Whole-chain CCS Modelling – Power station to Injection

Laurence Robinson APM Forum 18th April 2013

Energy Technologies Institute (ETI)

Public-private partnership between global industries and the UK Government set up with the objectives of

- ensuring clean, secure and affordable energy supplies are available to power everyday living and business
- reducing greenhouse gas emissions to tackle the effects of climate change

ETI members

corporate

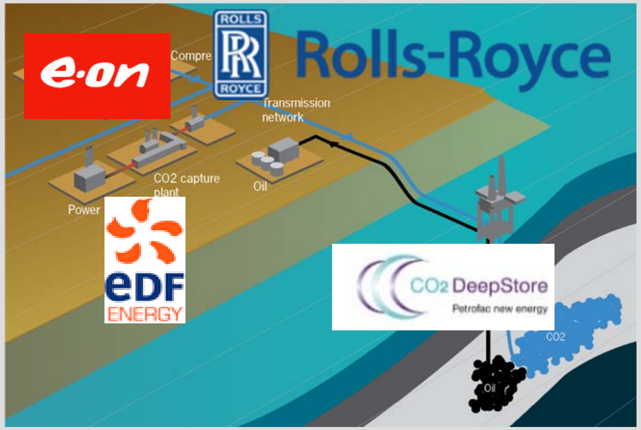
public institutions

The ETI is not a grant-giving body, but makes targeted investments in key technologies that will help the UK meet its' legally binding 2050 targets

System-wide modelling: Key enabling technology for CCS

CCS System Modelling Tool-kit Project

- Energy Technologies Institute (ETI) £3m project
- E.ON, EDF, Rolls-Royce, Petrofac/CO2DeepStore, PSE, E4tech



gPROMS modelling platform technology & expertise

E4tech

Management

➔ Create a commercially available product

- built on PSE's gPROMS platform
- High-fidelity system-wide CCS modelling
- Toolbox and ecosystem

Contents

1. Importance of Full Chain CCS modelling

2. Case Study – Building the first full chain CCS model in gCCS

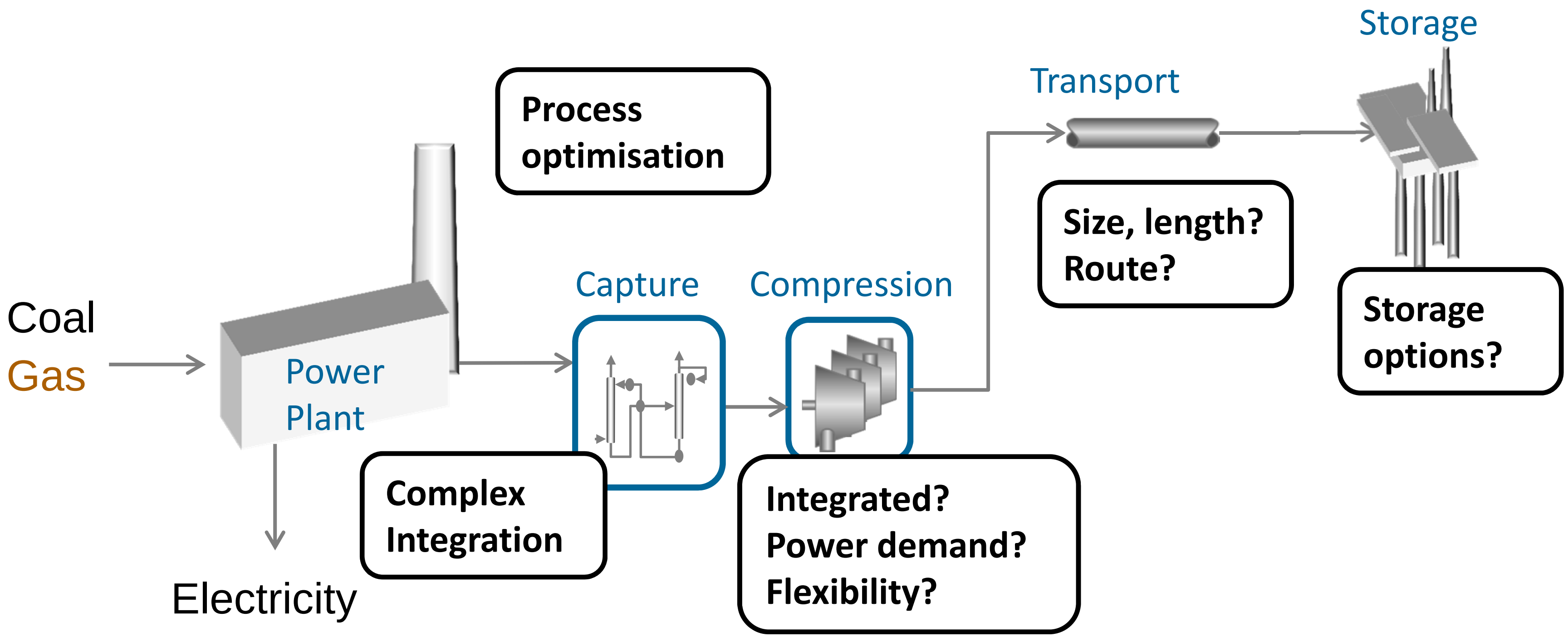
3. Case Study Scenarios

4. Preliminary results (January 2013)

5. Current and Future work

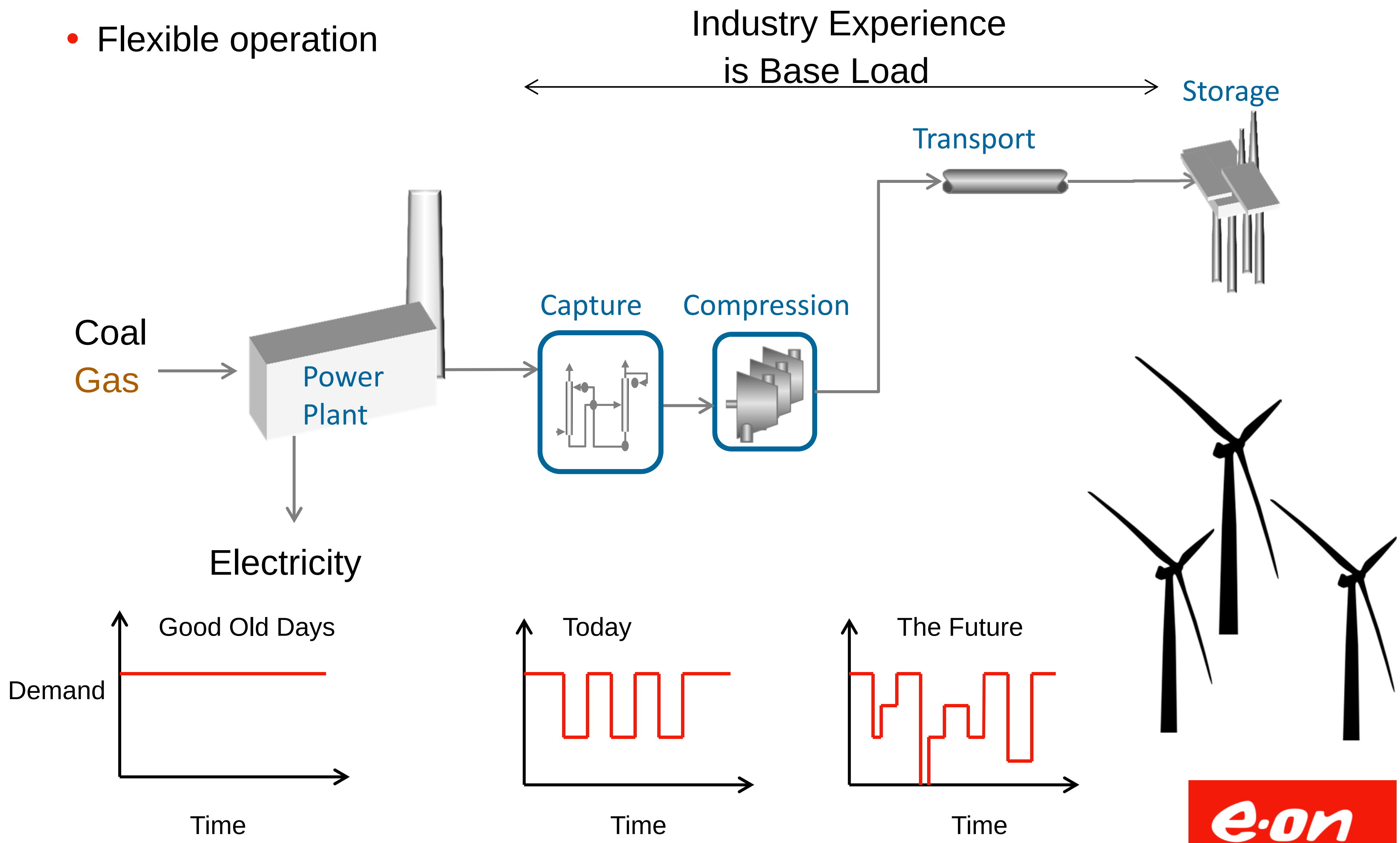
Importance of full chain CCS modelling

- Reminder of the Challenges posed by Carbon Capture and Storage.

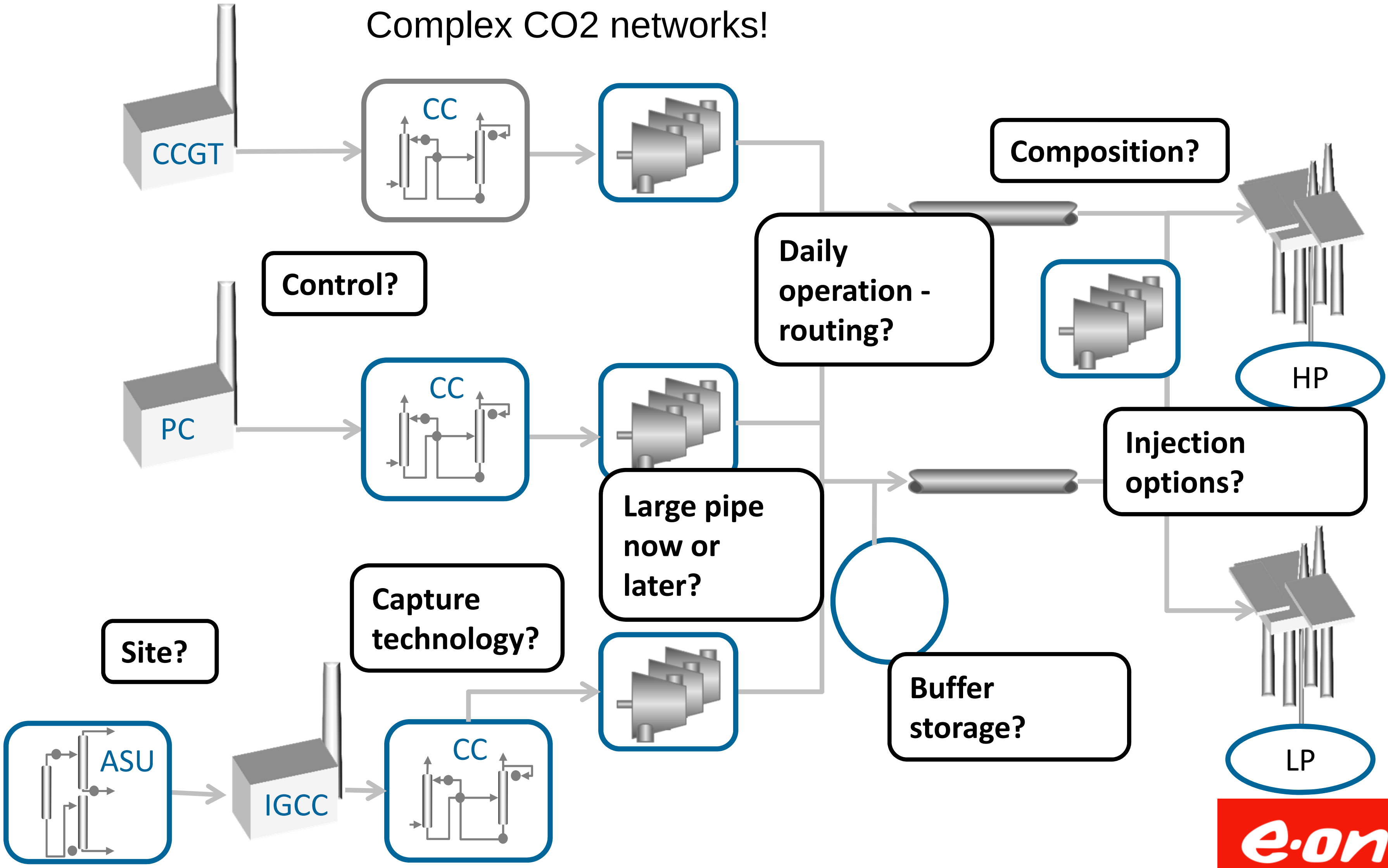


Importance of full chain CCS modelling

- Flexible operation



Importance of full chain CCS modelling



Importance of full chain CCS modelling

Key applications

- Problem/hazard identification
- Risk mitigation
- Design Optimisation & Flexibility
- Calculation and optimisation of economics
- Single tool - Fast Scenario Screening

Case Study – First Full Chain CCS Model in gCCS

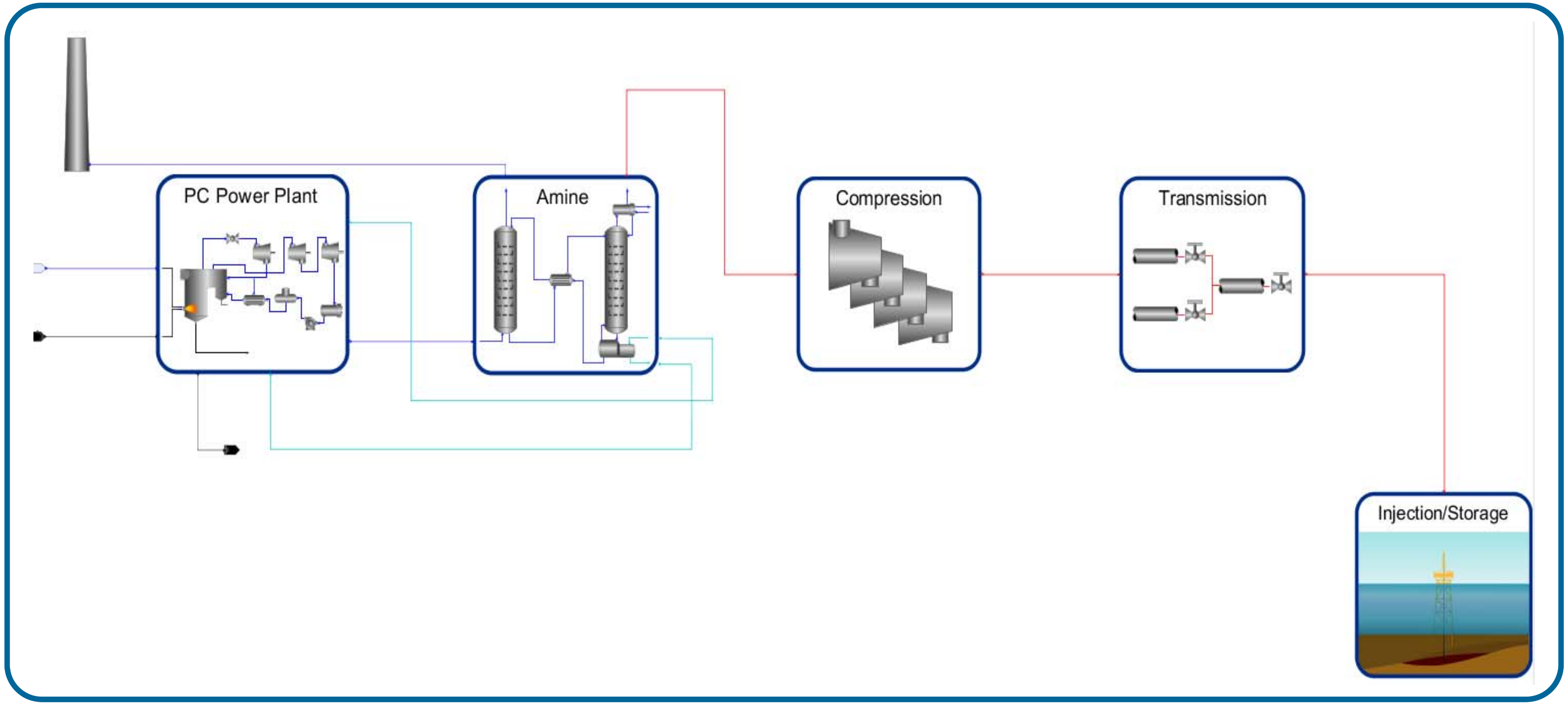
Aims

- To construct and simulate the single CCS chain
- Evaluate model accuracy against experimental data and validated models and studies
- Evaluate component model capabilities meet user requirements

Steady State Scenarios

- Five Scenarios
- Broad Range of operating conditions
- Tests model robustness and flexibility

Case Study - Overview



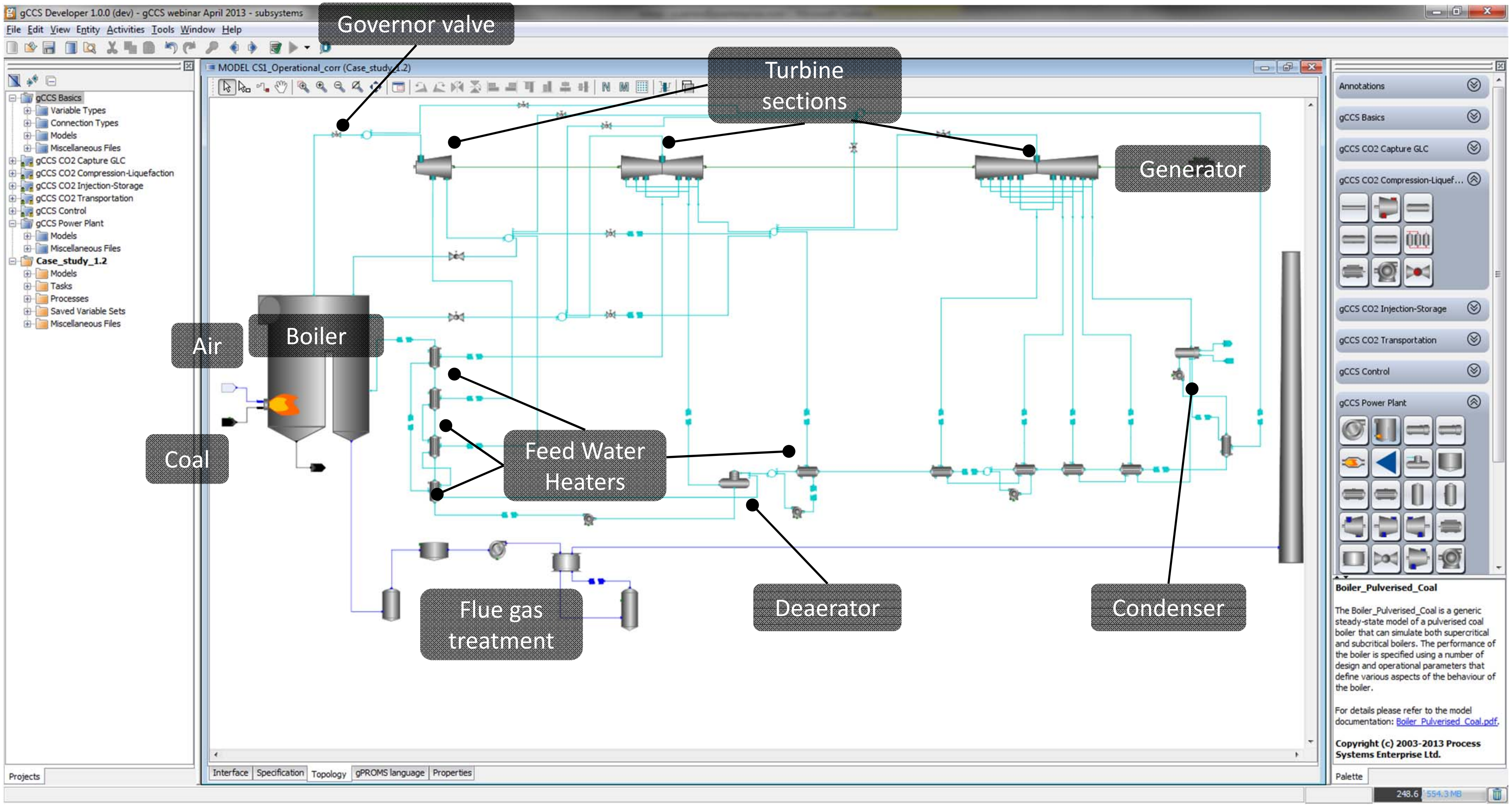
- Complex flow sheets with a large number of process units
- Many recycle streams
- May include complex, multi-scale unit operation model
- Strong interactions between components

Case Study – Workflow Building Each Subsystem

- Construct individual sub-systems independently
- Initialise sub-systems independently using provided initialisation procedures
- Generate Saved Variable Sets (SVS) files containing initial guesses for each of the subsystems

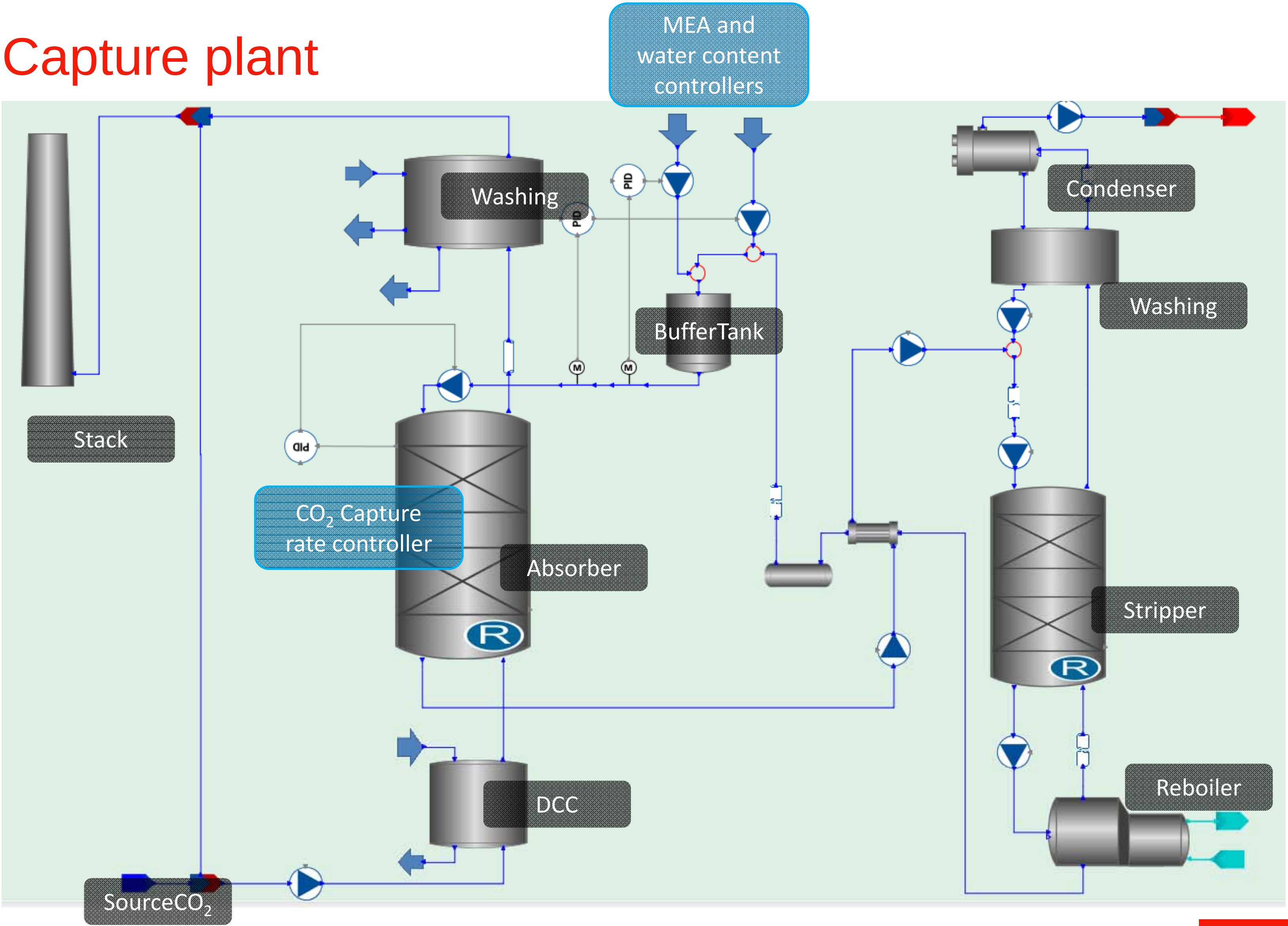
Section	Lead	Support
Power Plant	E.ON	PSE
CO2 Capture Plant	PSE	E.ON
CO2 Compression	Rolls Royce	PSE
CO2 Transport	PSE	CO2Deepstore, E.ON
Storage	PSE	CO2Deepstore, E.ON

Power Plant



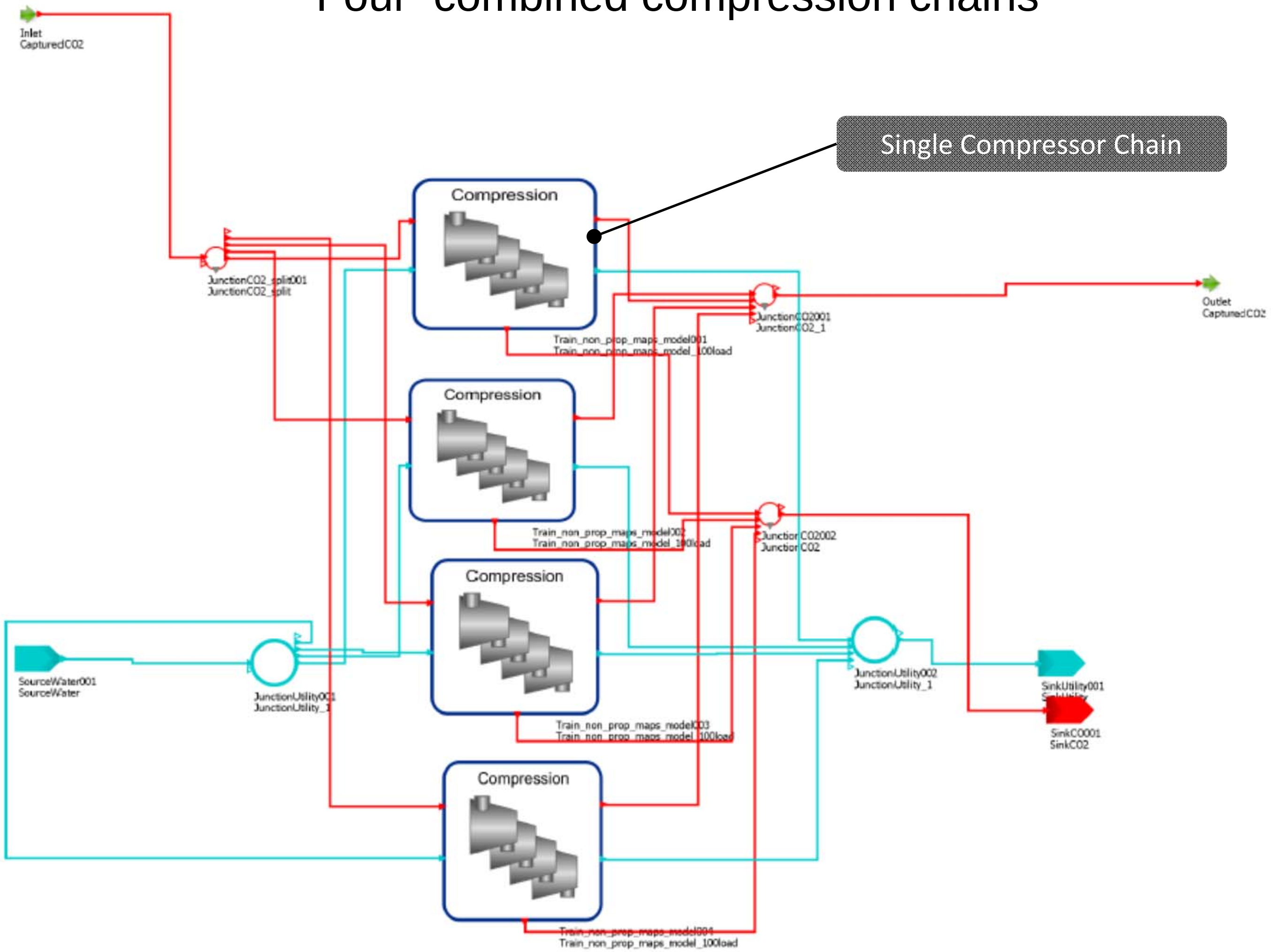
Governor valve
Turbine sections
Generator
Air
Boiler
Coal
Feed Water Heaters
Flue gas treatment
Deaerator
Condenser
Boiler_Pulverised_Coal
The Boiler_Pulverised_Coal is a generic steady-state model of a pulverised coal boiler that can simulate both supercritical and subcritical boilers. The performance of the boiler is specified using a number of design and operational parameters that define various aspects of the behaviour of the boiler.
For details please refer to the model documentation: Boiler_Pulverised_Coal.pdf.
Copyright (c) 2003-2013 Process Systems Enterprise Ltd.

Capture plant



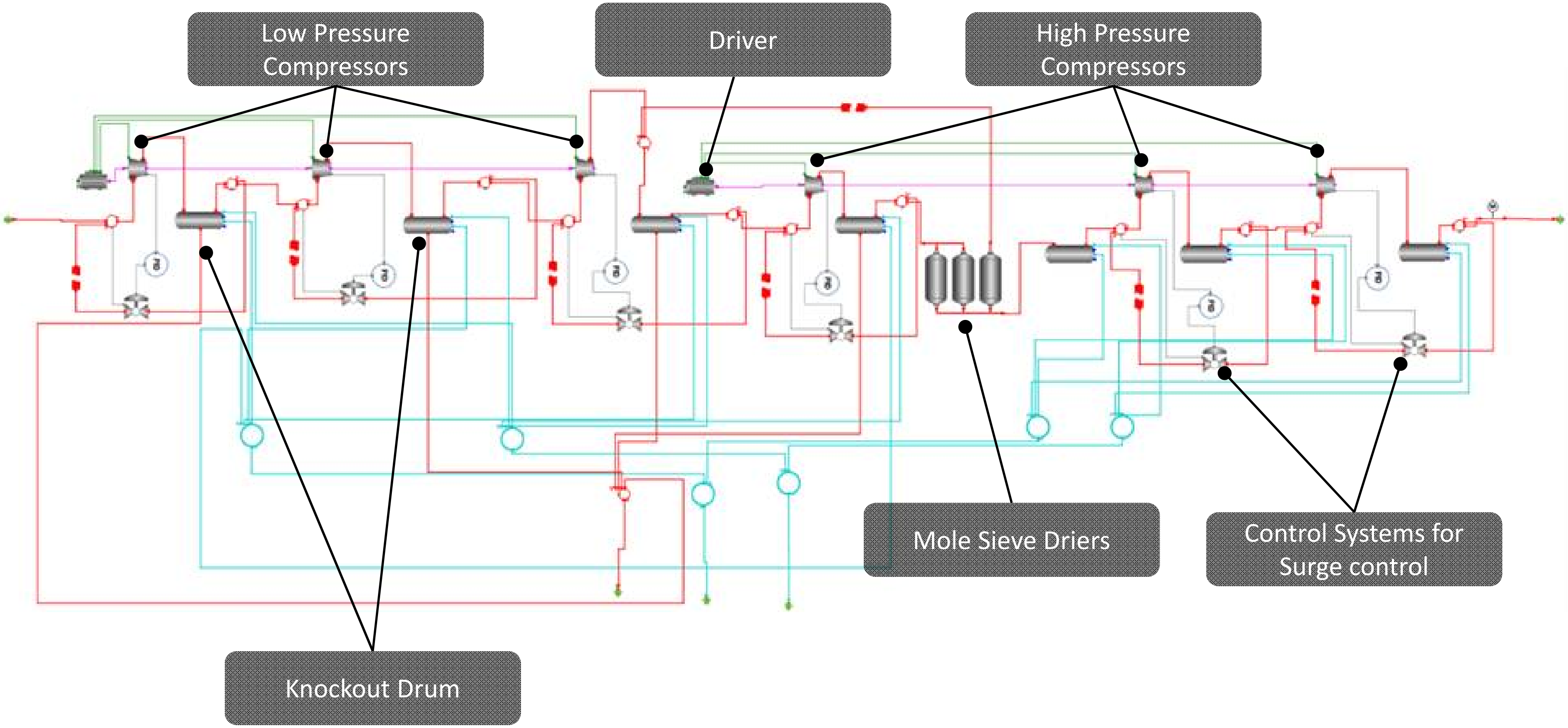
Compression

Four combined compression chains

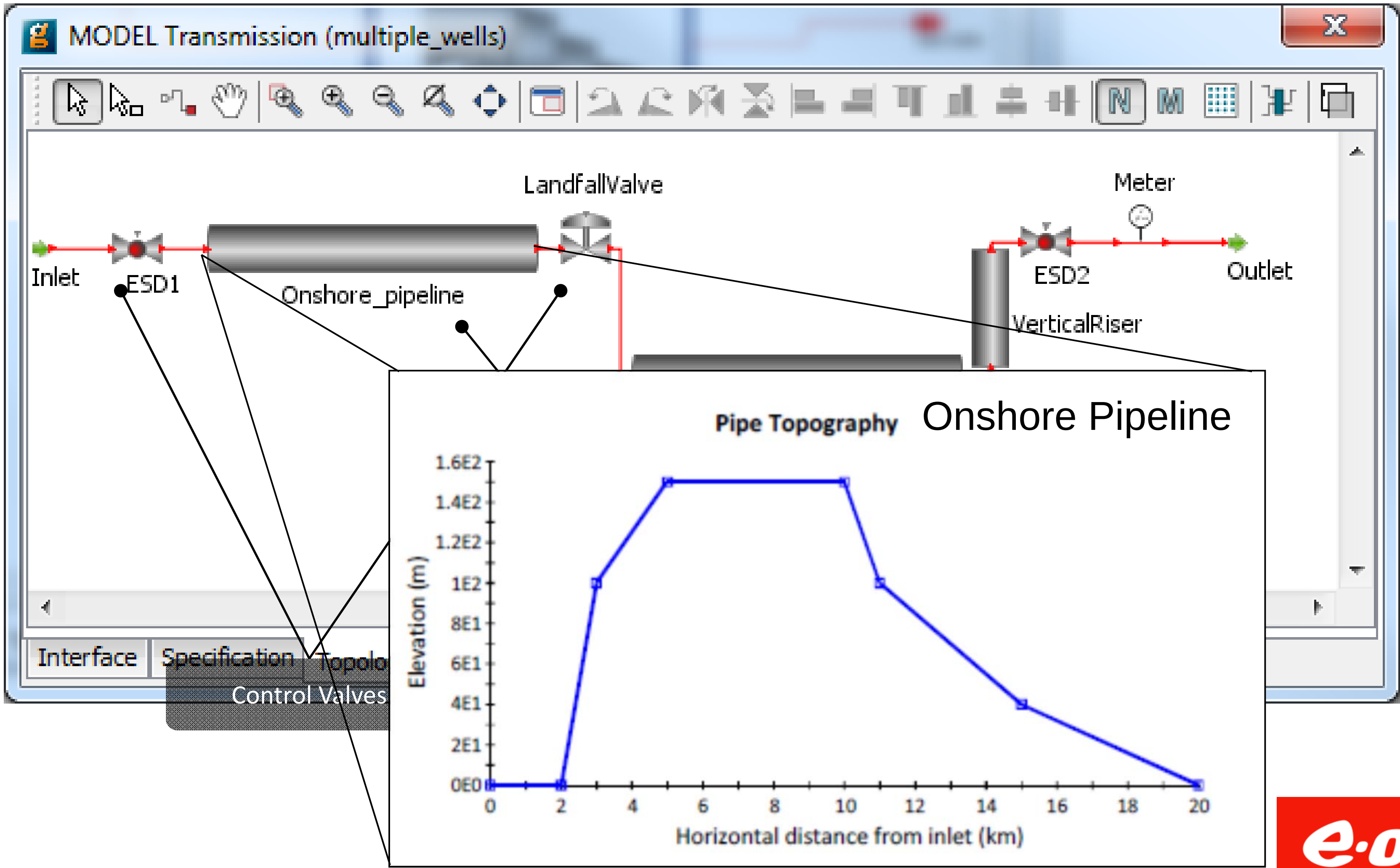


Compression

Single detailed compressor chain

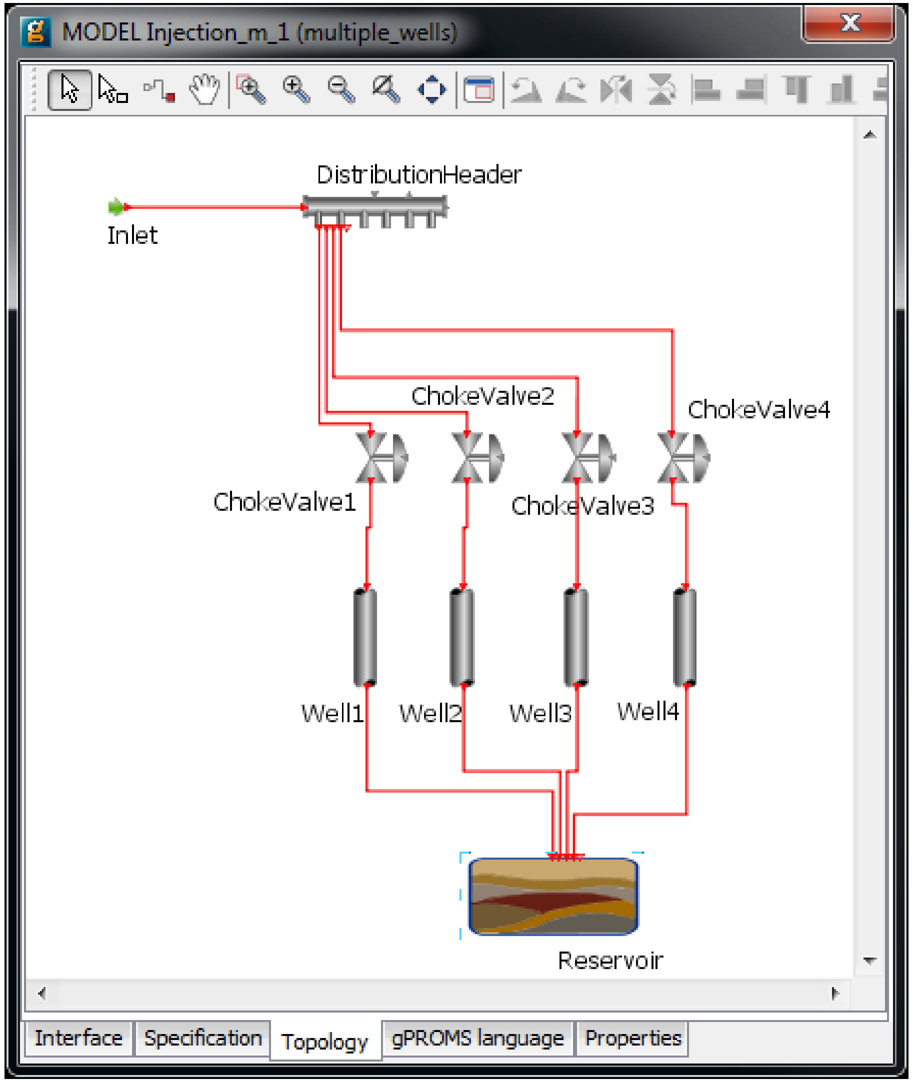


Transport

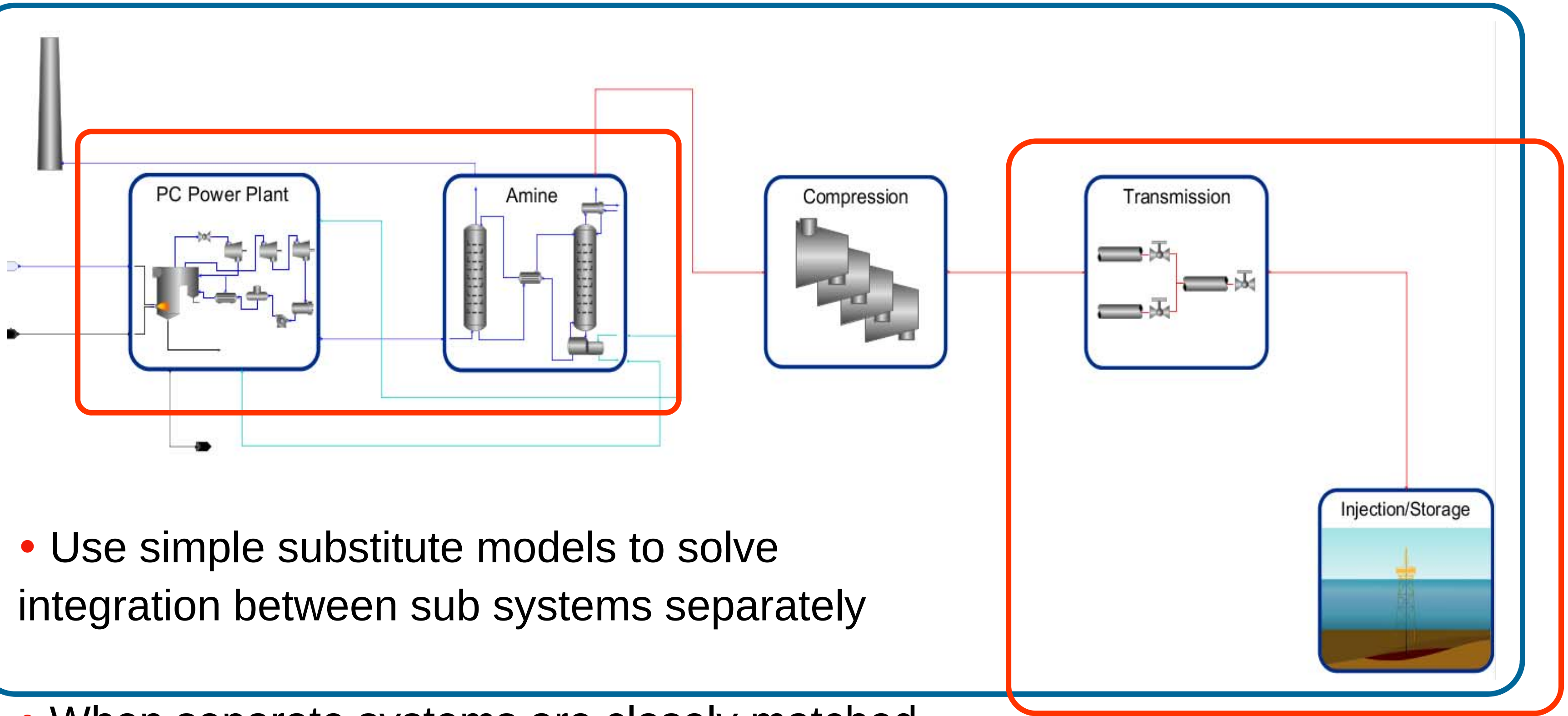


MODEL Transmission (multiple_wells)
LandfallValve
Meter
Inlet
ESD1
Onshore_pipeline
ESD2
Outlet
VerticalRiser
Interface
Specification
Topolo
Control Valves
Pipe Topography
Onshore Pipeline
1.6E2
1.4E2
1.2E2
1E2
8E1
6E1
4E1
2E1
0E0
Elevation (m)
0
2
4
6
8
10
12
14
16
18
20
Horizontal distance from inlet (km)

Storage


MODEL Injection_m_1 (multiple_wells)
DistributionHeader
Inlet
ChokeValve2
ChokeValve4
ChokeValve1
ChokeValve3
Well1
Well2
Well3
Well4
Reservoir
Interface
Specification
Topology
gPROMS language
Properties

Solving the Full Chain



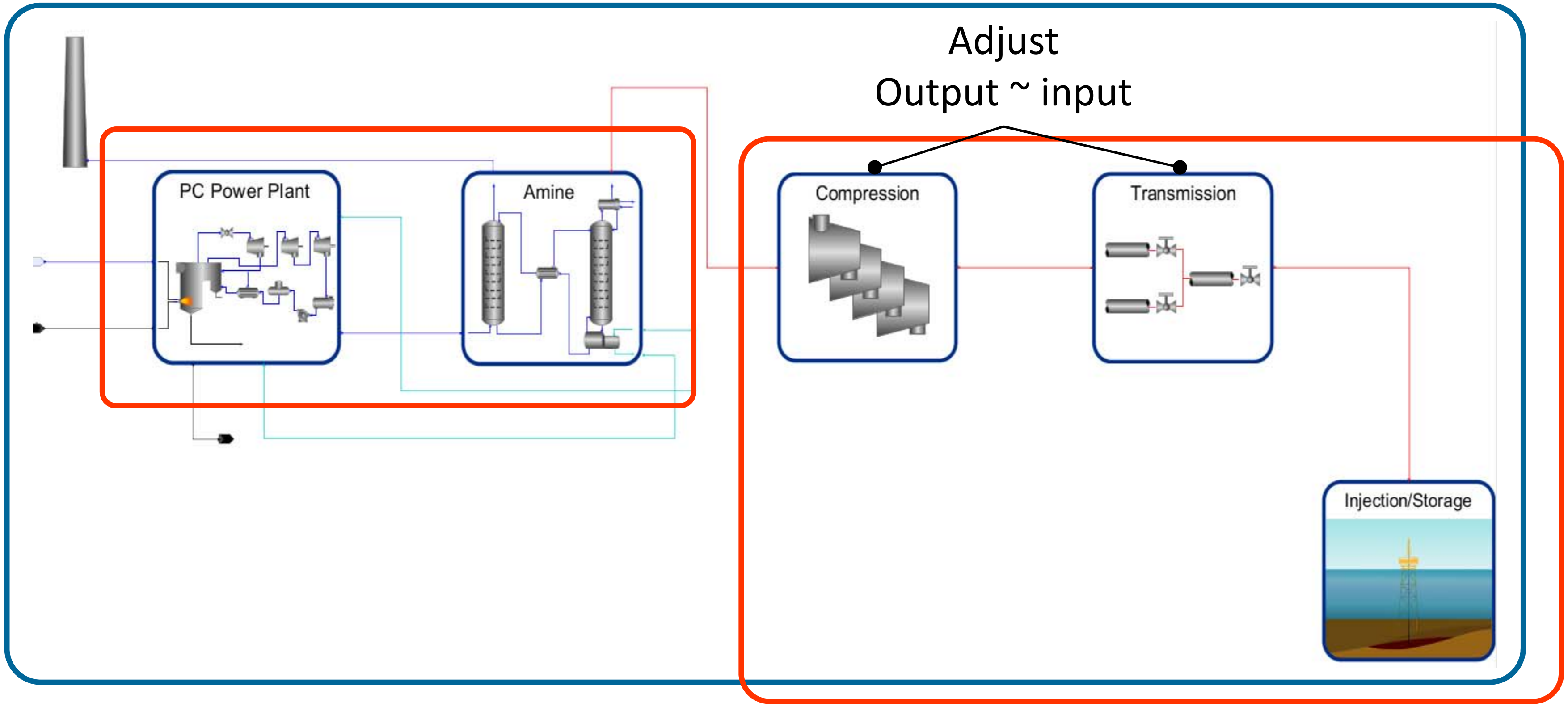
- Use simple substitute models to solve integration between sub systems separately

- When separate systems are closely matched – connect to solve, using saved variable sets for initial values

- Power plant and CO2 capture and Transport can be connected separately

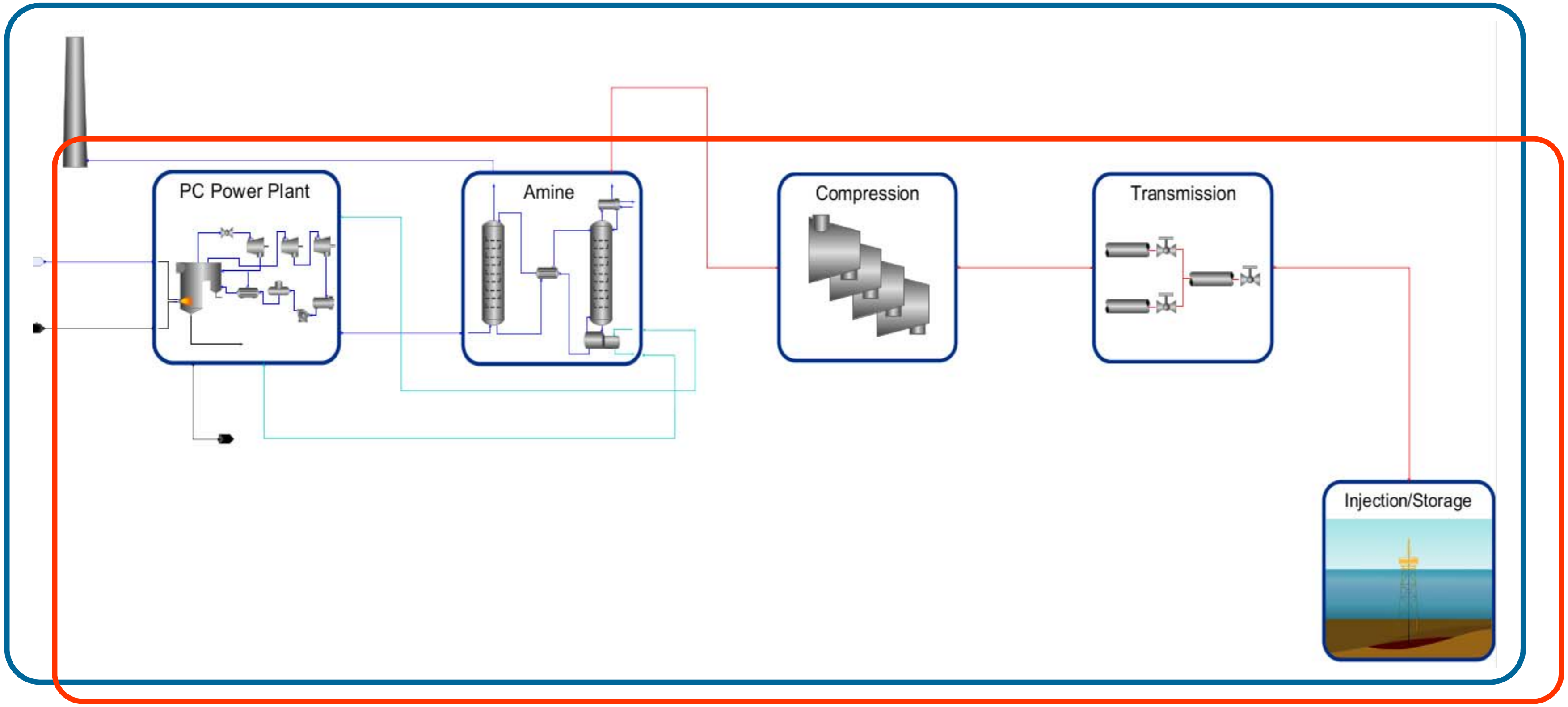
e·on

Solving the Full Chain



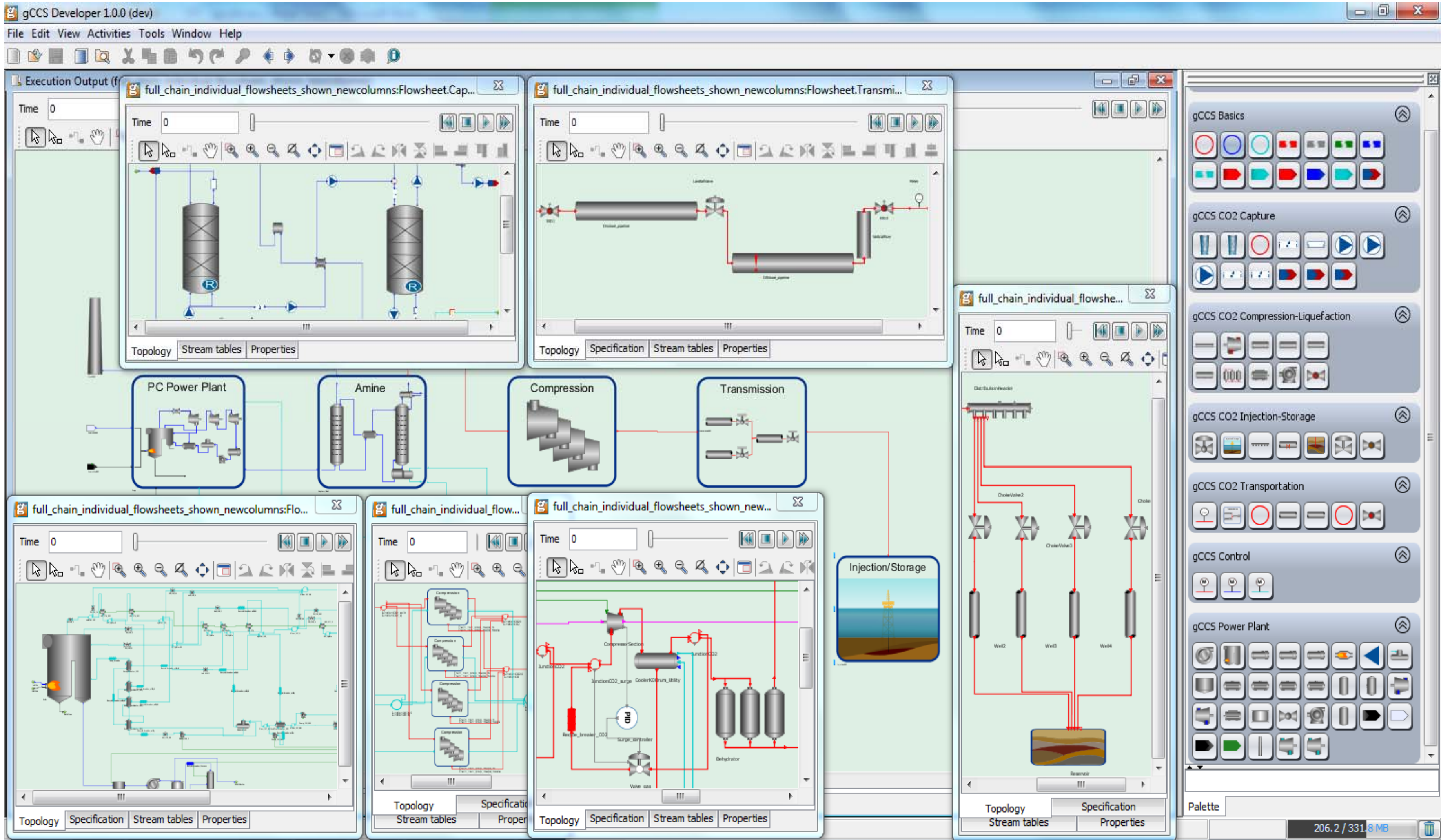
- Use Compressor outlet pressure as floating variable to connect to the network
- Solve each section and generate saved variable sets for each section

Solving the Full Chain



- Finally join both halves of the chain
- Complete initialised model is ready for steady state and transient analysis

Whole-chain simulation



Steady State Scenarios

Scenario #	Scenario name	Power Plant Specifications	Capture plant Specification
SS1.1	Base Load Power plant	100%, 75%, 50%	No capture
SS1.2	Base Load CCS chain	100% net Load	90% capture
SS1.3	Part load Power Plant	75% and 50% load cases	90% CO2 capture
SS1.4	Extreme Weather Summer	100% load Summer spec for CW and air	90% CO2 capture
SS1.5	Extreme Weather Winter	100% load Winter spec for CW and air	90% CO2 capture

Results –Scenario 1- Power Plant Only (No CCS)

- E.ON validated PROATES model used for model verification and comparison

Parameter	unit	gCCS 100% Load	PROATES 100% Load	Diff at 100% Load[%]	Diff at 75% Load[%]	Diff at 50% Load[%]
Total shaft power	MW	807.48	809.72	-0.28	0.05	1.30
Generator power	MW_e	797.32	800.00	-0.33	0.06	1.30
Gross cycle efficiency	%(LHV basis)	45.98	46.14	-0.33	-0.79	0.41
Coal firing rate	kg/s	68.95	68.89	0.09	0.84	0.86
HP steam temperature	°C	600.0	600.0	(Spec)	0.14	0.04
HP steam pressure	bara	285.0	285.0	(Spec)	1.54	0.41
HP steam flowrate	kg/s	635.81	635.81	(Spec)	0.75	-0.28
Hot reheat temperature	°C	620.0	620.0	(Spec)	Spec	3.28
Hot reheat pressure	bara	63.46	63.14	0.51	1.09	1.46
Hot reheat flowrate	kg/s	517.35	517.39	-0.01	0.65	-0.44
Cold reheat temperature	°C	363.0	364.0	-0.27	0.28	1.16
Cold reheat pressure	bara	65.72	66.86	-1.71	1.44	3.28
Final feed water pressure	bara	331.33	329.16	0.66	0.44	0.52
Final feed water temp	°C	313.11	312.8	0.10	0.17	0.45

- Bottom line – Deviation for Key values for Steam and Power mostly <1%, with max deviations of ~3% at 50% load.
- Missing - Auxiliary Power, Net Power and Net efficiency Implemented but results not available yet

Results –Scenario 2 – CCS Chain at Full Load

- Public study from European Benchmarking Taskforce used to evaluate Power plant Capture plant integration

Parameter	unit	gCCS	EBTF	Diff [%]
Gross power output without capture	MW_e	807.62	819.00	-1.39
Gross power output with capture	MW_e	669.80	684.20	-2.10
Gross efficiency without capture	% LHV	45.98	49.4	6.92
Gross efficiency with capture	% LHV	38.56	41.30	-6.63
Flue gas flow rate	kg/s	822.52	781.77	5.21
CO_2 inlet concentration	vol%	13.67	13.73	-0.44
CO2 removal efficiency	%	92	89	3.37
CO_2 Rich Loading	mol CO_2/ mol MEA	0.53	0.47	12.77
CO_2 Lean Loading	mol CO_2/ mol MEA	0.22	0.27	-18.52
Specific solvent demand	m^3/tonne CO_2	14.20	23.83	-42.85
Specific Reboiler duty	**GJ/tonne CO_2**	**4.32**	**3.73**	**15.82**
Solvent Concentration	wt%	31	30	3.33

- The CO2 capture plant did not predict the correct steam requirement, which impacts full analysis

- Relative impact on the power plant is as expected, demonstrating effectiveness of steam/water cycle calculations

Results –Scenario 2 – CCS Chain at Full Load

- Compressor was compared to Kingsnorth CCS demonstration Public FEED information (similar but not identical designs)

Parameter	unit	gCCS	Kingsnorth
Train CO_2 mass flow rate	kg/s	38.3	38.2
Inlet CO_2 Pressure	bar	1.5	1.2
Outlet CO_2 pressure	bar	97.9	88.2
Overall pressure ratio		65.3	73.5
Number of compressor sections		6	6
Total compression power	kW	13460	13101

- Transport and Storage Pressure and temperature relationships

	Kingsnorth ΔP between Reservoir and Bottomhole (bar)	gCCS ΔP between Reservoir and Bottomhole (bar)	% Error	Kingsnorth ΔP between Bottomhole and downstream the choke valve (bar)	gCCS ΔP between Bottomhole and downstream the choke valve (bar)	% Error	Kingsnorth Fluid temperature at Bottomhole (K)	gCCS Fluid temperature at Bottomhole (K)	Absolute Error (K)
Gas phase operation Reservoir pressure 2.1barg	5.4	5.36	~0.6	13.3	13.3	~0	279.05	280.9	-1.85

Current and Future Work

- Improvement in accuracy of current models in steady state – Significant overhaul of capture plant model already completed.
- Dynamic testing of component models and full chain interactions
- Utilising integration of proprietary software for chain subsystems e.g. E.ON's PROATES Power plant modelling platform for Power plants
- Integrating other power plant and capture plant technologies e.g. Combined Cycle gas turbines, Integrated Gasification Combined Cycle systems and Oxyfuel fired pulverised coal boilers
- Evaluating for CO_2 pipeline networks