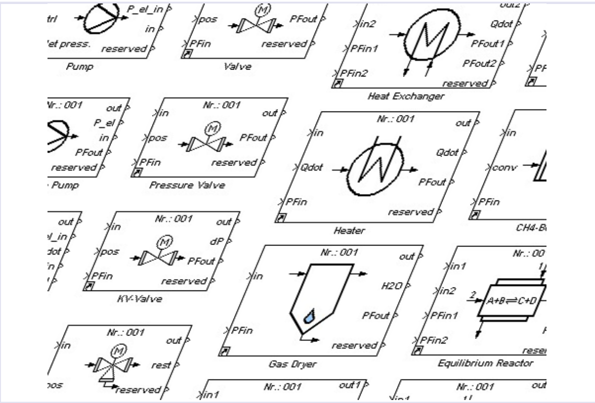
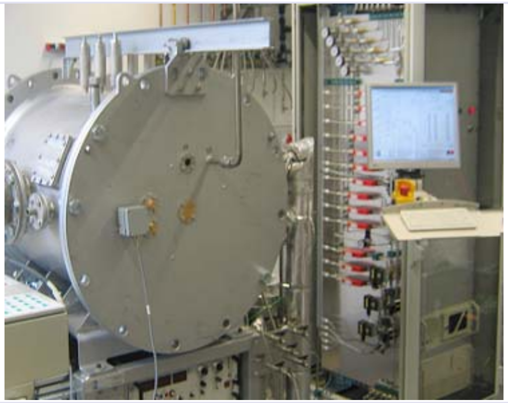
Thermolib

Thermodynamic systems library

Introduction and Applications

Release 5.0





5.0.0.2/5.0c

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Introduction

Thermolib ...

... is a Simulink® library for modeling and simulation of thermodynamic **systems**.

... focuses on modeling and simulation at the **systems level => simulation for control**.

... provides seamless integration with The MathWorks tools used for Model-Based Design and rapid control prototyping.

... fills a gap in The MathWorks products suite – engineering thermodynamic modeling.

EUtech Scientific Engineering GmbH is member in The MathWorks Connections program.

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Content

- Examples
  - Power Plants (Combined Cycle, Forced Circulation, Solar Thermal)
  - Fuel Cell Vehicle
  - Ammonia Production
  - Heating Installation
  - Air Conditioning
  - Reforming Process
- Architecture
  - Special features
  - Command line functions
- How does Thermolib integrate into The MathWorks tool chain?
- Summary

Systems that can be modeled …

Example – Combined Cycle Power Plant

Example – Combined Cycle Power Plant

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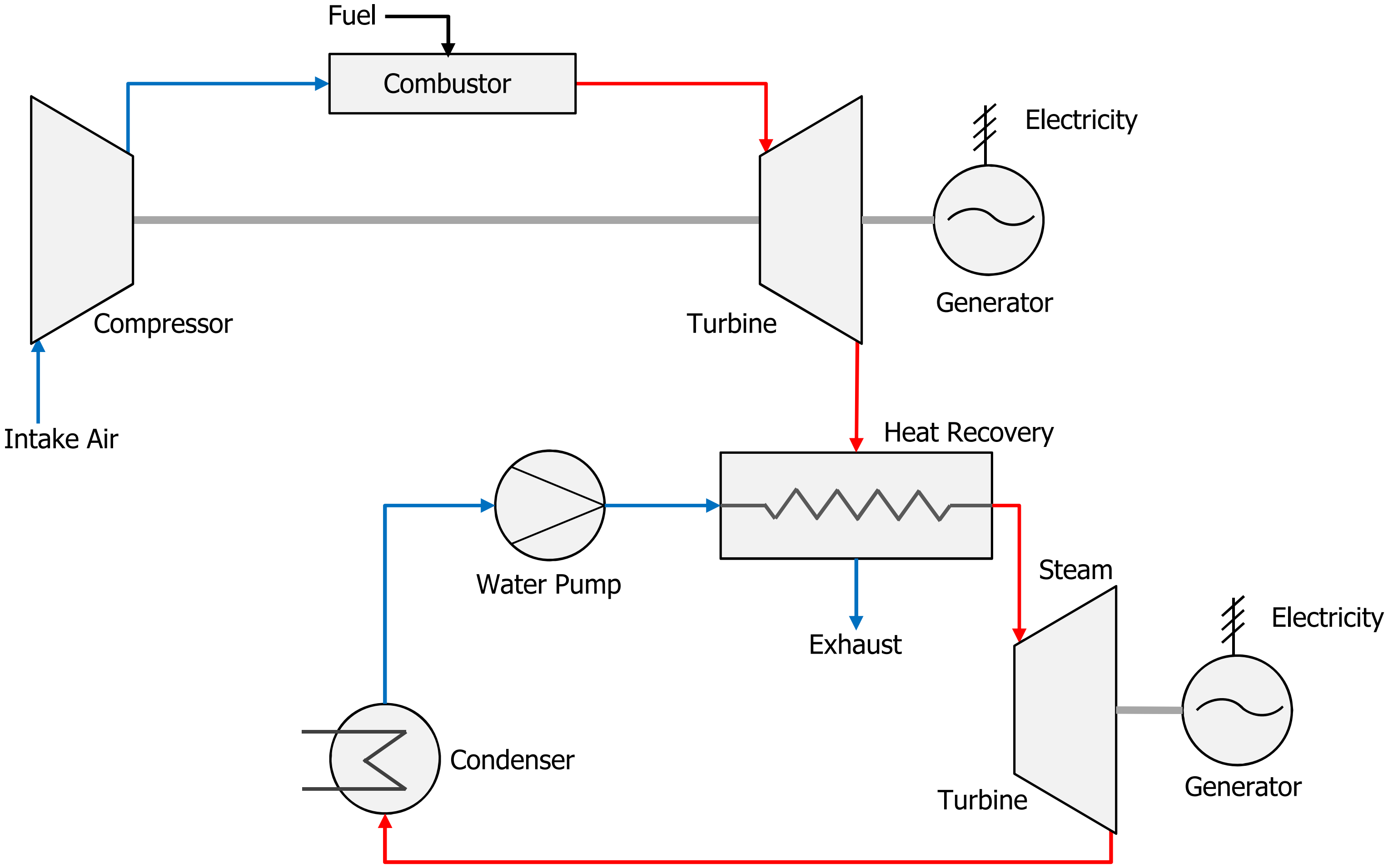
Flow scheme

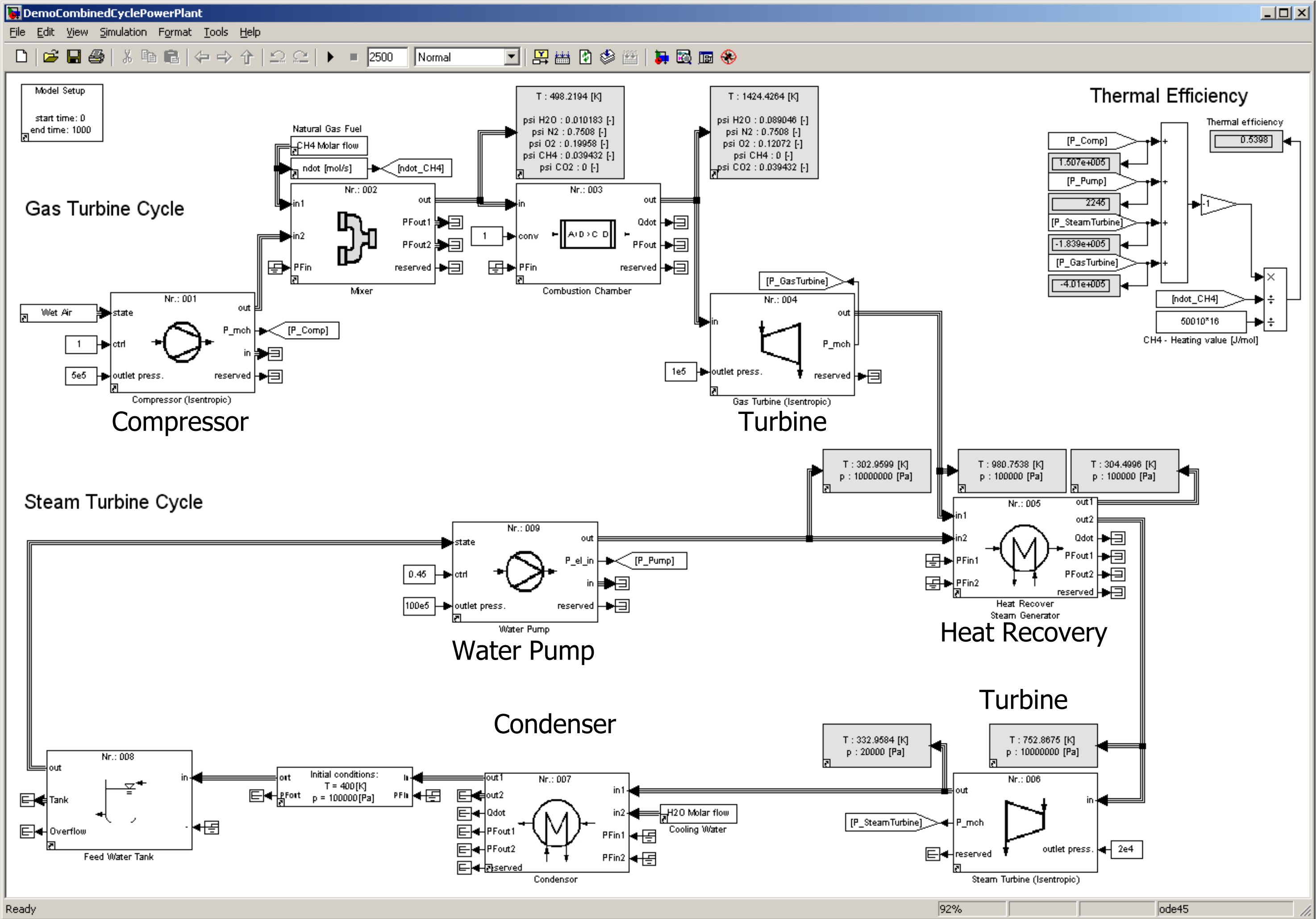
Gas Turbine (Brayton) Cycle

Steam Turbine (Rankine) Cycle



Example – Combined cycle power plant

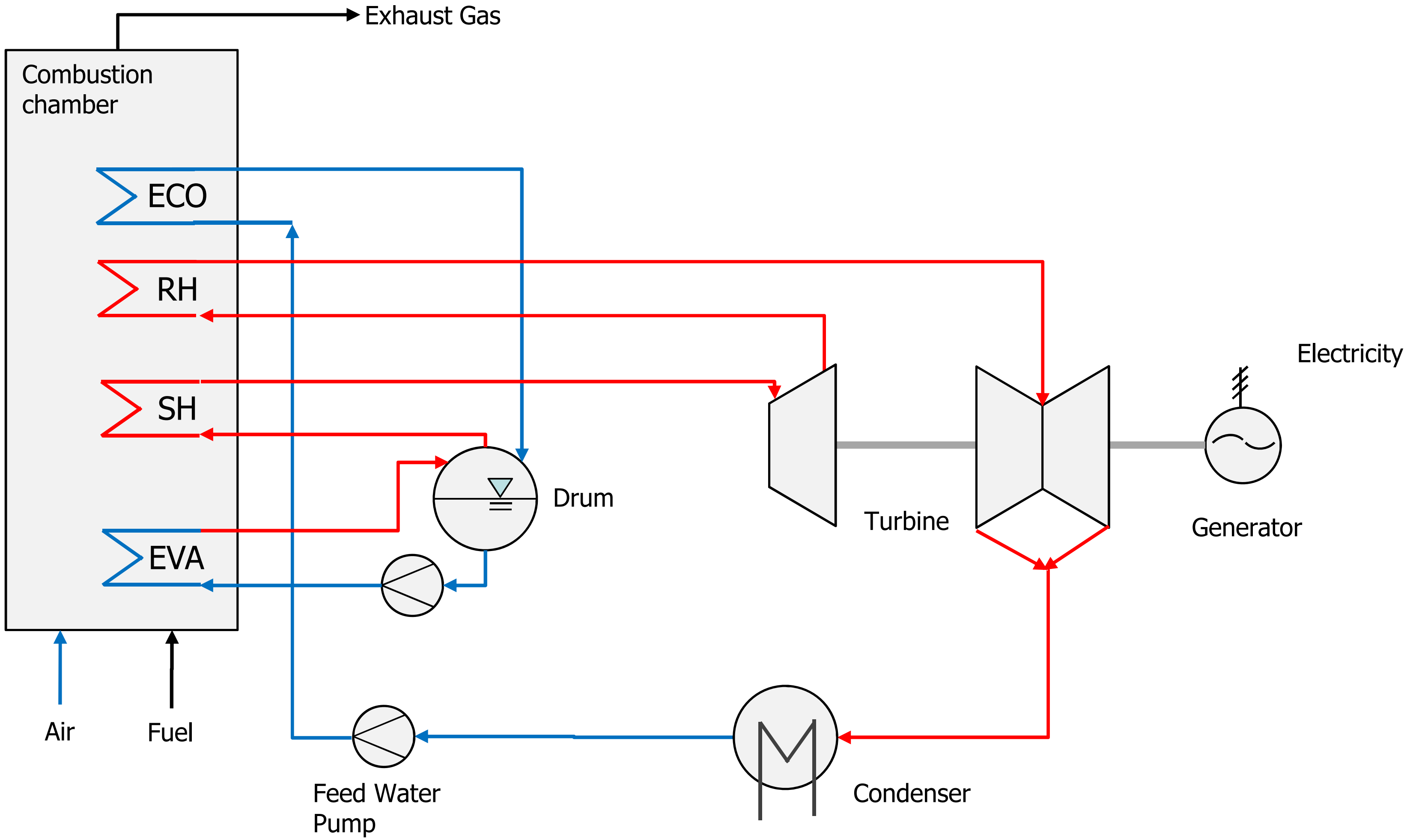
Simulink Model with Thermolib blocks



Example – Forced Circulation Boiler

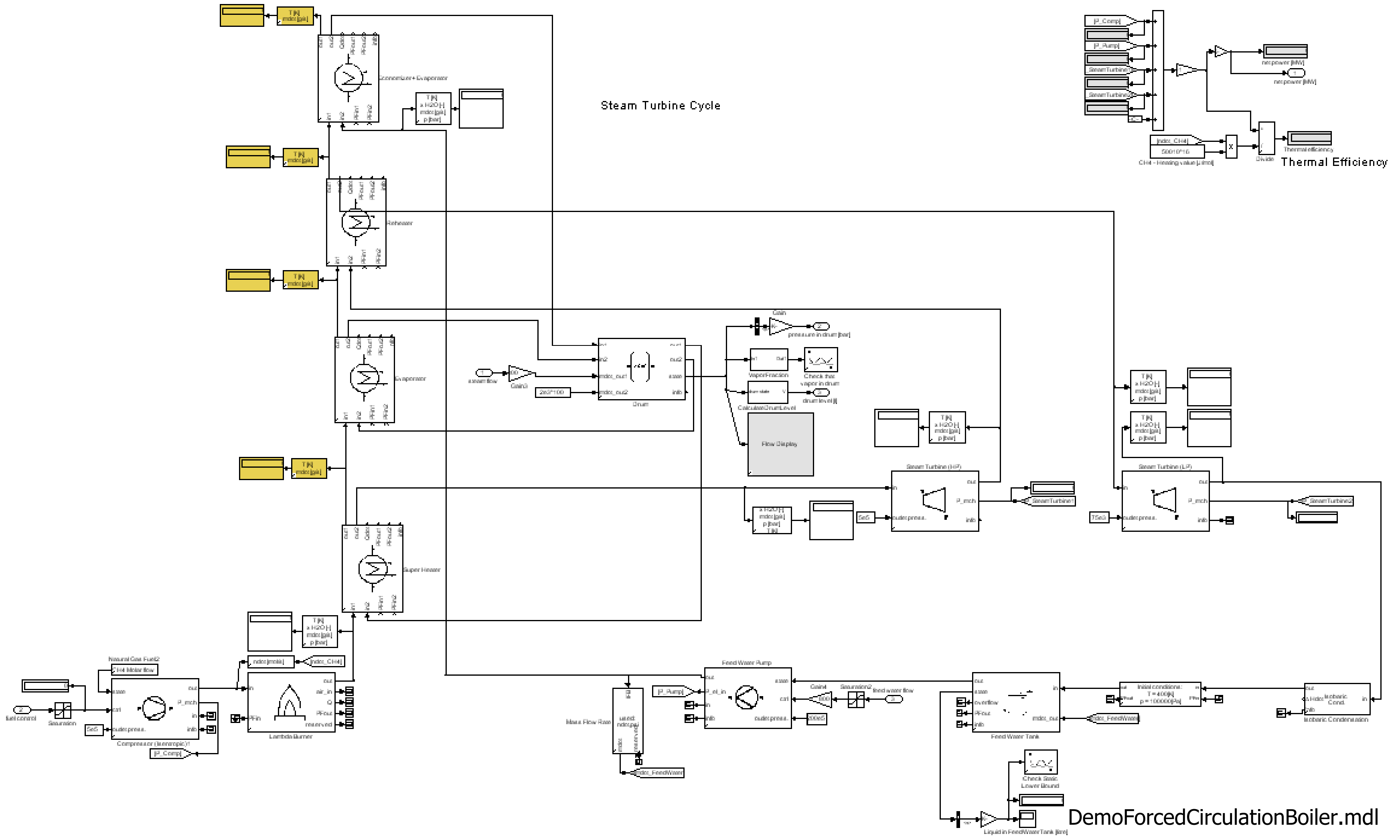
Example – Forced Circulation Boiler

Flow scheme



Example – Forced Circulation Boiler

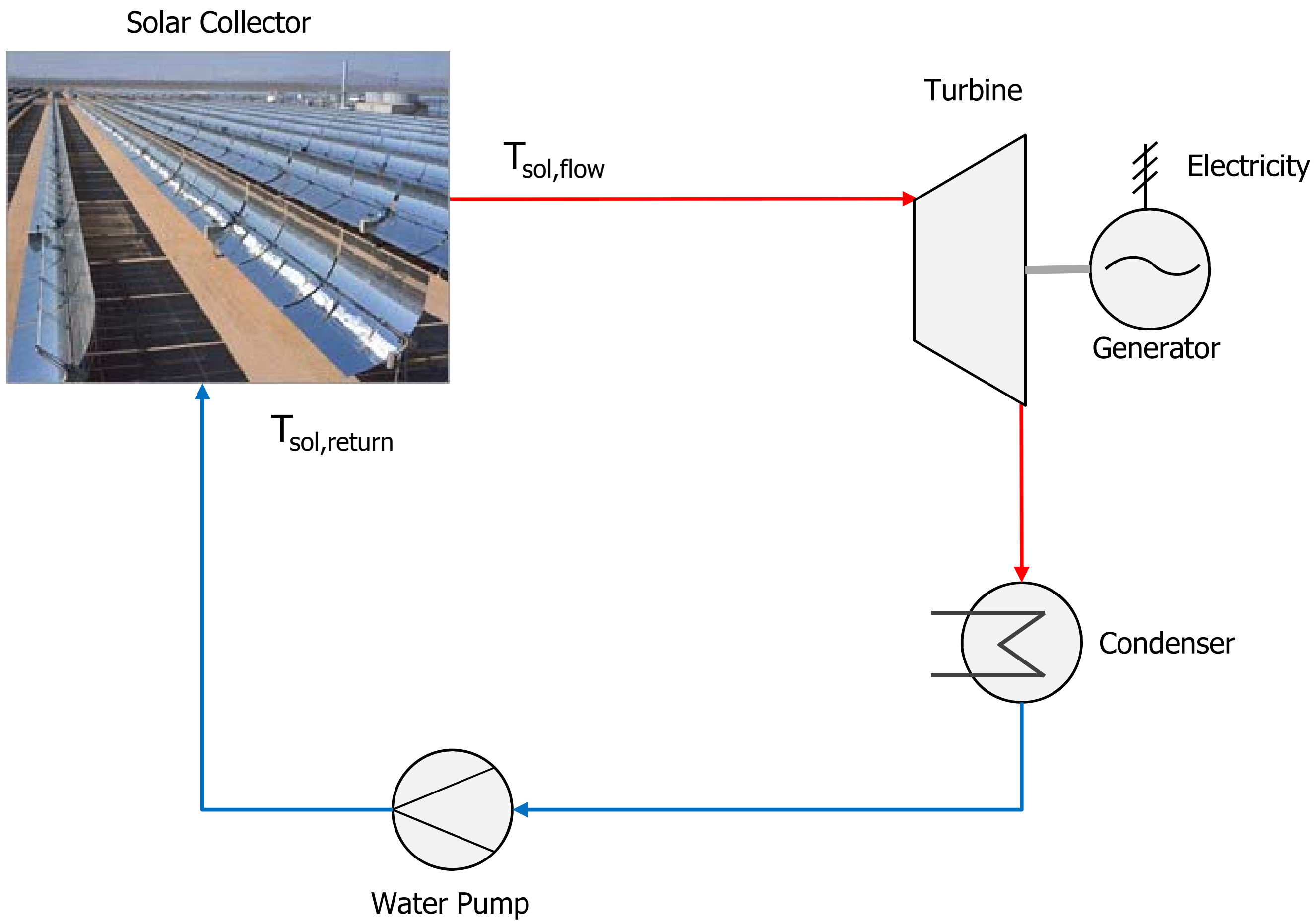
Simulink implementation using Thermolib



Example – Solar Thermal Plant

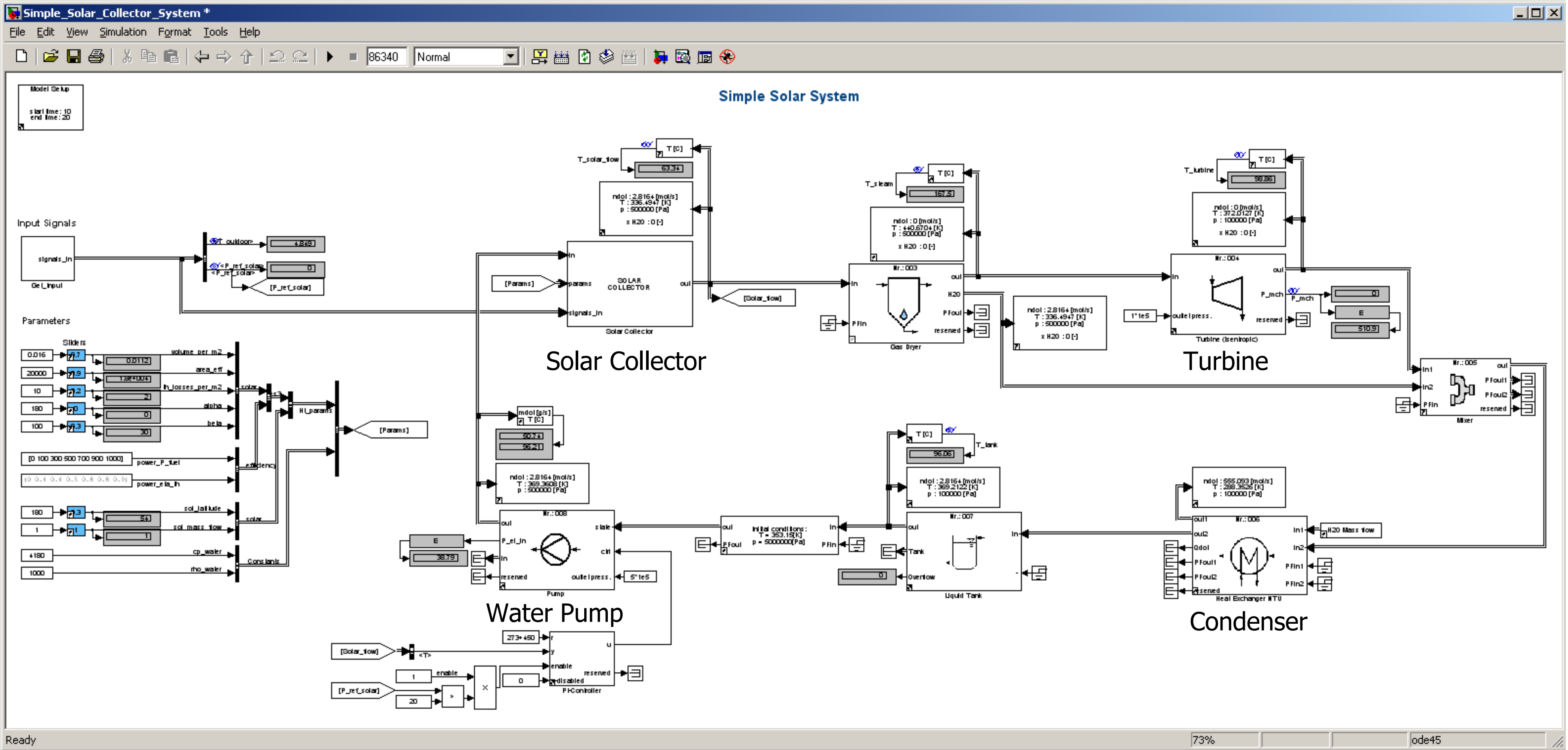
Example – Solar Thermal Plant

Flow scheme



Example – Solar Thermal Plant

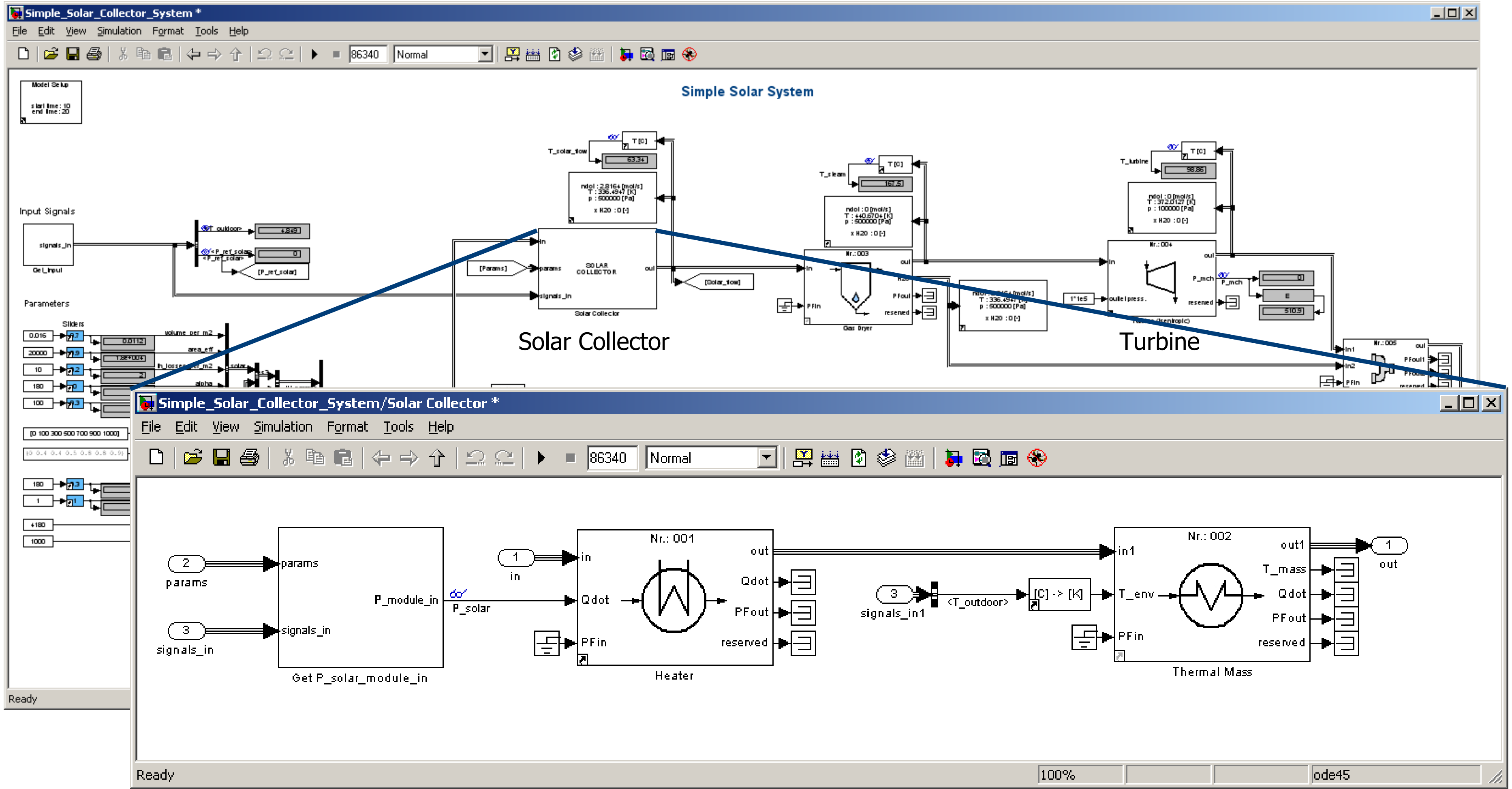
Simulink Model with Thermolib blocks



DemoSimpleSolarCollectorSystem.mdl

Example – Solar Thermal Plant

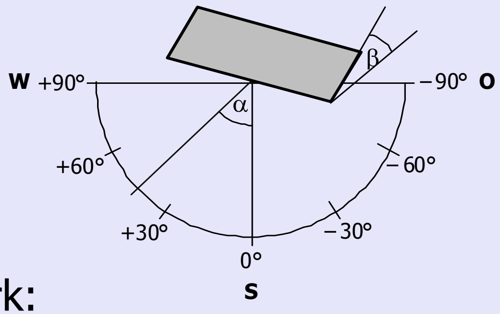
Solar Collector



Example – Solar Thermal Plant

Configuration

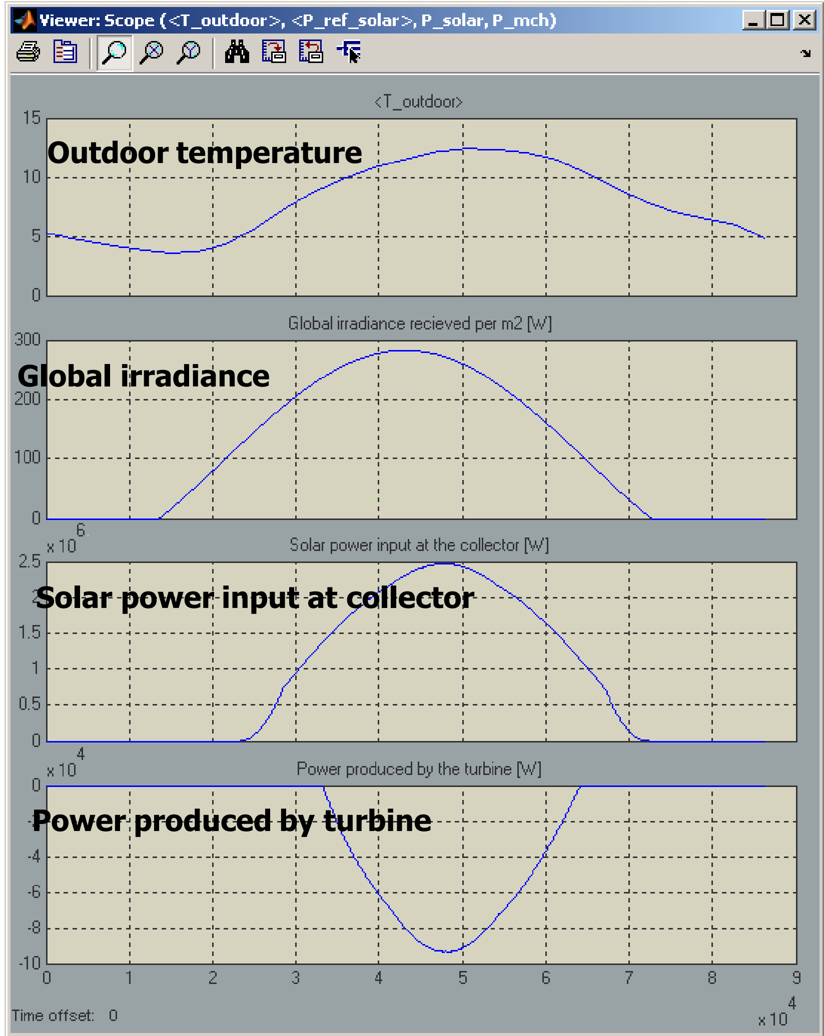
1. Effective area of solar collectors: 18,000 square meters.
2. Slope ß = 30°
3. Oriented 36°west of south



Remark:

The position and the west orientation is just to show the effects in this example (see lag of turbine power against irradiance).
A real world plant would adjust position to geographical location and could optionally use active tracking of current sun position to maximize input power.

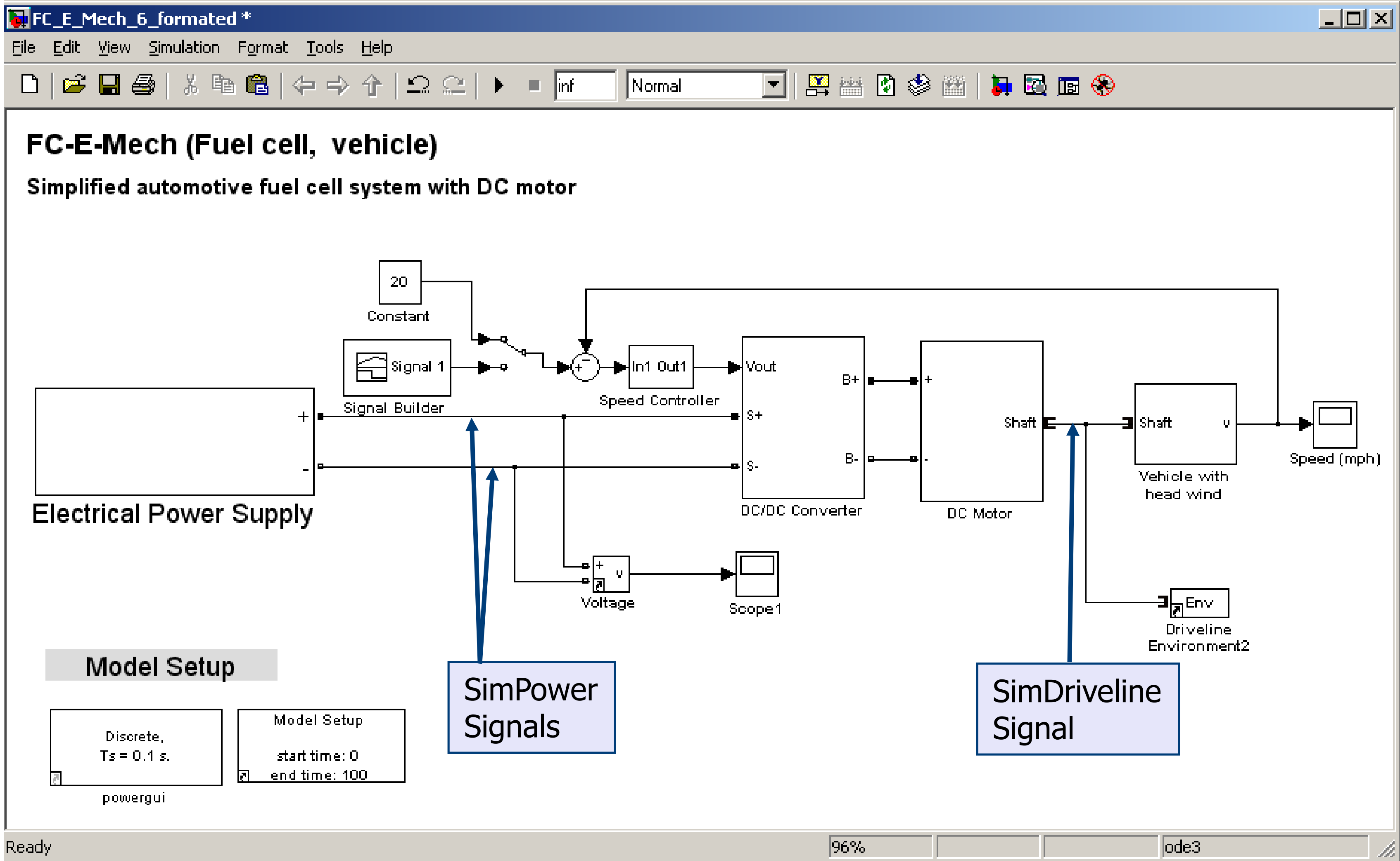
Simulation Results



Example – Fuel Cell Vehicle

Example – Fuel Cell Vehicle

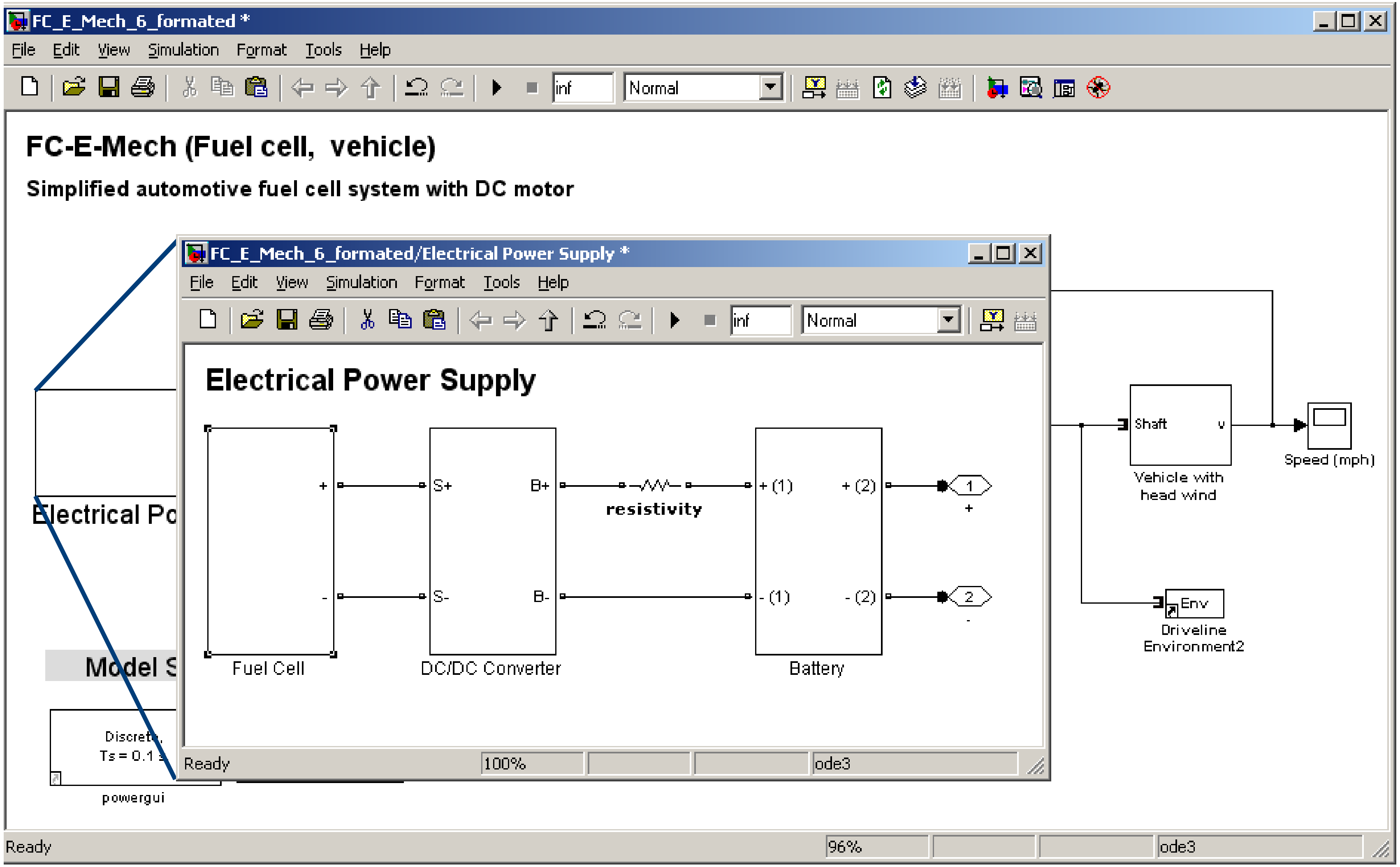
Overview



Simulink-version: DemoFuelCellVehicle.mdl

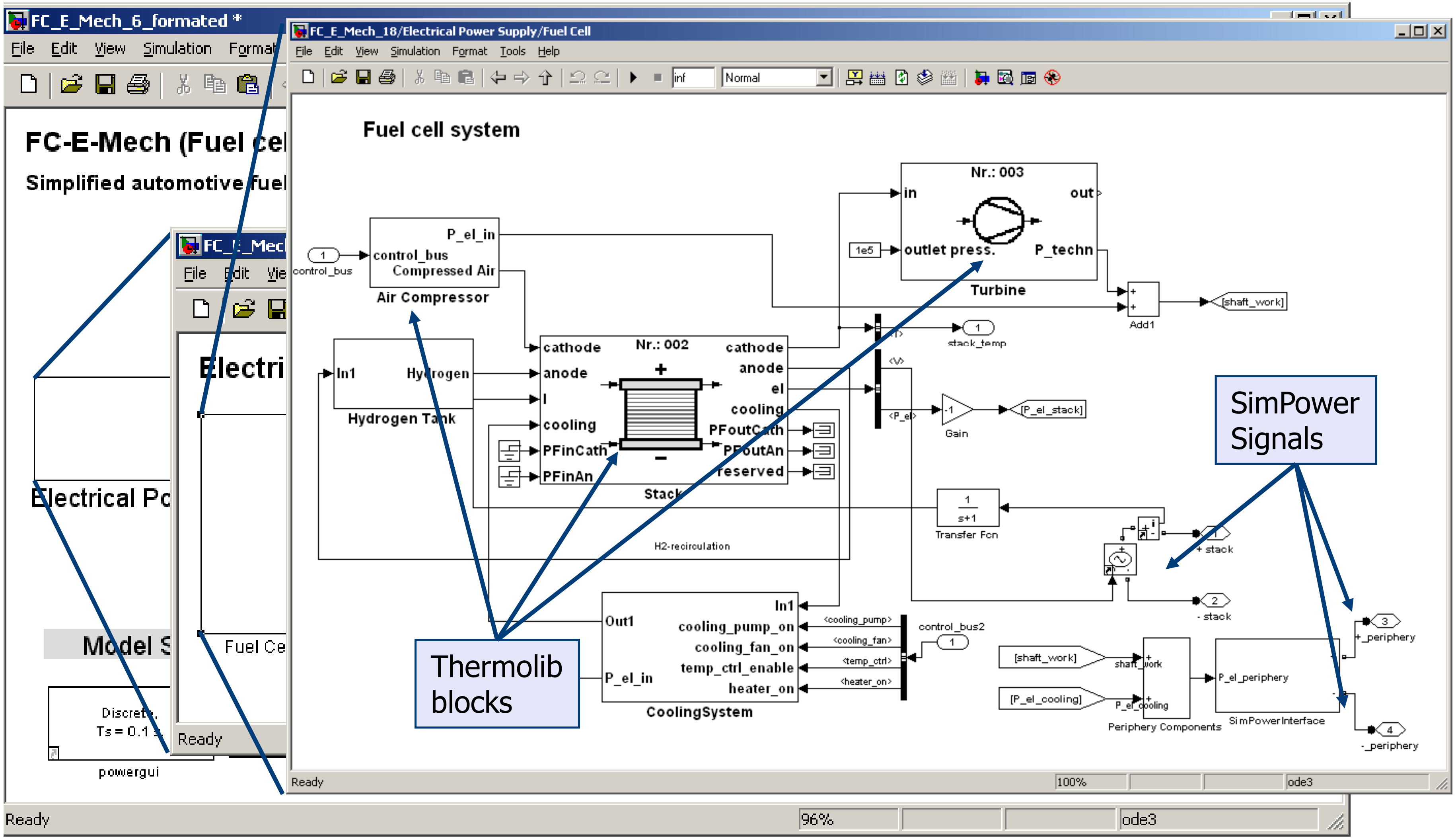
Example – Fuel Cell Vehicle

Electrical Power Supply



Example – Fuel Cell Vehicle

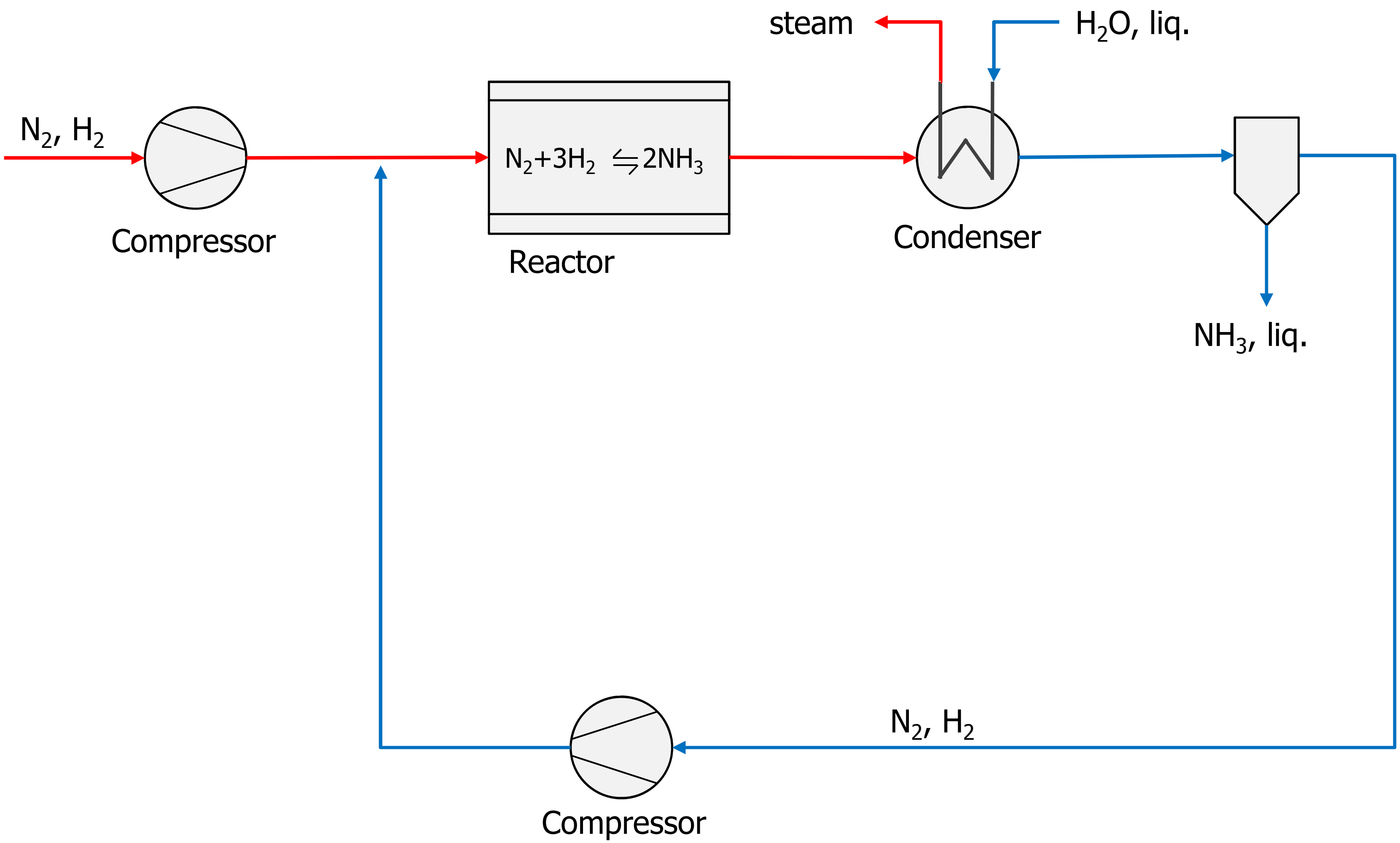
Fuel Cell modeled with Thermolib



Example – Ammonia Production

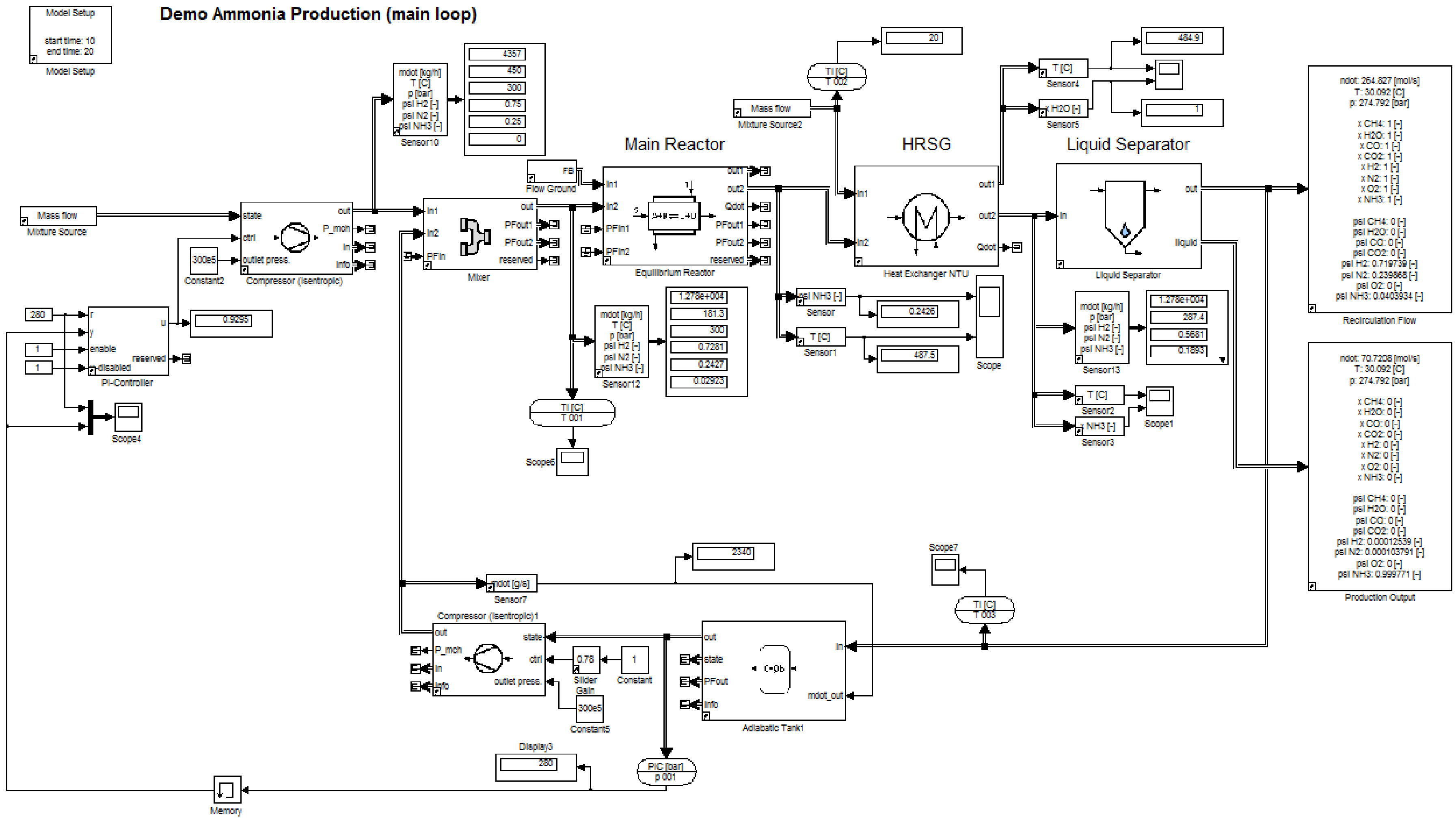
Example - Ammonia Production

Flow scheme – Main loop



Example - Ammonia Production

Flow scheme

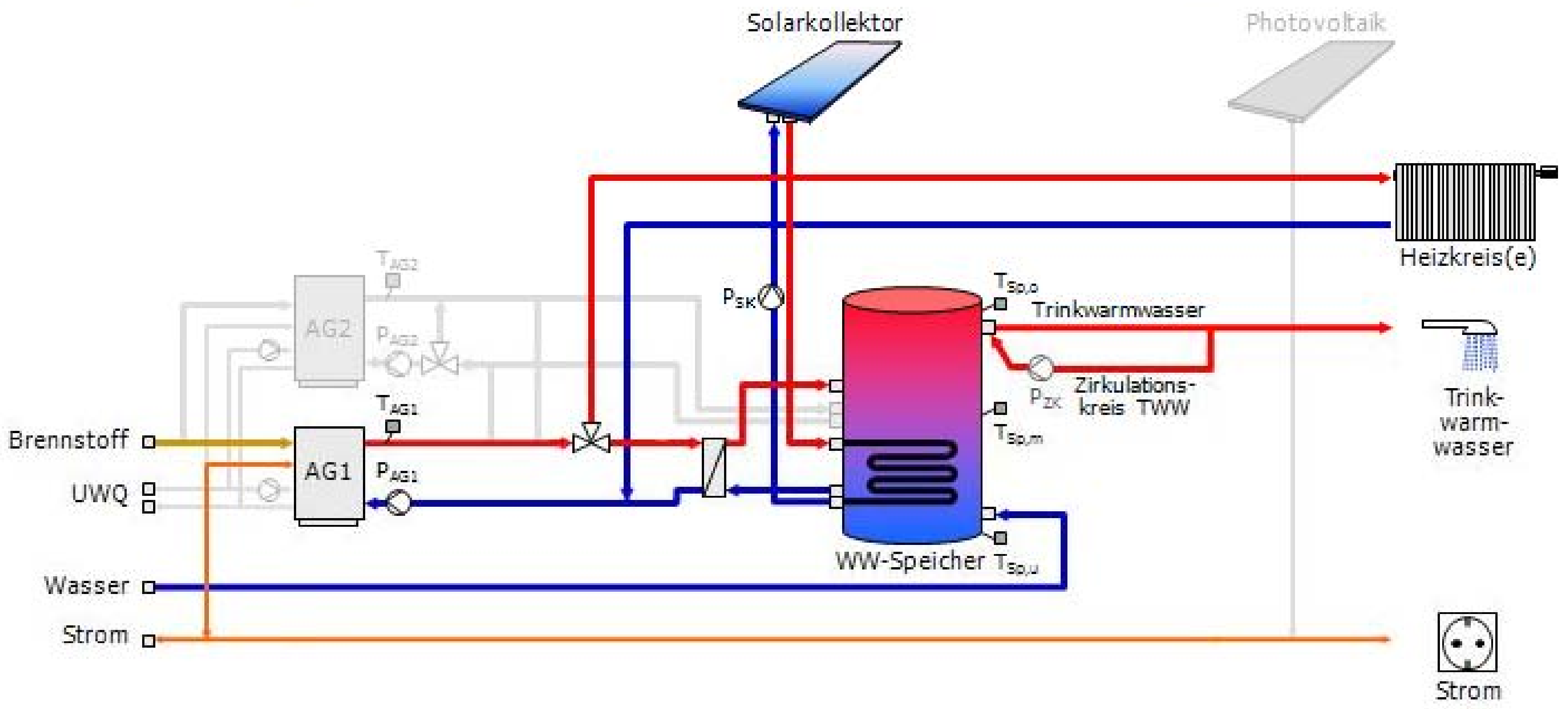


DemoAmmoniaProduction.mdl

Example – Heating Installation

Example – Heating Installation

Flow scheme



Example – Heating Installation

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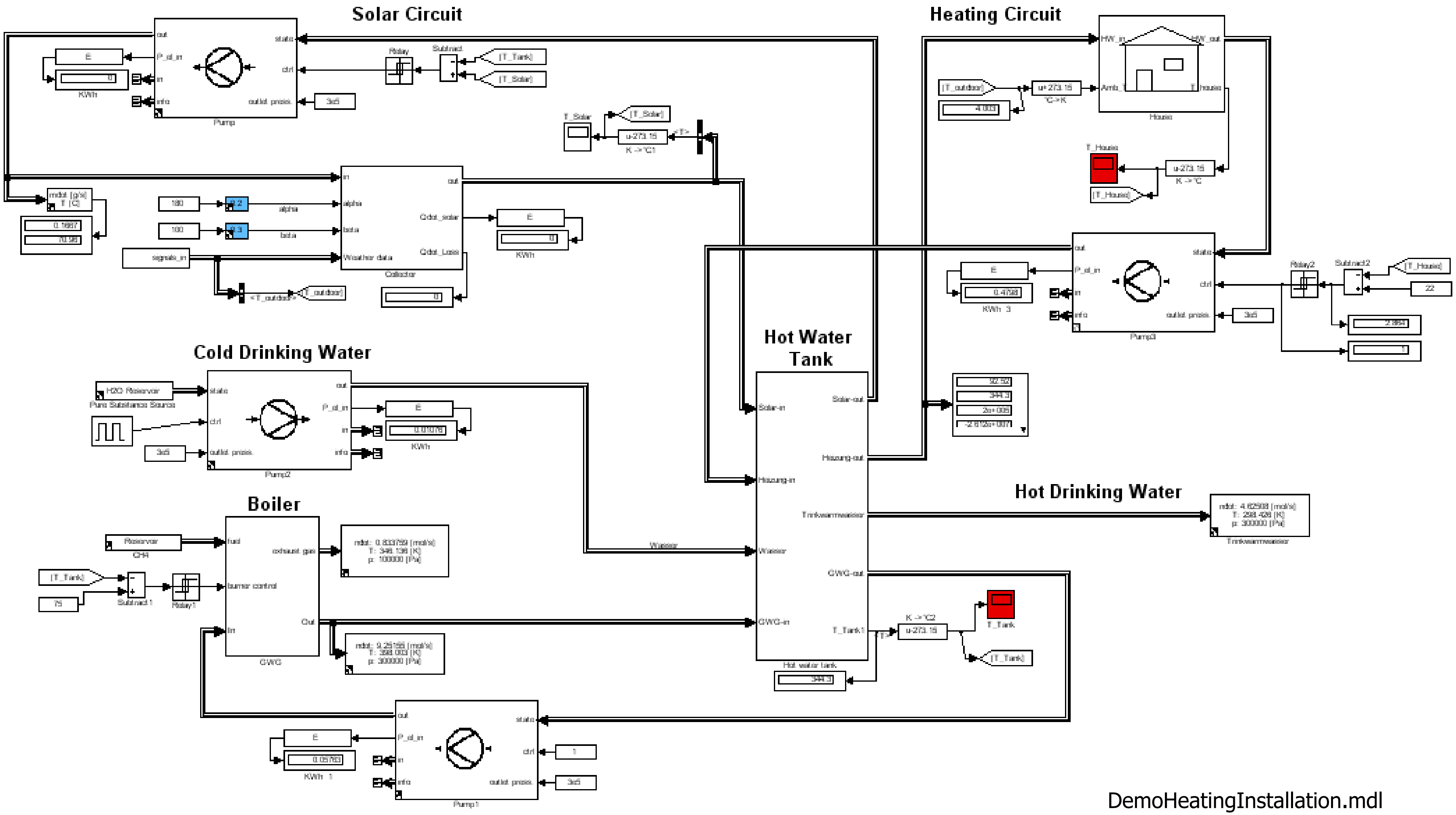
Simulink Model with Thermolib blocks

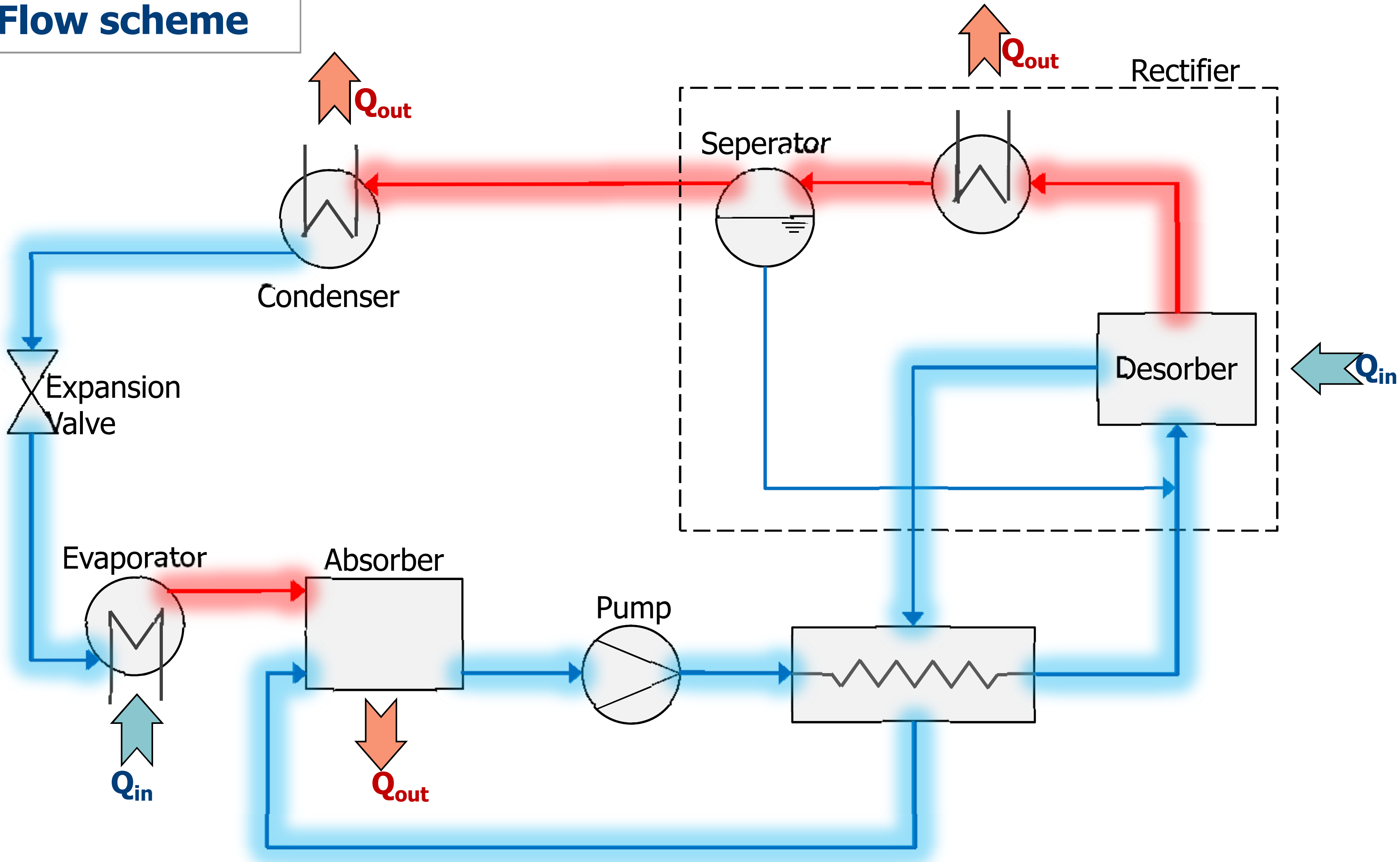


DemoHeatingInstallation.mdl

Example – Absorption Heat Pump

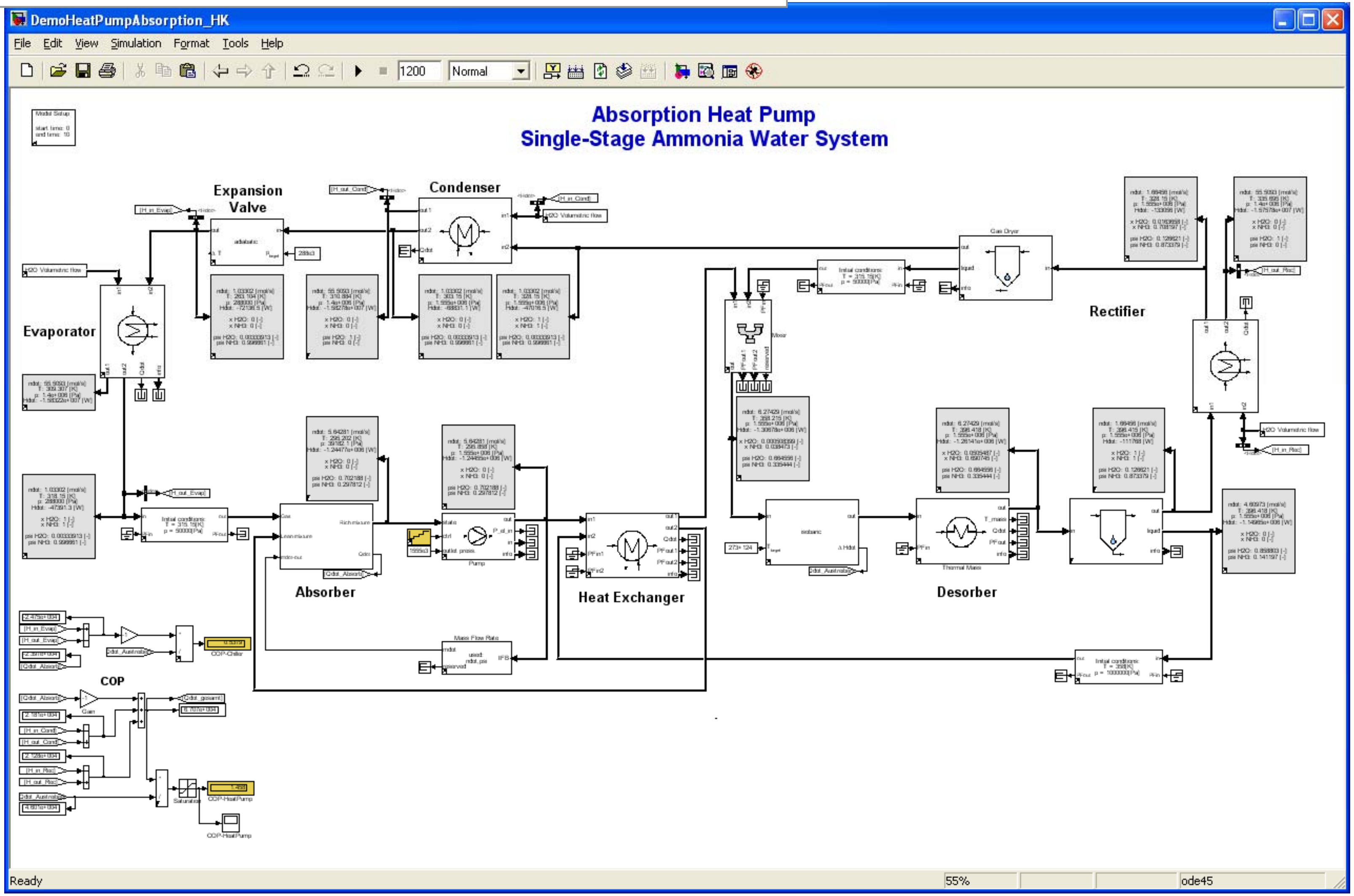
Example – Absorption Heat Pump

Flow scheme



Example – Absorption Heat Pump

Simulink Model with Thermolib blocks



DemoHeatPumpAbsorption2.mdl

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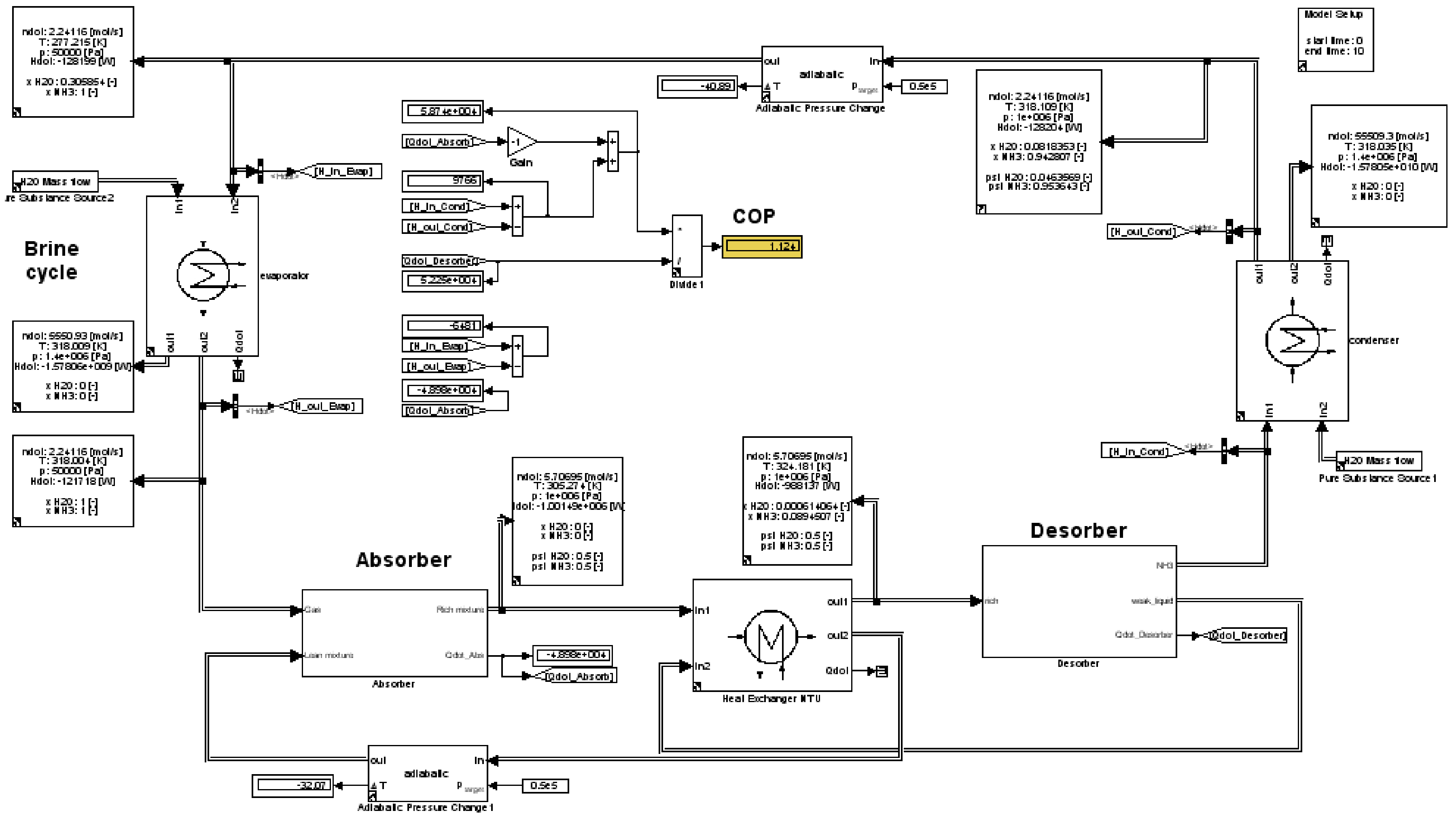
Example – Heat Pump

NH_3-H_2O – Absorption Heat Pump with Thermolib



DemoHeatPumpAbsorption1.mdl

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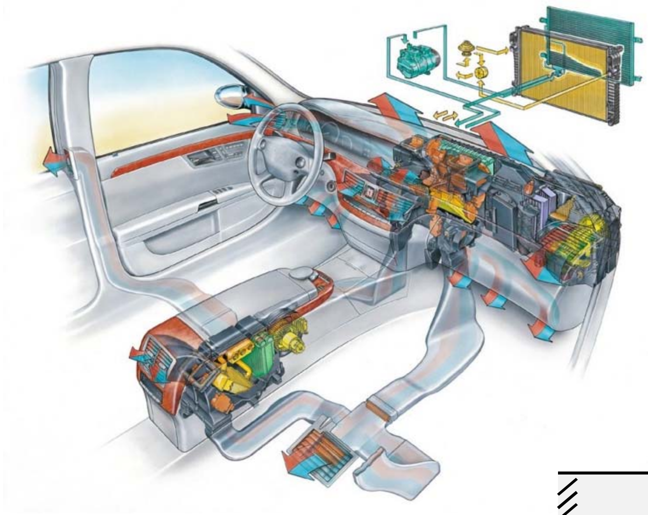
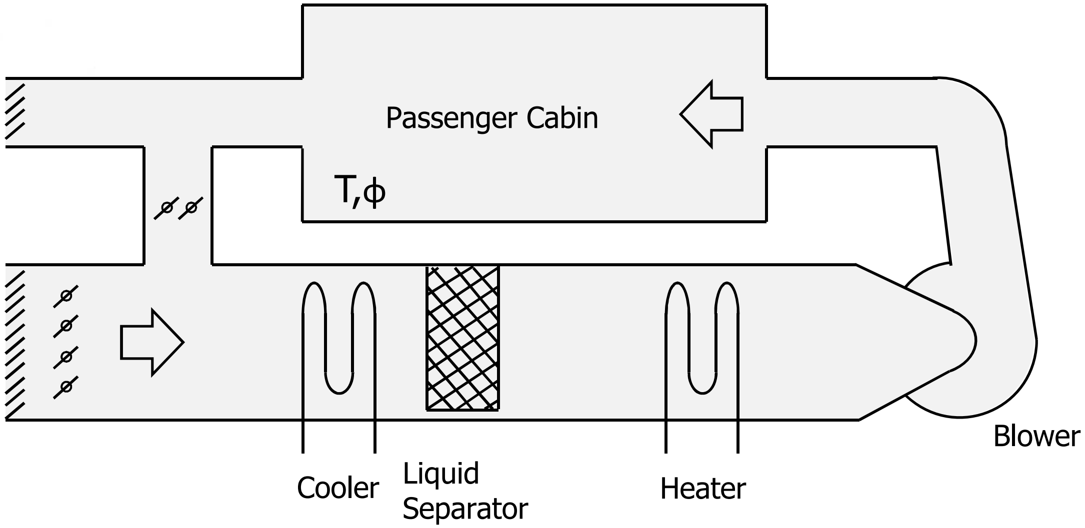
Example – Air Conditioning

Example – Air Conditioning Example

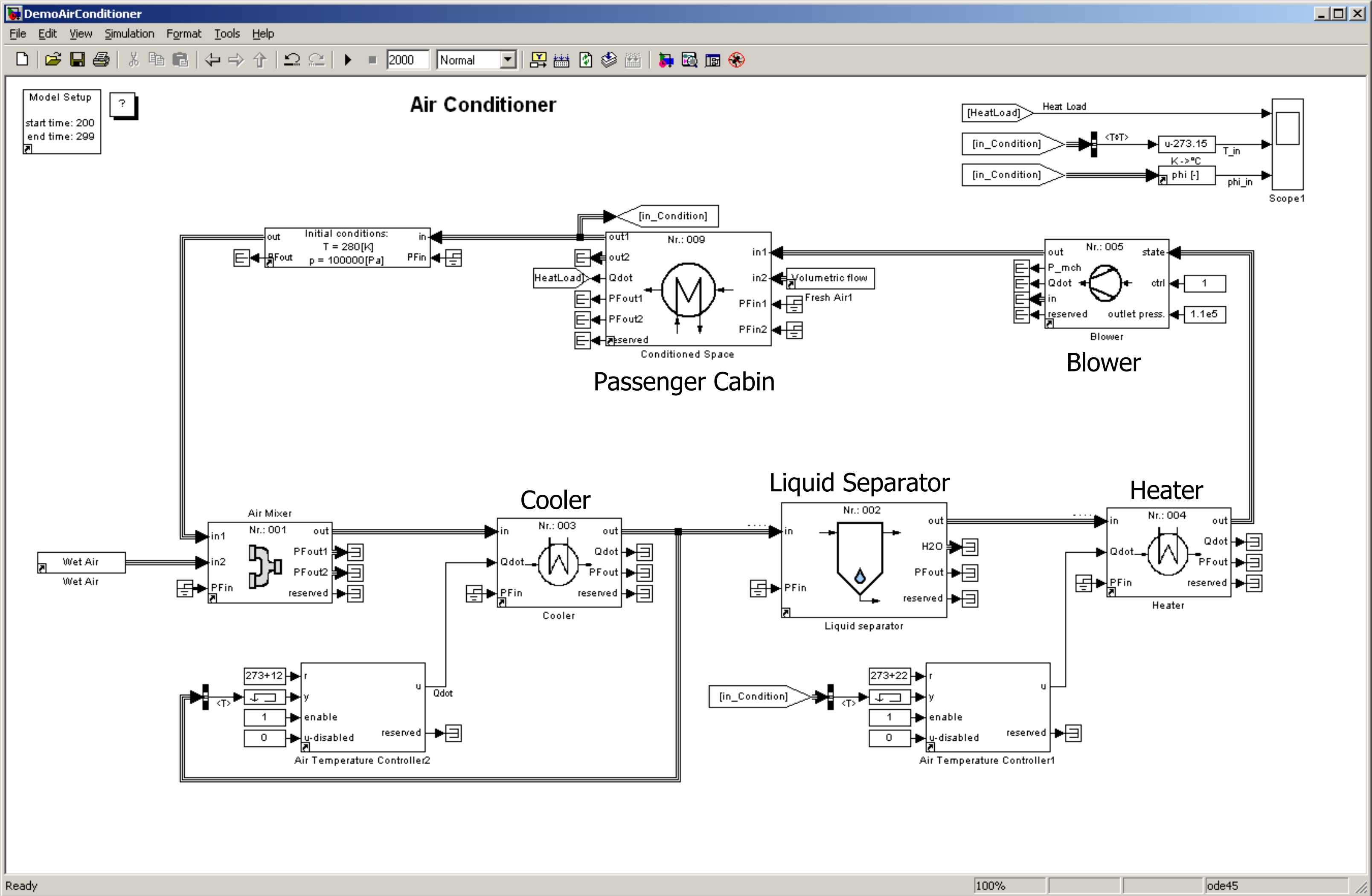
Flow Scheme





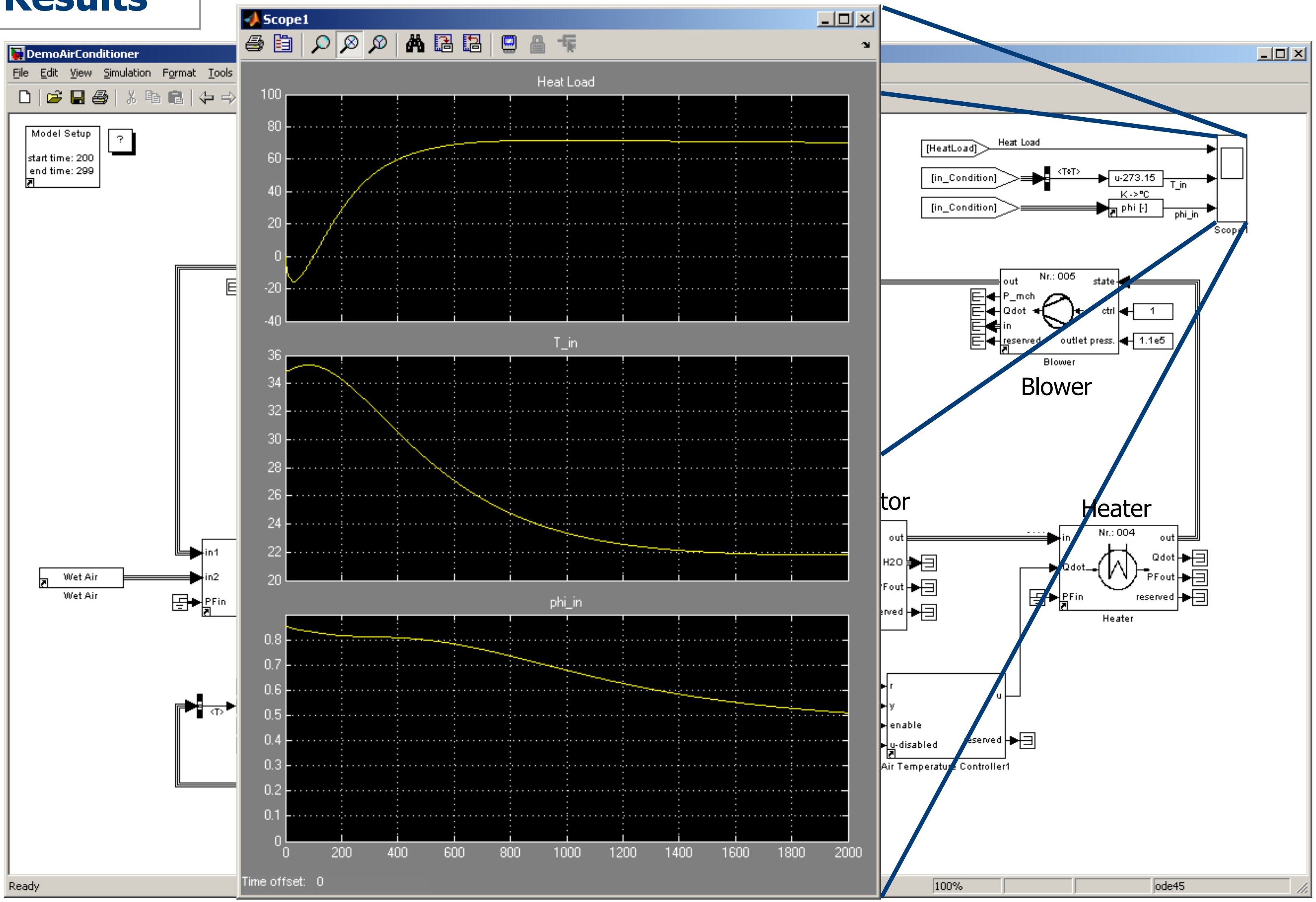
Example – Air Conditioning Example

Simulink Model with Thermolib blocks



Example – Air Conditioning Example

Results



Example – Chemical Reaction Modeling

Chemical Reactor

Easy to configure

1. Parameterize your reactions:

   $CH_4 + H_2O \leftrightarrow CO + 3\,H_2$

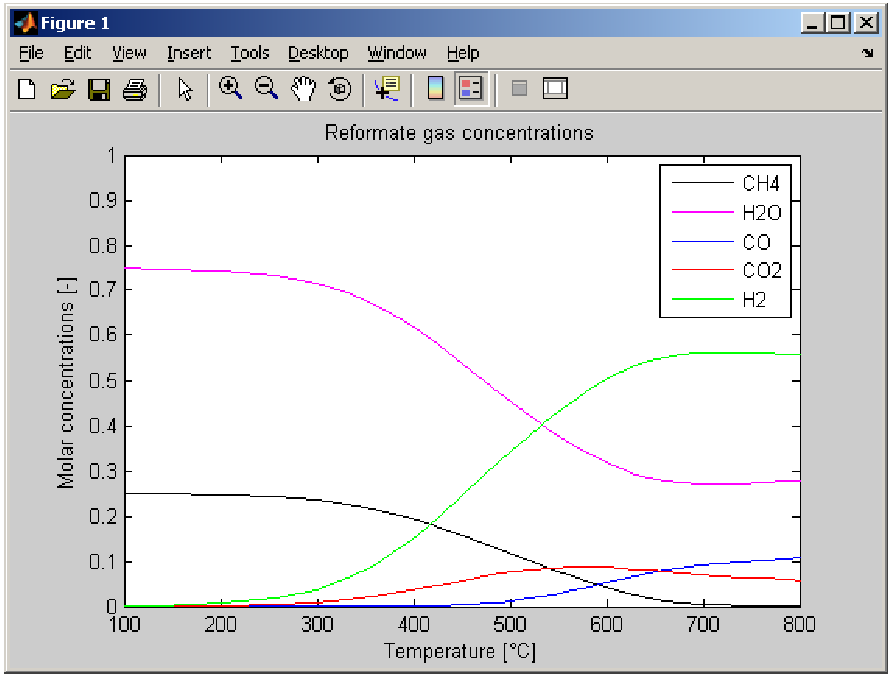
   $CO + H_2O \leftrightarrow CO_2 + H_2$

2. ThermoLib maintains chemical equilibrium at the outputs and correct heat transfer in Simulink®

$$\ln\left[\frac{\left(\frac{y_{CO}p_{CO}}{p_0}\right)\cdot\left(\frac{y_{H_2}p_{H_2}}{p_0}\right)^3}{\left(\frac{y_{CH_4}p_{CH_4}}{p_0}\right)\cdot\left(\frac{y_{H_2O}p_{H_2O}}{p_0}\right)}\right] = -\frac{\Delta G^0}{\overline{R}T}$$

$$\ln\left[\frac{\left(\frac{y_{CO_2}p_{CO_2}}{p_0}\right)\cdot\left(\frac{y_{H_2}p_{H_2}}{p_0}\right)}{\left(\frac{y_{CO}p_{CO}}{p_0}\right)\cdot\left(\frac{y_{H_2O}p_{H_2O}}{p_0}\right)}\right] = -\frac{\Delta G^0}{\overline{R}T}$$

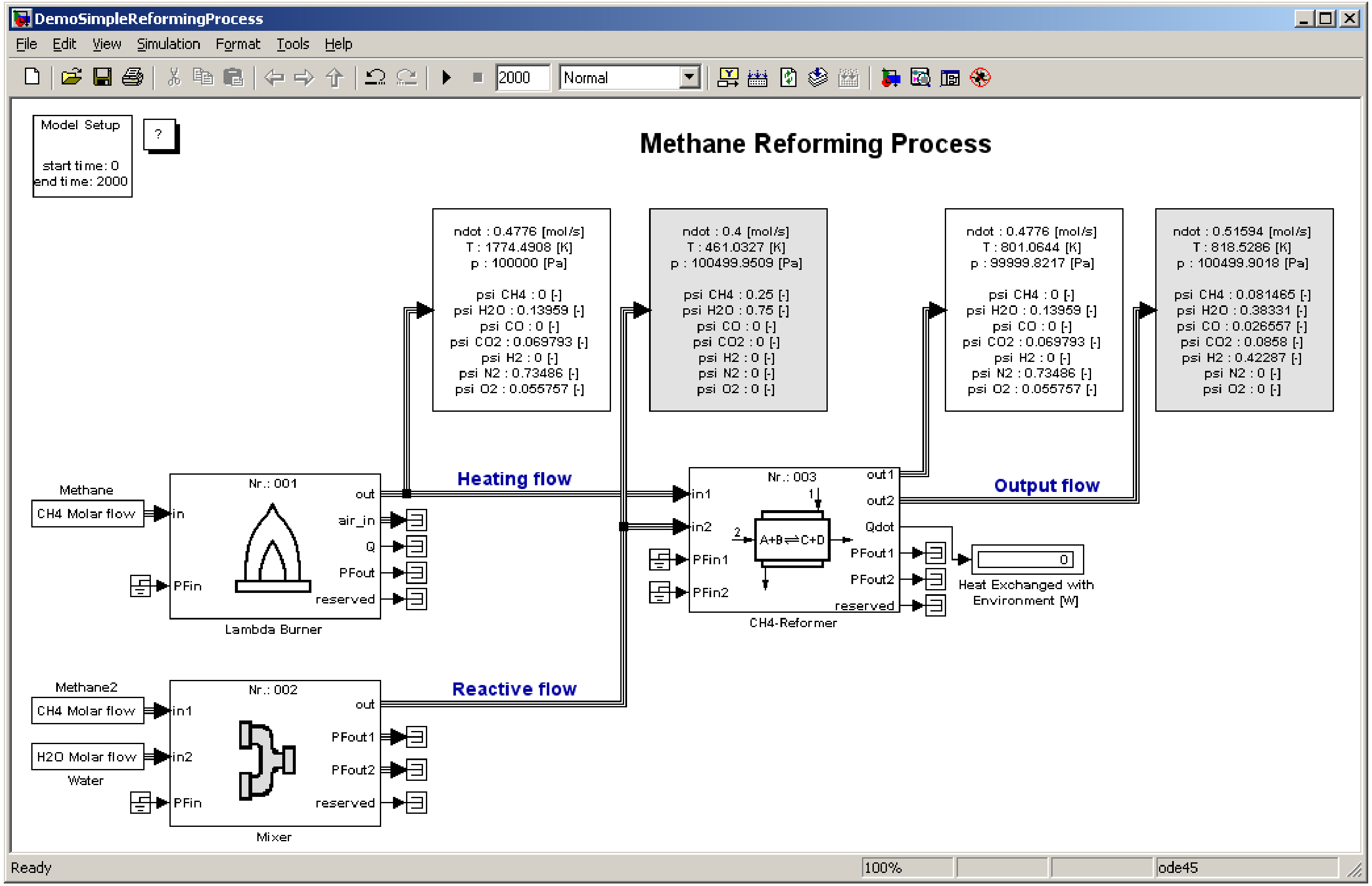
Simulation Results



Steady state molar fractions at different temperatures

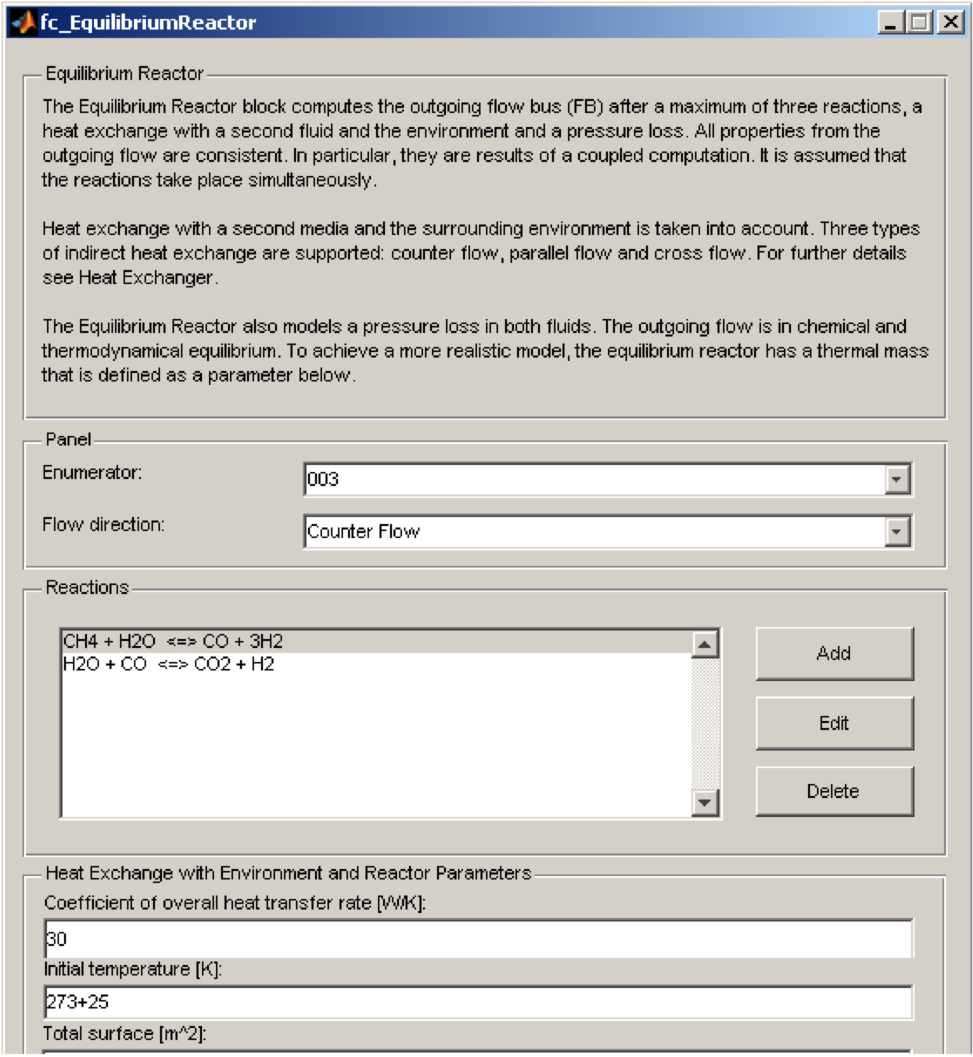
Example – Methane Reforming Process

Simulink Model with ThermoLib blocks



Example – Methane Reforming Process

Easy Definition of Chemical Reactions



Example – Methane Reforming Process

Thermodynamic Balancing

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	**Modelname**	DemoSimpleReformingProcess												
2	**date**	29-May-2009 07:55:16												
3														
4	**Balance Space Name**	**Port Name**	**Port Direction**	CH4 [g]	H2O [g]	CO [g]	CO2 [g]	H2 [g]	N2 [g]	O2 [g]	H [mol]	C [mol]	O [mol]	N [mol]
5	**TotalBalance**			3612,282	-6721,59	-656,437	-8877,99	-155,663	0	12799,6	0	0	0	0
6	**Lambda Burner**													
7		Input flow	in	200	0	0	0	0	0	0	800	200	0	0
8		Input Air	in	0	0	0	0	0	1654,576	439,824	0	0	879,648	3309,152
9		Output Gas	out	0	400	0	200	0	1654,576	39,824	800	200	879,648	3309,152
10														
11	**Mixer**													
12		Input flow 1	in	200	0	0	0	0	0	0	800	200	0	0
13		Input flow 2	in	0	27,2	0	0	0	0	0	54,4	0	27,2	0
14		Output flow	out	200	27,2	0	0	0	0	0	854,4	200	27,2	0
15														
16	**Equilibrium Reactor**													
17		Input heating	in	0	400	0	200	0	1654,576	39,824	800	200	879,648	3309,152
18		Input reacting	in	200	27,2	0	0	0	0	0	854,4	200	27,2	0
19		Output heatir	out	0	400	0	200	0	1654,576	39,824	800	200	879,648	3309,152
20		Output reacti	out	174,8375	0,310976	23,43582	1,726596	77,21384	0	0	854,3996	199,9999	27,19999	0
21														
22	**Balance**			403,6821	484,4058	-656,437	-75,9875	-155,663	0	0	0	0	0	0
23														

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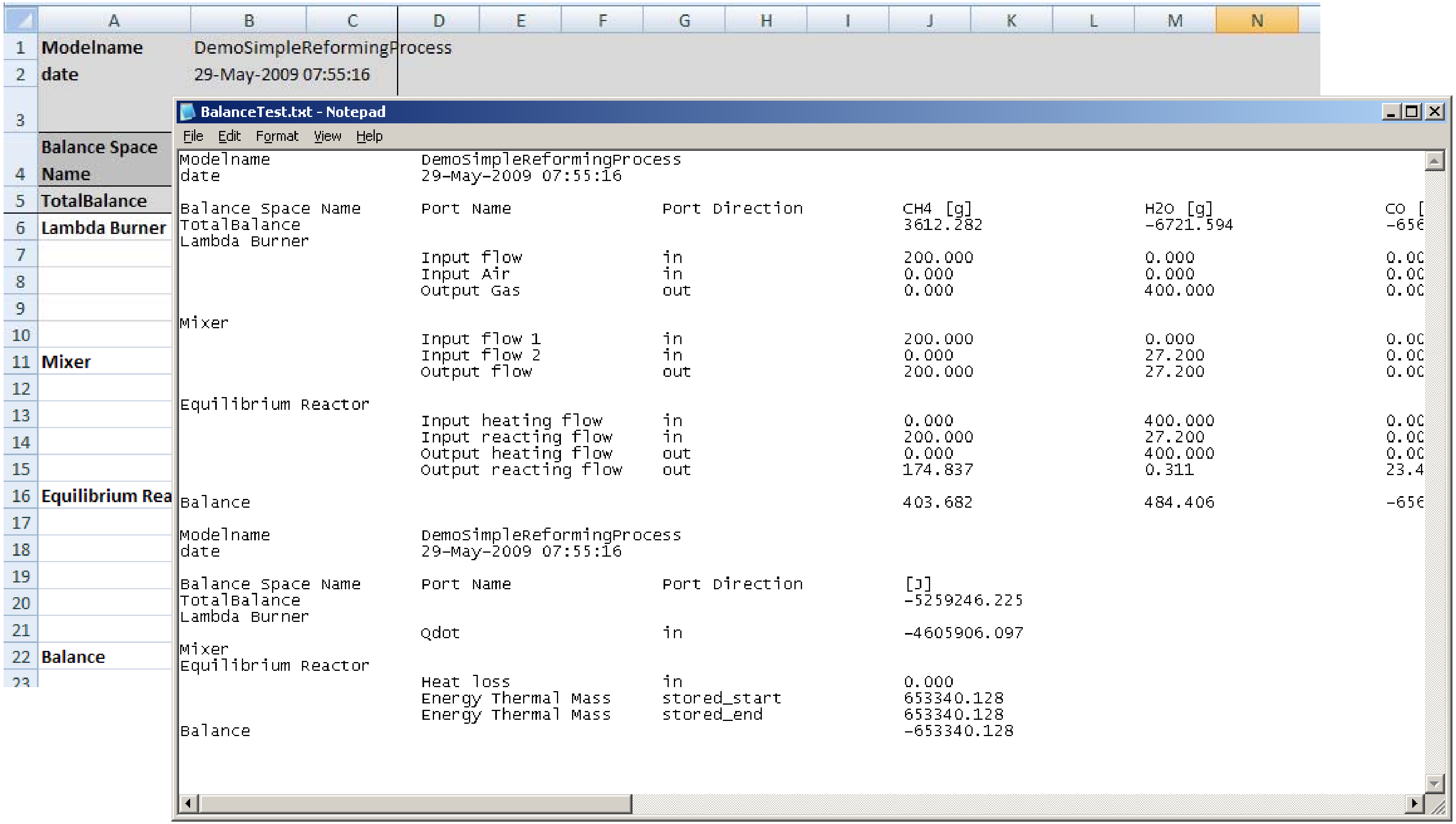
Example – Methane Reforming Process

Thermodynamic Balancing

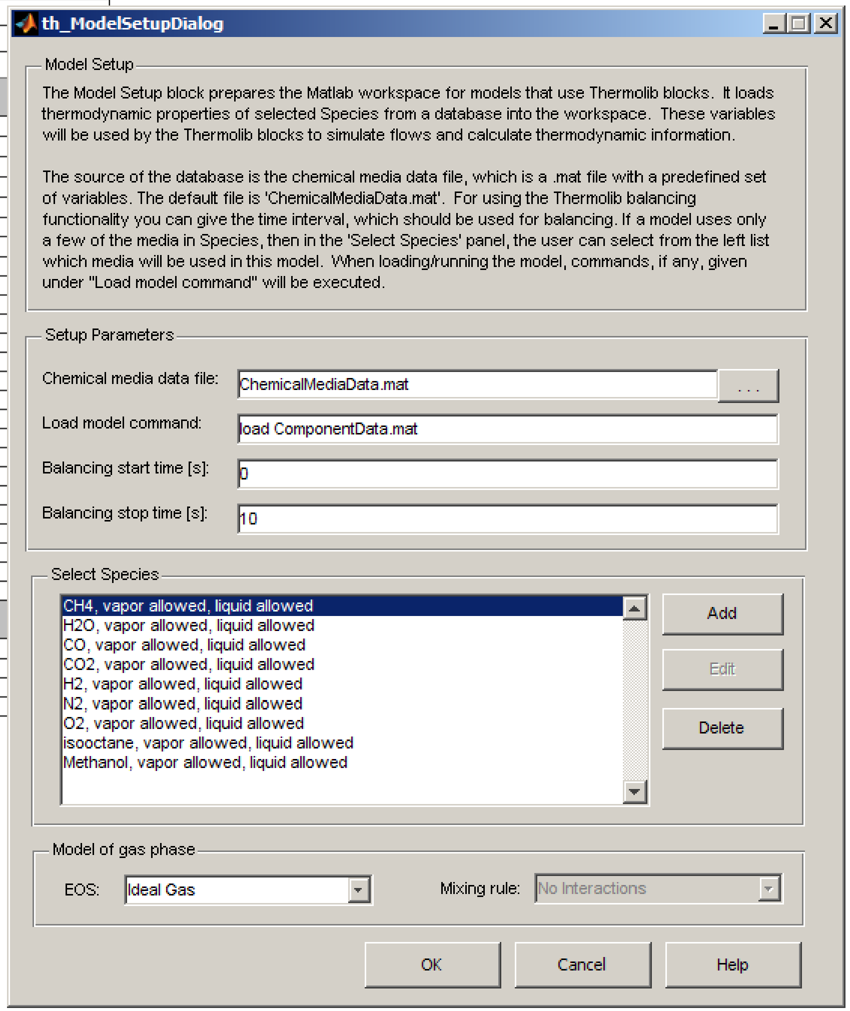


Example – Methane Reforming Process

Chemical Media Data

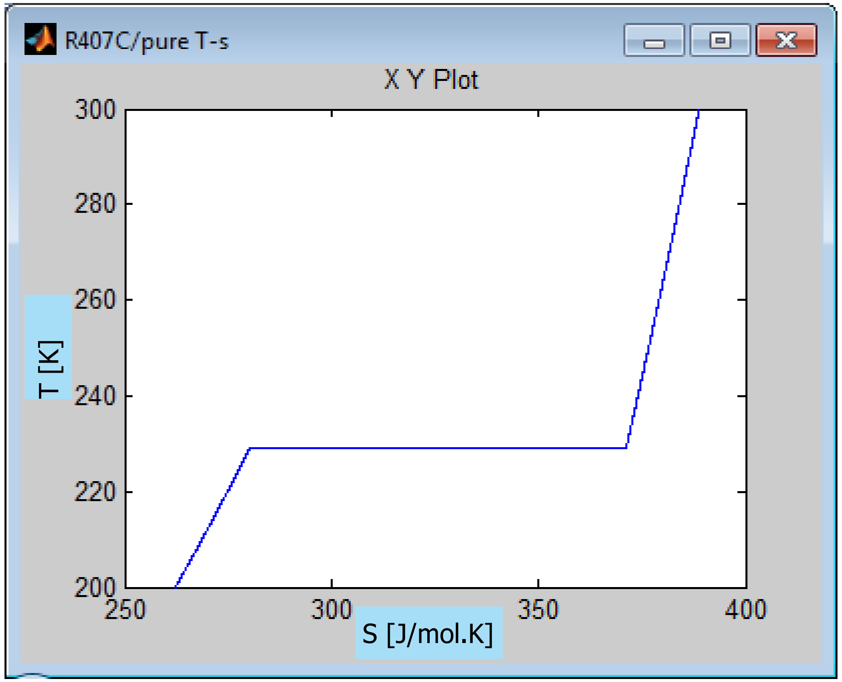
Chemical Media Data

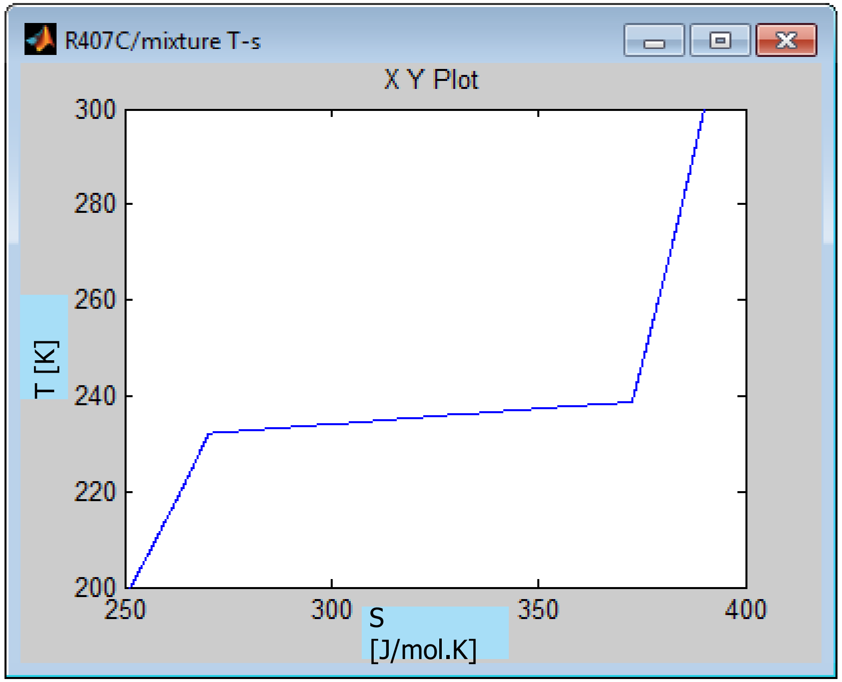
		CH4	H2O	H2O-IF97
	Species	CH4	H2O	H2O-IF97
	formula			
	full_name	methane	water	water IAPWS-IF97
Chemical media data				
Molar Mass *[kg/kmol]*	M	16,043	18,015	18,015
Liquid density *[g/m³]*	rho_liq	422620,0	1,00E+06	1,00E+06
Antonie equation_ A *[-]*	Antoine_A	3,9895	5,111	4,5396014
Antonie equation_ B *[-]*	Antoine_B	443,028	1685	846,3
Antonie equation_ C *[-]*	Antoine_C	-0,49	-43,22	-288,7
Reference temperaure for evap. properties *[K]*	T_fg_ref	111,6	298	298
Evaporation enthalpy *[Joule/mole]*	hm_fg	8183	43961,4	43961,4
Evaporation entropy *[Joule/mole-K]*	sm_fg	73,36664655	118,7557231	-1507,731428
Critical Temperatur *[K]*	T_c	190,600	647,300	647,300
Critical Pressure *[Pa]*	p_c	4,60E+06	2,21E+07	2,21E+07
Critical Volume *[m³/mol]*	vm_c	9,90E-05	5,60E-05	5,60E-05
Acentric Factor *[-]*	omega	0,288	0,344	0,344
Red. De-Broglie-Wavel. *[-]*	lambda_R	999,000	999,000	999,000
Critical Real-Factor *[-]*	Zc	0,288	0,229	0,229
Linear Molecule *[-]*	linear	1	0	0
Dipole Moment *[Debye]*	mue	0,0	1,8	1,8
Boiling Temperature *[K]*	Ts	111,7	373,2	373,2
Inner Rotation *[-]*	c_mir	999,0	-3,0	-3,0
Number of C atoms *[-]*	C_atoms	1	0	0
Number of H atoms *[-]*	H_atoms	4	2	2
Number of O atoms *[-]*	O_atoms	0	1	1
Number of N atoms *[-]*	N_atoms	0	0	0
Number of F atoms *[-]*	F_atoms	0	0	0
Number of Cl atoms *[-]*	Cl_atoms	0	0	0
Heat capacity of liquid (Cp = A + B*T +C*T^2 + D*T^3)				
A-element *[J/mol*K]*	Cp_liq_A	60	5,081069E+01	5,081069E+01
B-element *[J/mol*K^2]*	Cp_liq_B	0,000	2,129361E-01	2,129361E-01
C-element *[J/mol*K^3]*	Cp_liq_C	0,000	-6,309691E-04	-6,309691E-04
D-element *[J/mol*K^4]*	Cp_liq_D	0,000	6,483055E-07	6,483055E-07



Mixture Evaporation

- Thermolib allows multi-component vapor-liquid-equilibrium calculations / flash calculations
- Typical refrigerants in HVAC-systems are mixtures!
- Example R407c is a mixture of R134a, R125, R32
- DemoTempGlideR407c.mdl demonstrates the difference

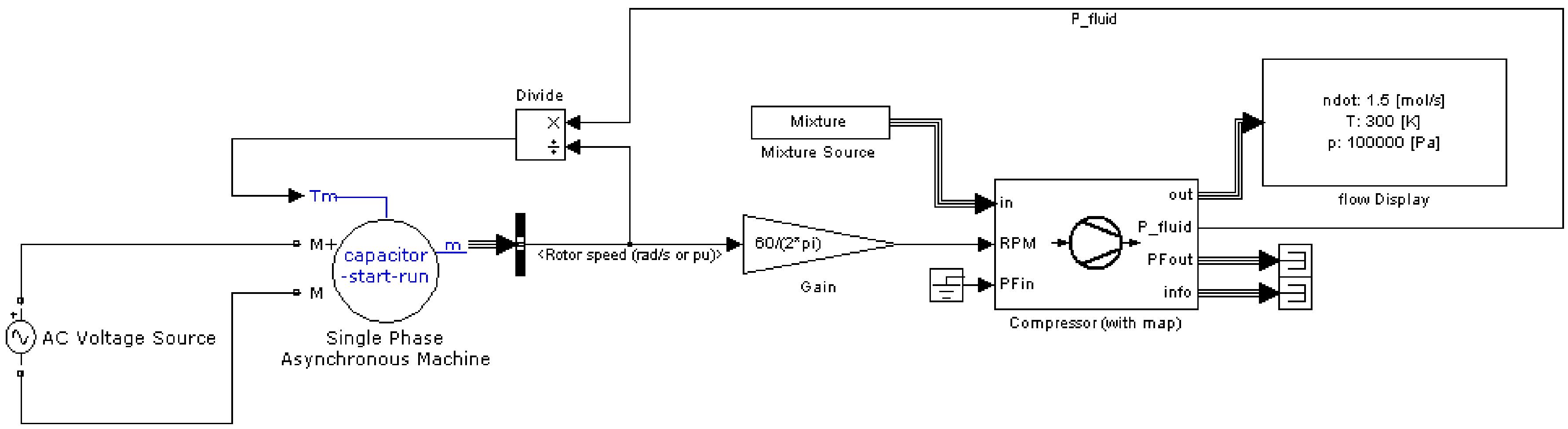




Interfacing Thermolib with SimScape & SimPowerSystems

Interfacing SimPowerSystems with Thermolib

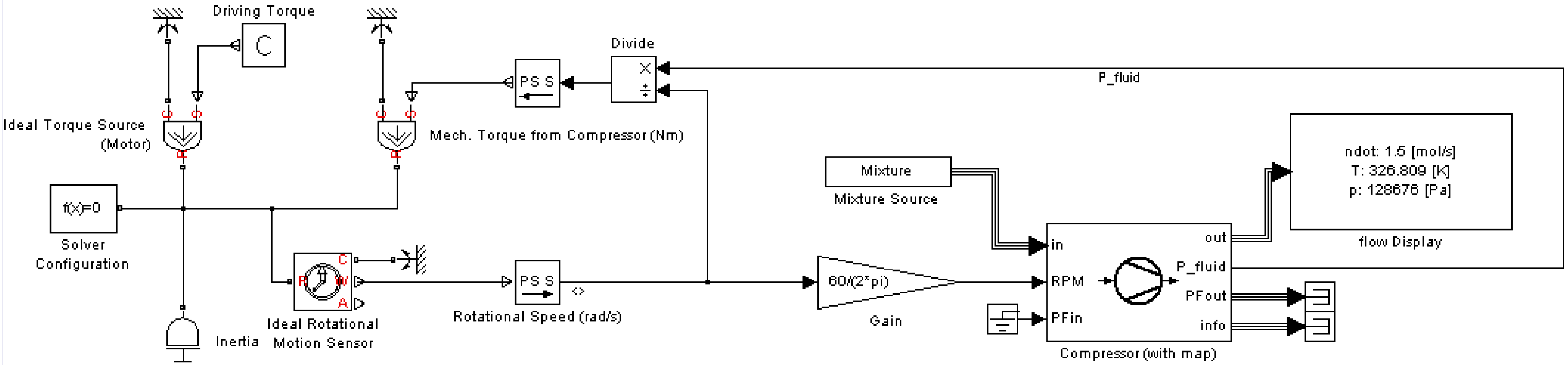
Thermolib Compressor driven by SimPower Machine



- Simple interface via mechanical torque (Tm) and rotor speed (w)
- Time scales need attention
  (in SimPowerSystems typically milliseconds, while in Thermolib seconds)

Interfacing SimScape with Thermolib

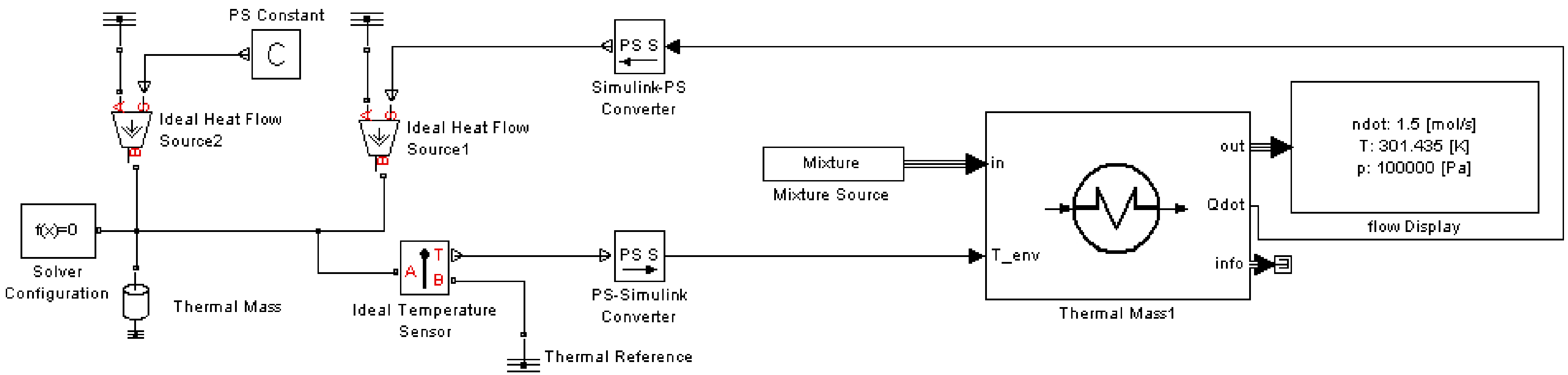
Thermolib Compressor driven by SimScape Rotational Elements



- Simple interface via mechanical torque (Tm) and rotor speed (w)

Interfacing SimScape with Thermolib

Thermolib thermal mass and thermal foundation domain

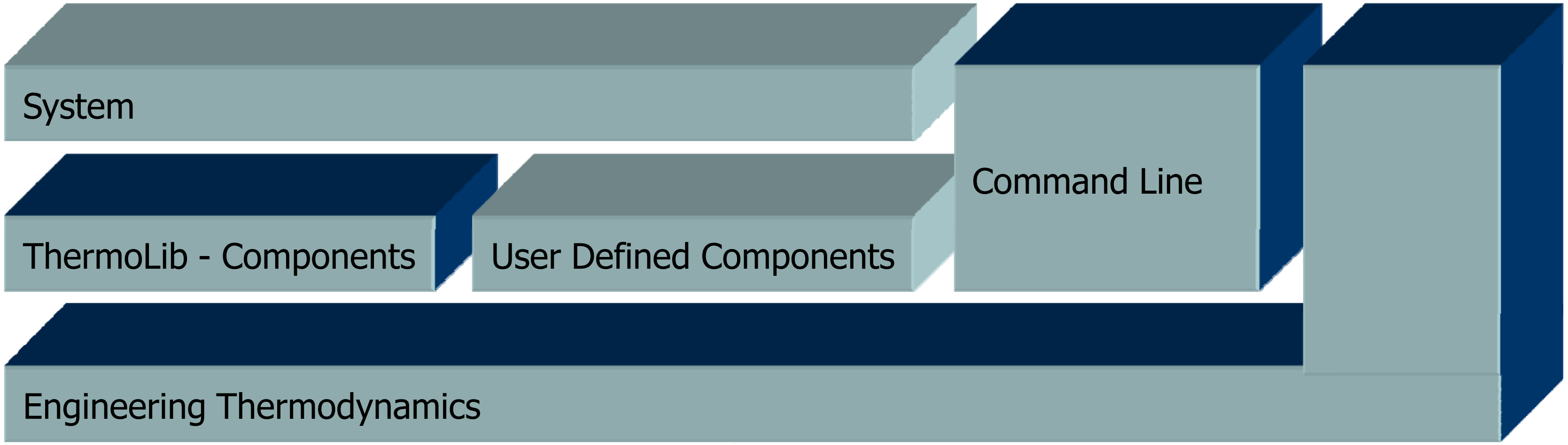


- Simple interface via heat flow and temperature

Architecture ...

Thermodynamics

Architecture



Key features

- High flexibility by systematic use of engineering thermodynamics
- Easy set up of new components => fast adaption to new processes
- EUtech offers development of customized blocks

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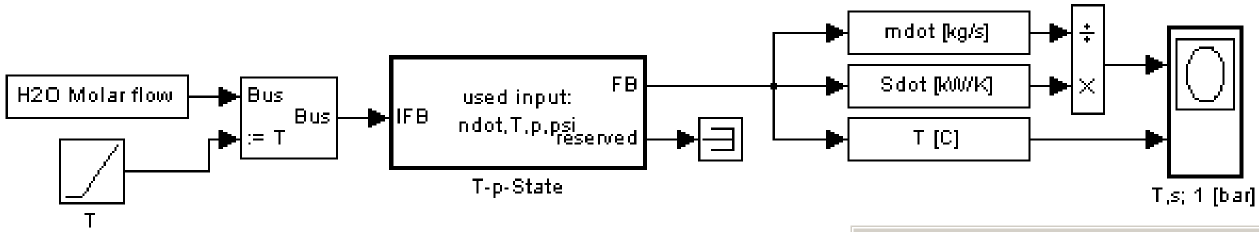
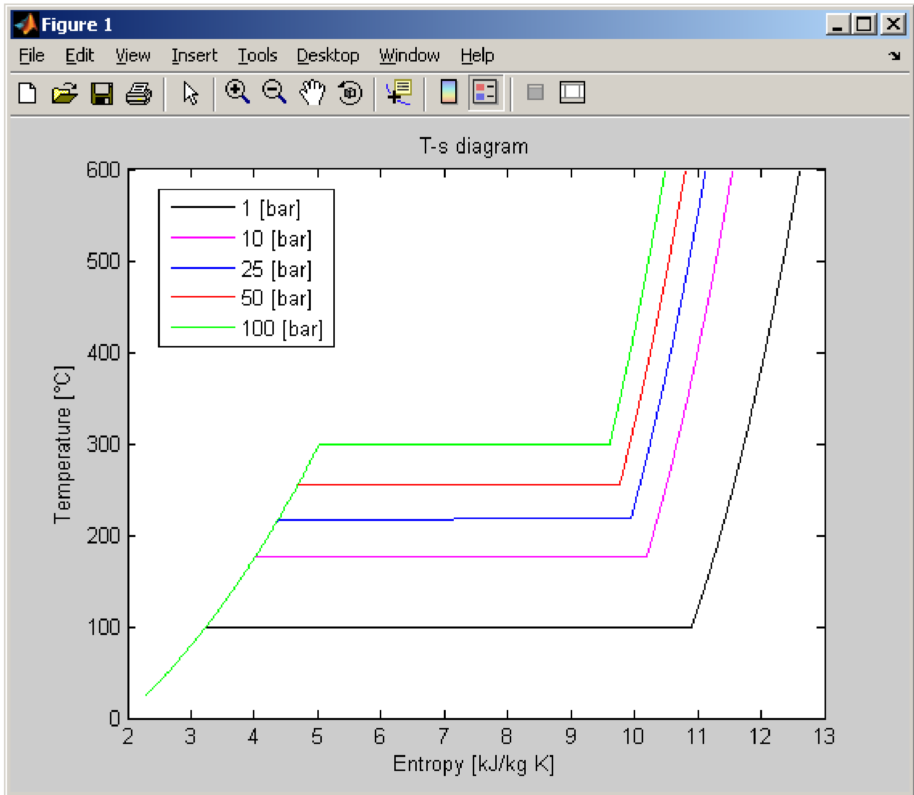
Example: Isobaric evaporation





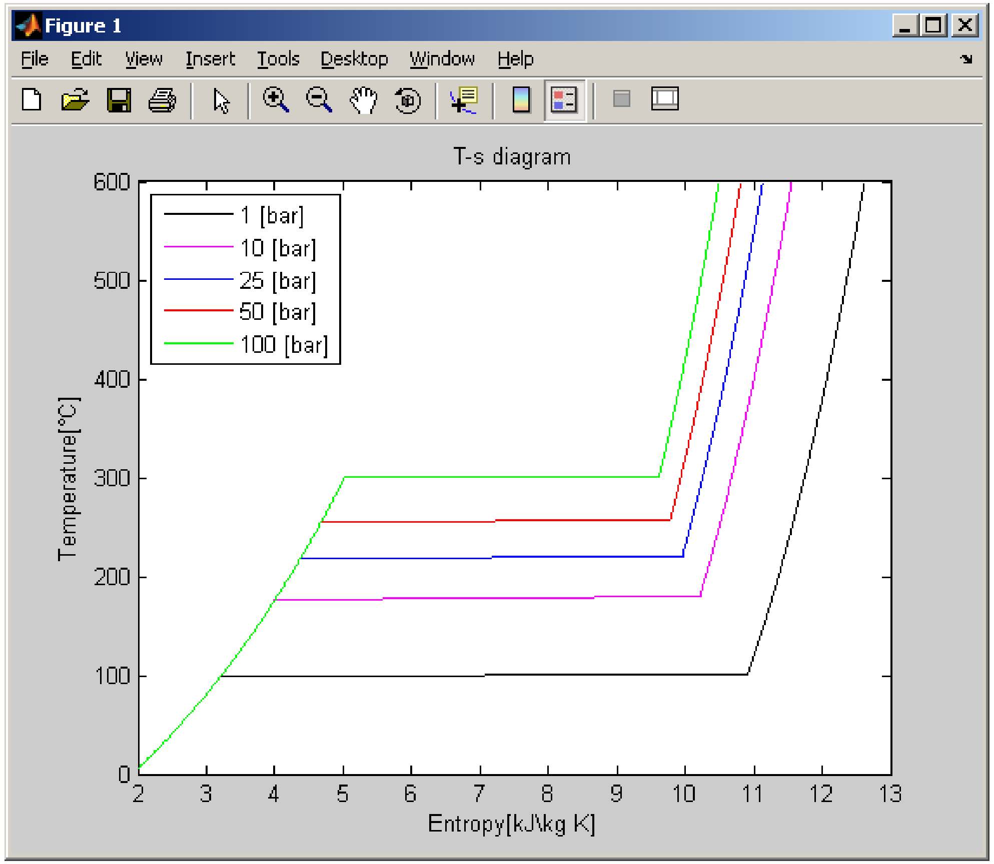
Key features

User accessible fundamental thermodynamic functionality

- build new components
- thermodynamic calculations
- ...

Command Line

- [hdot,b,c,d,e]=th_TpState('species',{'H2O'},'T',T,'p',p,'psi',[1],...
  'ndot',[1],'MediaData',SMediaData);



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Available Thermolib Add-on-Products

- Thermolib-IF97
  - Enables high precicision water calculations according to the International Association for Properties of Water and Steam with industrial formulation of 1997 (IAPWS-IF97)
  - Common standard for power plant calculations
- Thermolib-RTWE
  - Thermolib real time workshop extensions
  - Provides .tlc files and static linked libraries to compile Thermolib models into standalone applications with the following targets:
    - Generic Real Time target, S-function target, Rapid Simulation target, xPC-target
  - (currently not yet available, but coming within 2010).
- Planned 2011: Thermolib-DIPPR801
  - Access to standard DIPPR 801 species database to enable simulations with more than 2000 species (http://dippr.byu.edu/)

New features in Release 5.0

- Real gas behavior using Peng-Robinson equation of state.
- Precise water calculations using IAPWS-IF97 standard available as Add-on (Thermolib IF97).
- RTW-extension available to generate with standalone executable models using the Real-Time Workshop targets
- Thermolib can handle now general flash calculations.
- ChemicalMediaData now contain several new refrigerants (R125, R32, …)
- Viscosity and thermal conductivity data available (Reynolds number calculations)
- A general Tank block – outputs configurable “top” or “bottom”
- A new Li-Ion cell block models for battery thermal management simulations
- Licensing scheme based on software activation available

Summary

Key features

With Thermolib thermodynamic systems can be easily modeled.

- Based on fundamental engineering thermodynamic principles
- Focused on modeling for control (system level; dynamics)
- More than 40 thermodynamic components blocks
- Handles system hydraulics with pressure feedback
- Extensive thermodynamic balancing
- Customizable database of thermodynamic species
- Completely based on standard Simulink®
- Fully integrates with The MathWorks tool-chain
- Real-time capabilities (Rapid Control prototyping, HiL)

Summary

Field of Application

- Thermodynamic processes (cooling/heating circuits)
- Thermal Power Plants
- Process Industries
- µ-CHPs Systems
- Fuel Cells
- Heat-engines
- HVAC systems

Further information at [www. thermolib.de](www.thermolib.de)

Questions?

Contact: thermolib@eutech.de