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DEMONSTRATION OF GAS SWITCHING TECHNOLOGY FOR ACCELERATED SCALE-UP OF PRESSURIZED CHEMICAL LOOPING APPLICATIONS

(**GASTECH**)

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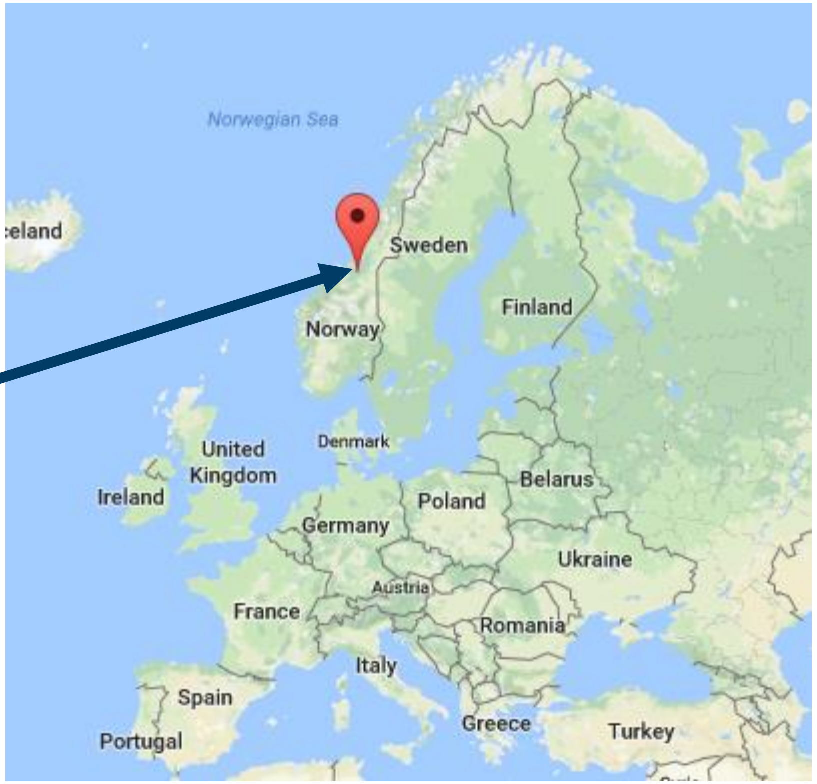
Questions to ACT and EC

- In the 2 degree C scenario, the IEA projects European CO_2 prices of €20/ton in 2020, rising rapidly to €100/ton in 2030. This rapid rise in CO_2 prices will generate great industrial interest in CCS.
  - Is this a realistic policy scenario to prepare for or will CO_2 prices remain at current low levels for longer?
  - If CO_2 prices may rise according to IEA projections, future project calls should be on scale-up and full value chain demos. However, more effort is needed to convince industry that CO_2 prices will rise rapidly in the near future, so that they have confidence to invest.
  - If **CO_2 prices stay lower** for longer, getting industry involvement in scale-up projects will remain very difficult and the emphasis could be on lower TRL concepts (bio CCS, H_2, etc.) with large long-term cost-reduction potential and specialized CCS retrofit technologies for preserving sunk capital

SINTEF, HQ at Trondheim, Norway



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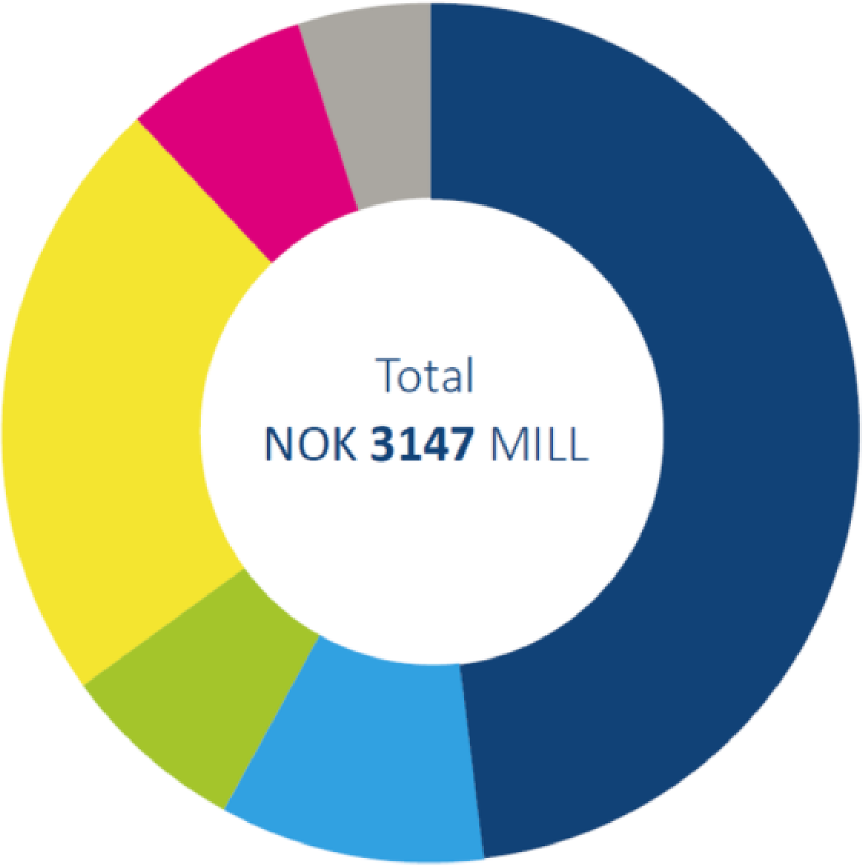
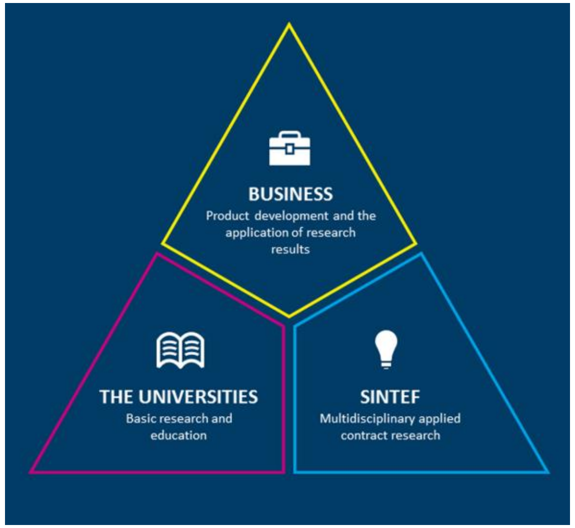
- SINTEF is a multidisciplinary research organisation with international top-level expertise in the fields of **technology**, the **natural sciences**, **medicine and the social sciences**.
- We conduct contract R&D as a partner for the private and public sectors, and we are one of the **largest contract research institutions in Europe**.
- Our vision is **Technology for a better society**.
- https://www.youtube.com/watch?v=3EAuxDE0C_c

Key facts SINTEF

MORE THAN 90 PER CENT OF OUR INCOME COMES FROM CONTRACTS WON IN OPEN COMPETITION



- Business and industry (Norway & international) 48 %
- Public sector 10 %
- EU 7 %
- Project grants from The Research Council of Norway 23 %
- Basic grants from The Research Council of Norway 7 %
- Other sources 5 %



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Gas Tech project

- Partners
- Background
- Scope
- Partners' roles
- Work packages
- Gantt chart

Partners

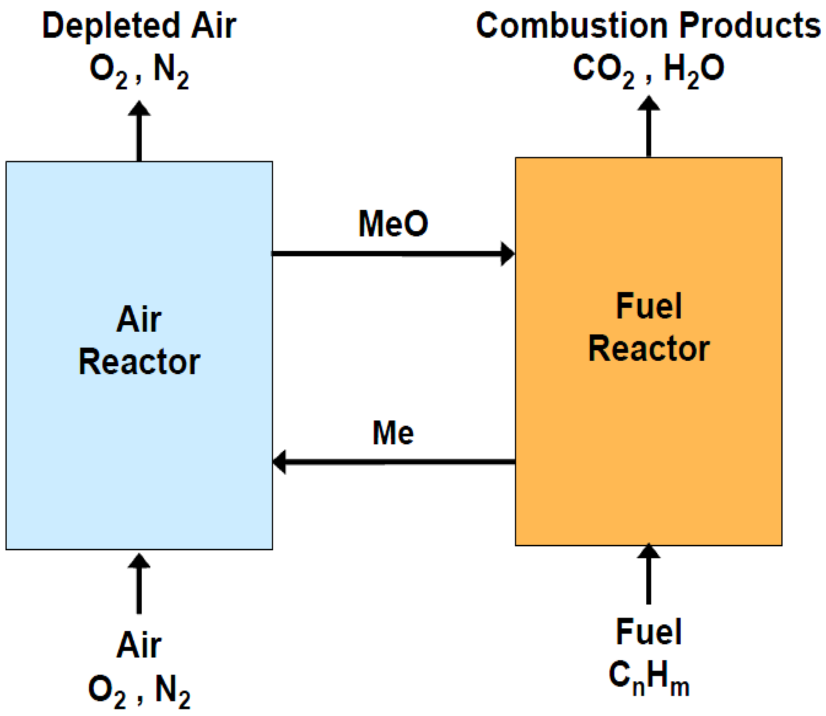
#	Participant legal name	Short name	Type	Country
1	Stiftelsen SINTEF	SINTEF	RTO	NO
2	Norwegian University of Science and Technology	NTNU	UNI	NO
3	Euro Support Advanced Materials B.V.	ESAM	SME	NL
4	Technische Universität Hamburg	TUHH	UNI	DE
5	Universitatea Babeș-Bolyai	UBB	UNI	RO
6	Hayat	HAYAT	IND	TR
7	ETH Zürich	ETH	UNI	CH
8	Universidad Politécnica de Madrid	UPM	UNI	ES

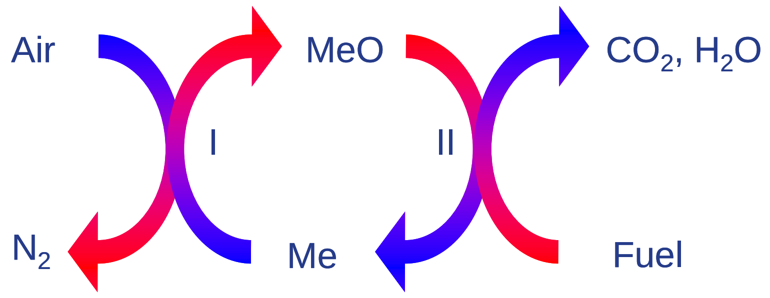
Background to the project

- Gas switching technology offers for highly efficient power or hydrogen production with integrated CO_2 capture. Highly efficient oxygen production for oxyfuel CO_2 capture is also possible.
- It utilizes simple standalone bubbling/turbulent fluidized beds that are alternatively fed with oxidizing and reducing gases.
- It can be scaled up and pressurized without facing unforeseen challenges.

Concept based on Chemical Looping Combustion (CLC)

1. Air reactor: Reduced metal (Me) is oxidized with air. High temperature N_2 stream produced
2. Fuel reactor: Metal oxide (MeO) provides the oxygen for combustion in the fuel reactor to produce only CO_2 and steam
3. Reduced metal (Me) is used again in step 1



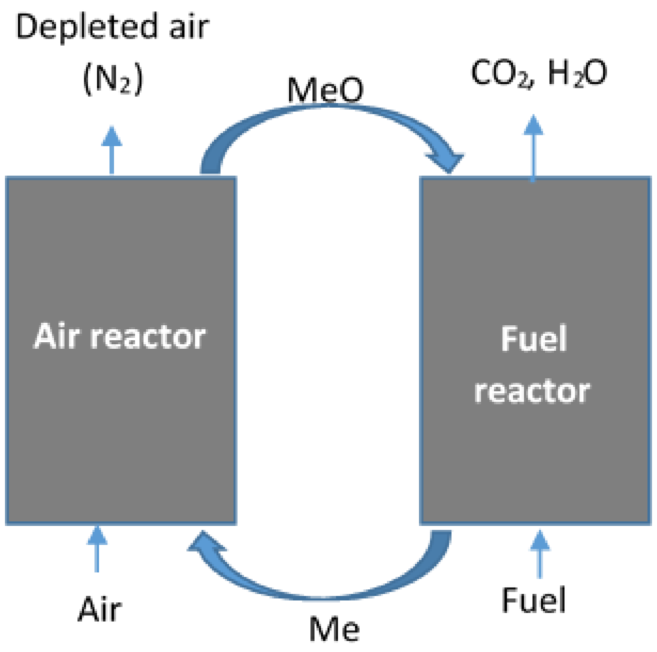


I: $4\ Me + 2\ O_2 \rightarrow 4\ MeO\ (\Delta H < 0)$

II: $4\ MeO + CH_4 \rightarrow 4\ Me + CO_2 + 2\ H_2O\ (\Delta H > 0)$

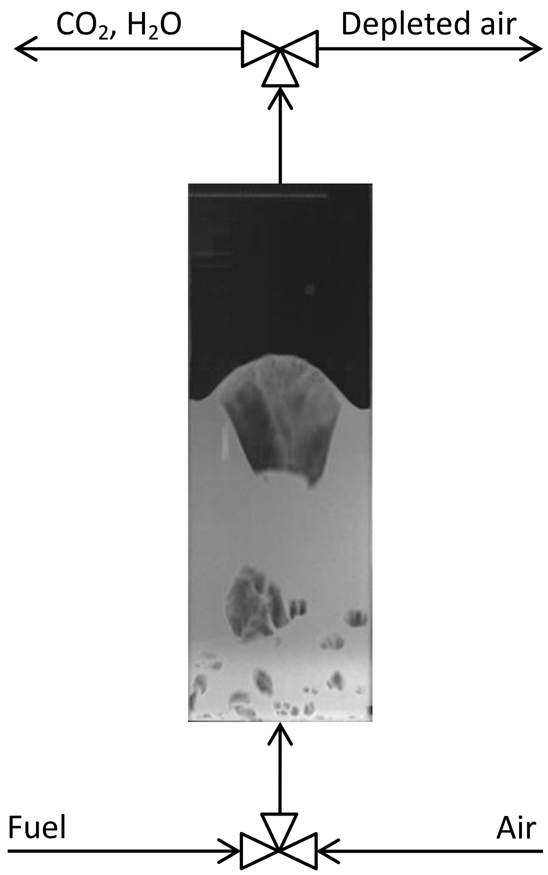
Gas Switching technology

Chemical Looping principle



Lack of pressurized CLC in the looping configuration

Gas Switching Reactor



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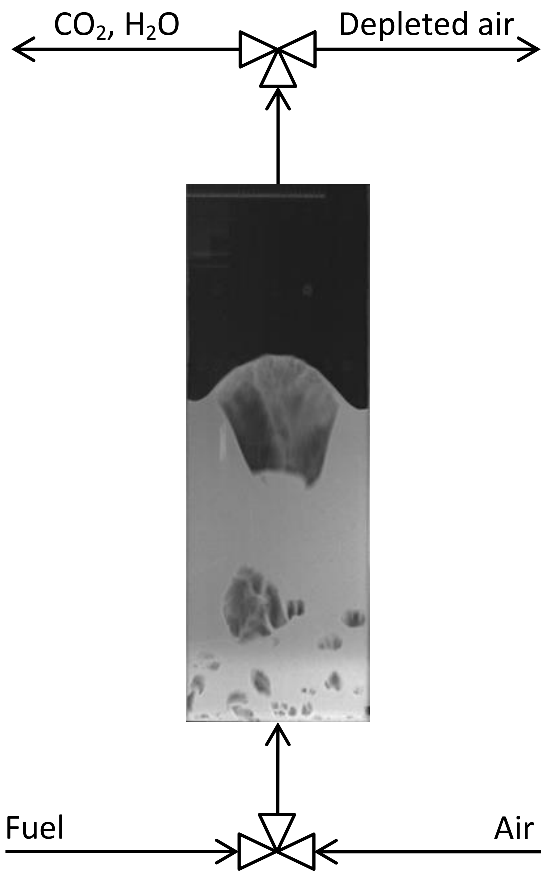
Gas Switching Technology

- GST is based on the Chemical looping process but uses a single reactor
- Alternation of air and fuel feeds
- Bubbling/turbulent fluidization regimes



Advantages

- No external circulation of solids
- Easy to pressurize
- Easy to scale up
- High load flexibility

Scope and budget

To accelerate the development of gas switching technologies by further technology scale-up through

- Lab-scale demonstration (TRL 4) of gas switching reactor concepts
- Large-scale technology implementation studies to evaluate the techno-economic feasibility of process concepts incorporating gas switching reactors.
- Business case development
- Budget: 2,602,000 Euro

Gas switching principle to investigate four chemical looping concepts

- **Combustion:** A fuel gas is indirectly combusted with inherent separation of N_2 and CO_2 in order to produce a high temperature gas stream for driving a gas turbine.
- **Reforming:** Redox reactions with the oxygen carrier supply heat to the endothermic steam-methane reforming reaction with inherent CO_2 capture. This application requires an oxygen carrier material that can also catalyse the reforming reaction.
- **Water splitting:** Steam is used to partially oxidize the oxygen carrier, producing hydrogen. Subsequently, the oxygen carrier is fully oxidized by air and reduced by carbon-rich fuel gases with inherent CO_2 capture.
- **Oxygen production:** An oxygen carrier with oxygen uncoupling properties is used to take up oxygen from air and then release it in a N_2-free outlet stream. The resulting stream can then be used for oxyfuel CO_2 capture.

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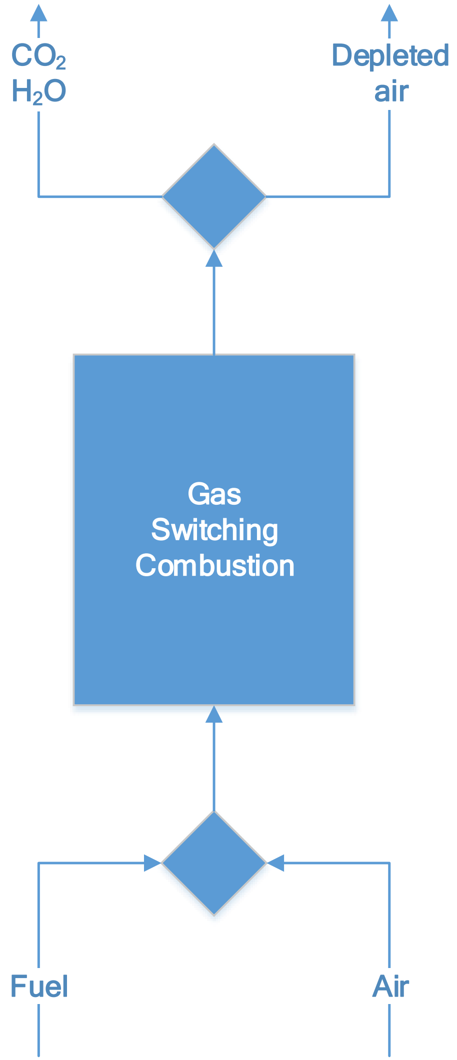
Gas Switching Combustion (GSC)

- Produces heat for power production
- Advantage: No energy penalty for CO_2 separation
- Challenge: Combined cycle efficiency depends on maximum temperature of depleted air
  - limitation on temperatures for oxygen carrier, downstream valves & filters



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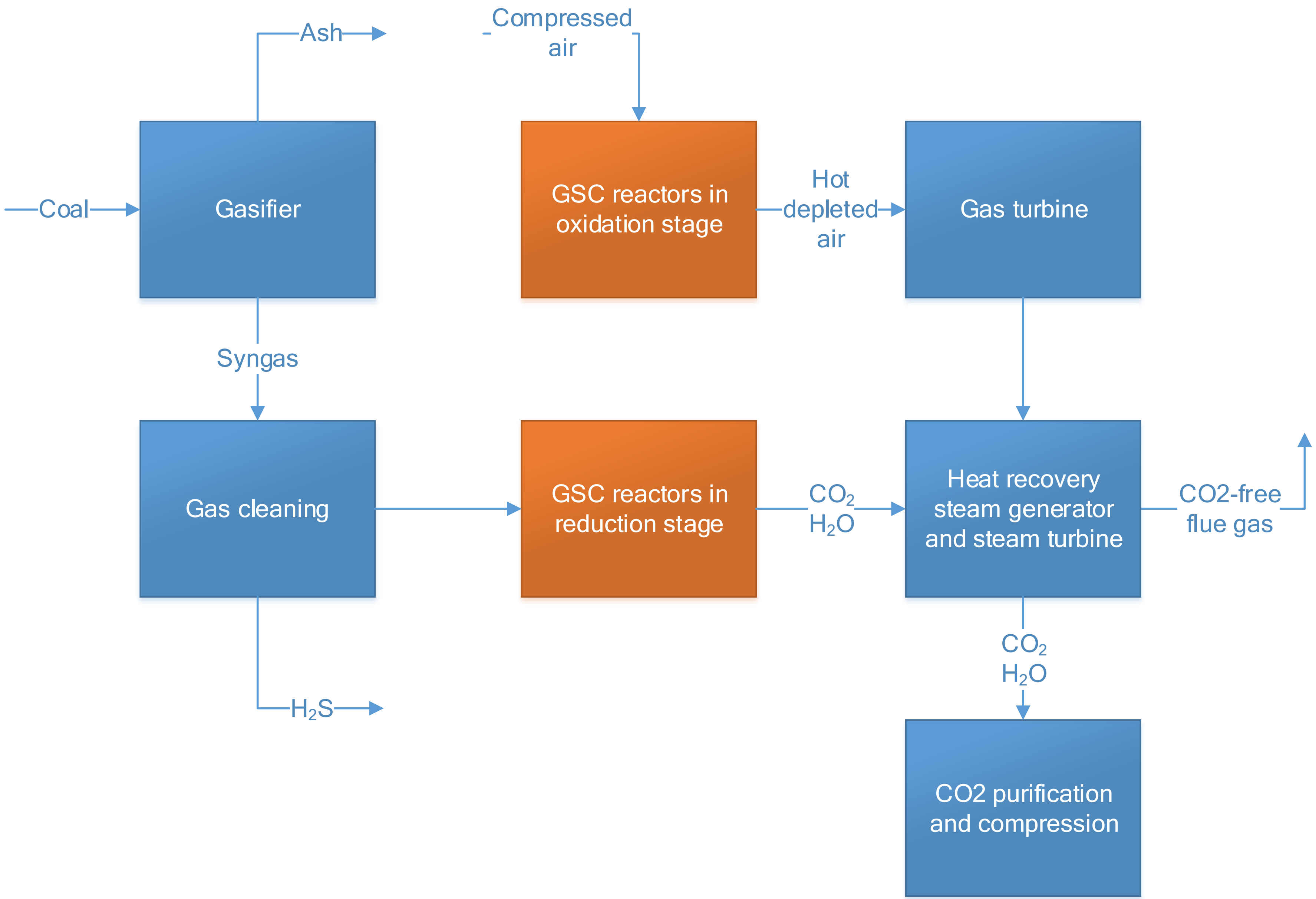
Gas Switching Combustion(GSC)



Ilmenite
1200 C

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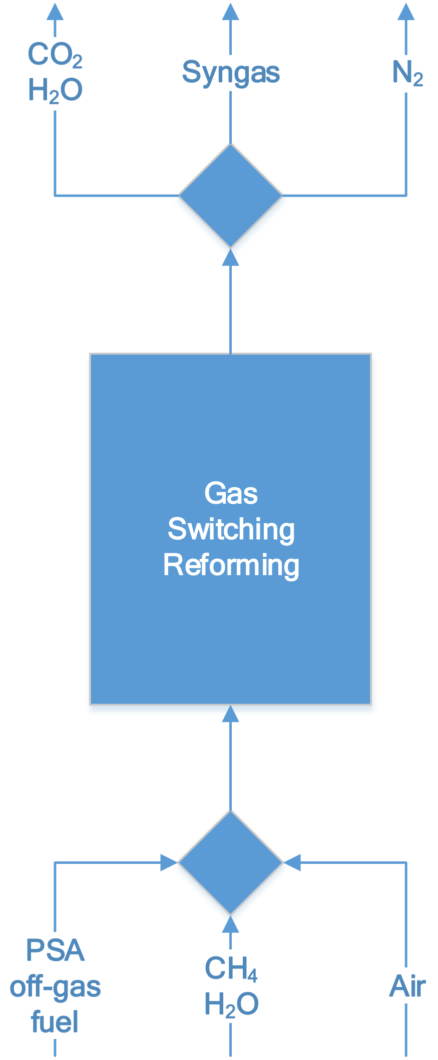
Gas Switching Reforming (GSR)

- Produces syngas for hydrogen or hydrocarbon synfuel production (classical SMR+heat from GSC)
- <u>Advantage:</u> Heat transfer to the reforming stage (GSC) with inherent CO_2 separation
- <u>Challenge:</u> Needs downstream process units for H_2 production



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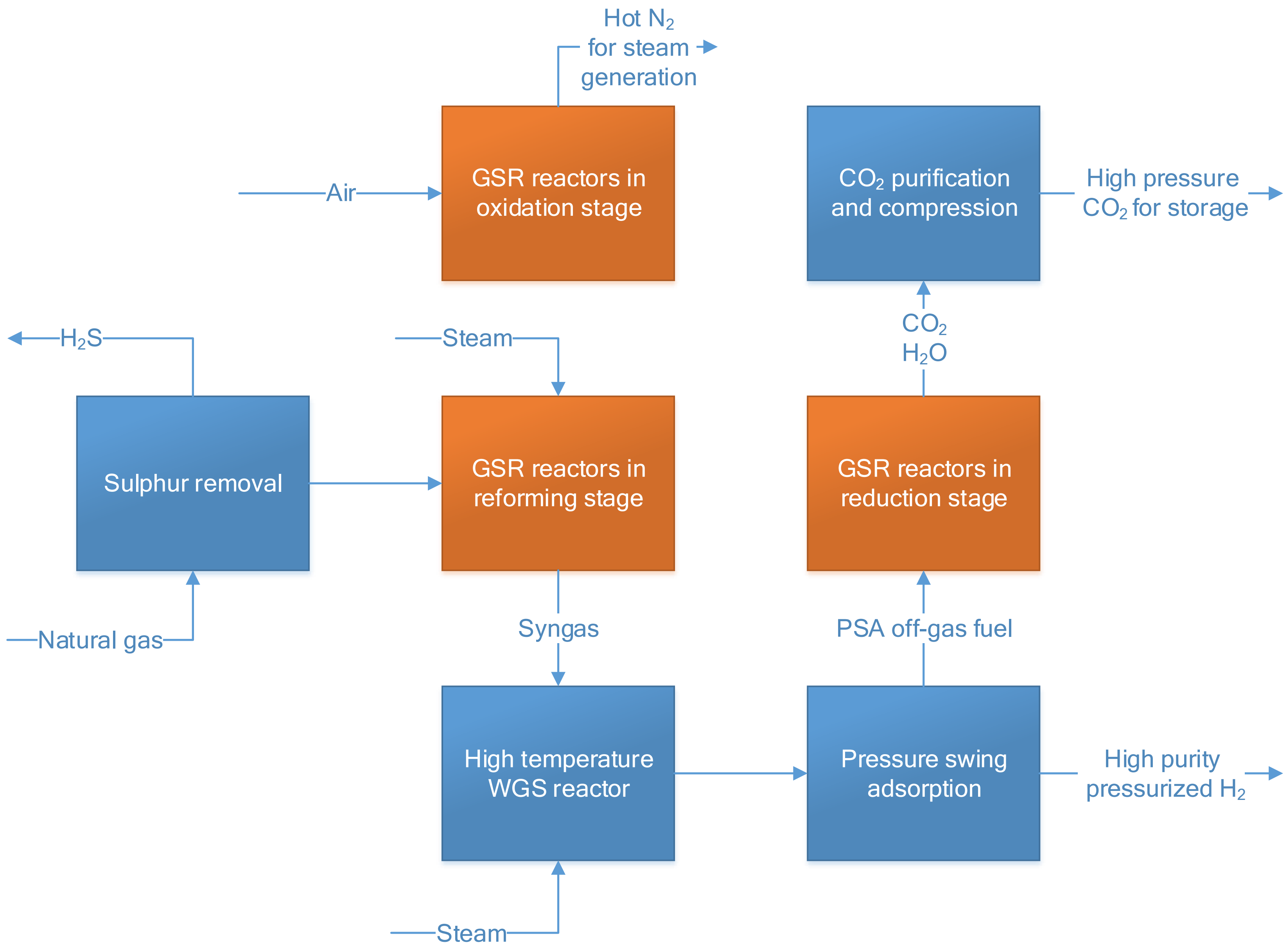
Gas Switching Reforming (GSR)



Alternative to Nickel
1100 C

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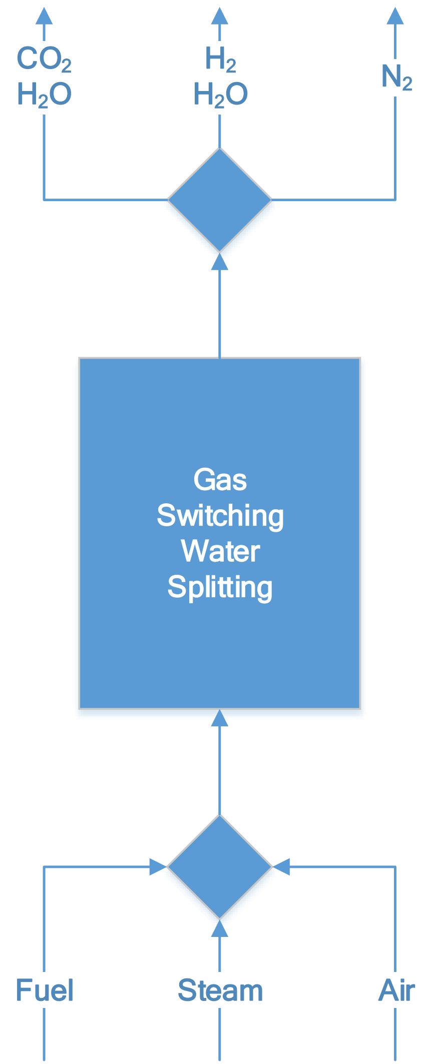
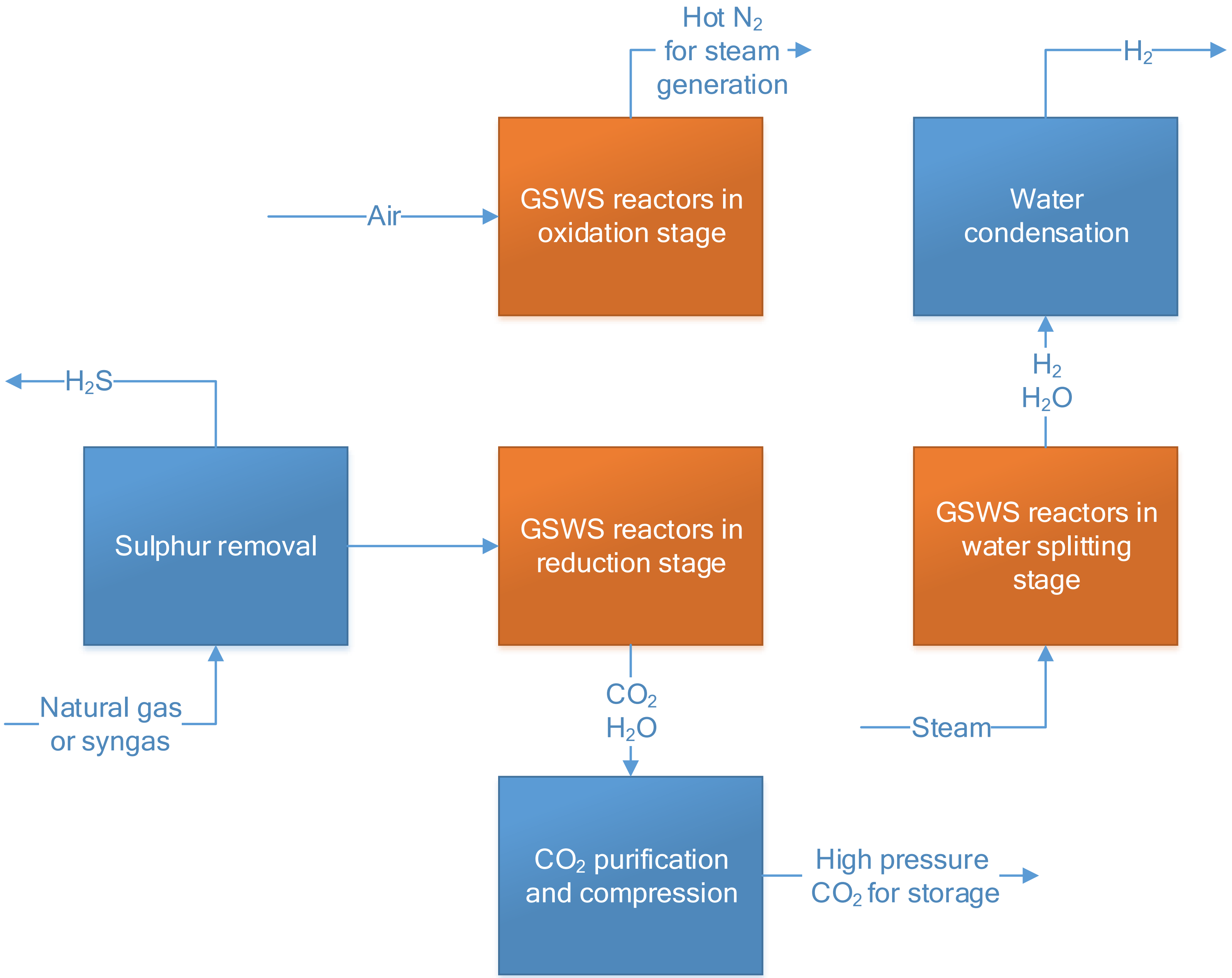
Gas Switching Water Splitting (GSWS)

- Produces hydrogen
- <u>Advantage:</u> Direct hydrogen production from any gaseous fuel with inherent CO_2 separation
- <u>Challenge:</u> Thermodynamically limited fuel conversion and high steam requirement during hydrogen production stage



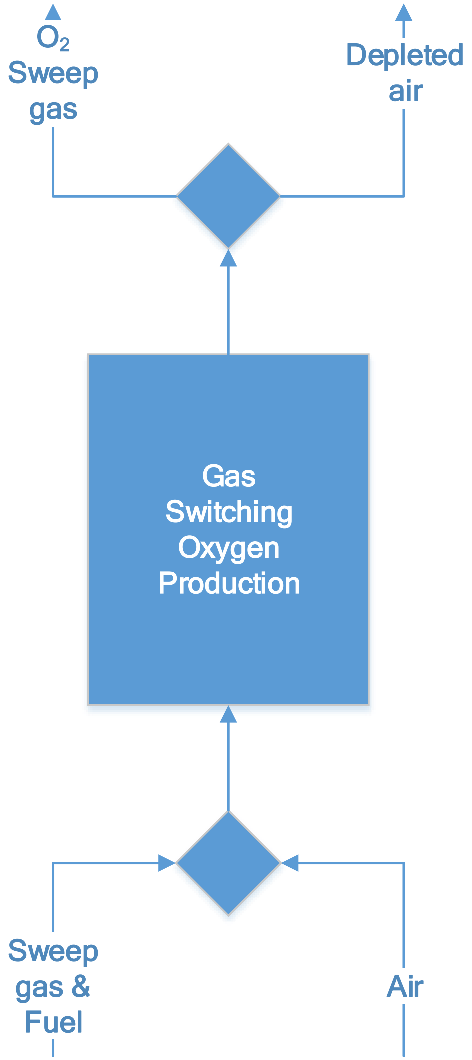
Gas Switching Water Splitting (GSWS)



Iron based OC
1000C

Gas Switching Oxygen Production (GSOP)

- Produces oxygen
- <u>Advantage:</u> Air separation with no direct energy penalty
- <u>Challenge:</u> O_2 is diluted in sweep gas and a large stream of hot depleted air is produced



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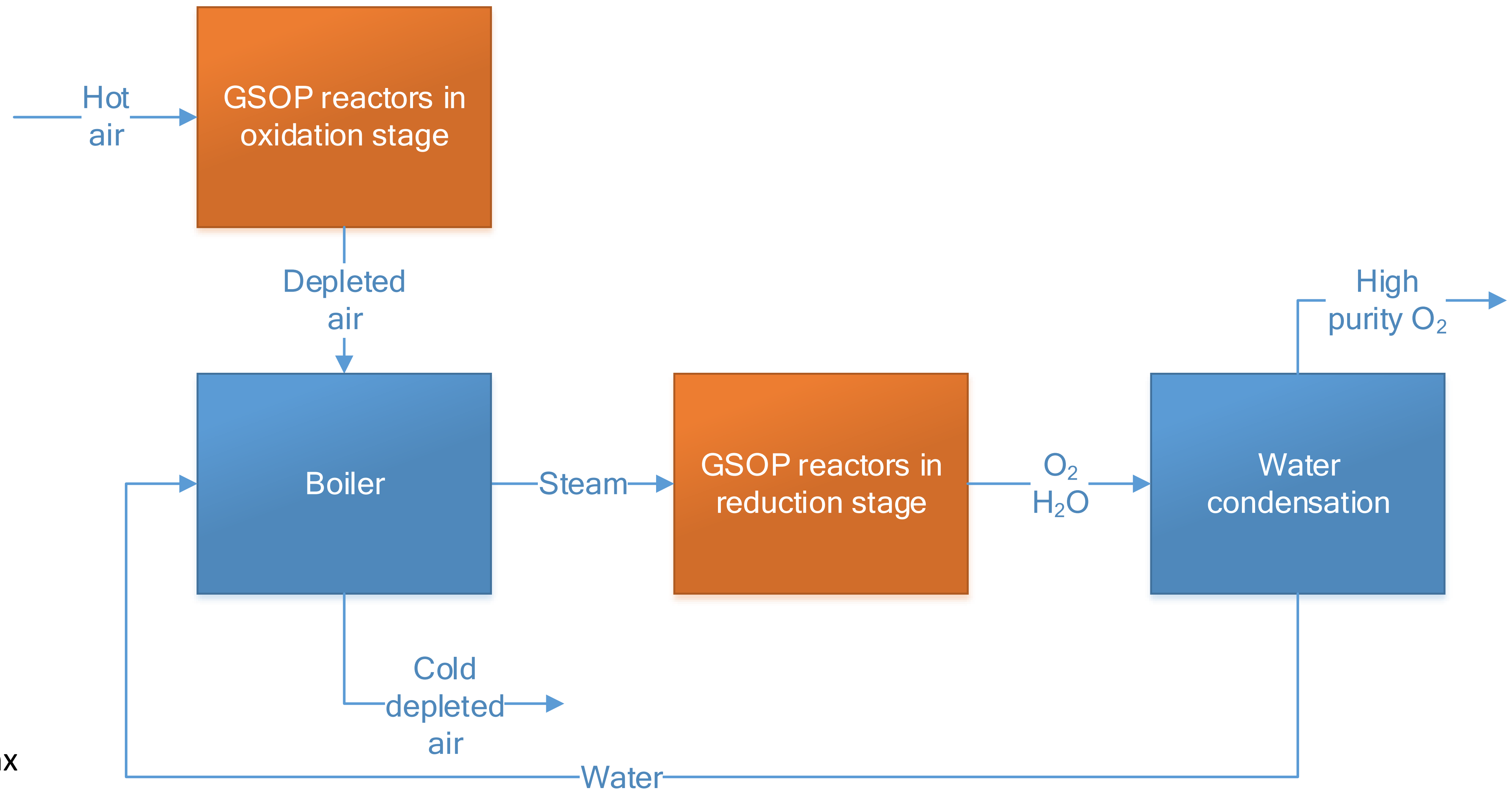
Gas Switching Oxygen Production (GSOP)



CaMnx
700C

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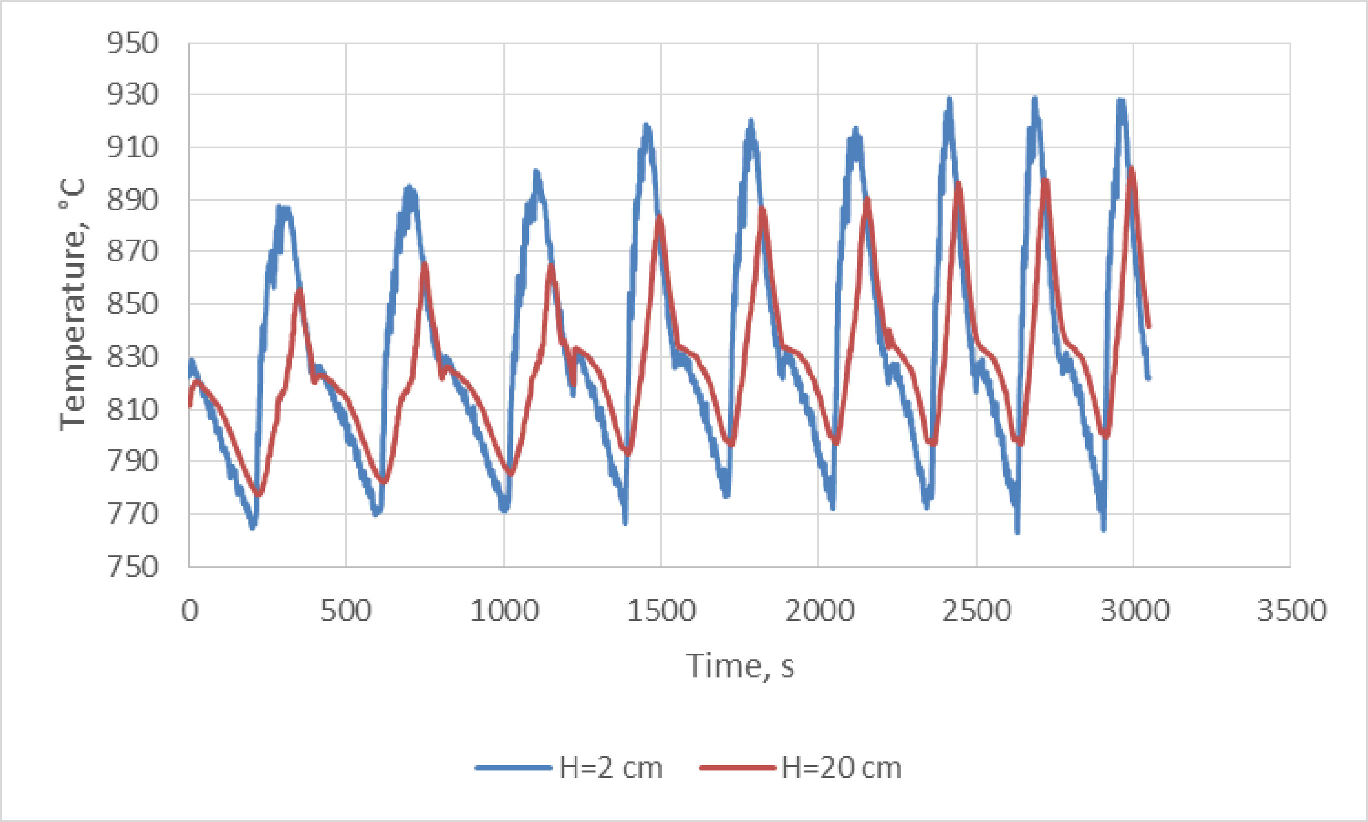
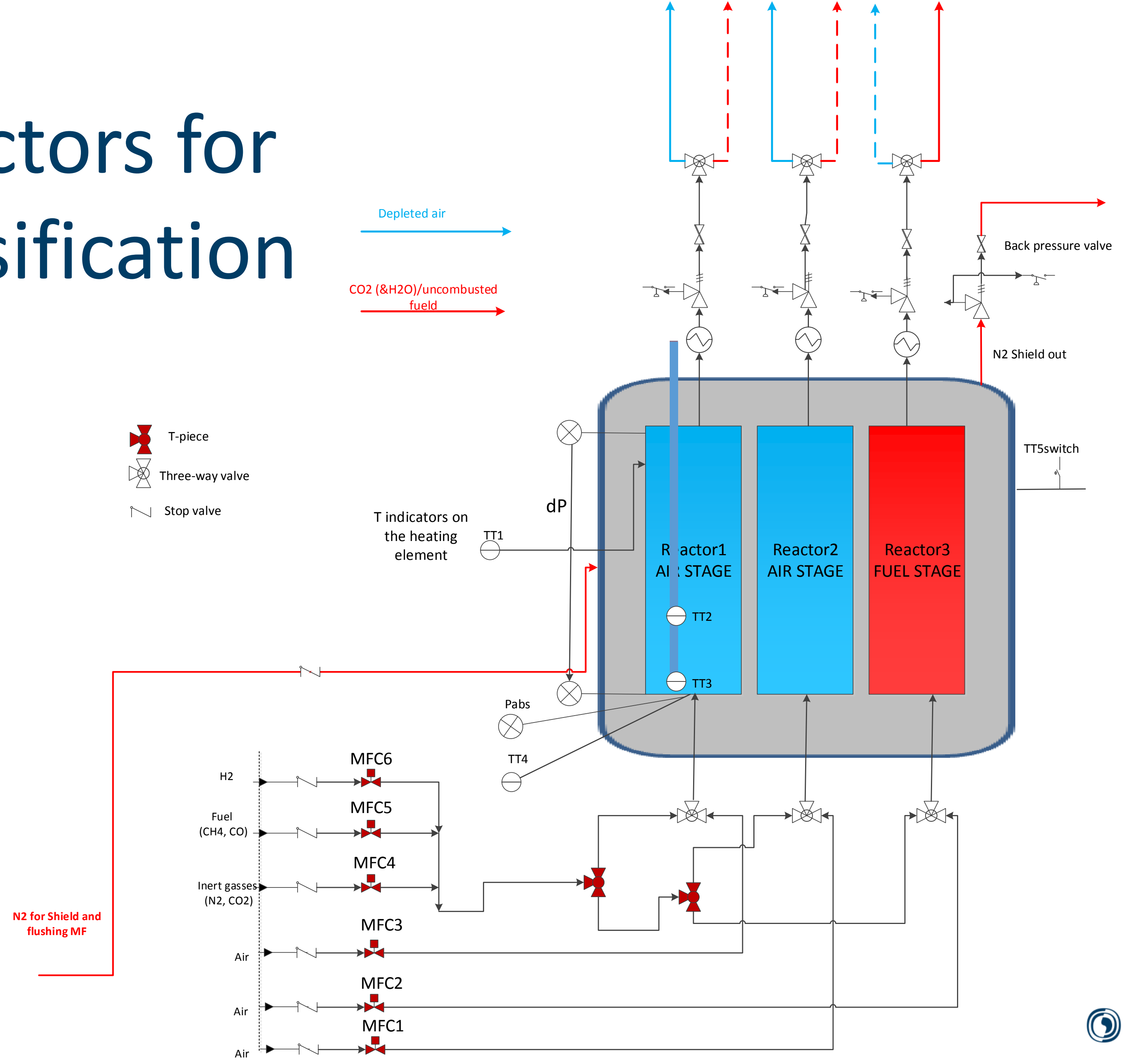
Gas Switching Combustion: Autothermal operation



Transient temperature variations during autothermal operation of the GSC reactor under operating pressures of 3, 4 and 5 bar

Cluster of reactors for Process intensification



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Partner roles

- Experimental demonstration of Gas Switching by **SINTEF** and **NTNU**
- Selection and pre-testing of the oxygen carrier materials by **ETH** to be manufactured by **ESAM**
- Modelling of large-scale gas switching reactor by **SINTEF** to provide input to process simulations done by **NTNU** and **UPM**
- Economic assessments for the different processes by **UPM**
- Evaluation of the business case based on the main project results by **HAYAT**

Work packages

WP No	WP title	Lead	Participants
WP1	Materials selection, testing and manufacturing	ETH	ESAM
WP2	Demonstration of pressurized GSC, GSR, GSWS and GSOP operation	SINTEF	NTNU
WP3	Large-scale process simulation of gas switching technology	NTNU	UPM SINTEF NTNU
WP4	Economic assessments of gas switching technology	UBB	ESAM
WP5	Business case	HAYAT	All partners
WP6	Management and dissemination	SINTEF	All partners

Gantt chart

T = Task		2017						2018												2019												2020					
MS = milestone		J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J
T 1.1	Identifying suitable materials																																				
T 1.2	Development of a production process for spray-drying																																				
T 1.3	Characterization of spray-dried oxygen carriers and investigation of their reactivity																																				
T 1.4	Establishment of quality protocols for spray-dried oxygen carriers																																				
T 1.5	Optimization of the large-scale synthesis process																																				
MS 1	Production of 10 kg sample of oxygen carrier for the demonstration of GSWS																																				
MS 3	Production of 10 kg sample of oxygen carrier for the demonstration of GSR																																				
MS 6	Production of 10 kg sample of oxygen carrier for the demonstration of GSOP																																				
MS 7	Production 10 kg sample of upgraded C28 oxygen carrier for the GSC tests																																				
T 2.1	Demonstration of pressurized GSWS operation																																				
T 2.2	Demonstration of pressurized GSR operation																																				
T 2.3	Demonstration of pressurized GSOP operation																																				
T 2.4	Testing the pressurized GSC concept with the optimized Mn-based oxygen carrier																																				
T 2.5	Demonstration of autothermal operation of a pressurized GSC cluster																																				
MS 2	Two additional reactors commissioned																																				
T 3.1	Reactor simulations																																				
T 3.2	GSR and GSWS process simulations																																				
T 3.3	Detailed transient process simulations																																				
T 3.4	Pre-combustion power plant simulations																																				
T 3.5	GSOP process simulations																																				
T 3.6	GSOP power plant simulations																																				
MS 4	Basic process layout for two process concepts based on gas switching technology																																				
MS 5	Unit sizing of the major process components in the two selected process concepts																																				
MS 8	Process efficiency and CO2 avoidance of the two selected process concepts																																				
T 4.1	Definition of main economic assumptions and benchmark cases																																				
T 4.2	Economic assessments of gas switching technologies																																				
MS 9	Identification of best performing technologies for the business case																																				
T 5.1	Planning Activities																																				
T 5.2	Business Plan																																				

Acknowlegment

- ACT GaSTech Project No 276321
- This project has received funding from funding bodies in the respective countries
  - Research Council of Norway, Norway
  - MINECO, Spain
  - Netherlands Enterprise Agency, Netherlands
  - Department of management and administration of thematic research programmes, Romania
  - TUBITAK, Turkey
  - Swiss Federal Office of Energy, Switzerlands
- Cofounded by the European Commission under the Horizon 2020 programme, ACT Grant Agreement No 691712.

Accelerating CCS Technologies


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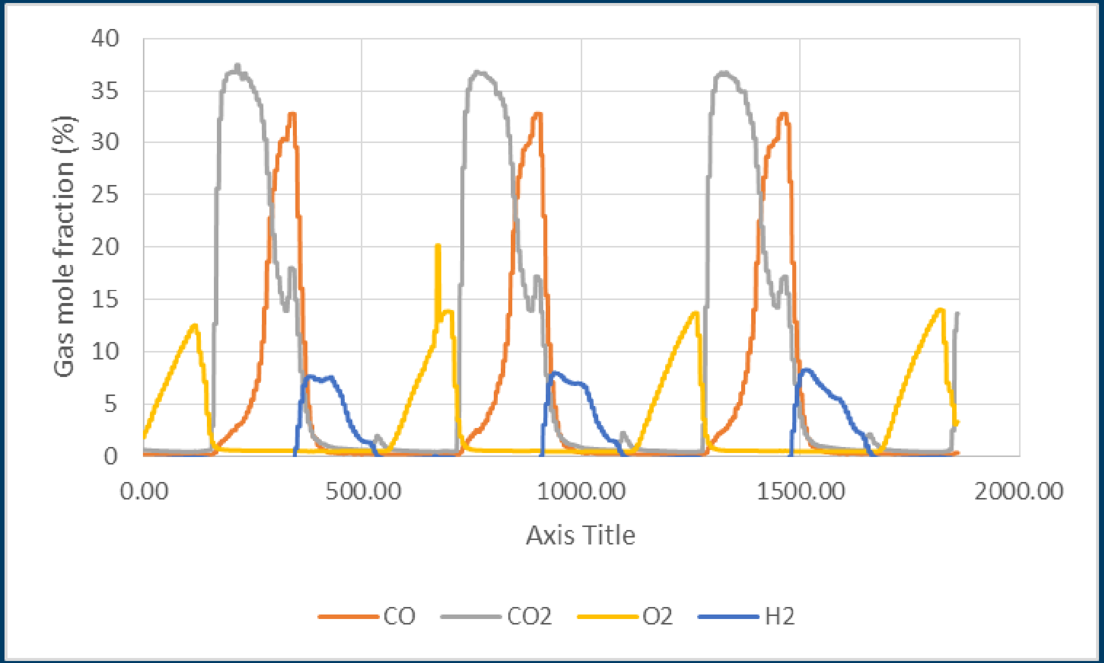
Teknologi for et bedre samfunn

Gas Switching Water-Splitting

- Iron based oxygen carrier
  - 33% active weight
- CO, steam and air were cycled to the iron-based OC at 900 C
- H2 was produced in the steam stage



Transient gas composition in 3 cycles of GSWS

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