«Hydrogen production via Steam Bio-methane Reforming»

Metacon Group

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2026/02/25

Personal information and studies

Personal information:

- Chalkidis I. Thomas
- Dr. Chemical Engineer
- Managing Director of METACON SA.

Education

1997: Diploma in Chemical Engineering with a focus on the Environment (University of Patras).

2002: PhD in Chemical Engineering in Environmental Catalysis (University of Patras)

2004: Master's Degree in Environment and Energy. (Univ. of Patras)

Source: Company information.

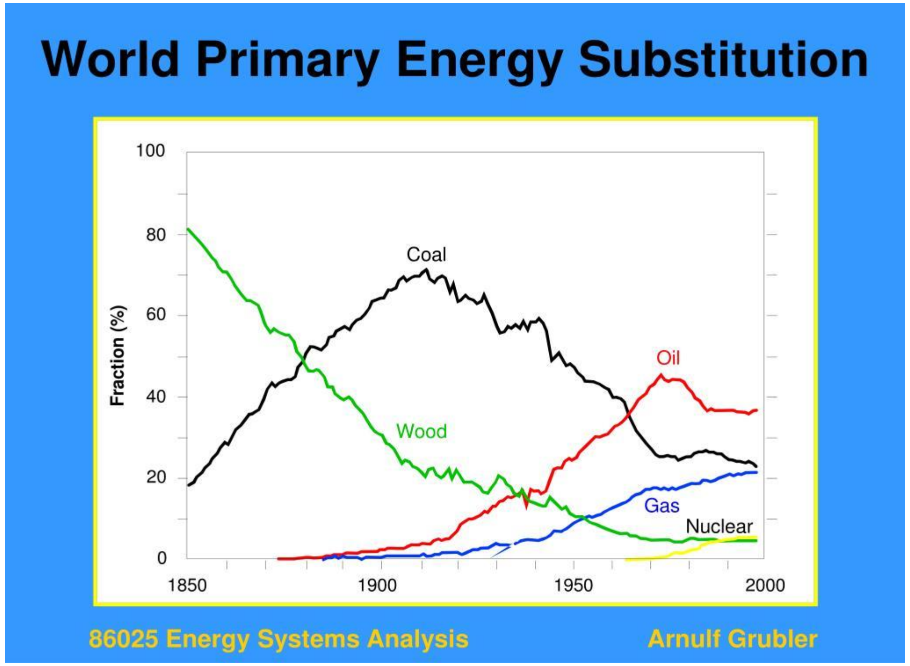
H Metacon SA

- ✓ It was founded in 2002 as a spin-off of the University of Patras for the commercialization of innovative processes and reform technologies developed at the university. Former name HELBIO SA.
- ✓ The core function of Metacon SA in the Metacon Group focuses on catalytic overhaul and R&D of reactors as well as the construction of hydrogen systems.
- ✓ The headquarters of Metacon SA remain in Patras and the university is still a talent pool for the company with many graduates among its employees, totaling 28 people.
- ✓ Metacon is active in the field of hydrogen and power generation, developing its own hydrogen production systems either for industrial use or integrated with fuel cells for Combined Heat and Power (CHP) solutions.
- ✓ Metacon S.A. has strong partnerships with Greek universities and institutions. The company is involved in many national and European funded projects with various national and European academic and industrial partners.
- ✓ Since 2023, Metacon S.A. has installed and operates a Management System in accordance with the requirements of ISO 9001:2015, ISO 14001:2015 and ISO 45001:2018 standards.

Source: Company information.
Source: Company information.

Hydrogen: The energy carrier of the (near) future

- High energy content: 120 MJ/kg
- Zero emissions at the point of use
- Versatile applications: industry, transport, energy
- Hydrogen Economy Roadmap Gains Global Traction



Fuel Type	Percent Hydrogen	Energy Content (Btu/lb)	Particulates (lb/Btu)	Carbon Dioxide (normal.)
Dry wood	5	6,900	5.22	100
Coal	50	10,000	5.00	31
Oil	67	19,000	0.18	21
Natural Gas	80	22,500	<0.01	15
Hydrogen	100	61,000	0.0	0

Source: Company information.

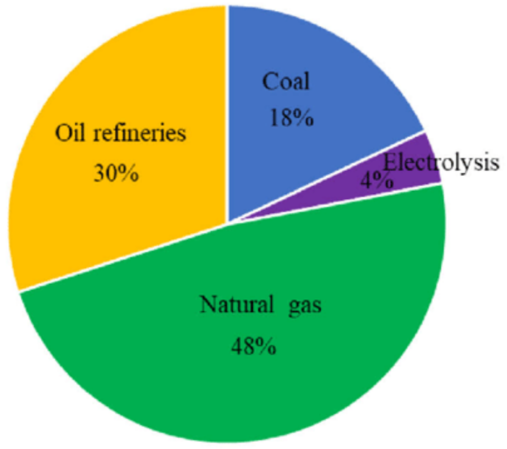
Hydrogen: The energy carrier of the (near) future

Current Hydrogen Production Landscape:
Total hydrogen production ~100 million tons in 2024
~96% from fossil fuels (natural gas, naphtha, coal)

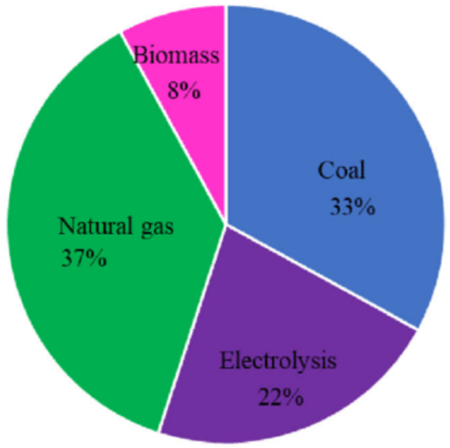
Dominant method: Catalytic Steam Methane Reforming (SMR)

Environmental impact: high CO_2 emissions
~9 kg CO_2/kg H_2 from natural gas
~20 kg CO_2/kg H_2 from carbon

Strong global push towards "blue" and "green" hydrogen



At present



Prediction Year 2050

Source: Company information.

Hydrogen production pathways

- Thermal: SMR, ATR, POX, Gasification, Methane Pyrolysis
- Electrolytic: Alkaline, PEM
- Biological : Dark or Photo fermentation
- Photolytic: Photoelectrochemical / photocatalytic water splitting (R&D)

Source: Company information.

CAPEX & OPEX technology comparison

Technology	CAPEX	OPEX	Efficiency	Emissions	TRL	Scalability
SMR	Low	Low	High (thermal)	High	Commercial	Very High
SMR/ATR + CCS	Med	Low–Med	High (thermal)	Low–Med	Commercial	High
Gasification (coal/biomass)	Med–High	Med	High	High→Low (with CCS)	Commercial	High
Alkaline Electrolysis	Med	High (power)	60–70% (LHV)	Near-zero (renewable power)	Commercial	High
PEM Electrolysis	High	High (power)	60–70% (LHV)	Near-zero (renewable power)	Commercial	High

SMR: Steam Methane Reforming
ATR: Autothermal Reforming
CCS: Carbon Capture & Sequestration

Source: Company information.

Case study:

Technology: Steam methane reforming for hydrogen production

Fuel origin: Biogenic methane (from upgraded Biogas)

Source: Company information.

Starting the design..

Inputs & Requirements:

- Feedstock Characteristics
- Water & Utility Requirements
- Hydrogen quantity and quality
- Catalyst Selection & Protection
- Energy Integration & Heat Management
- Carbon Management & Emissions
- Materials & Corrosion Management
- Plant Integration & Control Strategy
- Process Safety & Hazard Analysis
- Economic & Environmental Assessment

Source: Company information.

Modelling the process

Fuel: Biomethane (97 vol. % CH_4)*

Hydrogen output: 50 m^3/h*

Purity: >99.97 vol. % (ISO 14687:2025)*

H_2 production cost <2 euros/kg*

***Boundary conditions**

Design Objectives:

Hydrogen production technology: Steam reforming reaction (H_2> 70 vol. %)

Molar Steam to carbon ratio: 3.5

CO minimization reaction(s): Single stage water Gas Shift reaction (CO: <1.0 vol. %)

Purification: Pressure Swing Adsortion (PSA)

H_2 Recovery rate >80%

Source: Company information.

Modelling the process-Desulfurization

- **Fuels** may contain sulfur compounds (H_2S, mercaptans, odorants) and is essential to remove them to prevent poisoning of downstream catalysts

- Even a few ppm of sulfur can severely poison and deactivate them.

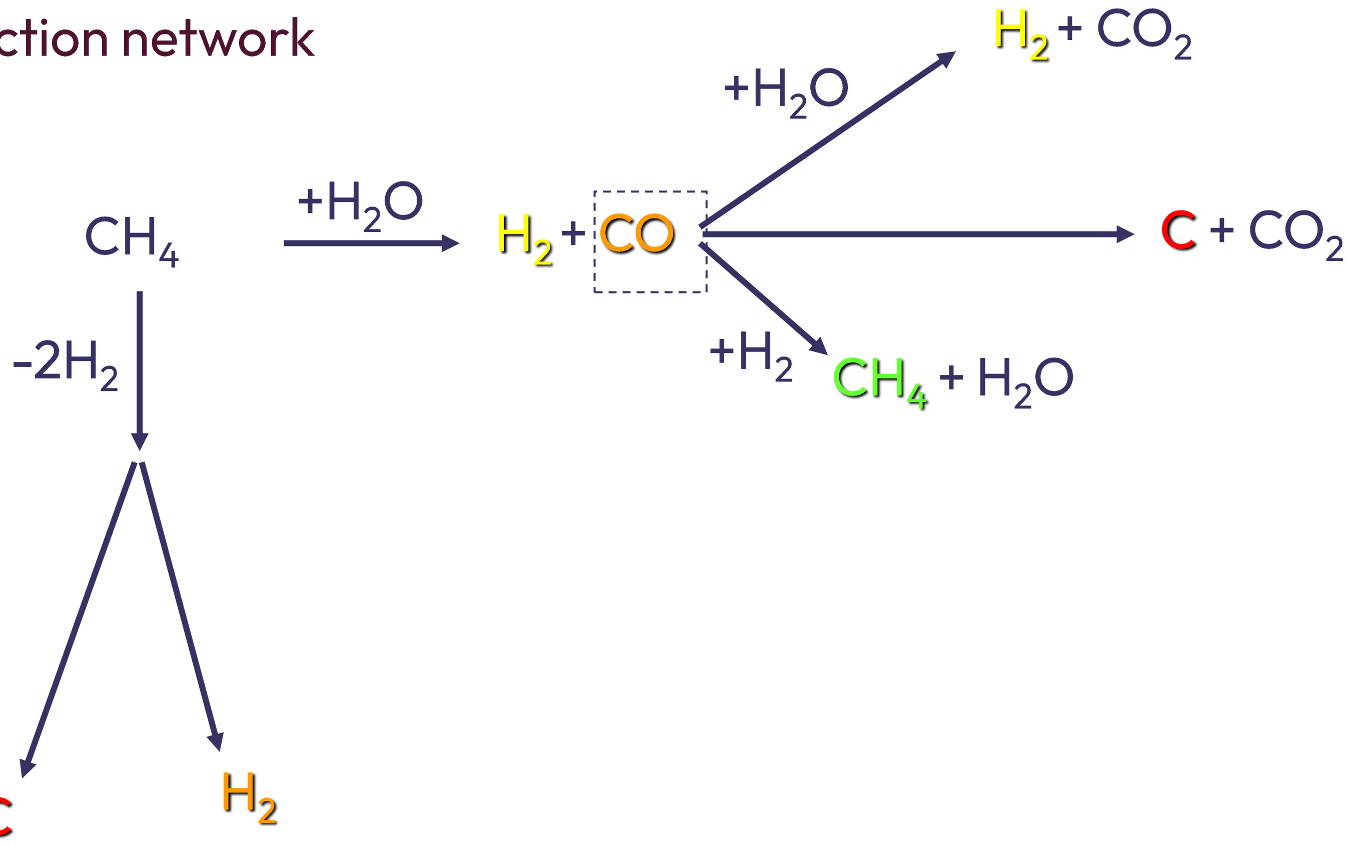
How is done…?

a) If sulfur content is high, a hydrogenation step (hydrotreater with Co–Mo catalyst) converts organosulfur to H_2S, followed by ZnO bed to capture H_2S.
b) For low sulfur fuels (odorant-level), a single ZnO guard bed or use of passive commercial adsorbent typically modified zeolites with additives like Cu, Zn, etc are often sufficient .
c) You need the expected sulfur content (mg/m3) and the uptake capacity of the adsorbent typically mg of S per g of adsorbent to calculate the amount of adsorbent needed for X m^3 of input fuel.

Source: Company information.

Modelling the process-Reformer

Steam/methane reaction network



Source: Company information.

Modelling the process-Reformer

Methane steam reforming reaction (700-800°C)

$CH_4 + H_2O \leftrightarrow CO + 3H_2$ (1) $\Delta H = +206$ kJ/mol *Highly endothermic*

Side reaction(s) in reforming:

$CO + H_2O \leftrightarrow H_2 + CO_2$ (2) $\Delta H = -41$ kJ/mol *slightly exothermic*

Combustion reactions (800-900°C)

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ (3) $\Delta H° = -890.578$ kJ/mol *exothermic*

$H_2 + ½ O_2 \rightarrow H_2O$ (4) $\Delta H° = -285.826$ kJ/mol *exothermic*

$CO + O_2 \rightarrow CO_2$ (5) $\Delta H° = -283.0$ kJ/mol *exothermic*

Catalyst reforming: Ni/Al_2O_3 plus promoters/stabilizers

Catalyst combustion: Proporietary on Al_2O_3

Pressure: 10-11 barg (reforming)

Steam/Carbon: 3.5

Outlet temperature: 750-770 °C

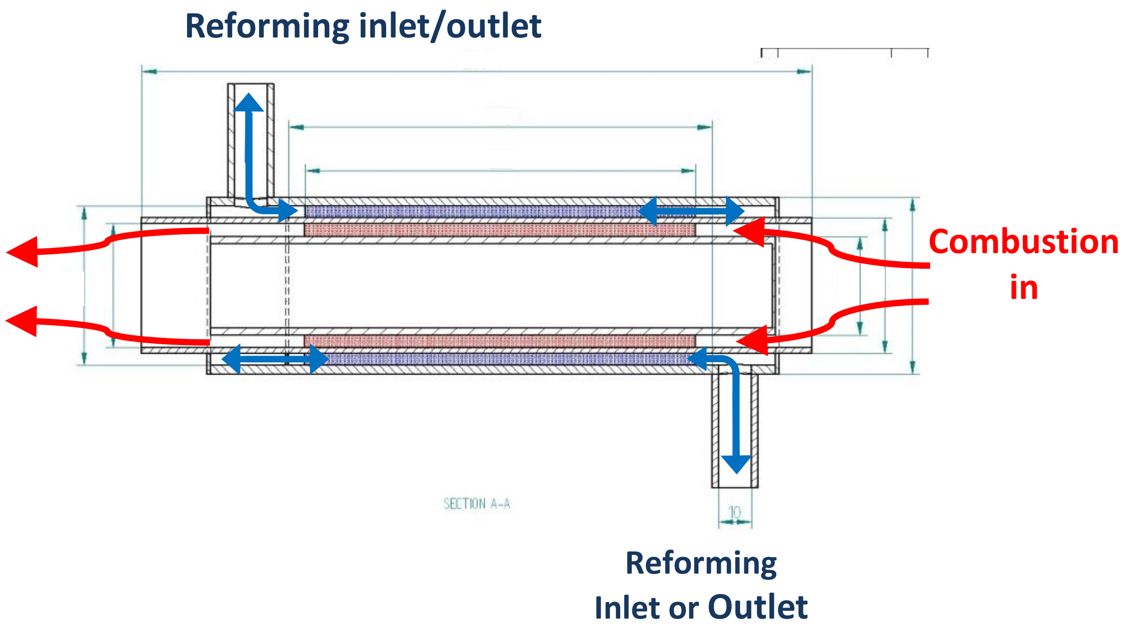
Reformer reactor

Source: Company information.

Modelling the process-Reformer

Reformer reactor:

- The reformer consists of a double pipe reactor incorporating separate flow passages in which, both combustion and reforming reactions take place simultaneously.
- The chemical process that produces hydrogen, is the fuel steam reforming which is endothermic. A small portion of the fuel is combusted catalytically together with the reject gas to provide the necessary heat to the reforming reaction.

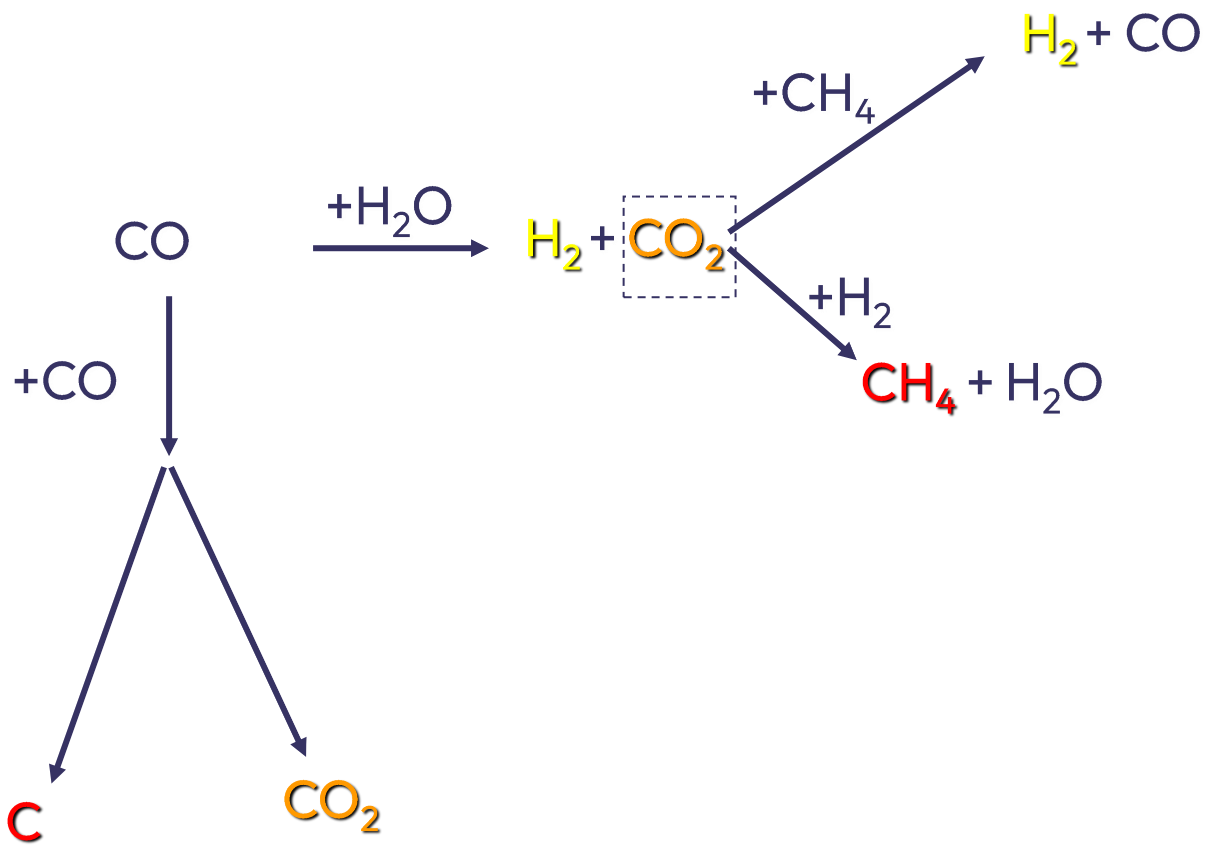


Suitable for:

- Methane steam reforming/combustion reaction

Source: Company information.

Modelling the process-WGS



Boudouard or CO **disproportionation**

Source: Company information.

Modelling the process-WGS

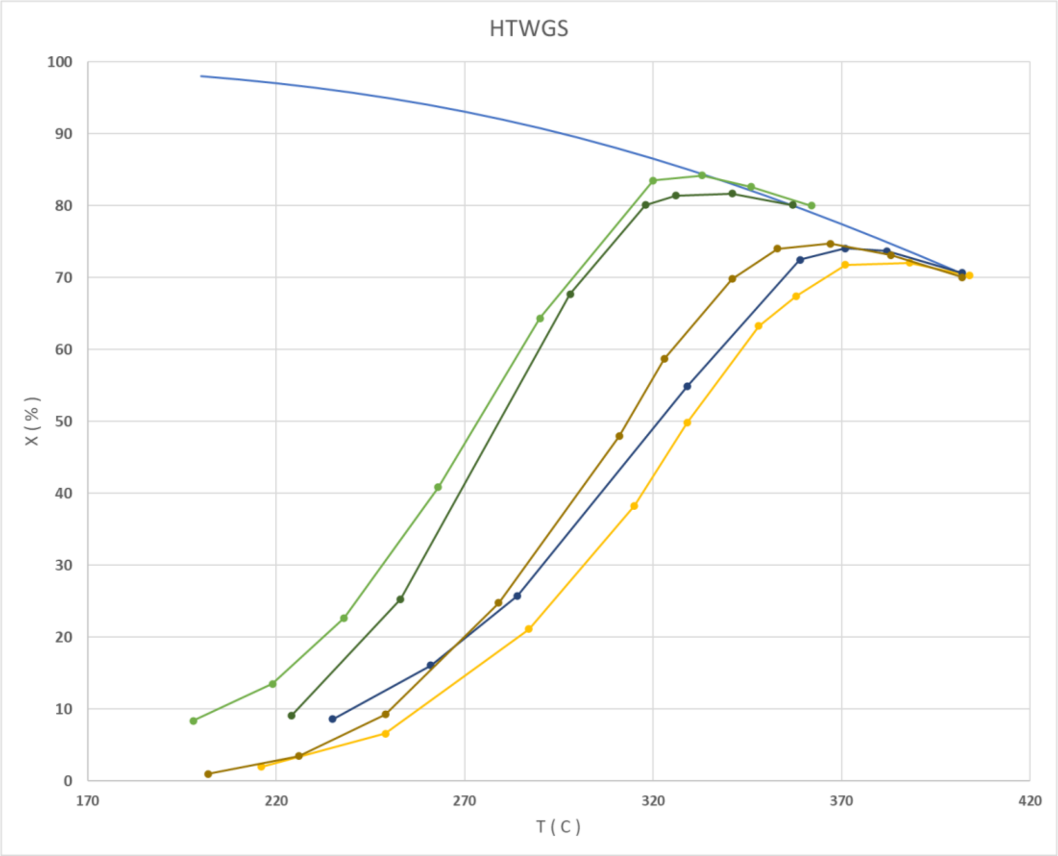
Water Gas Shift Reactor (WGSR)

$CO + H_2O \leftrightarrow H_2 + CO_2 \quad \Delta H = -41$ kJ/mol

$T_{in} = 400\ ^{o}C$
PGM catalyst
Heat exchanger type reactor

Typical inlet composition:

	Vol. %
CH_4	2.8
CO	8.5
H_2O	33.1
CO_2	8.7
H_2	46.9



Source: Company information.

Modelling the process-PSA

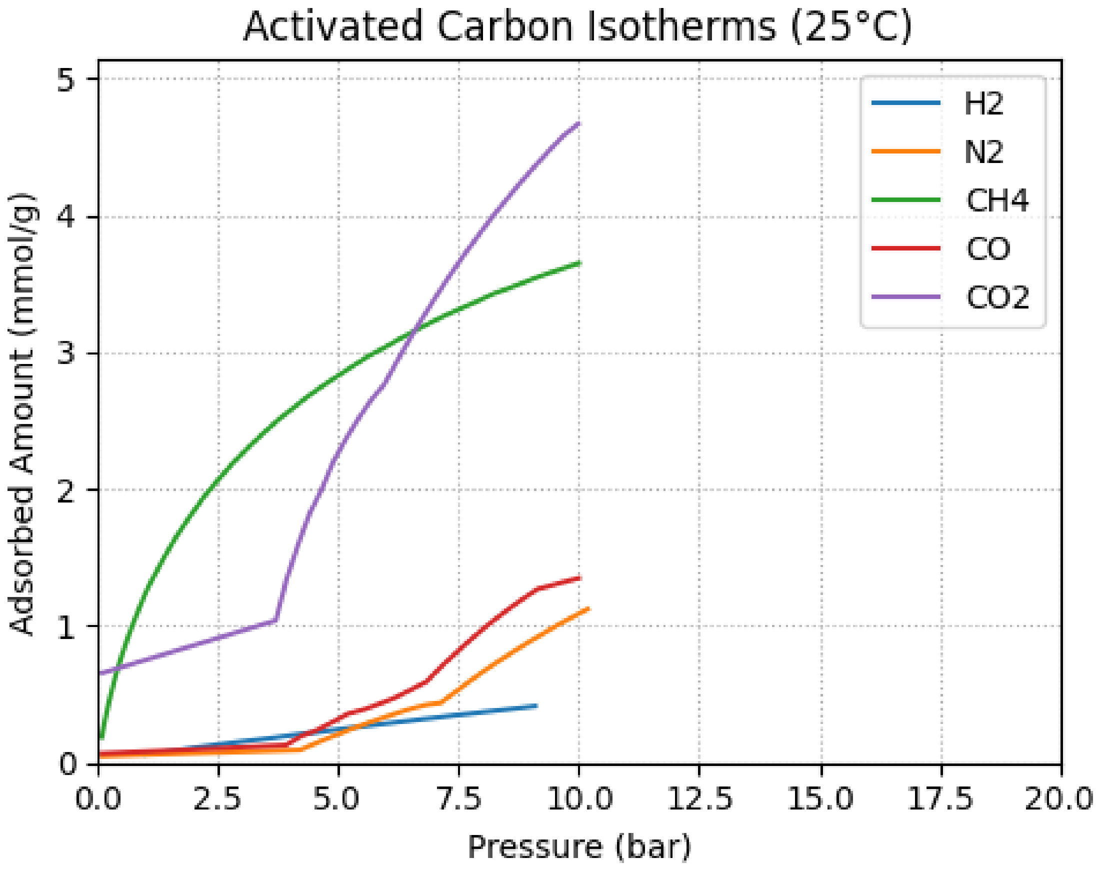
Some theory...

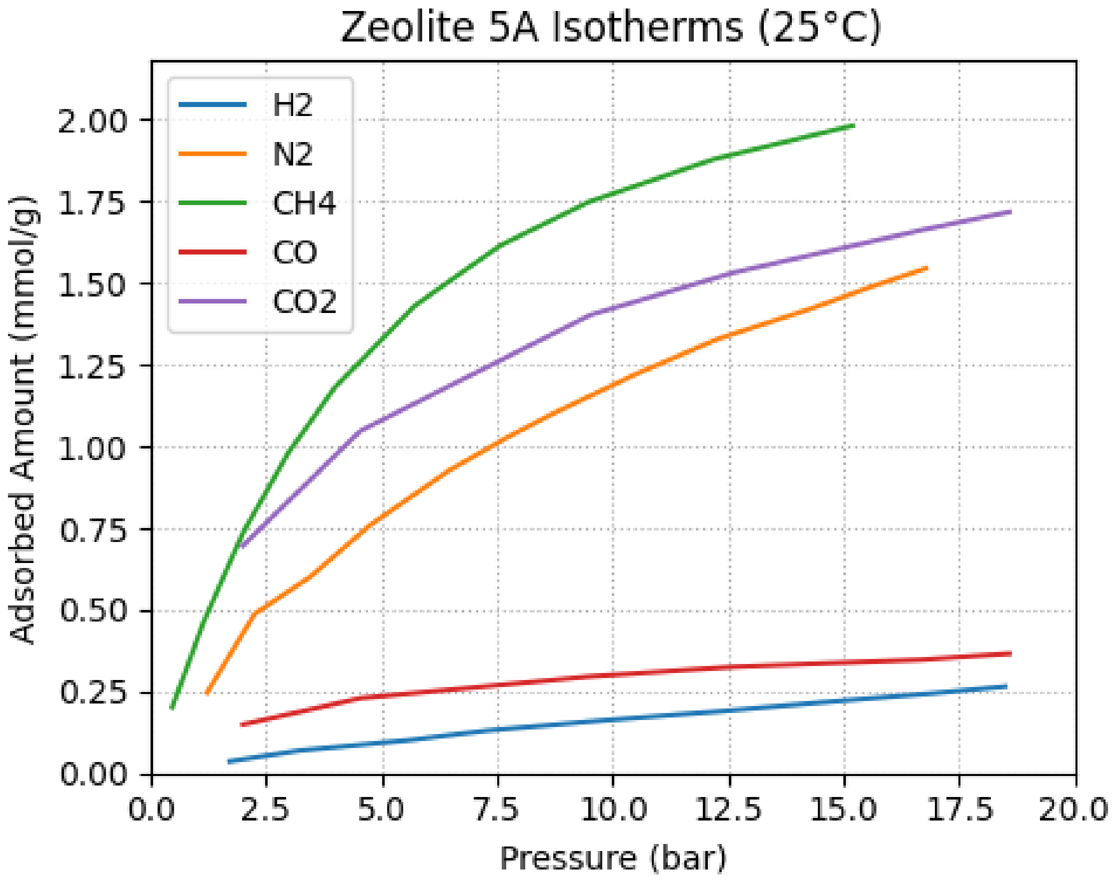
Pressure Swing Adsorption (PSA) is a cyclic gas-separation process that purifies a gas mixture by exploiting the fact that certain molecules are preferentially adsorbed onto solid adsorbents at high pressure and then released when the pressure is lowered.

Adsorption isotherms are curves that relate the amount of gas adsorbed on a solid adsorbent to the gas pressure (or concentration) at constant temperature. They help characterize adsorbents, predict PSA performance, calculate surface area, and design layered beds with optimal selectivity.

Source: Company information.

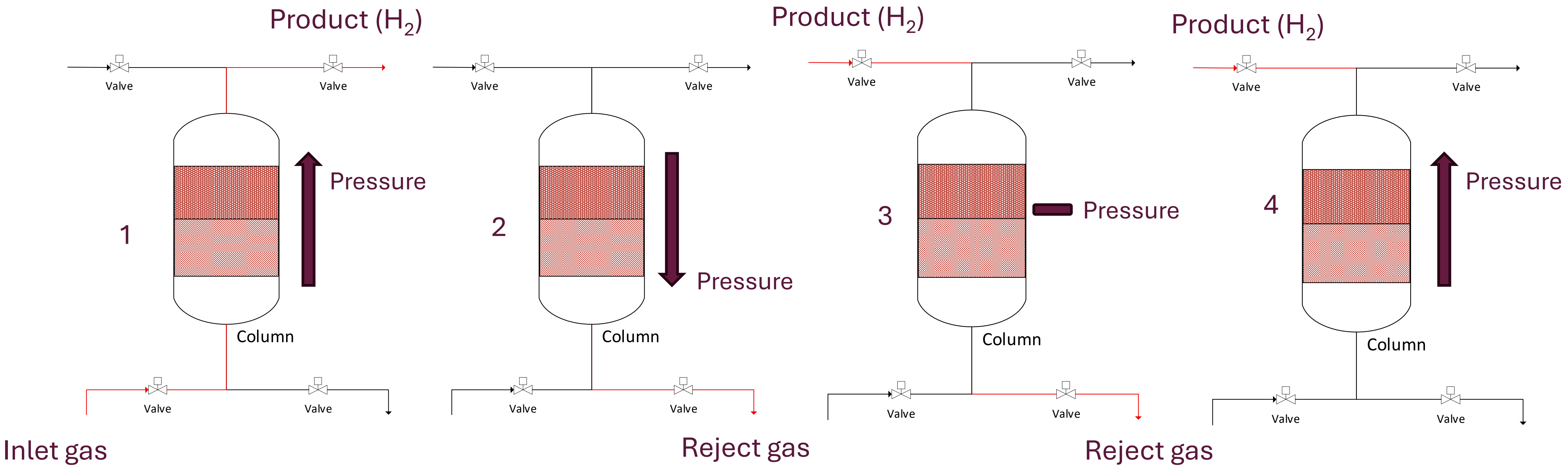
Modelling the process-PSA





Source: Company information.

Modelling the process-PSA



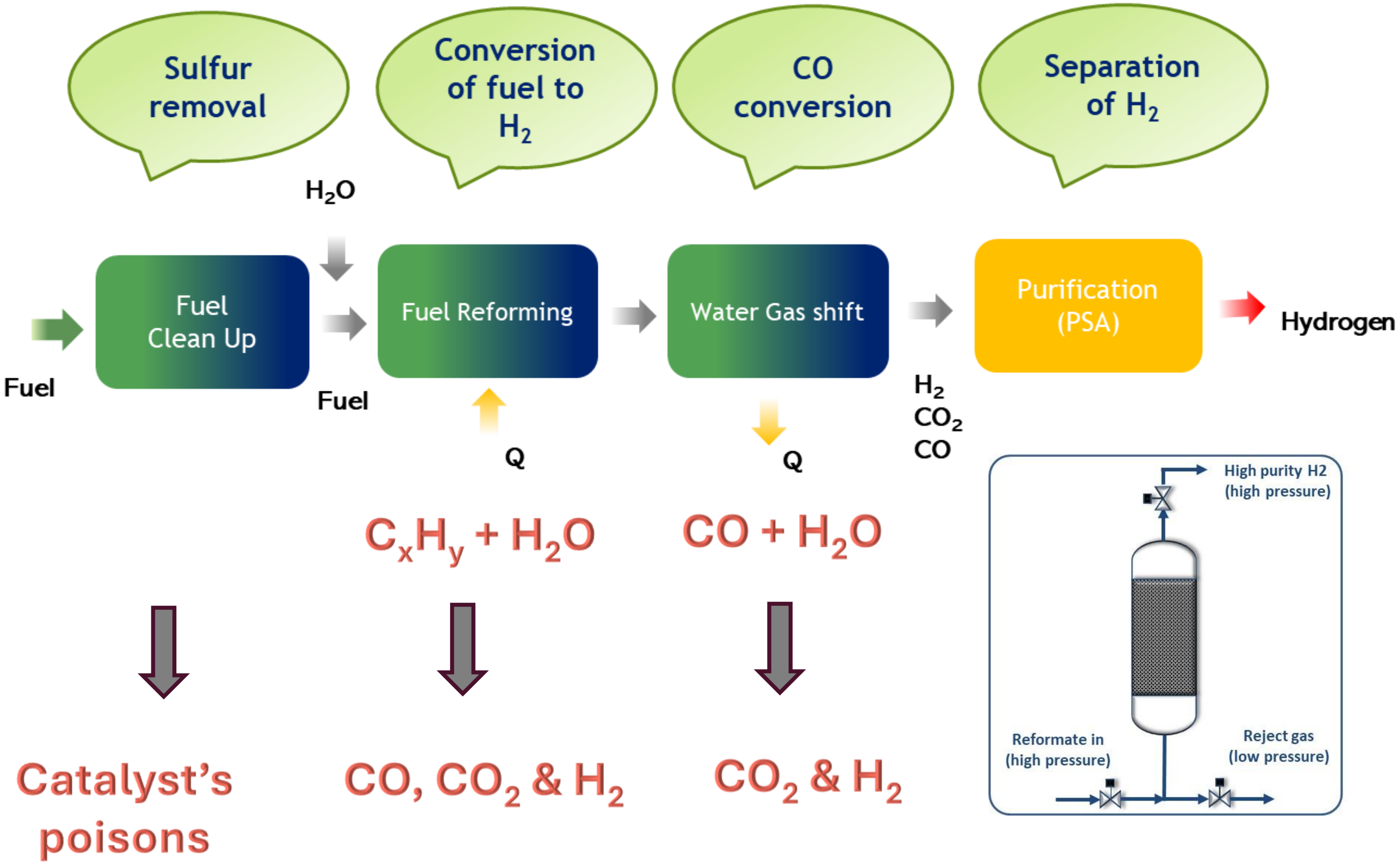
1. Adsortion/Equalization
2. Depressurization/Blowdown
3. Regenaration
4. Repressurization

Inlet gas composition (CH_4, CO, CO_2, H_2) : 4% 1% 20% 75%

Reject gas composition (CH_4, CO, CO_2, H_2): 12%, 3%, 48%, 37%

Source: Company information.

Modelling the process



Source: Company information.

Modelling the process

Unisim Design software

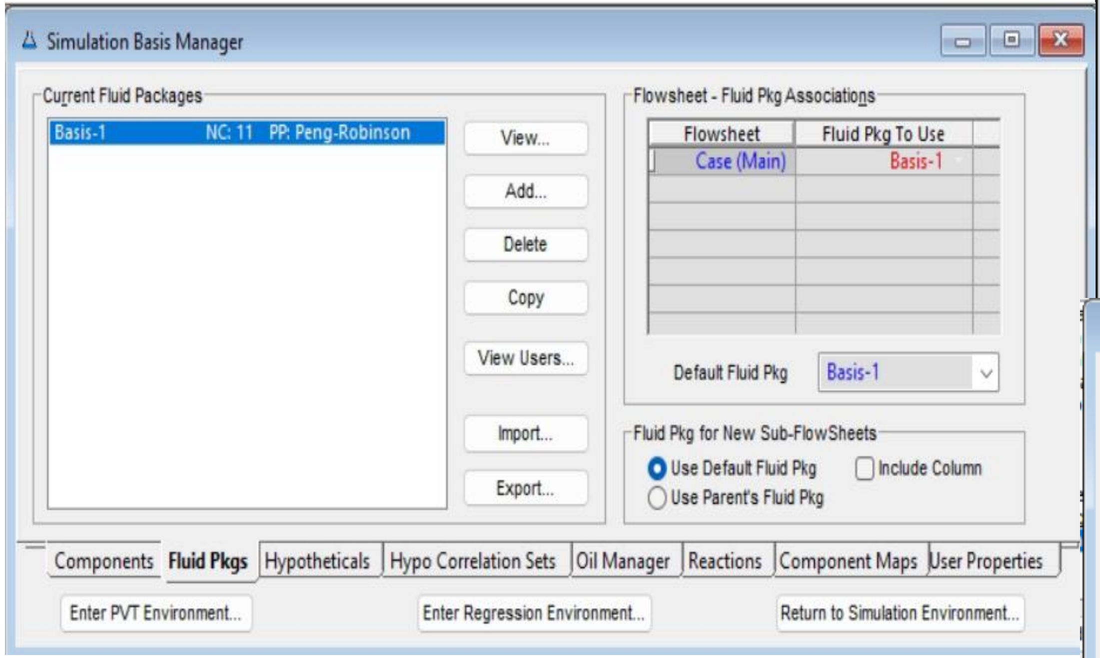
- **Selection:** of components and reactions
- **Thermodynamic Package**: Peng–Robinson is suitable for high-temperature syngas mixtures.
- **Reactor Models**: Equilibrium reactor for SMR and WGS, for CH_4, H_2O, CO, CO_2, H_2 at the given temperature (770 oC) and pressure (1200kPa).
- **Heat Integration:** We'll include heat exchangers to capture the energy exchange. We also model the furnace/combustor simply as a Gibbs reactor that takes fuel (PSA off-gas) and provides heat to the reformer reactor. By adjusting the fraction of fuel burned, we ensure the reformer outlet hits ~770 °C.
- **PSA Unit:** in UniSim we typically model it as a simple separator block that splits the stream into a hydrogen product (at the specified purity and recovery) and a tail gas.
- **Recycle Loops:** The simulation includes a recycle loop where the PSA tail gas is mixed with fresh fuel if needed and sent to the combustor. Convergence of this recycle loop in UniSim confirms that the system can reach a steady state where the energy from tail gas combustion is sufficient (or nearly sufficient) for the reformer needs. If not, we'd add a small fresh fuel makeup in the model.

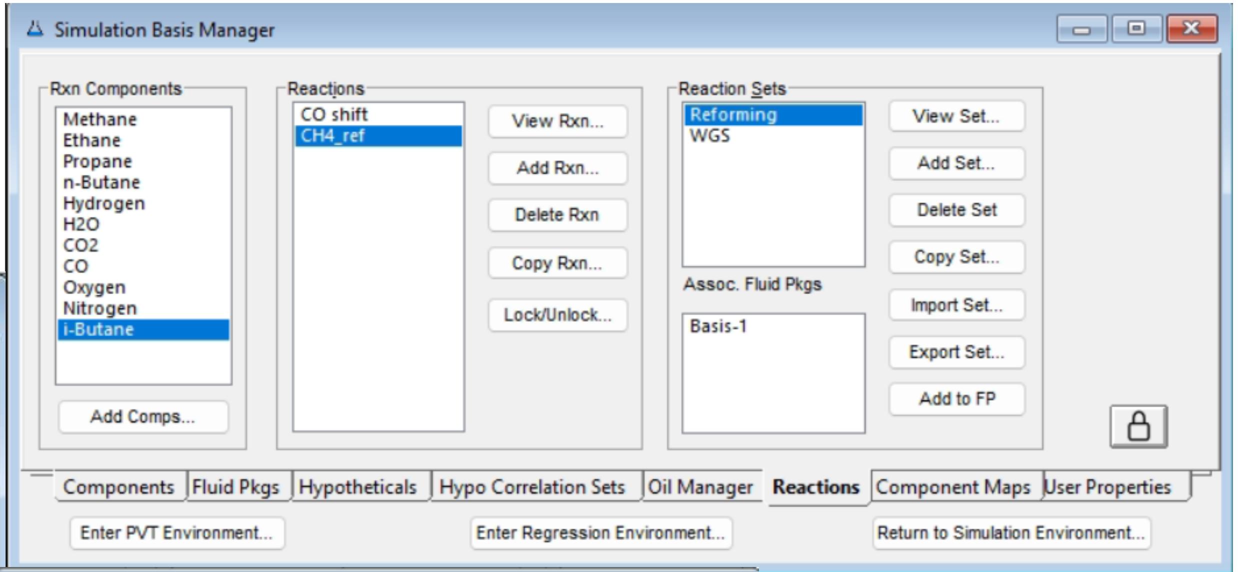
Hints: By iterating in UniSim, we adjust parameters for optimal results, e.g. we might tweak the steam-to-carbon ratio in the model: increasing steam ratio generally increases CH_4 conversion (by Le Chatelier's principle) and reduces coking risk, but too much steam lowers overall efficiency. The simulation might show that going from S/C=2.8 to 3.5 raises H_2 yield by a few percentage points while increasing furnace duty by 5% – a tradeoff the designer must consider. UniSim also helps size equipment: the flow rates and energy duties from the model inform the sizing of burners, heat exchangers, and catalyst volume.

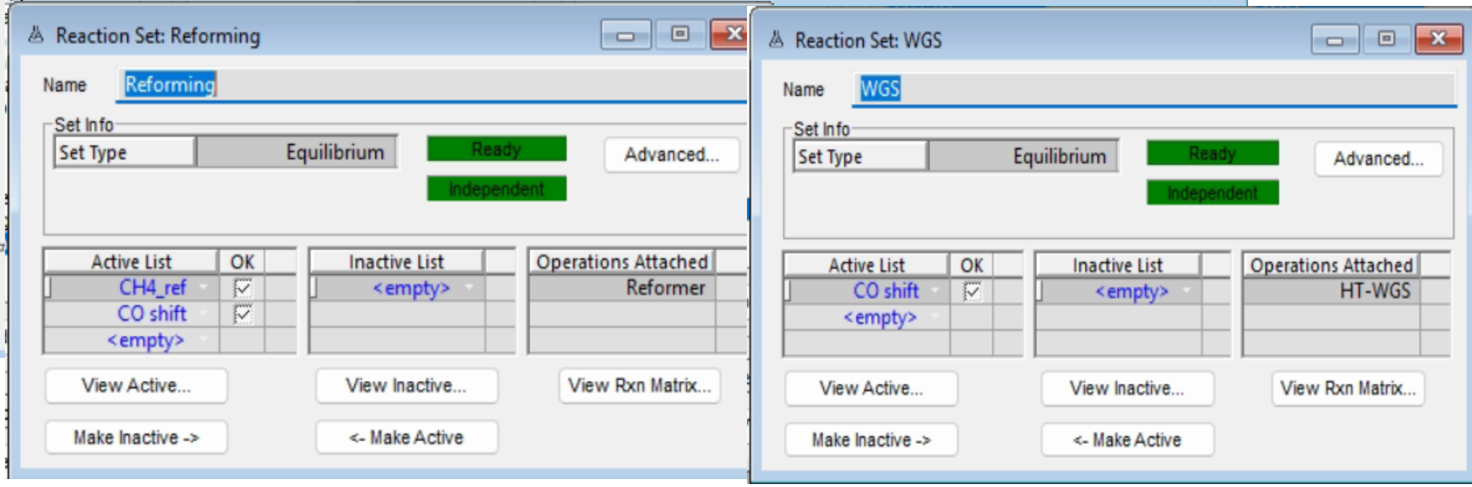
Source: Company information.

Modelling the process

Unisim Design software







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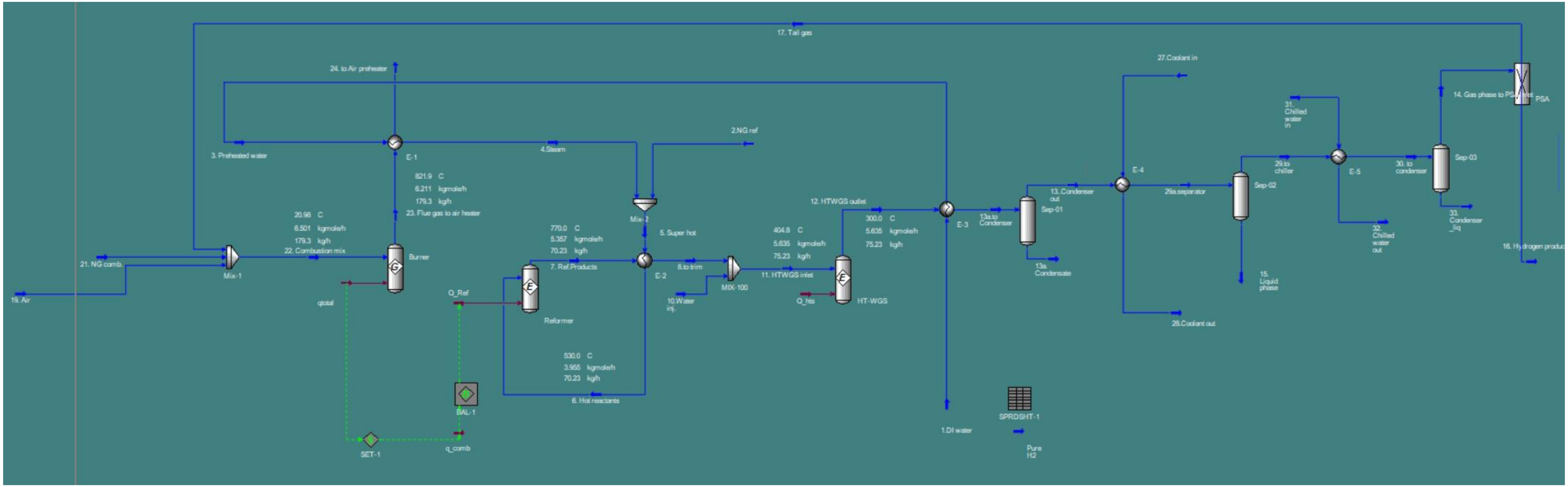
Modelling the process

Unisim Design software



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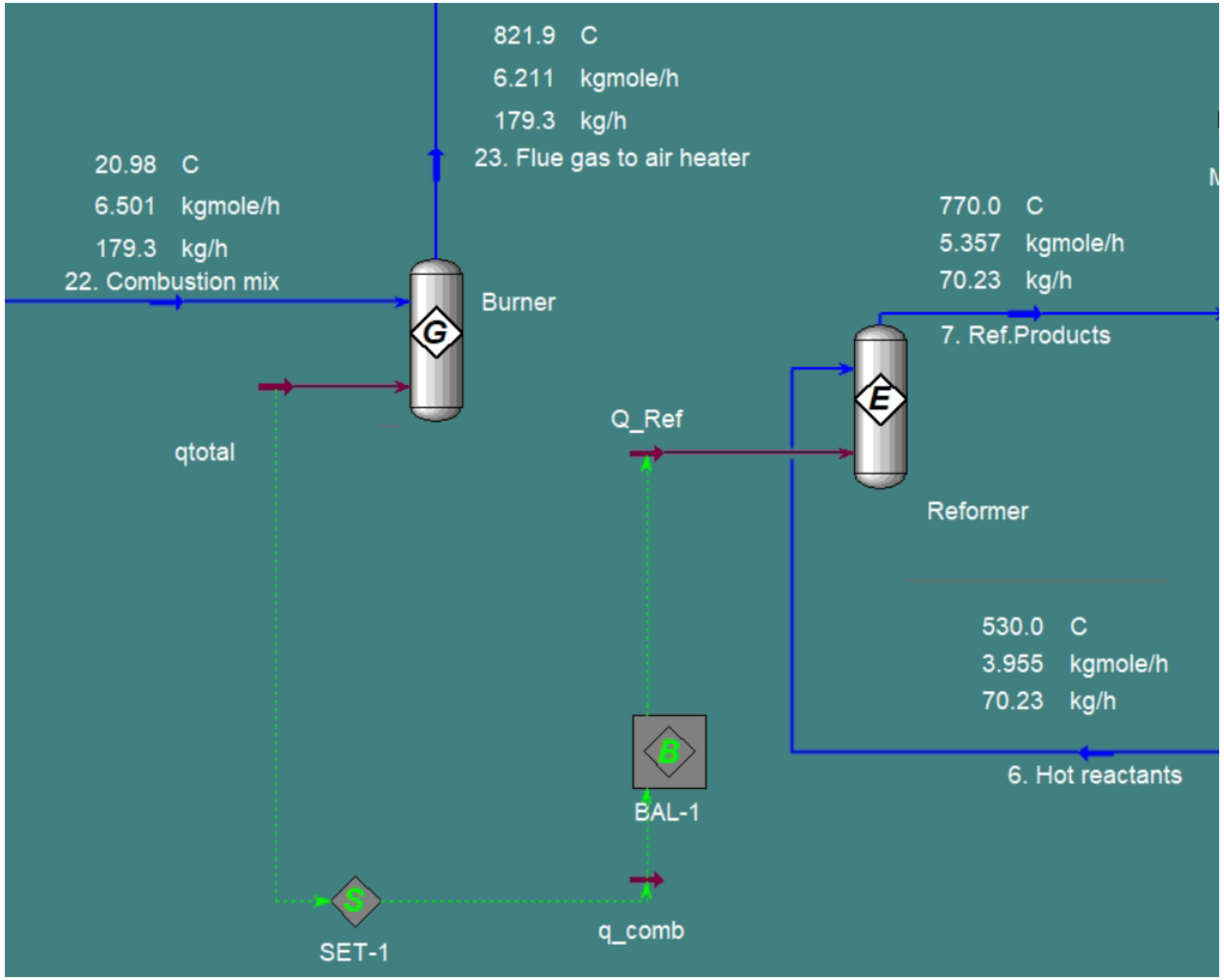
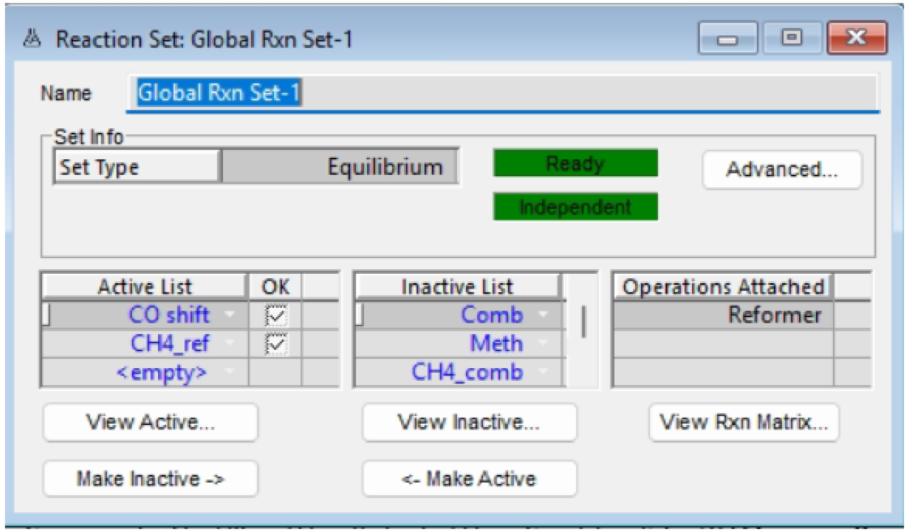
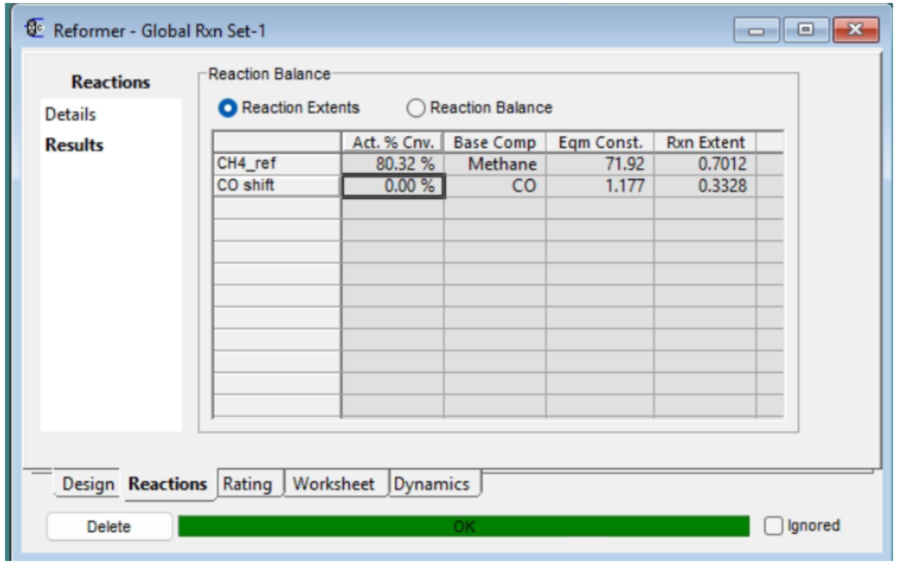
Modelling the process







Unisim Design software

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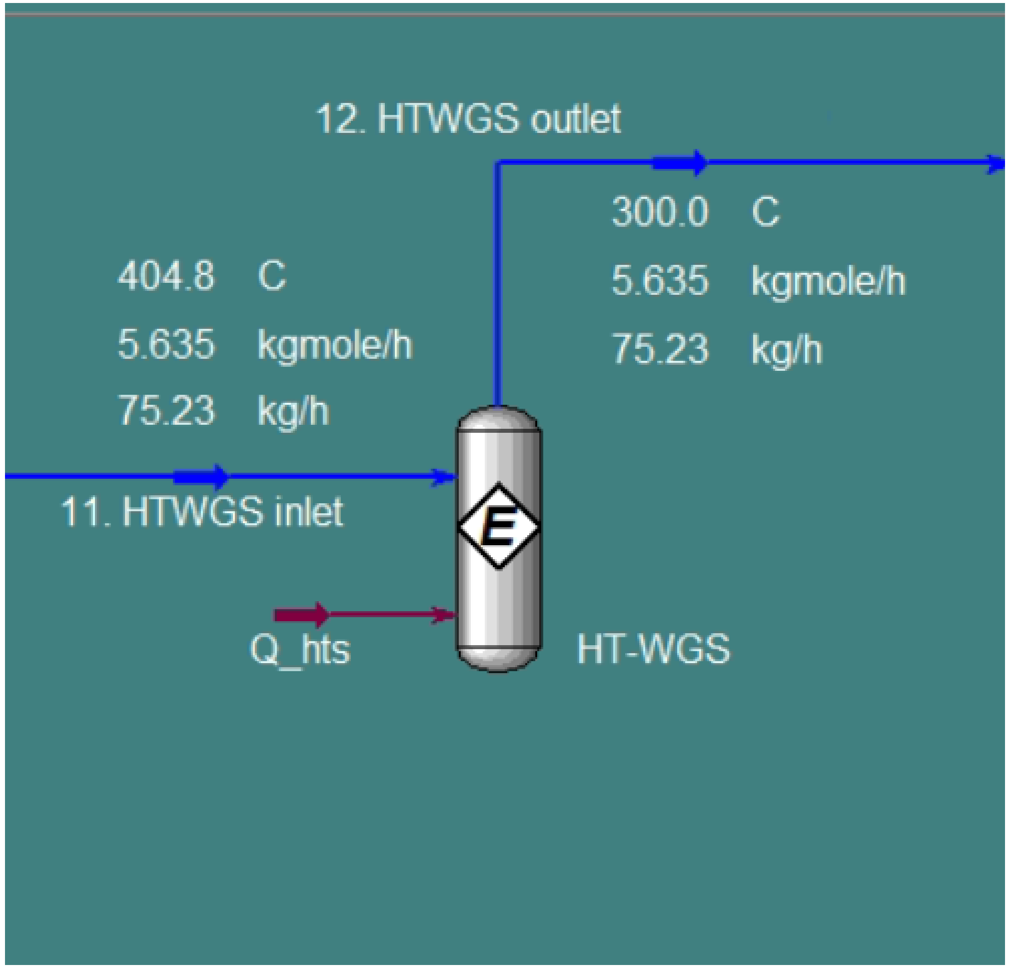
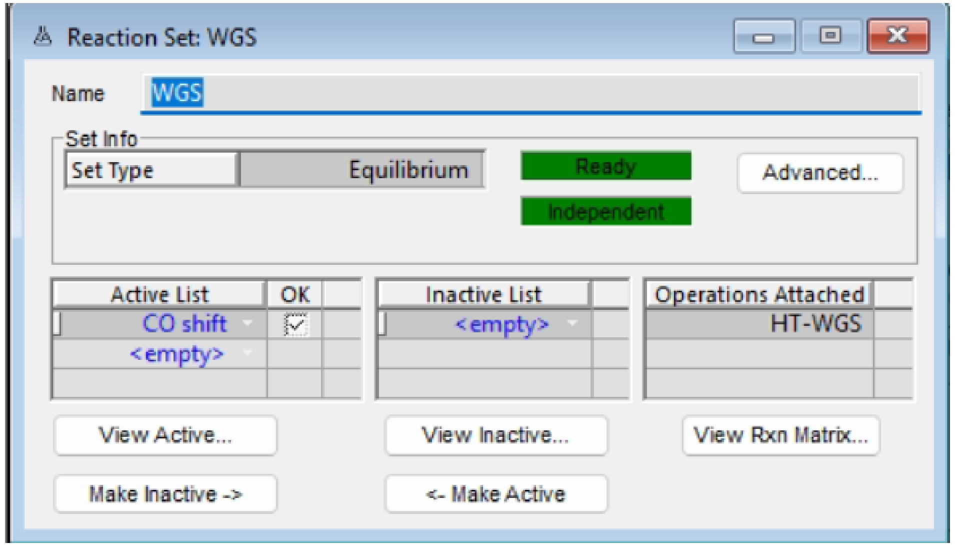
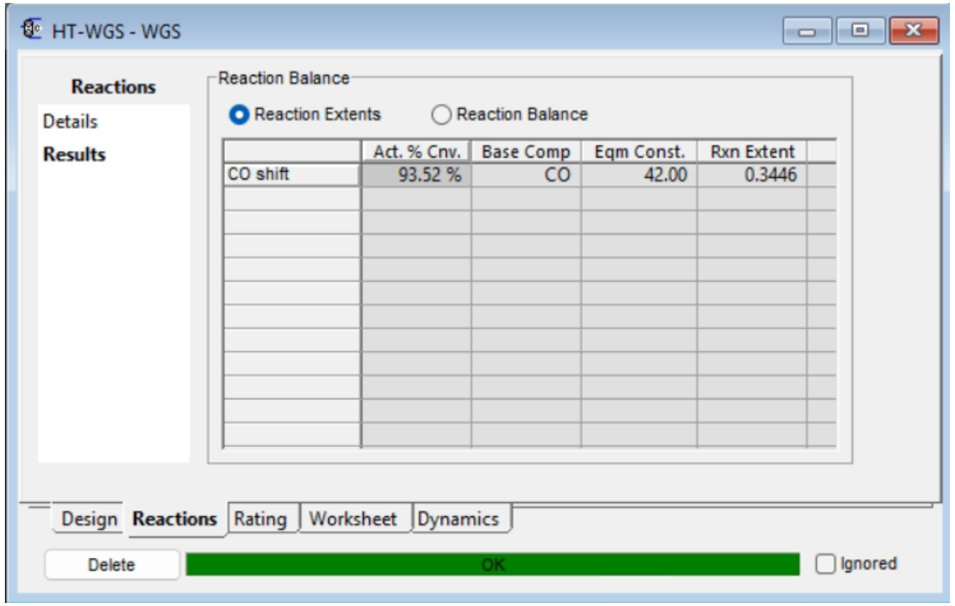
Modelling the process







Unisim Design software

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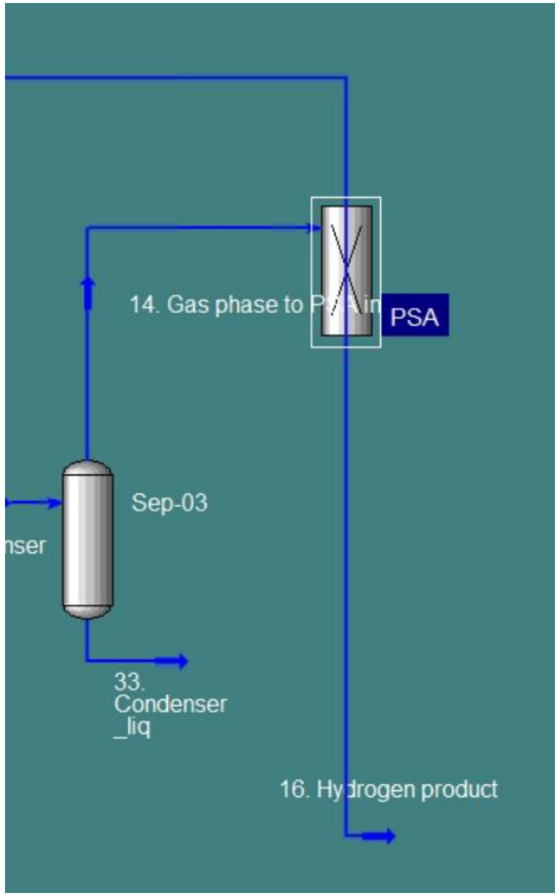
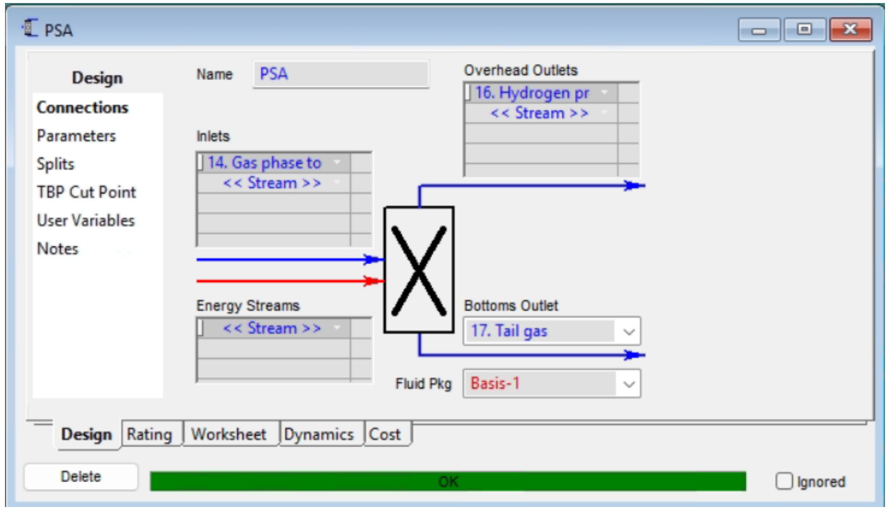
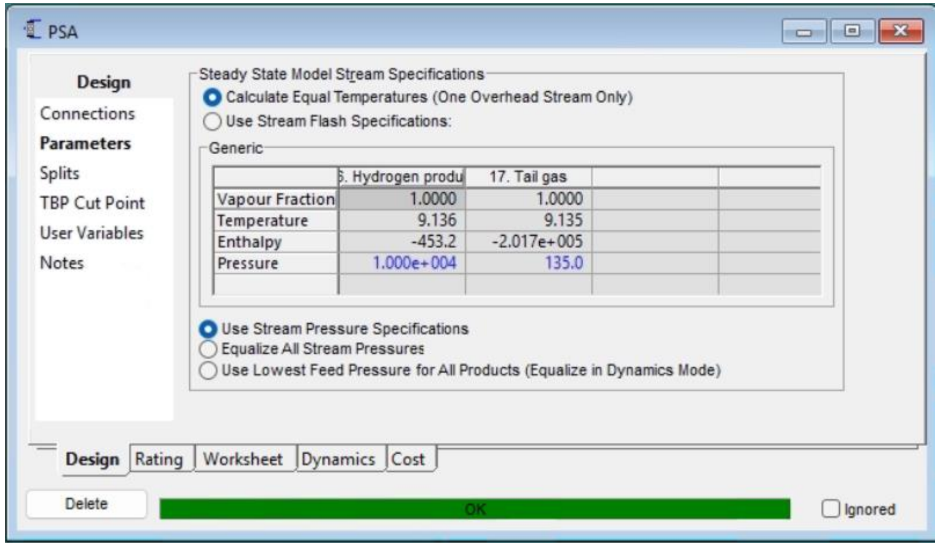
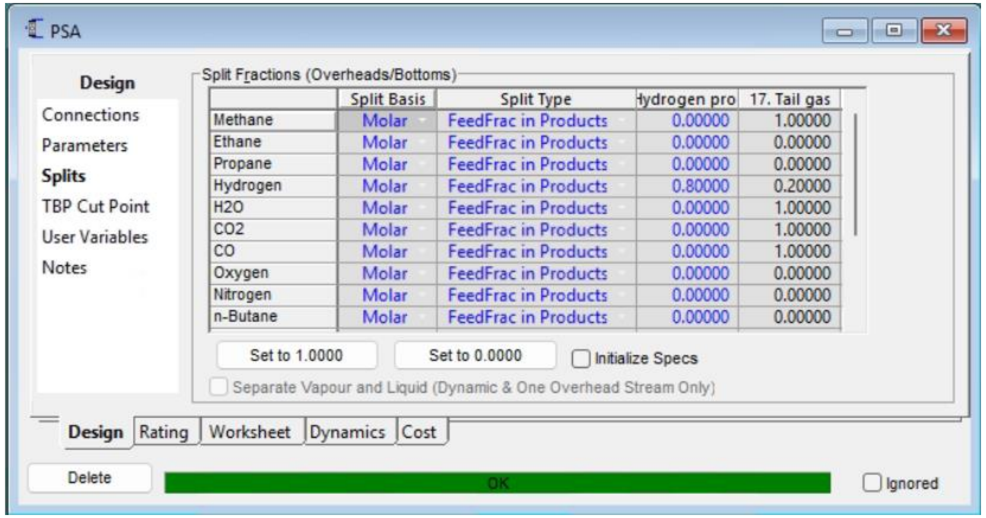








Unisim Design software

Source: Company information.

Process flow diagram and Mass and Energy balances

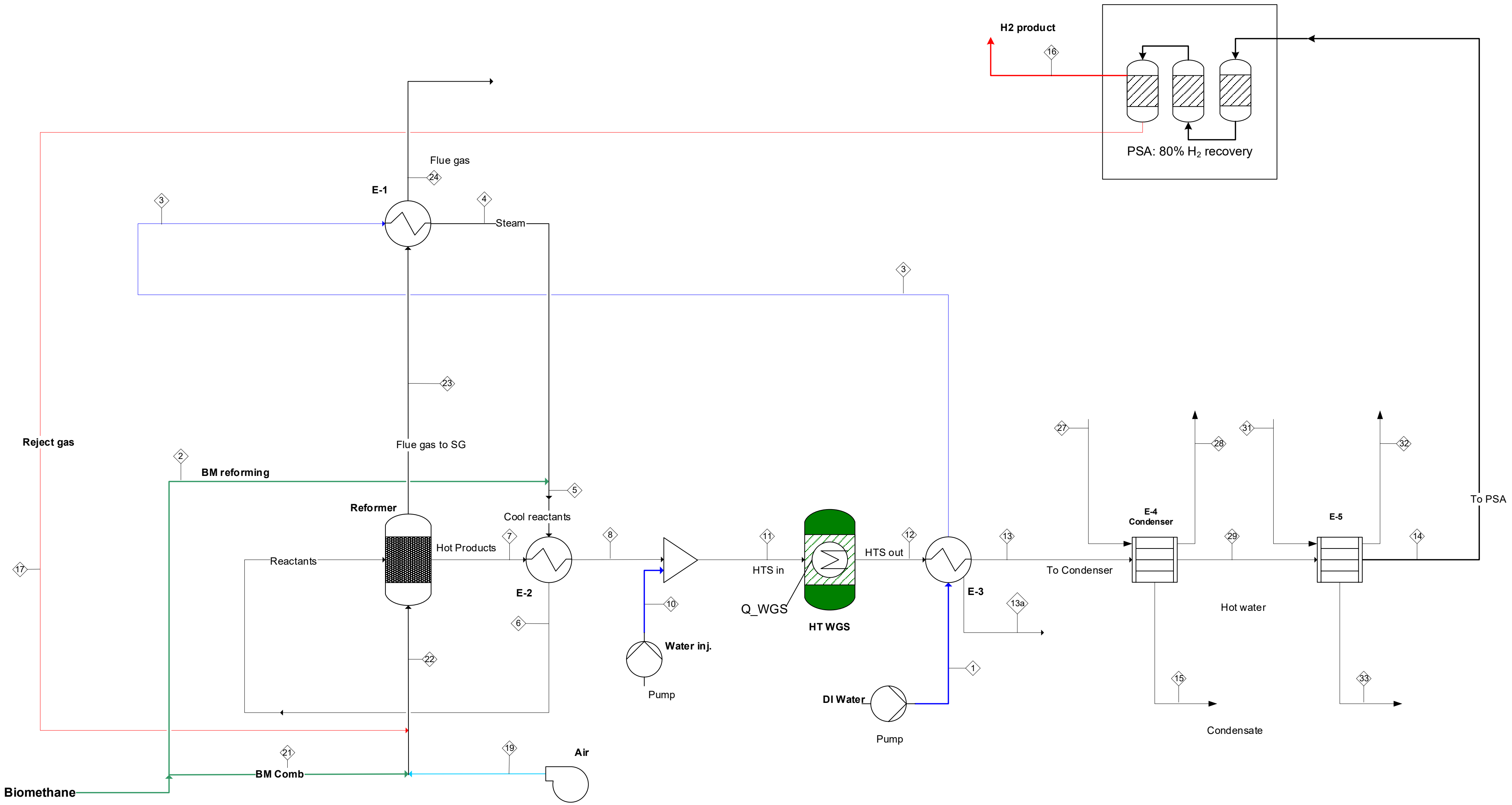
Process Flow Diagram **(PFD)** is a simplified sketch that uses symbols to identify instruments and vessels and to describe the primary flow path through a unit. It illustrates the general plant streams, major equipment and key control loops. They also provide detailed mass/energy balance data along with stream composition and physical properties.

A Piping and Instrumentation Diagram **(P&ID)** is a detailed diagram in the process industry which shows process equipment together with the instrumentation and control devices and control loops.

Source: Company information.

Process flow diagram and Mass and energy balances

PFD



Source: Company information.

Process flow diagram and Mass and energy balances

Name	1.DI water	2.NG ref	3. Preheated water	4.Steam	5. Super hot	6. Hot reactants	7. Ref.Products	8.to trim	10.Water inj.
Vapour Fraction	0	1	0	1	1	1	1	1	0
Temperature [C]	5.0	25.0	101.5	250.0	192.8	530.0	770.0	489.7	25.0
Pressure [kPa]	1200	1200	1195	1190	1190	1185	1175	1170	900
Molar Flow [kgmole/h]	3.055	0.9	3.055	3.055	3.955	3.955	5.35745686	5.35745686	0.277544941
Mass Flow [kg/h]	55.04	15.19	55.04	55.04	70.23	70.23	70.23	70.23	5.00
Std Ideal Liq Vol Flow [m3/h]	5.51E-02	4.82E-02	5.51E-02	5.51E-02	0.103366262	0.103366262	0.148093575	0.148093575	5.01E-03
Heat Flow [kJ/h]	-8.77E+05	-7.62E+04	-8.54E+05	-7.14E+05	-790360.1155	-734907.4212	-544224.0992	-599676.7935	-7.92E+04
Molar Enthalpy [kJ/kgmole]	-286942.7506	-84688.60244	-279411.3298	-233761.1696	-199838.2087	-185817.2999	-101582.5444	-111933.1073	-285393.0777
Mass Density [kg/m3]	1022.532592	8.39586963	947.1839305	5.138606363	5.660394458	3.167204177	1.773701731	2.41864383	1007.604864
Viscosity [cP]	1.501203667	0.011563874	0.274784532	1.80E-02	1.31E-02	0.024141402	2.89E-02	2.28E-02	0.890438924
Kinematic Viscosity [cSt]	1.468123049	1.37732891	0.290106835	3.506335122	2.313355192	7.622306829	16.29091509	9.438452857	0.883718366
Mass Heat Capacity [kJ/kg-C]	4.320375272	2.207746649	4.398486522	2.065769321	2.169187249	2.529434606	2.904361348	2.724397895	4.312582363
Thermal Conductivity [W/m-K]	0.577988737	3.40E-02	0.681297073	3.96E-02	3.98E-02	8.11E-02	0.182587683	0.14149498	0.611014986
Heat Of Vapourization [kJ/kgmole]	36219.42503	7196.154314	36231.56517	36243.85816	51031.48058	51034.57617	38296.6798	38295.95405	37012.16558
Comp Mole Frac (Methane)	0	0.97	0	0	0.220733249	0.220733249	3.21E-02	3.21E-02	0
Comp Mole Frac (Ethane)	0	0	0	0.00E+00	0.00E+00	0	0.00E+00	0.00E+00	0
Comp Mole Frac (Propane)	0	0	0	0	0	0	0	0	0
Comp Mole Frac (n-Butane)	0	0	0	0	0	0	0	0	0
Comp Mole Frac (Hydrogen)	0	0.00E+00	0	0.00E+00	0.00E+00	0.00E+00	0.454782778	0.454782778	0
Comp Mole Frac (H2O)	1	0	1	1	0.772439949	0.772439949	0.377227069	0.377227069	1
Comp Mole Frac (CO2)	0.00	0.03	0.00	0.00	0.01	0.01	0.07	0.07	0.00
Comp Mole Frac (CO)	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.07	0.00
Comp Mole Frac (Oxygen)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Comp Mole Frac (Nitrogen)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Comp Mole Frac (i-Butane)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Name	11. HTWGS inlet	12. HTWGS outlet	13..Condenser out	13a. Condensate	13a.to Condenser	14. Gas phase to PSA inlet	15. Liquid phase	16. Hydrogen product	17. Tail gas	19. Air	21. NG comb.
Vapour Fraction	1	1	1	0	1	1	0	1	1	1	1
Temperature [C]	404.8	300.0	180.0	180.0	180.0	10.0	35.0	9.1	9.1	25.0	25.0
Pressure [kPa]	900	880	875	875	875	871	873	10000	135	130	120
Molar Flow [kgmole/h]	5.635001801	5.635001801	5.635001801	0	5.635001801	3.685252007	1.930157898	2.224819354	1.460432653	4.9	0.14
Mass Flow [kg/h]	75.23	75.23	75.23	0.00	75.23	40.07	34.80	4.49	35.59	141.37	2.36
Std Ideal Liq Vol Flow [m3/h]	0.153103665	0.163126899	0.163126899	0.00E+00	0.163126899	0.127887621	3.49E-02	6.42E-02	6.37E-02	0.163419572	7.50E-03
Heat Flow [kJ/h]	-678886.1984	-713101.9161	-736110.4065	0.00E+00	-736110.4065	-295533.5966	-5.49E+05	-1.01E+03	-2.95E+05	-51.42454132	-1.18E+04
Molar Enthalpy [kJ/kgmole]	-120476.6604	-126548.6581	-130631.7961	-272932.1279	-130631.7961	-80193.5922	-284683.7238	-453.1568133	-201669.9667	-10.49480435	-84488.80493
Mass Density [kg/m3]	2.134870416	2.472074546	3.12444925	874.0272822	3.12444925	4.030445074	1000.293278	8.263750176	1.405706132	1.514050538	0.819442742
Viscosity [cP]	2.11E-02	1.85E-02	1.55E-02	0.149297086	1.55E-02	1.06E-02	0.718491259	8.62E-03	1.40E-02	1.88E-02	0.011375772
Kinematic Viscosity [cSt]	9.89871623	7.497920952	4.966517924	0.170815133	4.966517924	2.63958275	0.718280603	1.043586175	9.93900012	12.43975402	13.88232712
Mass Heat Capacity [kJ/kg-C]	2.624908036	2.589558528	2.509959702	4.739651144	2.509959702	2.831666506	4.309493028	14.43007457	1.390645682	1.01358398	2.141673312
Thermal Conductivity [W/m-K]	0.123561088	0.117031895	9.56E-02	0.676602971	9.56E-02	9.93E-02	0.625068154	0.174575923	4.65E-02	2.59E-02	3.31E-02
Heat Of Vapourization [kJ/kgmole]	40059.85141	38214.82581	38215.16291	73137.60954	38215.16291	13130.12865	39894.84076	<empty>	18603.41064	5823.080866	9400.811649
Comp Mole Frac (Methane)	3.05E-02	3.05E-02	3.05E-02	2.56E-06	3.05E-02	4.66E-02	3.92E-09	0	0.117616901	0	0.97
Comp Mole Frac (Ethane)	0	0.00E+00	0.00E+00	0	0	0	0	0.00E+00	0.00E+00	0.00E+00	0
Comp Mole Frac (Propane)	0	0	0	0	0	0	0	0	0	0	0
Comp Mole Frac (n-Butane)	0	0	0	0	0	0	0	0	0	0	0
Comp Mole Frac (Hydrogen)	0.432383023	0.493530067	4.94E-01	3.64E-04	0.493530067	7.55E-01	9.60E-06	1	3.81E-01	0.00E+00	0.00E+00
Comp Mole Frac (H2O)	0.407900968	0.346753924	0.346753924	0.999104364	0.346753924	1.48E-03	0.999366637	0	3.73E-03	0	0
Comp Mole Frac (CO2)	0.06	0.12	0.12	0.00	0.12	0.19	0.00	0.00	0.48	0.00	0.03
Comp Mole Frac (CO)	0.07	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.00
Comp Mole Frac (Oxygen)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.00
Comp Mole Frac (Nitrogen)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.79	0.00
Comp Mole Frac (i-Butane)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Name	22. Combustion mix	23. Flue gas to air heater	24. to Air preheater	27.Coolant in	28.Coolant out	29.to chiller	29a.separator	30. to condenser	31. Chilled water in	32. Chilled water out	33. Condenser _liq
Vapour Fraction	1	1	1	0	0	1	0.65746987	0.994711816	0	0	0
Temperature [C]	21.0	821.9	199.1	25.0	32.1	35.0	35.0	10.0	5.0	7.4	10.0
Pressure [kPa]	120	120	115	250	248	873	873	871	150	148	871
Molar Flow [kgmole/h]	6.500432653	6.21039489	6.21039489	200	200	3.704843902	5.635001801	3.704843902	20	20	1.96E-02
Mass Flow [kg/h]	179.32	179.32	179.32	3603.02	3603.02	40.43	75.23	40.43	360.30	360.30	0.35
Std Ideal Liq Vol Flow [m3/h]	0.234603905	0.214593144	0.214593144	3.610291139	3.610291139	0.128242076	0.163126899	0.128242076	0.361029114	0.361029114	3.54E-04
Heat Flow [kJ/h]	-306405.2618	-518275.6196	-657736.8589	-57080835.7	-56970047.11	-297414.4661	-846899.0041	-301150.3762	-5739221.199	-5735485.288	-5.62E+03
Molar Enthalpy [kJ/kgmole]	-47136.13357	-83452.92509	-105909.0236	-285404.1785	-284850.2355	-80277.19221	-150292.588	-81285.57751	-286961.0599	-286774.2644	-286688.9374
Mass Density [kg/m3]	1.355076305	0.380464786	0.846093687	1007.409993	1002.028963	3.721727352	6.903570302	4.065859962	1022.234396	1020.468889	1019.253353
Viscosity [cP]	1.74E-02	4.33E-02	2.32E-02	0.890438966	0.762112334	1.13E-02	<empty>	<empty>	1.50120411	1.398963045	1.234307796
Kinematic Viscosity [cSt]	12.87270179	113.759624	27.43818002	0.883889352	0.760569167	3.037880965	<empty>	<empty>	1.468551749	1.3709022	1.210992137
Mass Heat Capacity [kJ/kg-C]	1.104243414	1.333440476	1.152791538	4.313295725	4.313512028	2.841676249	3.520716786	2.844597639	4.321321489	4.319700237	4.31037425
Thermal Conductivity [W/m-K]	3.01E-02	7.44E-02	3.52E-02	0.611014416	0.621195361	0.10586831	<empty>	<empty>	0.577987829	0.5823102	0.587545327
Heat Of Vapourization [kJ/kgmole]	15666.08183	30611.1443	30624.11055	39667.7551	39681.19165	14288.46714	38215.14429	14288.65698	40465.18873	40484.70169	42920.27284
Comp Mole Frac (Methane)	4.73E-02	9.68E-38	9.68E-38	0	0	4.64E-02	3.05E-02	4.64E-02	0	0	8.31E-10
Comp Mole Frac (Ethane)	0.00E+00	1.98E-47	1.98E-47	0	0	0.00E+00	0	0	0	0	0
Comp Mole Frac (Propane)	0	1.70E-48	1.70E-48	0	0	0	0	0	0	0	0
Comp Mole Frac (n-Butane)	0	3.11E-87	3.11E-87	0	0	0	0	0	0	0	0
Comp Mole Frac (Hydrogen)	8.56E-02	1.37E-09	1.37E-09	0	0	0.750645467	0.493530067	0.750645467	0	0	4.53E-06
Comp Mole Frac (H2O)	8.39E-04	1.89E-01	1.89E-01	1	1	6.75E-03	0.346753924	6.75E-03	1	1	0.998849627
Comp Mole Frac (CO2)	0.11	0.17	0.17	0.00	0.00	0.19	0.12	0.19	0.00	0.00	0.00
Comp Mole Frac (CO)	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00
Comp Mole Frac (Oxygen)	0.16	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Comp Mole Frac (Nitrogen)	0.60	0.62	0.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Comp Mole Frac (i-Butane)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: Company information.

Process flow diagram and Mass and energy balances

Name	1.DI water	2.NG ref	3. Preheated water	4.Steam	6. Hot reactants	7. Ref.Products	10.Water inj.	11. HTWGS inlet	12. HTWGS outle	. Hydrogen produ	17. Tail gas	19. Air	21. NG comb.
Vapour Fraction	0	1	0	1	1	1	0	1	1	1	1	1	1
Temperature [C]	5.0	25.0	101.5	250.0	530.0	770.0	25.0	404.8	300.0	9.1	9.1	25.0	25.0
Pressure [kPa]	1200	1200	1195	1190	1185	1175	900	900	880	10000	135	130	120
Molar Flow [kgmole/h]	3.055	0.9	3.055	3.055	3.955	5.35745686	0.277544941	5.635001801	5.635001801	2.224819354	1.460432653	4.9	0.14
Mass Flow [kg/h]	55.04	15.19	55.04	55.04	70.23	70.23	5.00	75.23	75.23	4.49	35.59	141.37	2.36
Std Ideal Liq Vol Flow [m3/h]	5.51E-02	4.82E-02	5.51E-02	5.51E-02	0.103366262	0.148093575	5.01E-03	0.153103665	0.163126899	6.42E-02	6.37E-02	0.163419572	7.50E-03
Heat Flow [kJ/h]	-8.77E+05	-7.62E+04	-8.54E+05	-7.14E+05	-734907.4212	-544224.0992	-7.92E+04	-678886.1984	-713101.9161	-1.01E+03	-2.95E+05	-51.42454132	-1.18E+04
Molar Enthalpy [kJ/kgmole]	-286942.7506	-84688.60244	-279411.3298	-233761.1696	-185817.2999	-101582.5444	-285393.0777	-120476.6604	-126548.6581	-453.1568133	-201669.9667	-10.49480435	-84488.80493
Mass Density [kg/m3]	1022.532592	8.39586963	947.1839305	5.138606363	3.167204177	1.773701731	1007.604864	2.134870416	2.472074546	8.263750176	1.405706132	1.514050538	0.819442742
Viscosity [cP]	1.501203667	0.011563874	0.274784532	1.80E-02	0.024141402	2.89E-02	0.890438924	2.11E-02	1.85E-02	8.62E-03	1.40E-02	1.88E-02	0.011375772
Kinematic Viscosity [cSt]	1.468123049	1.37732891	0.290106835	3.506335122	7.622306829	16.29091509	0.883718366	9.89871623	7.497920952	1.043586175	9.93900012	12.43975402	13.88232712
Mass Heat Capacity [kJ/kg-C]	4.320375272	2.207746649	4.398486522	2.065769321	2.529434606	2.904361348	4.312582363	2.624908036	2.589558528	14.43007457	1.390645682	1.01358398	2.141673312
Thermal Conductivity [W/m-K]	0.577988737	3.40E-02	0.681297073	3.96E-02	8.11E-02	0.182587683	0.611014986	0.123561088	0.117031895	0.174575923	4.65E-02	2.59E-02	3.31E-02
Heat Of Vapourization [kJ/kgmole]	36219.42503	7196.154314	36231.56517	36243.85816	51034.57617	38296.6798	37012.16558	40059.85141	38214.82581	<empty>	18603.41064	5823.080866	9400.811649
Comp Mole Frac (Methane)	0.0%	97.0%	0.0%	0.0%	22.1%	3.2%	0.0%	3.0%	3.0%	0.0%	11.8%	0.0%	97.0%
Comp Mole Frac (Ethane)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Comp Mole Frac (Propane)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Comp Mole Frac (n-Butane)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Comp Mole Frac (Hydrogen)	0.0%	0.0%	0.0%	0.0%	0.0%	45.5%	0.0%	43.2%	49.4%	100.0%	38.1%	0.0%	0.0%
Comp Mole Frac (H2O)	100.0%	0.0%	100.0%	100.0%	77.2%	37.7%	100.0%	40.8%	34.7%	0.0%	0.4%	0.0%	0.0%
Comp Mole Frac (CO2)	0.0%	3.0%	0.0%	0.0%	0.7%	6.7%	0.0%	6.4%	12.5%	0.0%	48.1%	0.0%	3.0%
Comp Mole Frac (CO)	0.0%	0.0%	0.0%	0.0%	0.0%	6.9%	0.0%	6.5%	0.4%	0.0%	1.6%	0.0%	0.0%
Comp Mole Frac (Oxygen)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	21.0%	0.0%
Comp Mole Frac (Nitrogen)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	79.0%	0.0%
Comp Mole Frac (i-Butane)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Source: Company information.

Initial equipment sizing: BoP

Name	1.DI water	19. Air
Vapour Fraction	0	1
Temperature [C]	5.0	25.0
Pressure [kPa]	1200	130
Molar Flow [kgmole/h]	3.055	4.9
Mass Flow [kg/h]	55.04	141.37
Std Ideal Liq Vol Flow [m3/h]	5.51E-02	0.163419572
Heat Flow [kJ/h]	-8.77E+05	-51.42454132
Molar Enthalpy [kJ/kgmole]	-286942.7506	-10.49480435
Mass Density [kg/m3]	1022.532592	1.514050538
Viscosity [cP]	1.501203667	1.88E-02
Kinematic Viscosity [cSt]	1.468123049	12.43975402
Mass Heat Capacity [kJ/kg-C]	4.320375272	1.01358398
Thermal Conductivity [W/m-K]	0.577988737	2.59E-02
Heat Of Vapourization [kJ/kgmole]	36219.42503	5823.080866
Comp Mole Frac (Methane)	0%	0%
Comp Mole Frac (Ethane)	0%	0%
Comp Mole Frac (Propane)	0%	0%
Comp Mole Frac (n-Butane)	0%	0%
Comp Mole Frac (Hydrogen)	0%	0%
Comp Mole Frac (H2O)	100%	0%
Comp Mole Frac (CO2)	0%	0%
Comp Mole Frac (CO)	0%	0%
Comp Mole Frac (Oxygen)	0%	21%
Comp Mole Frac (Nitrogen)	0%	79%
Comp Mole Frac (i-Butane)	0%	0%

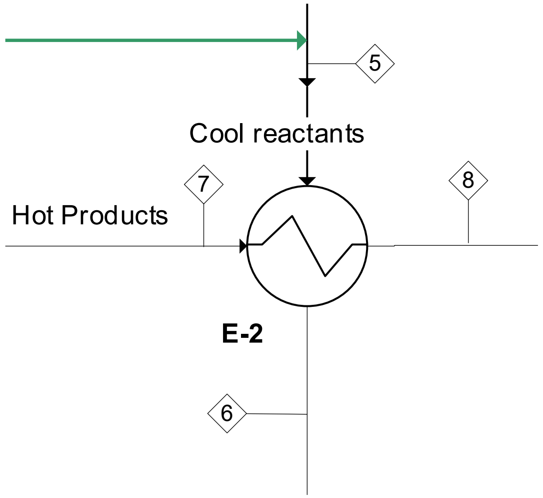
Example of equipment for preliminary sizing:

- Water pump preliminary sizing
- Air blower preliminary sizing

Source: Company information.

Initial equipment sizing-HEx

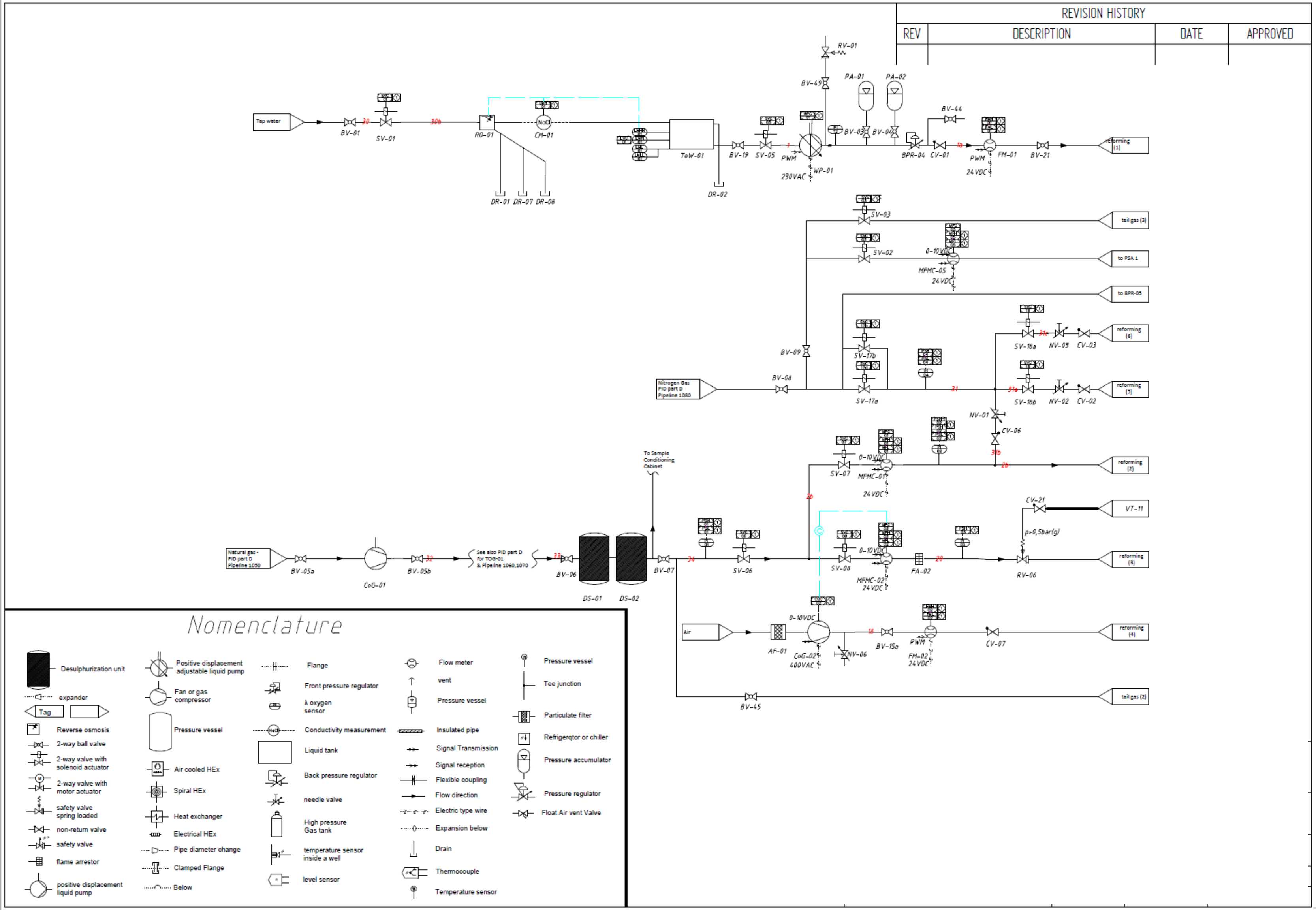
- **Heat exchanger type** (shell-and-tube, plate, air-cooled, spiral, etc.)
- **Duty type**: heating, cooling, condensation, vaporization.
- **Hot & cold fluids**: identify both streams and their roles.
- **Operating conditions**: Flow rates, inlet/outlet temperatures, pressures, Phase states (liquid, gas, two-phase), allowable pressure drops (tube side & shell side). [
- **Constraints**: space limits, materials, corrosion, fouling tendency.



Name	5. Super hot	6. Hot reactants	7. Ref.Products	8.to trim
Vapour Fraction	1	1	1	1
Temperature [C]	192.8	530.0	770.0	489.7
Pressure [kPa]	1190	1185	1175	1170
Molar Flow [kgmole/h]	3.955	3.955	5.35745686	5.35745686
Mass Flow [kg/h]	70.23	70.23	70.23	70.23
Std Ideal Liq Vol Flow [m3/h]	0.103366262	0.103366262	0.148093575	0.148093575
Heat Flow [kJ/h]	-790360.1155	-734907.4212	-544224.0992	-599676.7935
Molar Enthalpy [kJ/kgmole]	-199838.2087	-185817.2999	-101582.5444	-111933.1073
Mass Density [kg/m3]	5.660394458	3.167204177	1.773701731	2.41864383
Viscosity [cP]	1.31E-02	0.024141402	2.89E-02	2.28E-02
Kinematic Viscosity [cSt]	2.313355192	7.622306829	16.29091509	9.438452857
Mass Heat Capacity [kJ/kg-C]	2.169187249	2.529434606	2.904361348	2.724397895
Thermal Conductivity [W/m-K]	3.98E-02	8.11E-02	0.182587683	0.14149498
Heat Of Vapourization [kJ/kgmole]	51031.48058	51034.57617	38296.6798	38295.95405
Comp Mole Frac (Methane)	0.220733249	0.220733249	3.21E-02	3.21E-02
Comp Mole Frac (Ethane)	0.00E+00	0	0.00E+00	0.00E+00
Comp Mole Frac (Propane)	0	0	0	0
Comp Mole Frac (n-Butane)	0	0	0	0
Comp Mole Frac (Hydrogen)	0.00E+00	0.00E+00	0.454782778	0.454782778
Comp Mole Frac (H2O)	0.772439949	0.772439949	0.377227069	0.377227069
Comp Mole Frac (CO2)	0.01	0.01	0.07	0.07
Comp Mole Frac (CO)	0.00	0.00	0.07	0.07
Comp Mole Frac (Oxygen)	0.00	0.00	0.00	0.00
Comp Mole Frac (Nitrogen)	0.00	0.00	0.00	0.00
Comp Mole Frac (i-Butane)	0.00	0.00	0.00	0.00

Source: Company information.

Piping and Instrumentation diagram



Source: Company information.

Hazardous Operation – Risk assesment

Aspect	HAZOP	Risk Analysis
Goal	Identify deviations & operability issues	Evaluate and prioritize risks
Timing	Detailed design stage	Any project stage
Inputs	P&ID, control logic, process data	Varies (concept design to detailed engineering)
Approach	Guidewords, structured brainstorming	Risk matrices, models (QRA), expert judgement
Output	Actionable deviations & safeguards	Risk ranking, mitigation strategy
Scope	Narrow, process-specific	Broad, system-level or project-level

Source: Company information.

HAZOP example

Node	1b	Reformer reforming feed: From BV-01 and BV-06 (through SV-07) to FM-01 and RV-02							
Drawing	xx-xxx-xxx-xx								
Parameter	Nr.	Deviation	Cause	Consequences	Safeguards	Additional safeguards	Severity	Frequency	Recommendations/ Actions
Flow	1	High	WP-01 malfunction	High water flow. Low quality steam. Low reformer temperature	FMH01	TSL25, TSL23	Low	moderate	
	1		FM-01 instrument malfunction		TSL25	TSL23	Low	Low	
	2		MFMC-01 instrument malfunction	High Natural gas flowrate in reforming side. Low reformer temperature, Low quality hydrogen,	MFH01		Low	Low	
	2		SV-16 fails to shut-off	Nitrogen in the reforming side	PSH04		Low	Low	
	3	Low	WP-01 malfunction/failure	Low or no water flow. High reformer temperature, Catalyst coking, High CO at WGS reactor effluent	FML01	TSH25, TSH23	Low	Moderate	
	3		FM-01 instrument malfunction		TSH25	TSH23	Low	Low	
	3		ToW-01 low water level		LML01		Low	Low	
	3		SV-05 fails open		FML01	TSH25, TSH23	Low	Low	
	3		Air bubbles in tubing to WP-01		FML01	TSH25, TSH23	Low	Low	
	4		MFMC-01 instrument malfunction	Low Natural gas flowrate in reforming side. High reformer temperature, Low hydrogen flowrate	MFL01	PSL02	Low	Low	
	4		SV-07 fails open		MFL01	PSL02	Low	Low	
	4		SV-06 fails open		MFL01	PSL02	Low	Low	
Temperature	5	High	None						
	6	Low	None						
Pressure	7	High	Downstream blokage,	Limited or no reactants flow. Reforming temperature high. Possible reformer shell or combustion tube rupture	PSH02	FML01, MFL01	High	Low	
	8	High	High flowrate of NG	Reforming temperature low. Catalyst coking. Possible reformer shell or combustion tube rupture	MFH01		High	Low	
	9	Low	Natural gas compressor failure.	High reformer temperature. Low or no hydrogen production.	PSL01	MFL01	Low	Moderate	
	10	Low	No or low water flowrate	High reformer temperature. Low hydrogen production. Catalyst coking	FML01		Low	Moderate	
	11	Low	Natural gas compressor failure.	Low combustion temperature or no combustion	PSL01	MFL01	Low	Moderate	
Level	12	High	SV-04 fails close	High water level. Possible water ovelflow	LMH01	LMHH01	Low	Low	
	13	Low	SV-01 fails open	Low water level in ToW-01	LML01	LMLL01	Low	Low	
	13		SV-02 fails open		LML01	LMLL01	Low	Low	
	13		SV-03 fails open		LML01	LMLL01	Low	Low	
	13		Prefilter PF-01 partial/full blockage		LML01	LMLL01	Low	High	Check/clean filter
Concentration	14	High	None						
	15	Low	None						
Contamination	16	High	Reverse osmosis device(s) need replacement	High water conductivity. Fouling effects of the water heater and steam generator	CMH01		Low	Moderate	
	17	High	Sulfur traps uptake capacity reached	Reforming Catalyst deactivation. Reduced hydrogen production. Contamination of WGS catalyst, PSA and fuel cell.	None	None	Low	Low	Use of a safety factor during DS-01 unit desing. Use of precious metals catalyst
	18	Low	None						

Source: Company information.

Equipment list

Instrument List

Displayed Text	Description	Connection Size	Service	Manufacturer	Model
MFC-1	Mass Flow Controller	1/4"		-W	
MFC-2	Mass Flow Controller	1/4 "		-W	
TC-01	TC	K-type	0-1000 oC	co	
TC-02	TC	K-type	0-1000 oC	co	
TC-03	TC	K-type	0-1000 oC	co	
TC-04	TC	K-type	0-1000 oC	co	
TC-05	TC	K-type	0-1000 oC	co	
TC-06	TC	K-type	0-1000 oC	co	
TC-07	TC	K-type	0-1000 oC	co	
TC-08	TC	K-type	0-1000 oC	co	
TC-09	TC	K-type	0-1000 oC	co	
TC-10	TC	K-type	0-1000 oC	co	
TC-11	TC	K-type	0-1000 oC	co	
TC-12	TC	K-type	0-1000 oC	co	
PI-02	Pressure transducer	1/4"	0-4 barg	IO	
LV-1	Level meter		On/Off	no	

Valve List

Displayed Text	Description	Line Size	Valve Class	Manufacturer	Model
CV-1	Check Valve	1/4"	SS 304	(	-
CV-2	Check Valve	1/4"	Spring loaded	(	-
V-1	On/Off Valve (Normally Closed)	1/4"	Brass	i	-
V-2	On/Off Valve (Normally Closed)	1/4"	Brass	i	-
V-3	On/Off Valve (Normally Closed)	1/4"	Brass	i	-
V-4	On/Off Valve (Normally Closed)	1/4"	Brass	i	-
V-5	On/Off Valve (Normally Open)	1/4"	Brass	i	-
V-6	On/Off Valve (Normally Closed)	1/4"	Brass	i	-
V-7	On/Off Valve (Normally Open)	1/2"	Brass	i	-
V-8	On/Off Valve (Normally Open)	1/2"	Brass	i	-
V-9	On/Off Valve (Normally Open)	1/2"	Brass	i	-

Equipment List

Displayed Text	Description	Manufacturer	Materi
BL-1	Air Pump	s	Aluminiu
DI water tank	Distilled water tank	e	Plas
DS	Desulfurization	e	SS 3
E-1	Steam Gen	e	SS 3
E-2	Heat Exchanger (Recuparator)	)	SS 3
E-3	Air cooled HEx	)	SS 3
E-5 (Condenser)	Heat Exchanger (Condenser)	)	SS 3
E-6	Air Preheater	e	SS31
EHL-1	Heat Exchanger (External heat load)	-	Aluminu
Preheater BL-2	Air Pump	n	Aluminu
REFORMER	Reformer	e	SS 3
RP-1	Recirculation pump	n	Plas
SG-WGS	Reactor Vessel	e	SS 3
WP-1	Water Pump	s	Plas

Source: Company information.

Final equipment sizing

Summary Table – SMR Equipment to Be Sized	
Section	Equipment (valves, pressure meter, level meter, etc.)
Feed	Filters, desulfurizers
Reforming	SMR reactor
Shift	HTS reactor
Heat Recovery	Heat Exchangers
Separation	Knock Out drums
Purification	PSA
Product	Compressors, storage
Utilities	Water, fuel, nitrogen
Safety	PSV, flare

Source: Company information.

Example of solenoid valve sizing

1. Process Data (Mandatory)

Fluid type (water, steam, gas, nitrogen, fuel gas)
Flow rate (normal & max)
Upstream pressure (P_1)
Downstream pressure (P_2)
$\Delta P = P_1 - P_2$
Fluid temperature
Fluid density / specific gravity
Viscosity (important for liquids)

2. Valve Functional Requirements

Normally Open (NO) or Normally Closed (NC)
Fail position (fail open / fail closed)
On–off or modulating (solenoids are normally on–off)
Opening time requirement (fast / standard)

3. Mechanical & Design Inputs

Line size
Design pressure & temperature
Valve body material
Seal material (EPDM, Viton, PTFE, etc.)
End connections (threaded, flanged)

4. Electrical Inputs

Voltage (e.g. 24 VDC, 110 VAC, 230 VAC)
Area classification (safe / ATEX / IECEx)
IP rating

Kv Equation for Liquid Flow

$$Q = K_v \sqrt{\frac{\Delta P}{SG}}$$

Where:
Q = liquid flow rate (m^3/h)
Kv = valve flow coefficient
ΔP = pressure drop across valve (bara)
SG = specific gravity (water = 1.0)
Rearranged (to size Kv):

$$K_v = \frac{Q}{\sqrt{\Delta P / SG}}$$

Source: Company information.

Boring section...☺

Economic and Environmental Considerations

No engineering design is complete without evaluating its economics and environmental impact. We consider these aspects for hydrogen via steam reforming of biomethane.

Why?

Environment: Regulations are becoming stringer and processes must comply otherwise can be rejected from permitting.

Projects need investment: We must justify it by either cost reduction or new revenue stream creation.

Source: Company information.

Economic considerations

- **Cost-effective** hydrogen production with mature, proven technology.
- **Lower** €/kg H_2 compared to electrolysis; competitive as blue hydrogen with CCS.
- High overall efficiency **(>85% in CHP setups)** through integrated heat recovery.
- Uses existing biomethane infrastructure, **reducing logistics costs**.
- PSA delivers high-purity H_2 (>99.97%), enabling **premium applications**.
- Catalyst and feed-gas quality influence OPEX; biomethane requires less sulfur removal devices.
- Modular design **reduces installation costs** and supports scalable deployment.
- **Low NO_x emissions** with catalytic combustion lower environmental compliance costs.

Source: Company information.

Environmental Impact and Sustainability

- **Low-carbon hydrogen pathway:** Biogenic methane originates from recent biomass, significantly reducing lifecycle greenhouse gas emissions compared to fossil SMR.
- **Potential for net-negative emissions:** When combined with carbon capture and storage (CCS), SMR on biogenic methane can achieve near-zero or carbon-negative CO_2 emissions.
- **Circular-economy benefits:** Utilizes renewable, waste-derived feedstocks (e.g. biogas, landfill gas), reducing methane emissions from waste streams.
- **Controlled local environmental impact:** Comparable air emissions to conventional SMR; NO_x and sulfur emissions are effectively mitigated through proven design and controls.
- **High efficiency and scalability:** Leverages mature SMR technology with extensive heat recovery and compatibility with existing infrastructure.
- **Feedstock sustainability dependent:** Environmental performance depends on certified, responsibly sourced biogenic methane, with waste-based sources offering the highest benefit.

Source: Company information.

Conclusions

Source: Company information.

THANK YOU FOR YOUR ATTENTION

Questions...?

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Conclusions

- Process design is rigorous process that pertains to selection, sequencing and specifications of the units (equipment) required for the conversion of raw materials into finished products.
- Process design is considered the "pinnacle" of Chemical Engineering, as it combines all the individual knowledge (thermodynamics, kinetics, mass and energy transfer) to create a functional industrial unit.
- Chemical engineering design software are powerful tools for process design, but we need to pay extra attention for delivering concrete results.
- PFD (Process Flow Diagram) and P&ID (Piping & Instrumentation Diagram) are the two most basic tools in the design and operation of industrial facilities, functioning complementary at different stages of a project.
- The HAZOP (Hazard and Operability Study) is a systematic and structured risk assessment technique, which aims to identify potential safety and operability problems in an industrial process.
- Environmental and economic considerations of the process determines the “go or no-go” decision for a process/project.

Source: Company information.