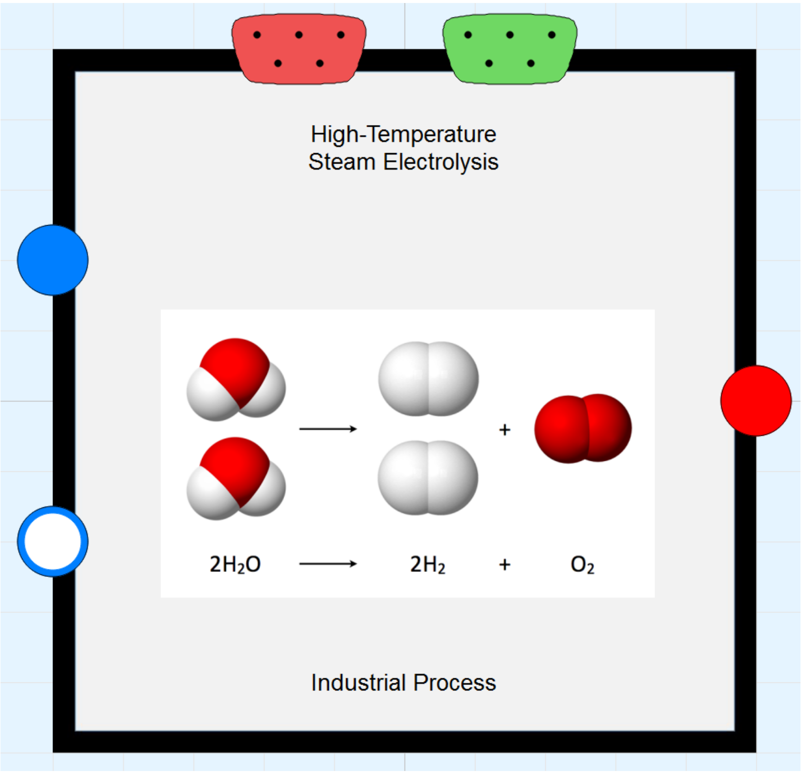


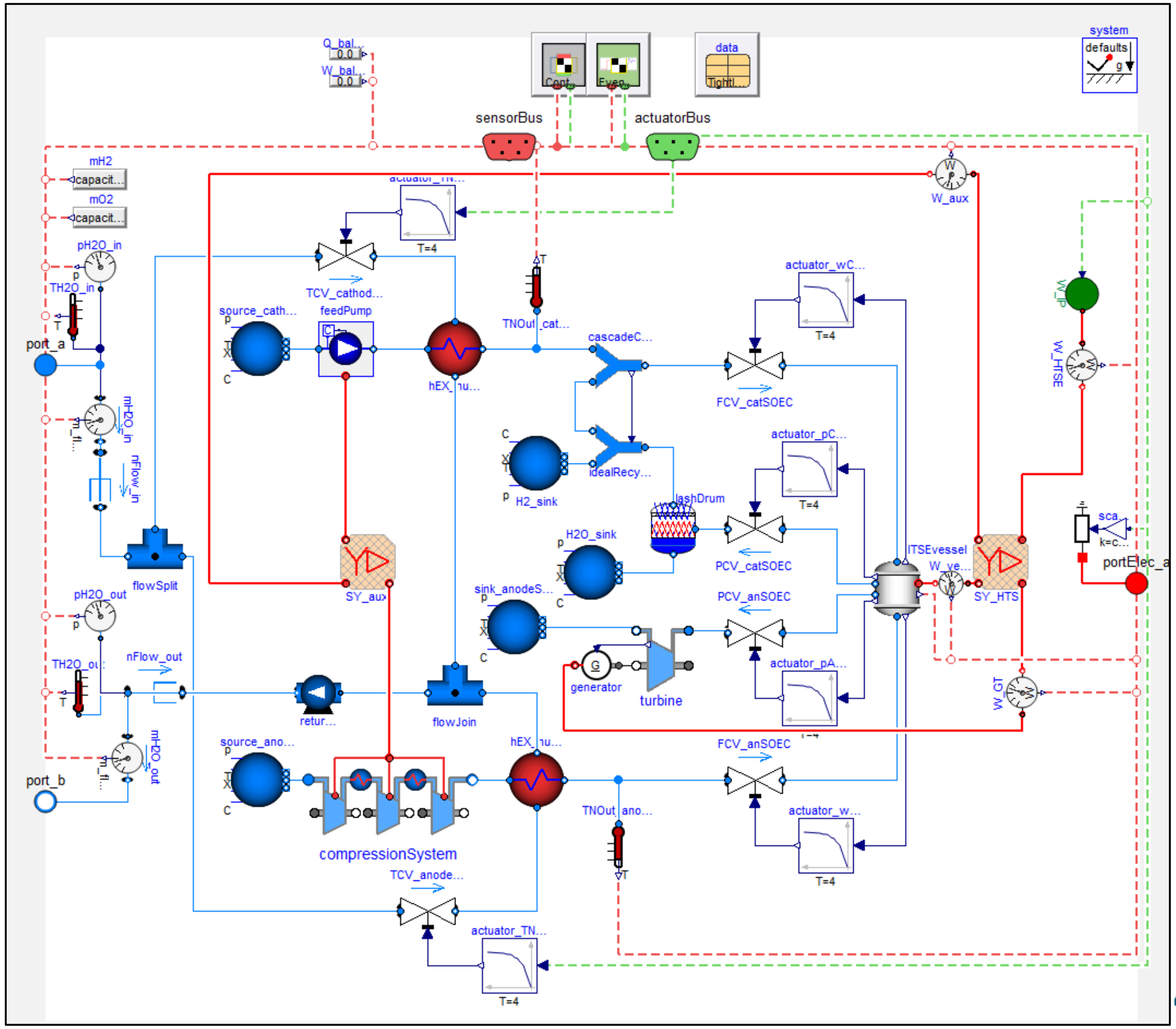
ES – Sensible Thermal Energy Storage (TES)



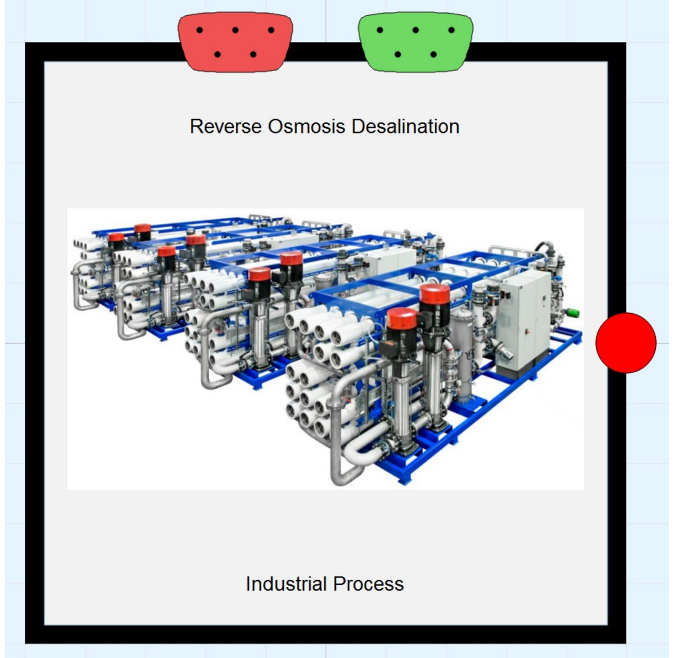


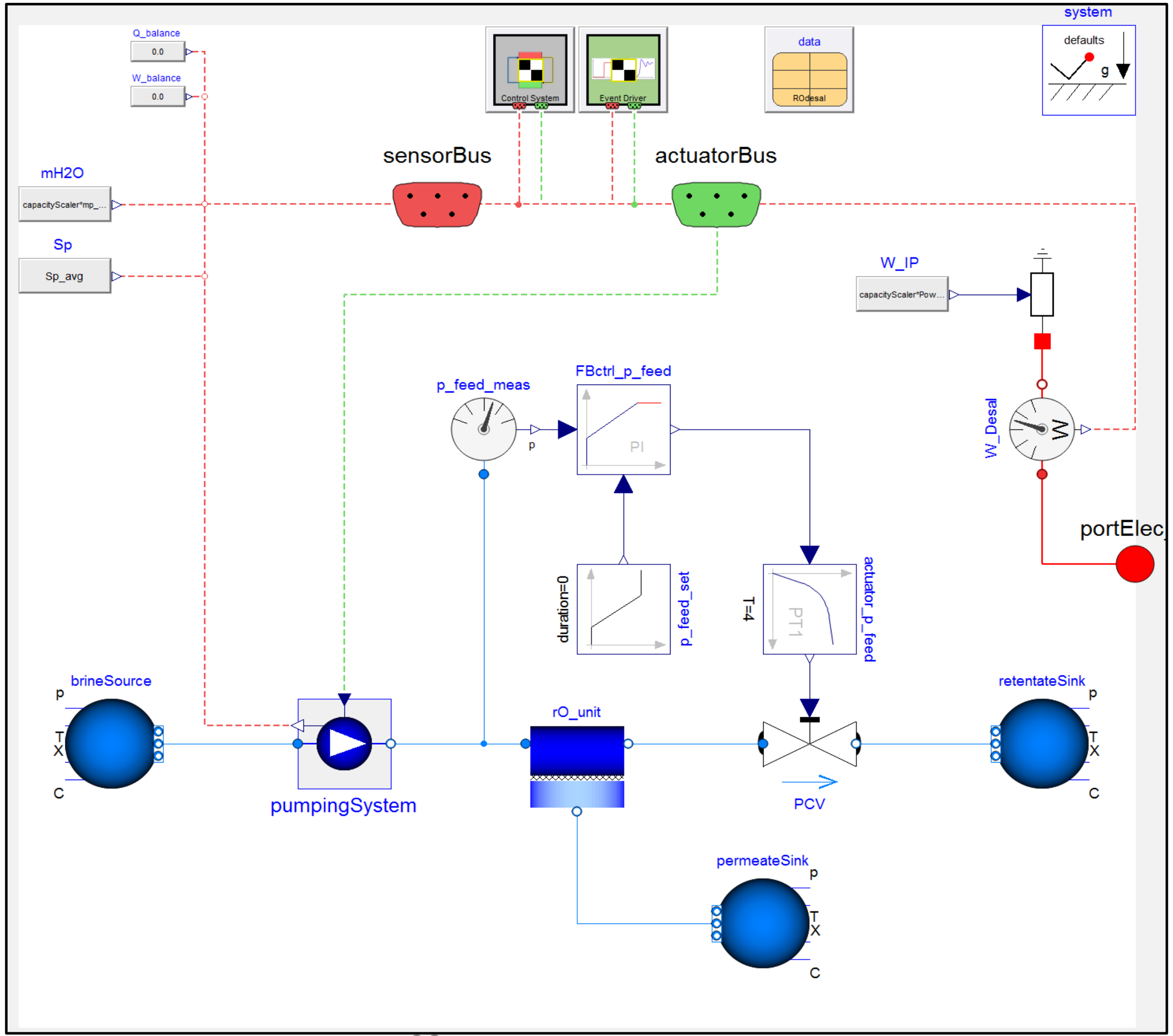
High-Temperature Steam Electrolysis (HTSE)





Reverse Osmosis (RO) Desalination





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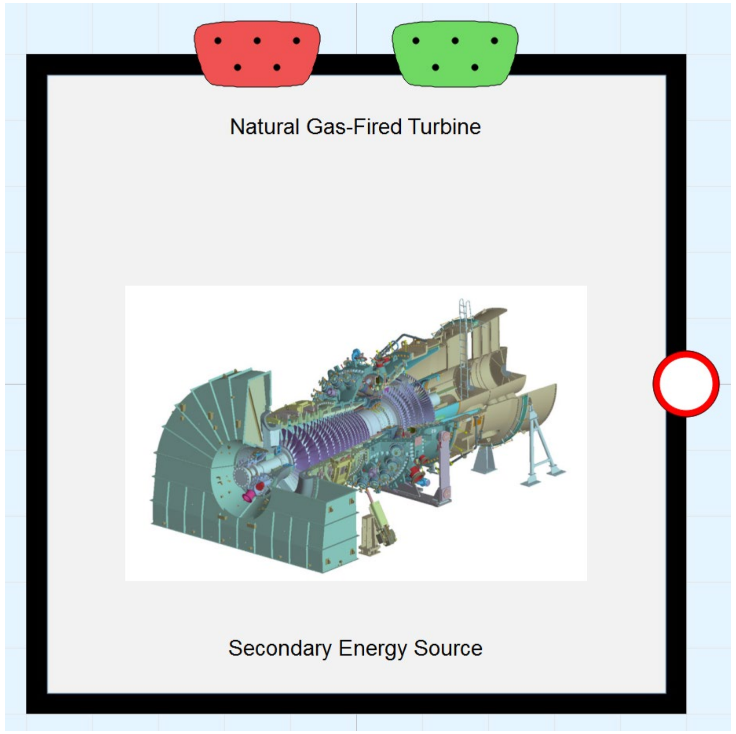
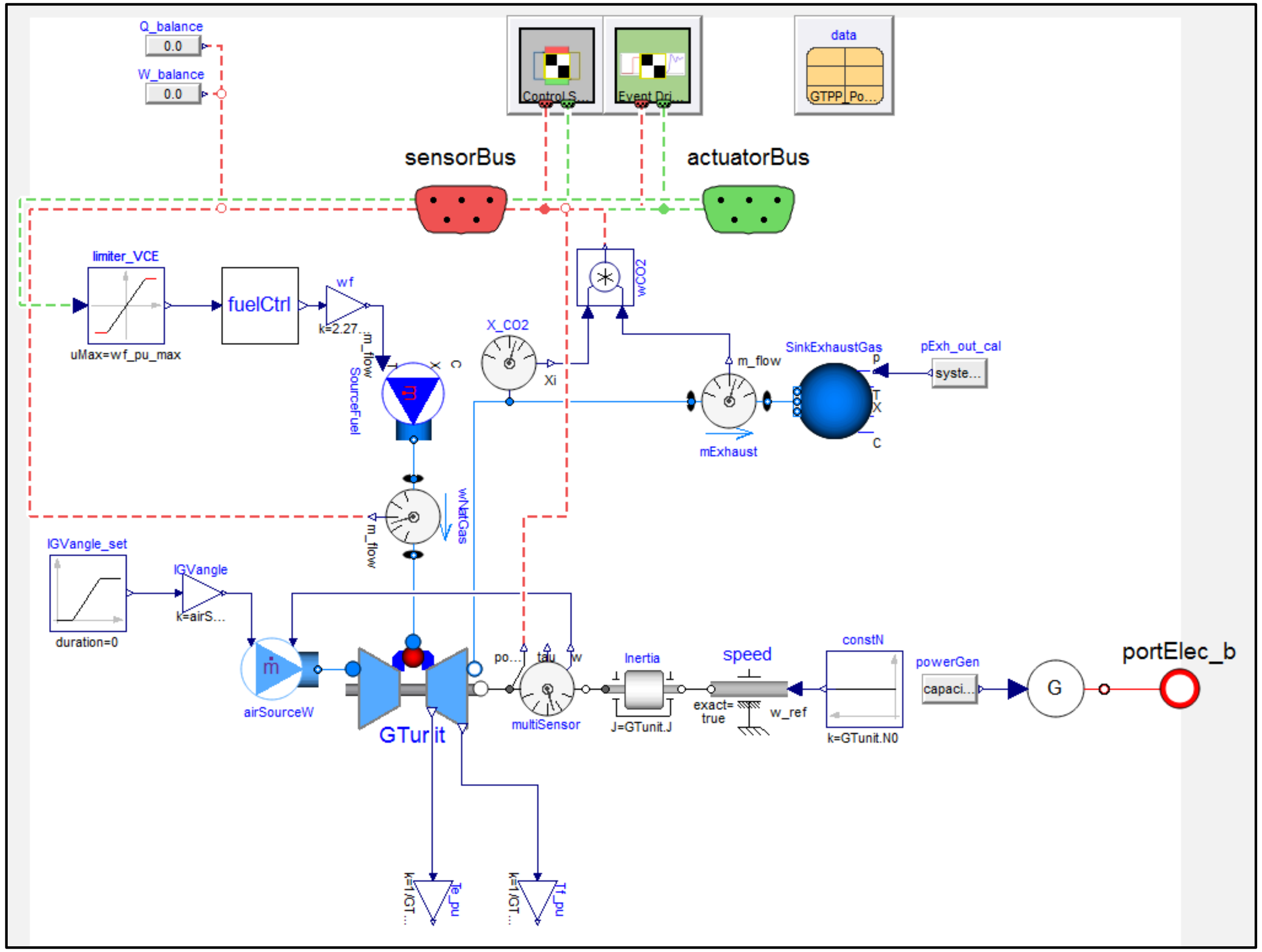
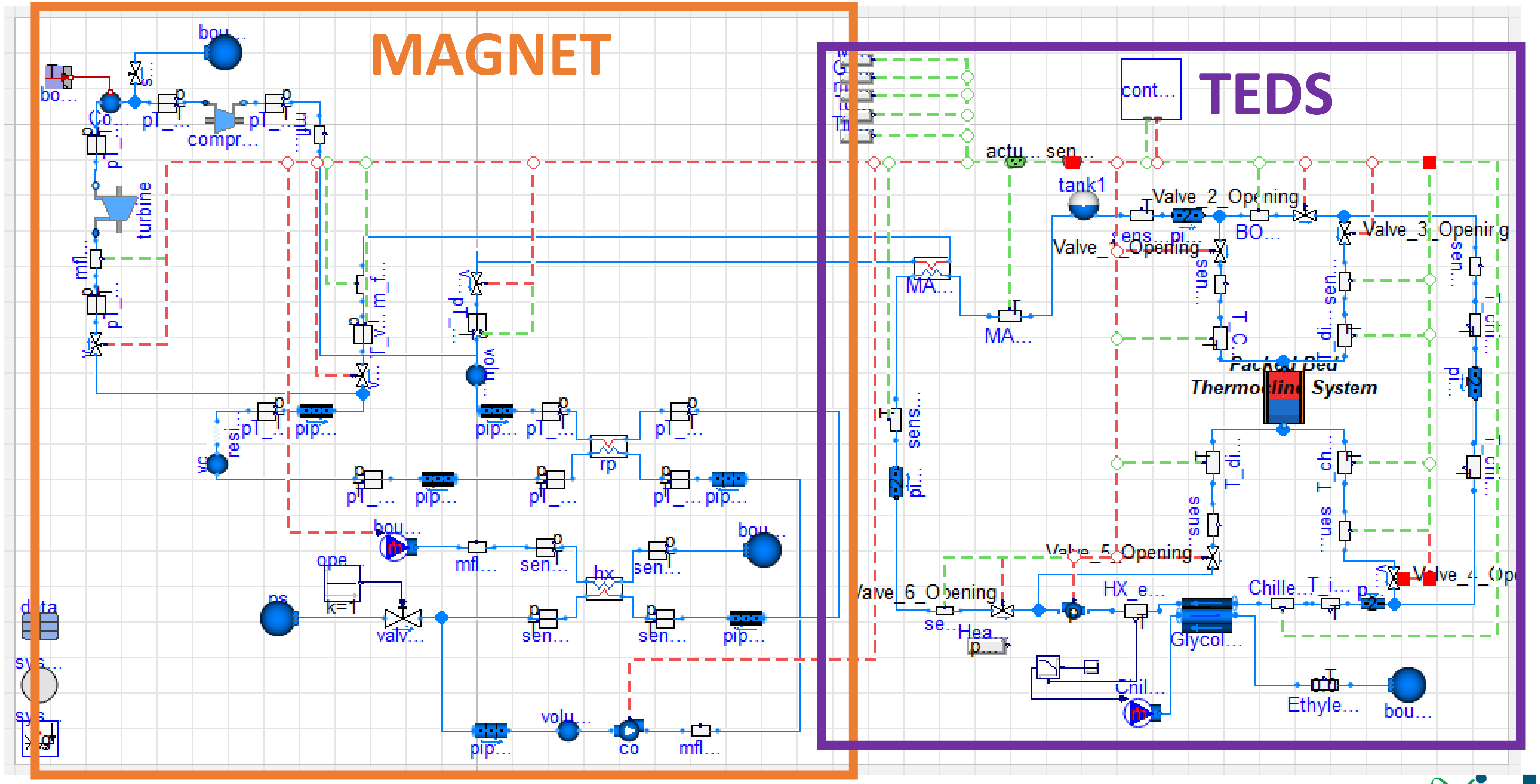
[ ] HYBRID and FORCE [X] **Modeling Features** [ ] Model Construction

Natural Gas Fired Turbine





DETAIL Model



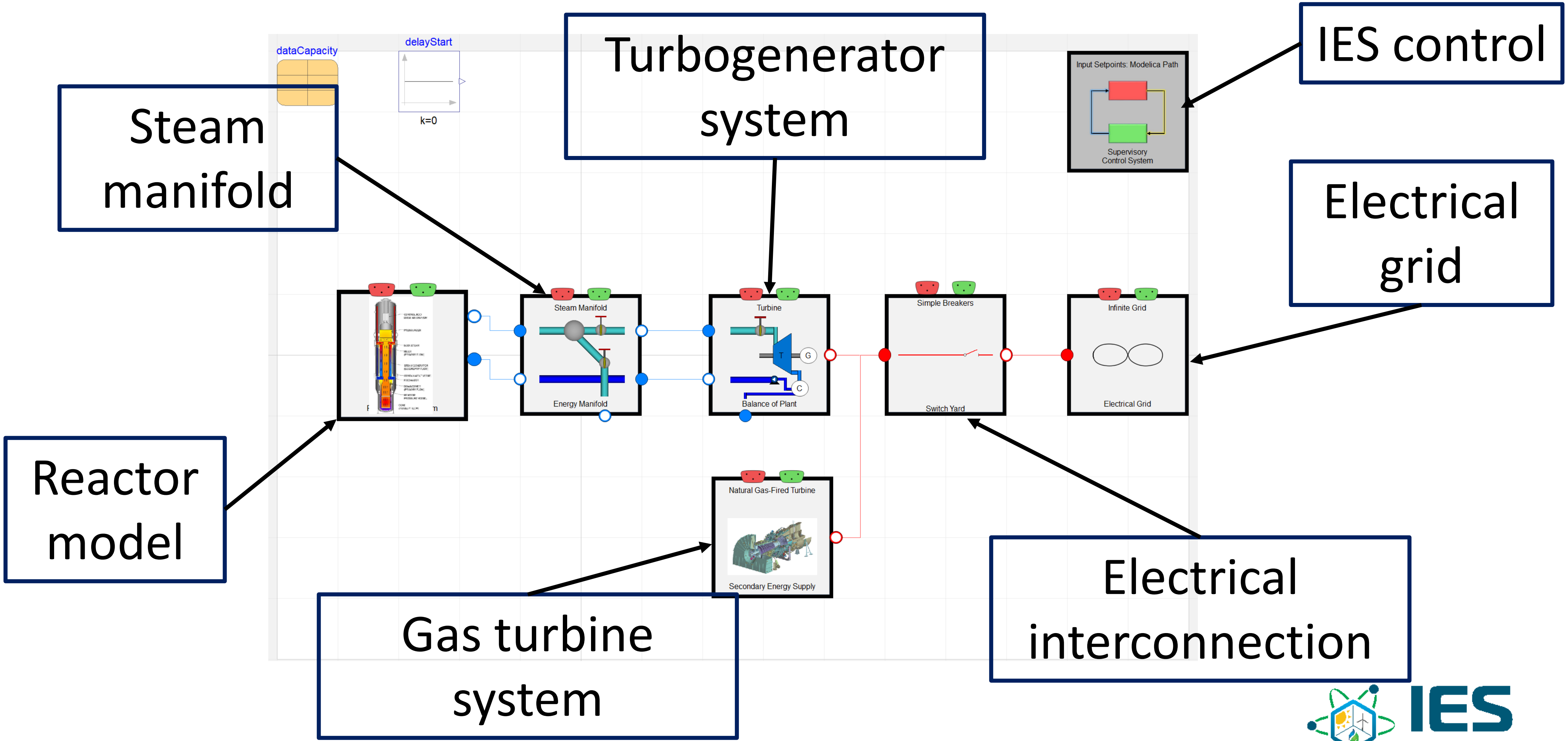
Integration of Existing Models

- Drag and drop of models is the most common method of building top-level systems
  - Example: IES, Reactor model
  - Prebuilt models combined in unique ways for simulation setup
  - Primary simulation difficulties are system-wide initialization and proper calibration of controls
- Subcomponents can be combined to make usable components
  - Example: Shell and tube heat exchanger
  - Configured models allow for standardized components for full system builds
  - Primary difficulty is to ensure appropriate parameter pass-through

Integration of Existing Models

- Using existing models takes advantage of object building within Modelica
- The same components can be used repeatedly
- Subsystems have been tested and verified
- Ports impose consistent communication between components

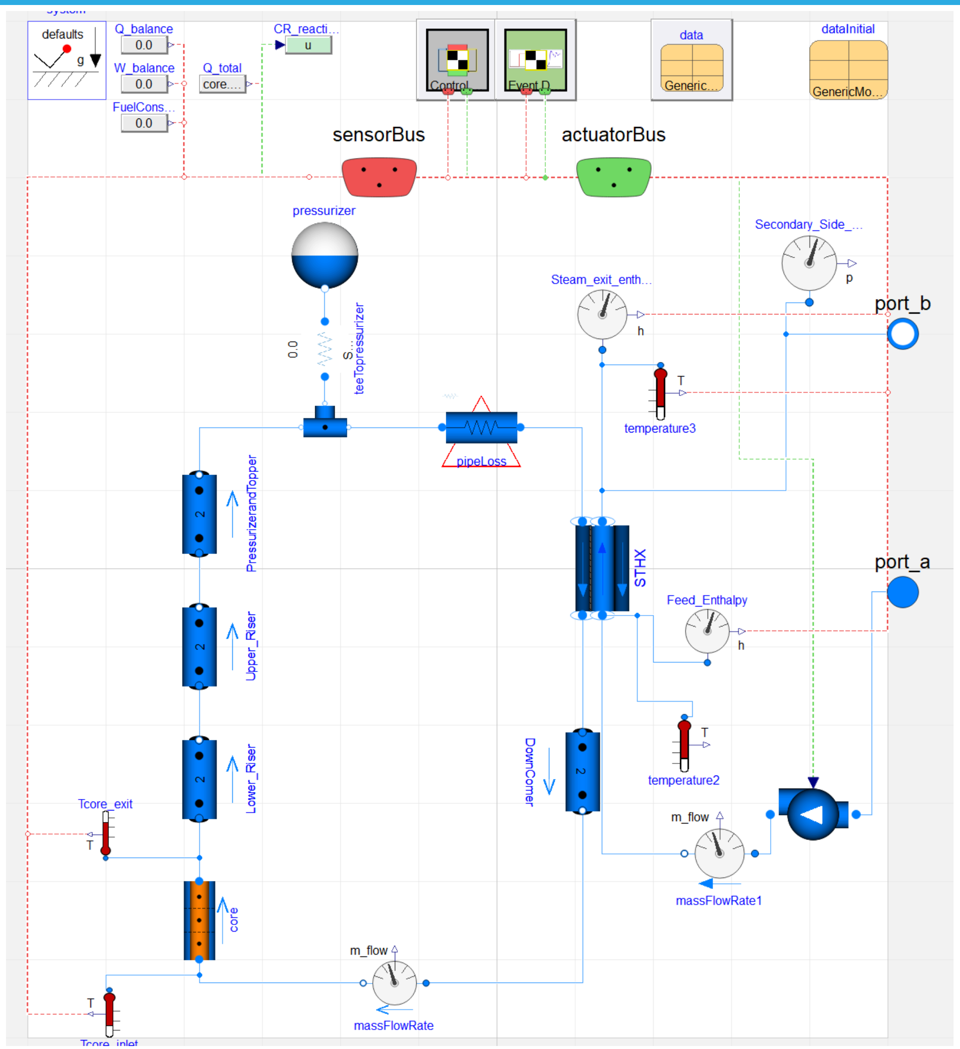
Example: IES



Steam manifold
Turbogenerator system
IES control
Electrical grid
Reactor model
Gas turbine system
Electrical interconnection
dataCapacity
delayStart
k=0
Input Setpoints: Modelica Path
Supervisory Control System
Steam Manifold
Energy Manifold
Turbine
Balance of Plant
Simple Breakers
Switch Yard
Infinite Grid
Electrical Grid
Natural Gas-Fired Turbine
Secondary Energy Supply

Example: IES – Reactor Model

- Sixteen different drag-and-drop components make up reactor model
  - Includes pipes, sensors, feedwater pump, primary heat exchanger, nuclear core model, and control signals
  - Some of these models have drag-and-drop subcomponents
- Subsystem level is self-contained, only needing feed flow and steam produced connections.



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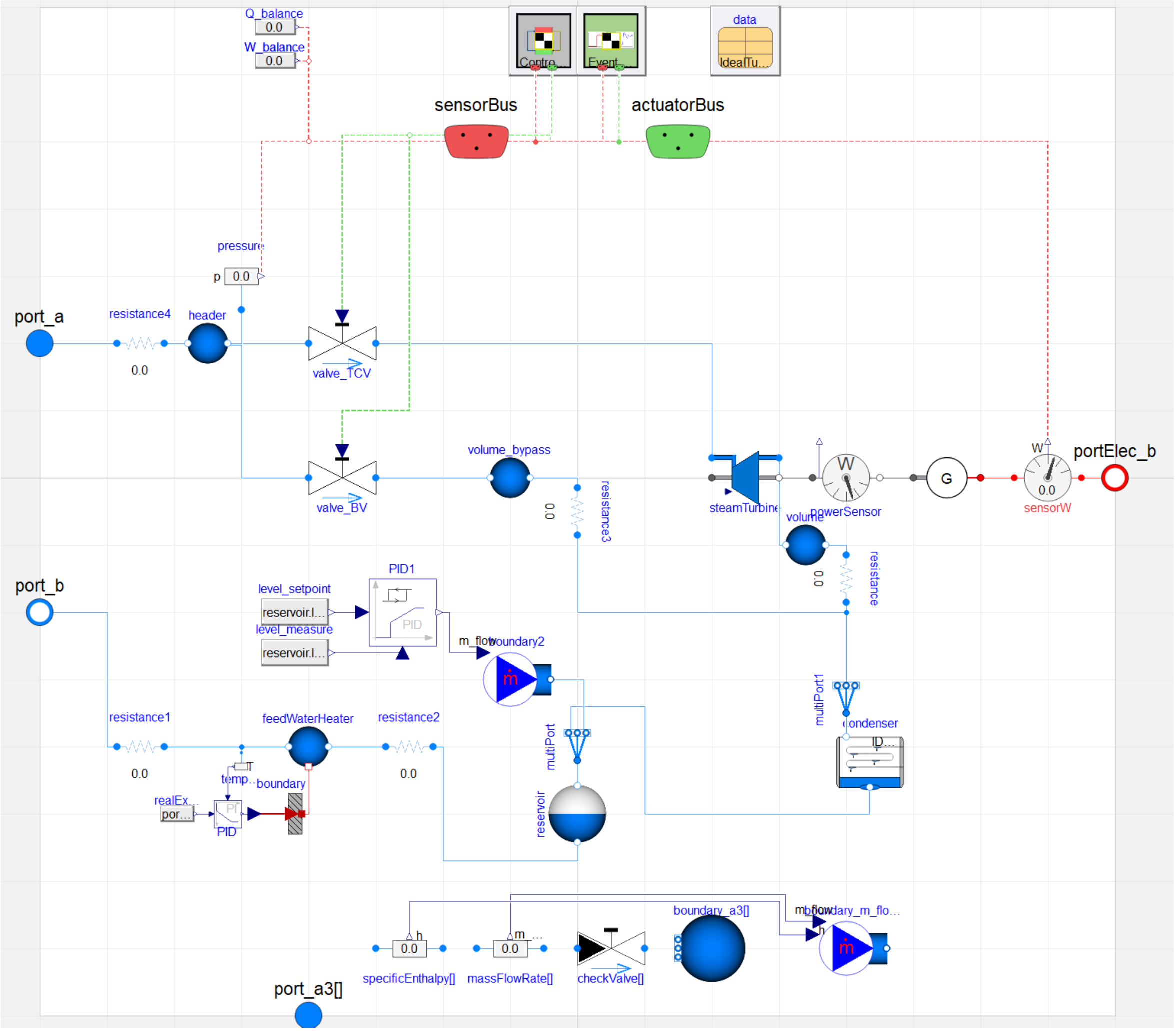
Example: IES – Turbogenerator

- Turbogenerator system demonstrates five connection types
  - Fluid (blue)
  - Heat (red solid)
  - Mechanical (gray)
  - Electrical (red solid)
  - Control (red & green dashed)



Integration of Existing Models

- Construction using pre-existing models creates instantiations of the objects within current level model
- Typically, ports and connectors are used to communicate information between objects
- Assuming the building block models exist, the construction process can happen quite intuitively
  - Example: Shell & tube heat exchanger
- Parameter passing must be handled at every level

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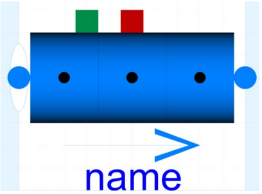
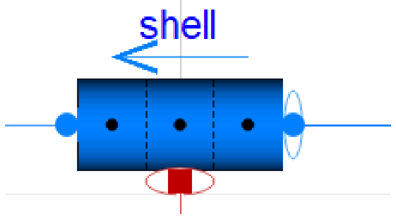
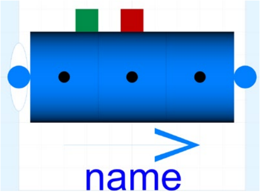
Example: Shell & Tube Heat Exchanger

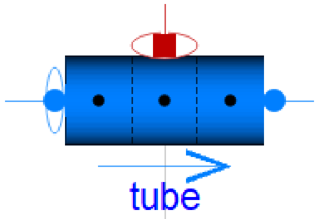
- What do we need to make a STHX?
  - Shell fluid flow path



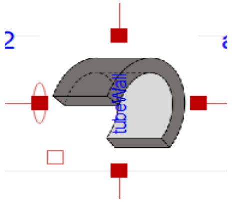


  - Tube fluid flow path

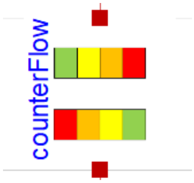




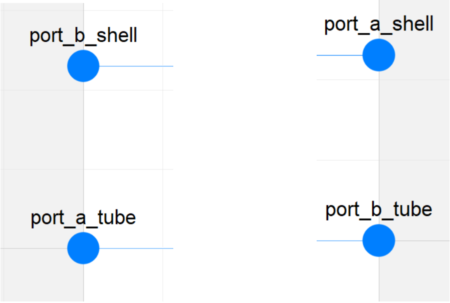
  - Pipe model to establish conductivity



- Possibly a vectorization reversing unit to allow for counter-flow OR concurrent flow



- External fluid connectors



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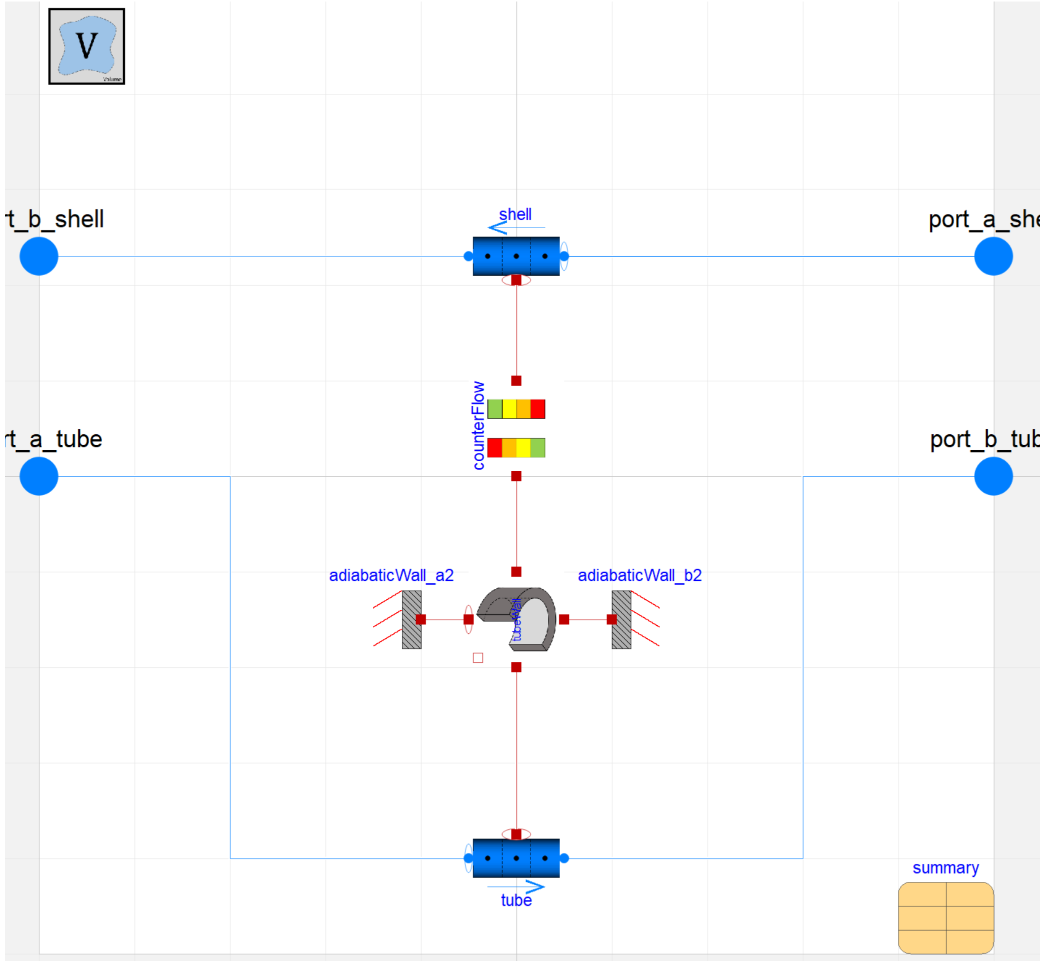
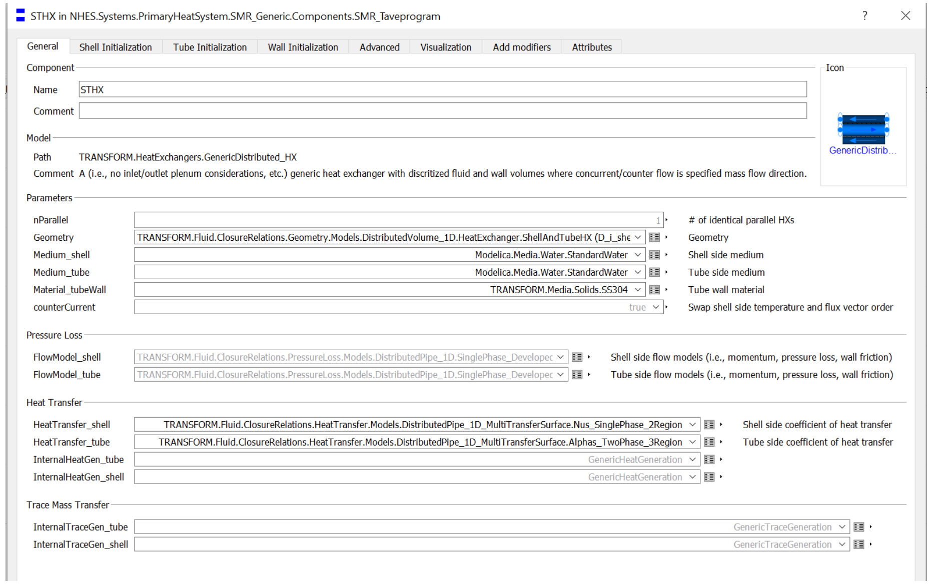
Example: Shell & Tube Heat Exchanger

- Finished product thermally connects two fluid streams
- One final question: how do we properly pass parameters to next-level modeling?
  - Each component in the figure on the right has its own parameters
  - For example: what is the diameter of the tube in the tube model?



Integration of Existing Models: Passing Parameters

- Typically, parameters must be re-declared at every level
  - Default values can be put in, as the highest modeling level will be distributed down
- “Replaceable” keyword allows for all potential values matching the type of that parameter to be selected via drop-down menu
  - For example: two-phase media types
- Parameters can be grouped into data structures for easier pass-through



Parameter interface seen above. Interface method depends on type of parameter (single value, package selection, set of values, etc)

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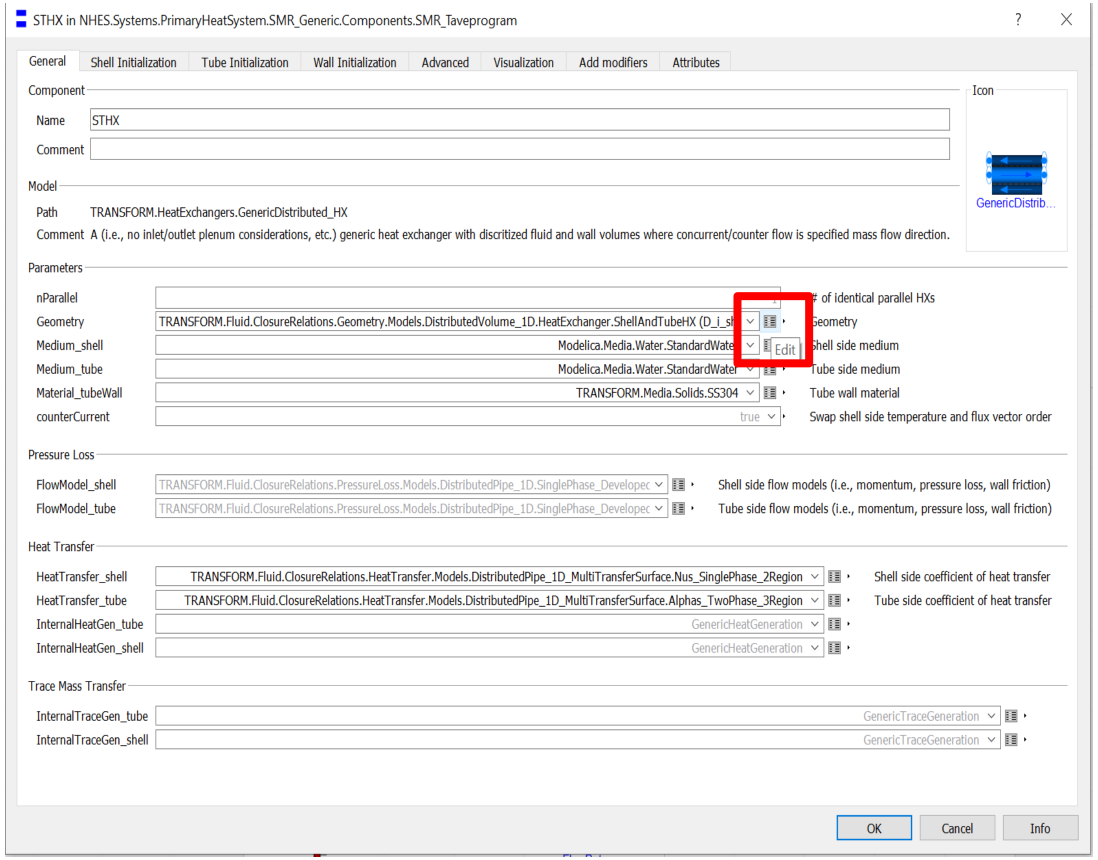
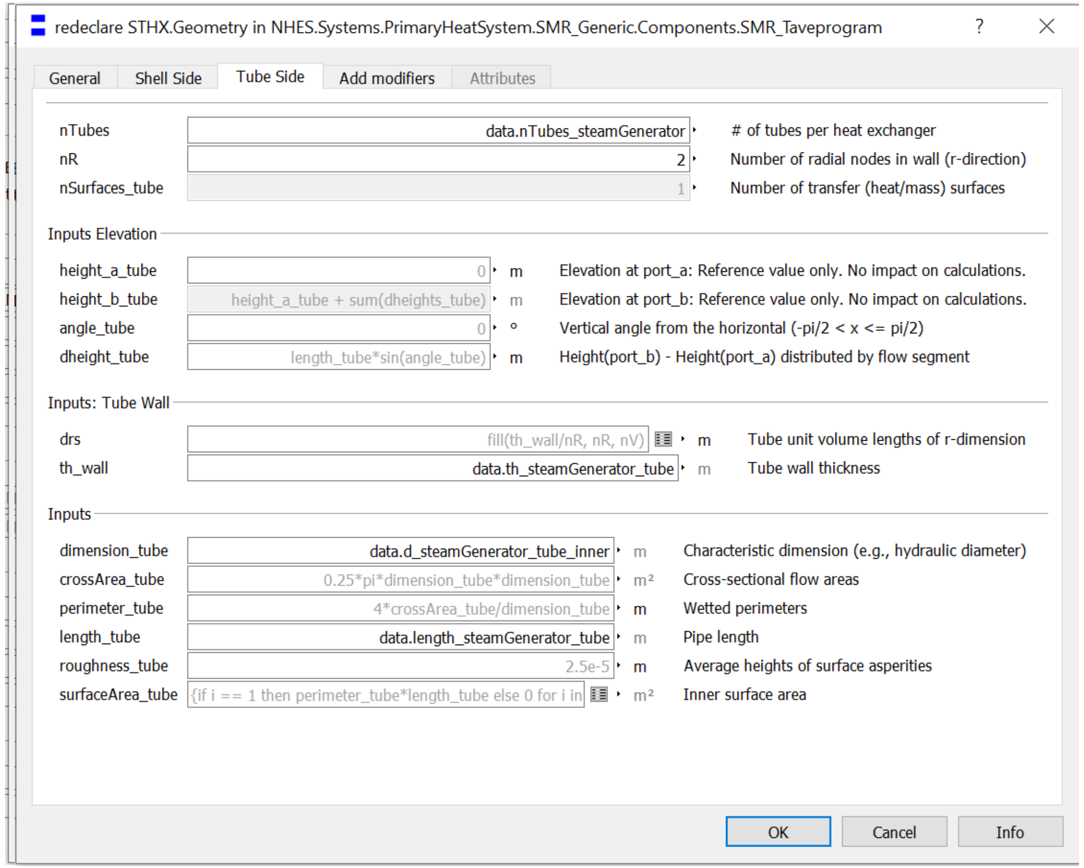
Passing Parameters



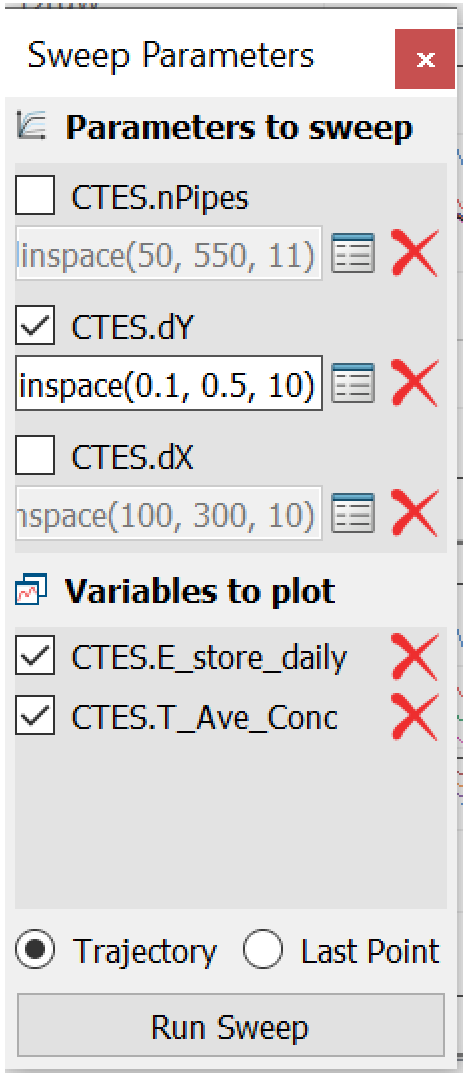


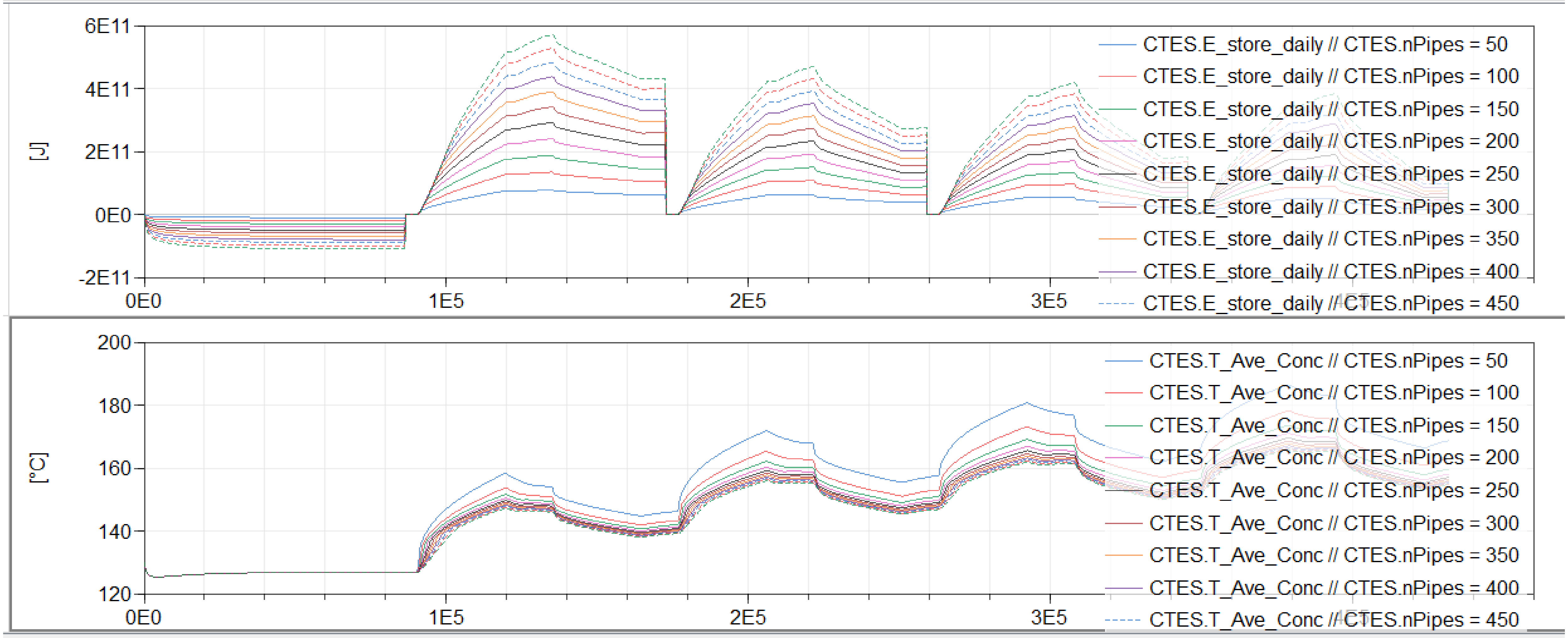
Integration of Existing Models

- Using existing models takes advantage of object building within Modelica
- The same components can be used repeatedly
- Ports impose consistent communication between components
- When building sub-models and subsystems, make sure that relevant parameter passing methods are set up

Parameter Sweeping

- Dymola has internal parameter sweeping method
- Allows for output space generation across single altered parameter at a time
- Auto generates separate output files to keep post simulation
- Auto generates plotting set of output values desired by user

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4E11
2E11
0E0
-2E11
[J]
0E0
1E5
2E5
3E5
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CTES.E_store_daily // CTES.nPipes = 100
CTES.E_store_daily // CTES.nPipes = 150
CTES.E_store_daily // CTES.nPipes = 200
CTES.E_store_daily // CTES.nPipes = 250
CTES.E_store_daily // CTES.nPipes = 300
CTES.E_store_daily // CTES.nPipes = 350
CTES.E_store_daily // CTES.nPipes = 400
CTES.E_store_daily // CTES.nPipes = 450
200
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[°C]
CTES.T_Ave_Conc // CTES.nPipes = 50
CTES.T_Ave_Conc // CTES.nPipes = 100
CTES.T_Ave_Conc // CTES.nPipes = 150
CTES.T_Ave_Conc // CTES.nPipes = 200
CTES.T_Ave_Conc // CTES.nPipes = 250
CTES.T_Ave_Conc // CTES.nPipes = 300
CTES.T_Ave_Conc // CTES.nPipes = 350
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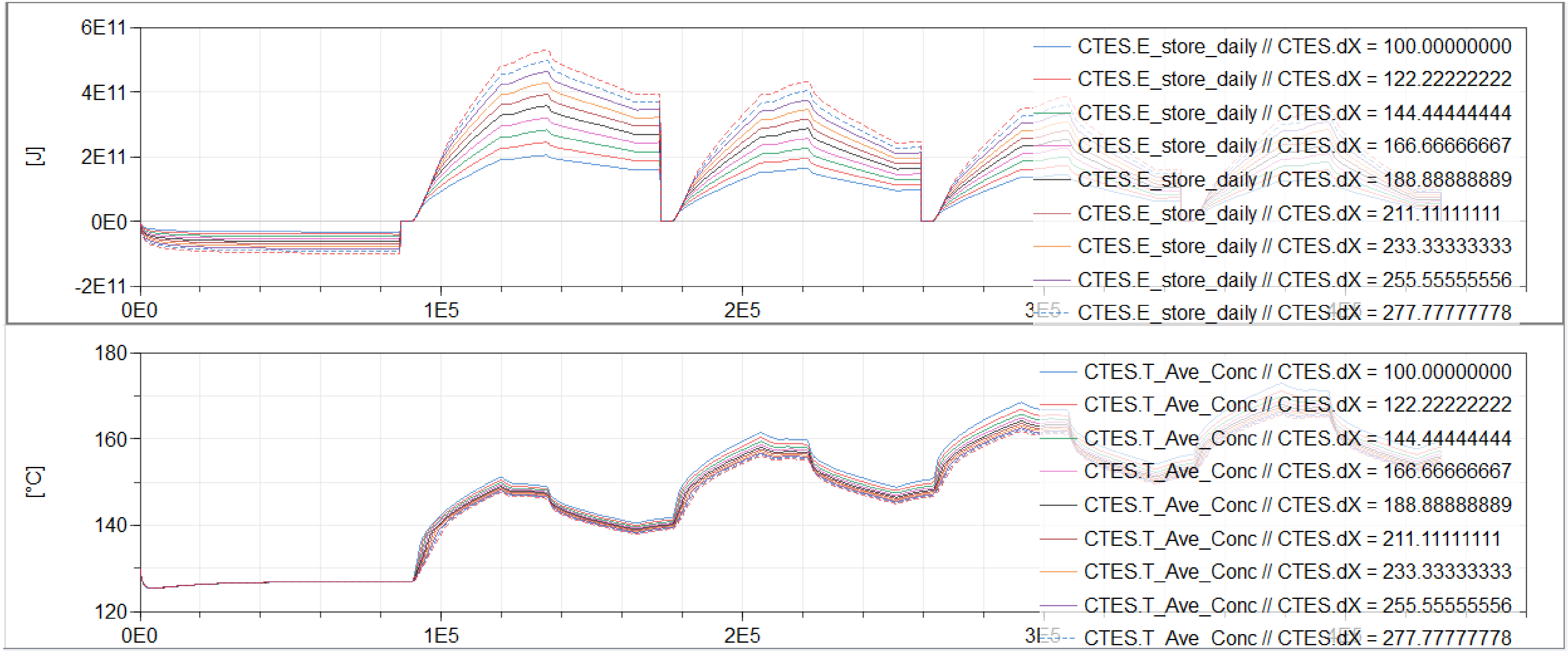

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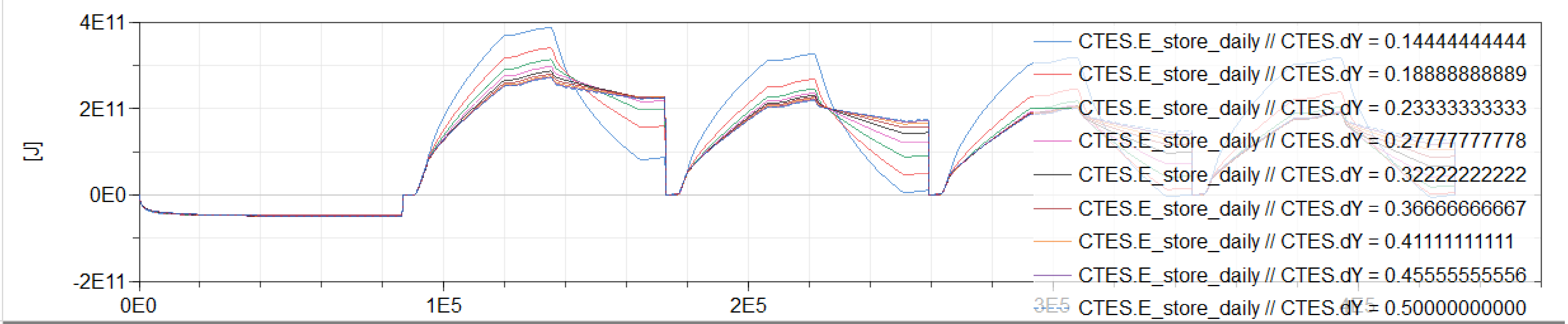
4E11
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CTES.E_store_daily // CTES.dY = 0.14444444444
CTES.E_store_daily // CTES.dY = 0.18888888889
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CTES.E_store_daily // CTES.dY = 0.27777777778
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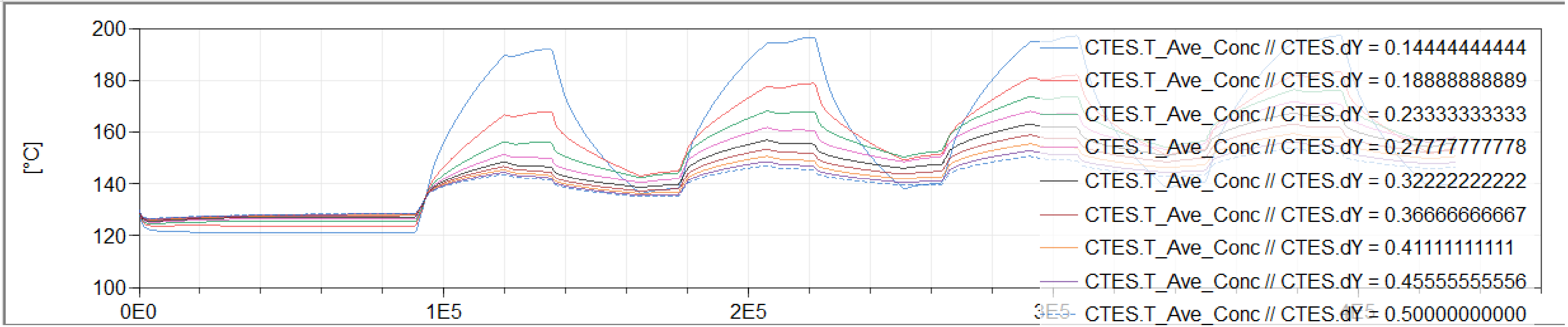
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CTES.T_Ave_Conc // CTES.dY = 0.14444444444
CTES.T_Ave_Conc // CTES.dY = 0.18888888889
CTES.T_Ave_Conc // CTES.dY = 0.23333333333
CTES.T_Ave_Conc // CTES.dY = 0.27777777778
CTES.T_Ave_Conc // CTES.dY = 0.32222222222
CTES.T_Ave_Conc // CTES.dY = 0.36666666667
CTES.T_Ave_Conc // CTES.dY = 0.41111111111
CTES.T_Ave_Conc // CTES.dY = 0.45555555556
CTES.T_Ave_Conc // CTES.dY = 0.50000000000

Manual Parameter Sweep

- In the case that a model is sensitive to initial conditions, it is possible to manually alter parameters via the dsfinal.txt file to effectively manually parameter sweep

- Combined with script generation, this process can be automated so that there is less user attention required

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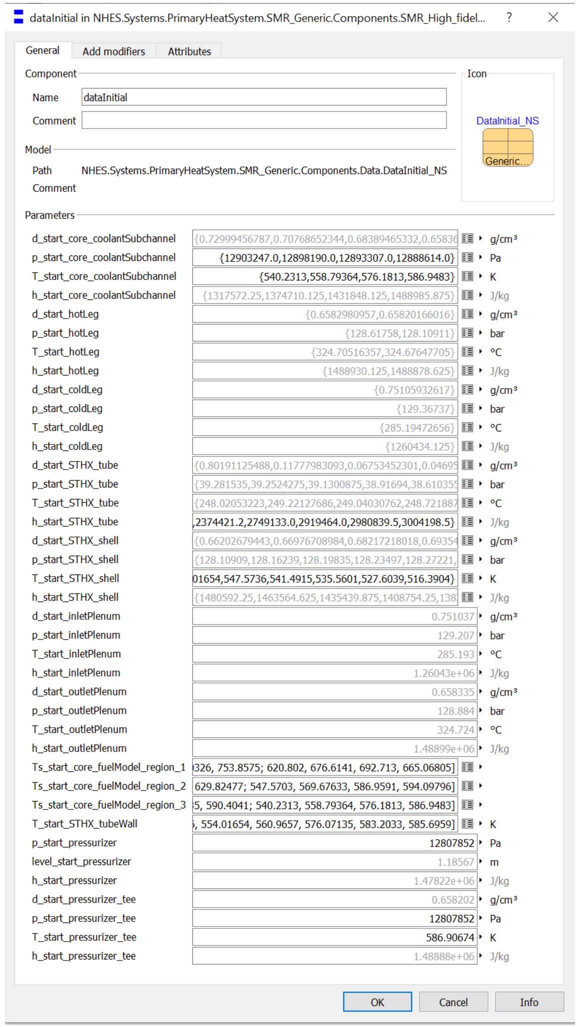
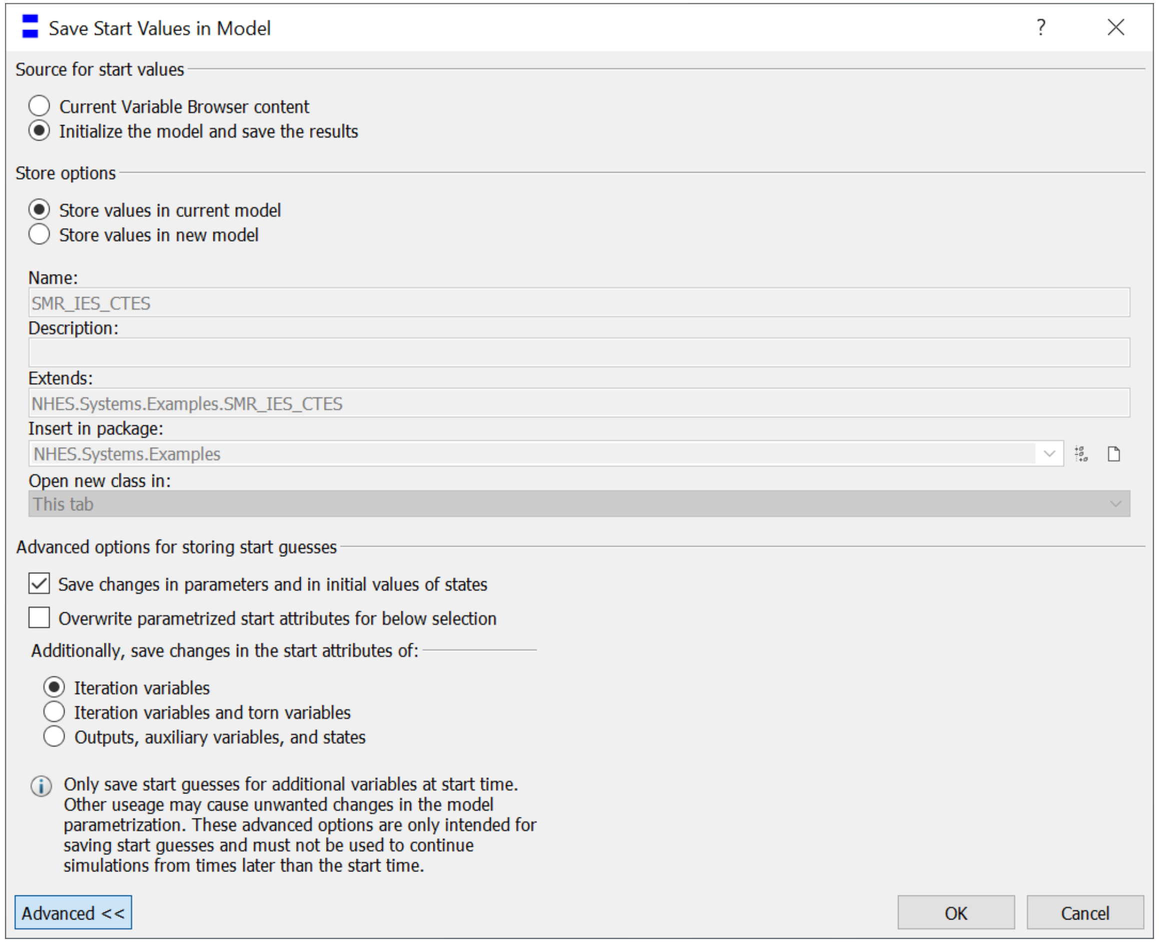
Initial Conditions

- Model initialization is key to obtaining results, especially if a simulation stabilization time frame can be avoided
- One method of creating an initial state is to use a robust outside result to create an initial conditions table
  - ASPEN HYSYS is often used



Initial Conditions

- Inherent method within Dymola to save within a model the initial conditions
- When used, the output space is saved within the model directly as adjustments to the attributes



Initial Conditions

```
BOP(
  CS(
    BV_openingNominal(k(start=0.001)),
    PID_BV_opening(
      I(k(start=0.1)),
      addP(
        k1(start=1.0),
        u1(start=0.0300000001485),
        u2(start=0.0300000001485)),
      gainPID(k(start=-1.0)),
      gainTrack(k(start=-1.1111111111111112)),
      gain_u_m(k(start=5E-10)),
      gain_u_s(k(start=5E-10)),
      limiter(uMax(start=0.999), uMin(start=-0.0009)),
      null_bias(k(start=0.0)),
      yMax(start=0.999),
      yMin(start=-0.0009)),
    PID_TCV_opening(
      I(k(start=2.0)),
      addP(
        k1(start=1.0),
        u1(start=0.0086185),
        u2(start=0.0086185)),
      gainTrack(k(start=1.1111111111111112)),
      gain_u_m(k(start=2.5E-09)),
      gain_u_s(k(start=2.5E-09)),
      limiter(uMax(start=0.5), uMin(start=-0.4999)),
      null_bias(k(start=0.0)),
      u_s(start=3447400.0),
      yMax(start=0.5),
      yMin(start=-0.4999)),
    TCV_openingNominal(k(start=0.5)),
    delayStartBV(start=100.0),
    p_Nominal1(k(start=3447400.0)),
    switch_P_setpoint(y(start=60000000.297)),
    valvedelay(k(start=100.0)),
    valvedelayBV(k(start=100.0))),
  PID(
    I(k(start=2.0)),
    addP(
      k1(start=1.0),
      u1(start=1.0),
      u2(start=1.0)),
    gainPID(k(start=100000000.0)),
    gainTrack(k(start=1.1111111111111112E-08)),
    gain_u_m(k(start=0.002374343174368348)),
    gain_u_s(k(start=0.002374343174368348)),
    k_m(start=0.002374343174368348),
    k_s(start=0.002374343174368348),
    limiter(
      u(start=100000000.0),
      uMax(start=1E+60),
      uMin(start=-1E+60)),
    null_bias(k(start=100000000.0)),
    u_m(start=421.1691093331664),
    yMin(start=-1E+60)),
  PID1(
    PID(
      I(k(start=2.0)),
      Nd(start=10.0),
      Ni(start=0.9),
      Td(start=0.1),
      Ti(start=0.5),
      addP(
        k1(start=1.0),
        u1(start=1.0),
        u2(start=1.0)),
      gainPID(k(start=100.0)),
      gainTrack(k(start=0.011111111111111112)),
      gain_u_m(k(start=0.1))
```

```
actuatorBus(opening_BV(start=0.001), opening_TCV(start=0.5)),
boundary(port(T(start=421.1691093331664))),
boundary2(medium(
    T(start=298.16763607879363),
    T_degC(start=25.017636078793657),
    d(start=998.544943058541),
    p_bar(start=34.473800000000004),
    sat(Tsat(start=514.8425665422984)),
    u(start=104571.53362749857)), ports(h_outflow(start={108023.9370710939}),
```

```
     Kt(start=0.013324090093760938),
     Q_mech(start=65056859.70577499),
     Q_units(start={42261285.79911617,42261285.79911617}),
     Q_units_start(start={42261285.79911617,42261285.79911617}),
     Qbs(start={-9732855.946228676,-9732855.946228676}),
     T_a_start(start=293.15),
     T_b_start(start=293.15),
     T_nominal(start=293.15),
     bubble_in(d(start=820.3581983078773), h(start=1013666.6724914373)
     bubble_out(d(start=989.8436373961912), h(start=191812.29519356362
     d_nominal(start=13.671247252758716),
     dew_in(d(start=15.307197090608243), h(start=2803284.170249812)),
     dew_out(d(start=0.06816373081854721), h(start=2583886.8570257137)
     h_a_start(start=2997670.0),
     h_b_start(start=2058530.3155751962),
     h_is(start=2070197.5860370956),
     h_out(start=2209318.4481315315),
     p_a_start(start=3337380.0),
     p_b_start(start=10000.0),
     p_inlet_nominal(start=3337380.0),
     p_outlet_nominal(start=10000.0),
     p_ratio(start=0.0032668200354825697),
     portHP(
```

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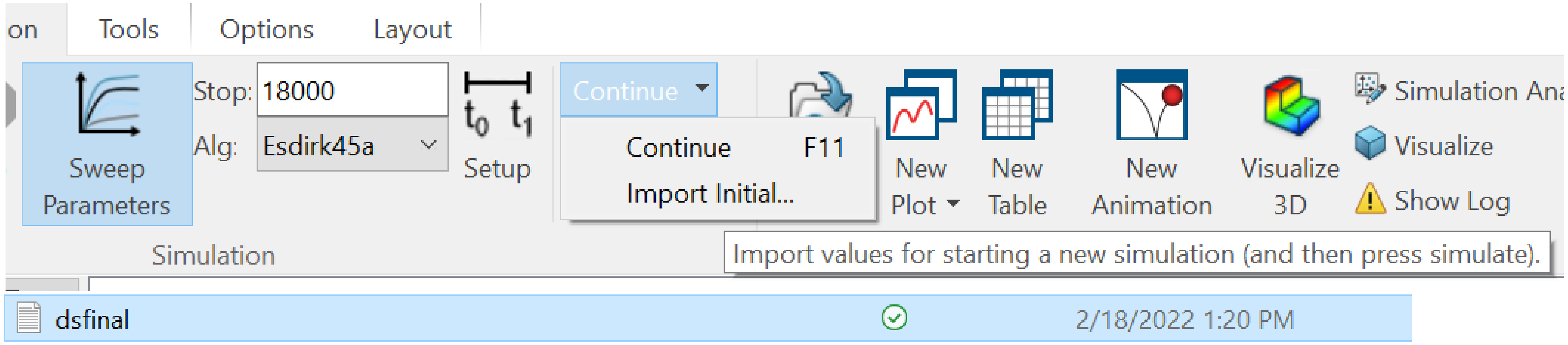
Initial Conditions

- Another method of importing initial conditions is using default output format



- This method can be used to alter parameters by altering the text file

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RAVEN Interfacing

- Default initialization or final status text file is standard RAVEN input method
- Values identified in RAVEN input substituted

```
-2  1.0000000000000001E-01       0                        0
 1   280 # nuScale_Tave_enthalpy_Pressurizer_CR.PID.k
-2  5.0000000000000000E-01  9.9999999999999997E-61 1.0000000000000000E+100
 1   280 # nuScale_Tave_enthalpy_Pressurizer_CR.PID.Ti
-2  1.0000000000000001E-01       0                 1.0000000000000000E+100
 1   280 # nuScale_Tave_enthalpy_Pressurizer_CR.PID.Td
-2       0                       0                        0
 1   280 # nuScale_Tave_enthalpy_Pressurizer_CR.PID.yb
-2  5.0000000000000000E-01       0                        0
 6   256 # nuScale_Tave_enthalpy_Pressurizer_CR.PID.k_s
-2  5.0000000000000000E-01       0                        0
 6   256 # nuScale_Tave_enthalpy_Pressurizer_CR.PID.k_m
-2  5.6600000000000001E+00       0                        0
 1   280 # nuScale_Tave_enthalpy_Pressurizer_CR.PID.yMax
-2       0                       0                        0
 1   280 # nuScale_Tave_enthalpy_Pressurizer_CR.PID.yMin
```

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RAVEN Interface

- Executable made via Dymola and path input into RAVEN
  - User should make sure that “evaluate parameters at translation” option is disabled
- Dymola is subType “Dymola” in the input deck
- Input name type is “DymolaInitialisation”

Model Analysis

- Scripting allows for manual creation of parameter sweep
  - Method is: Translate(), import(), simulate()
- Dymola has internal parameter sweep methods
  - Only one parameter can be changed at once
- RAVEN interface uses standard input to accept new parameter methods
- Reminder from previous: models can use text reading for input, which can read dispatch information generated by another code

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

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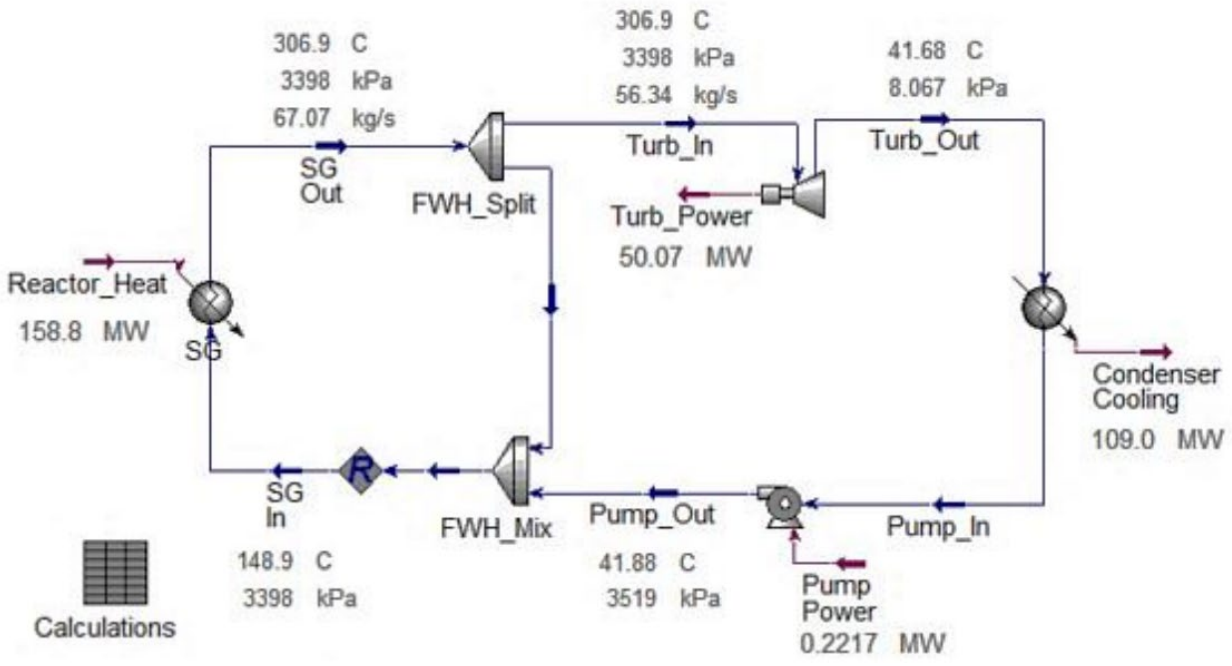
Why Aspen?

- Industry-standard thermodynamic and chemical analyses tool
- Allows for process changes, flow rearrangements
- Chemical reactors allow for process calculations



Why ROMs?

- Allow for shorter computation times
- Accuracy relative to trained model will be identical
- RAVEN contains many ROM training methods
- DMDc is nominal method of choice, allows for analysis of systems that use controllers

Questions?

Integrated Energy Systems

HYBRID – What Is It?

- Hybrid is a collection of physical models written to characterize:
  - Thermal and electrical integration of different processes
  - Ramp speed
  - Evaluation of novel control schemes
  - Off-design system states
  - Dispatch feasibility
  - Safety limit approaches, considering control system effects

  - https://github.com/idaholab/HYBRID

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