SINTEF

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

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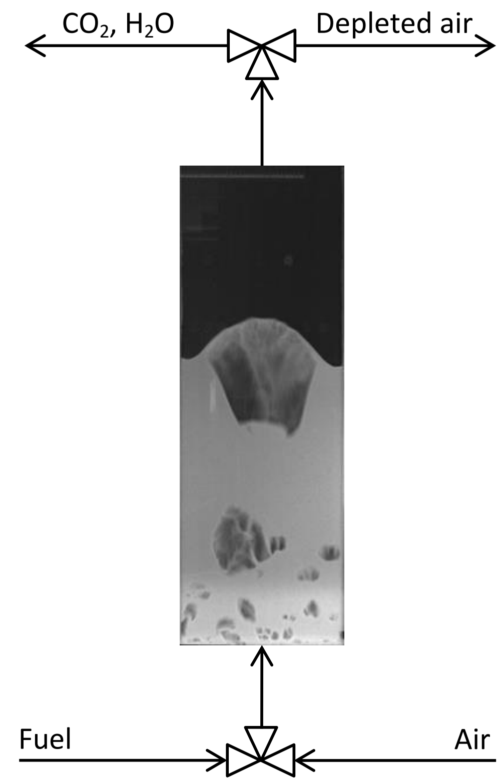
Partners

#	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	Universitatea Babeș-Bolyai	UBB	UNI	RO
5	Hayat	HAYAT	IND	TR
6	ETH Zürich	ETH	UNI	CH
7	Universidad Politécnica de Madrid	UPM	UNI	ES

Background to the project

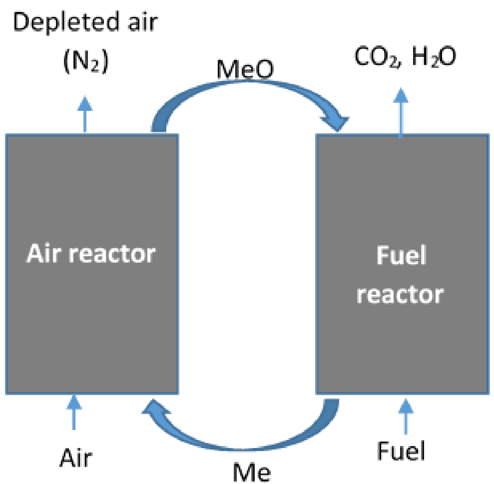
- Gas Switching Technology offers for highly efficient power or hydrogen production with integrated CO_2 capture.
- Highly efficient oxygen production for oxyfuel CO_2 capture is also possible.
- It utilizes simple standalone bubbling/turbulent fluidized beds that are alternatively fed with oxidizing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



Gas Switching Technology
GasTech

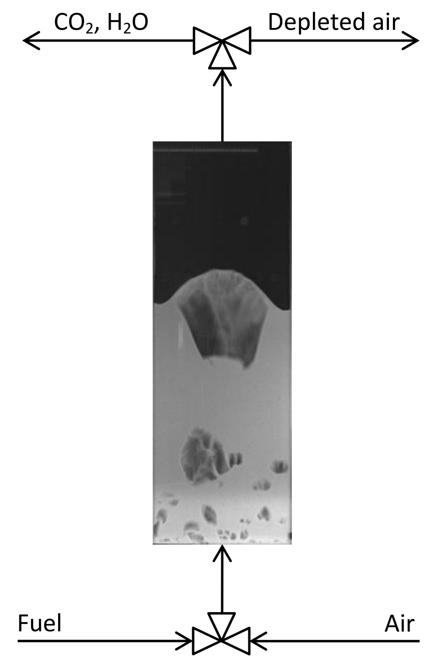
Gas Switching technology

Based on Chemical Looping principle



Process simplification

Gas Switching Reactor



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

Advantages

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

Scope and budget of GaSTech

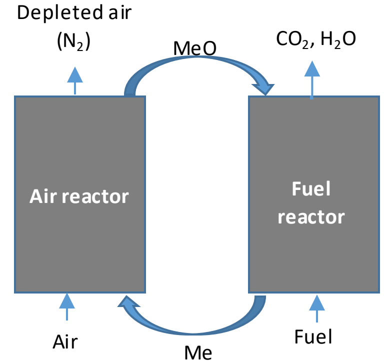
Project objective: *To accelerate the development of gas switching technologies by further technology scale-up through:*

- 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

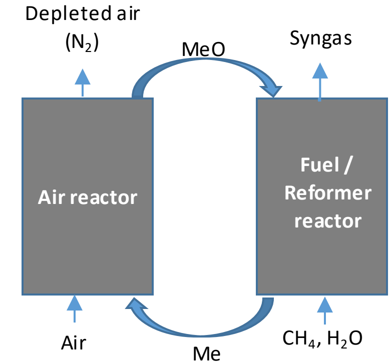
GasTech will be applied to different Chemical looping processes

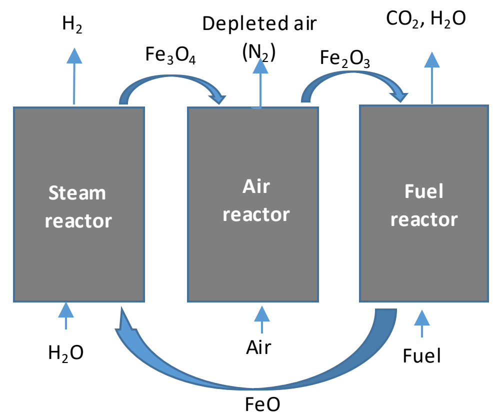
- Combustion (cluster of reactors)
- Reforming
- Water splitting
- Oxygen production

Gas Switching Combustion (GSC)

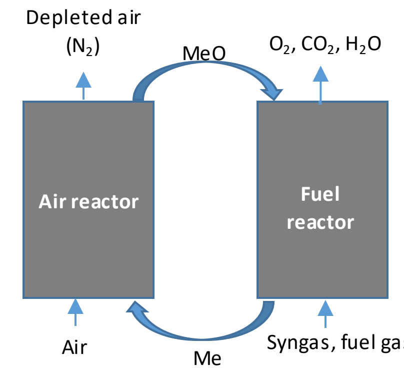


Gas Switching Reforming (GSR)



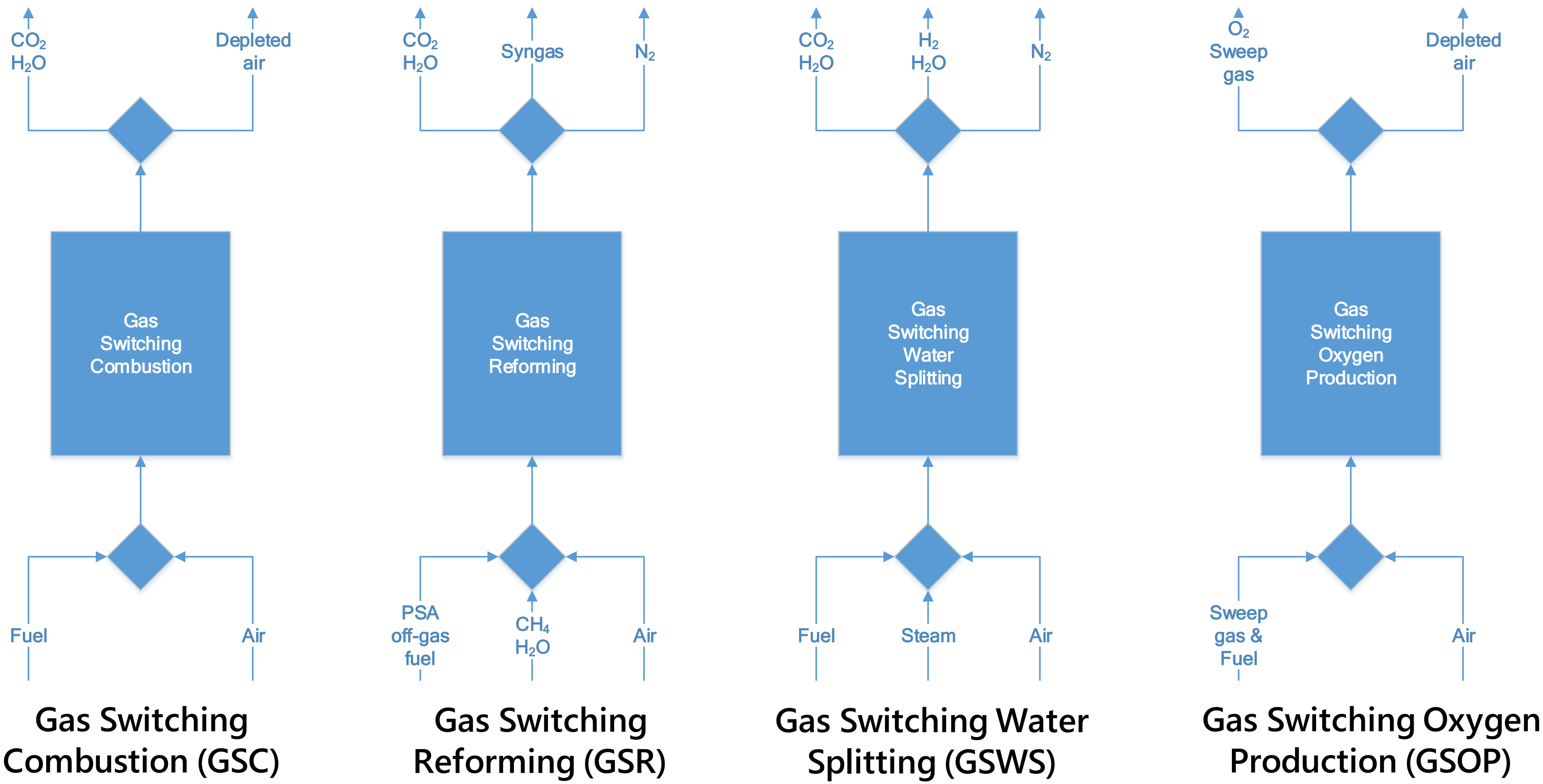


Gas Switching Water Splitting (GSWS)



Gas Switching Oxygen Production (GSOP)

GasTech will be applied to different Chemical Looping processes



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

Project outcome– in short!

- Materials production
  - Development and testing of oxygen career materials in react set up for GSWS and GSC, scale up
- Techno-economic assessment
  - Successfully modelled four promising gas switching process configurations that clearly outperform benchmarks in terms of efficiency (GSC-IGCC, GSOP-IGCC, GSR-H2) and flexibility (GSR-CC)
  - Creating reference for the best economic performing technologies

Partner roles

- Experimental demonstration of Gas Switiching 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 UBB
- Evaluation of the business case based on the main project results by HAYAT

Gant chart

T = Task MS = milestone	
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

2017: J A S O N D — 2018: J F M A M J J A S O N D — 2019: J F M A M J J A S O N D — 2020: J F M A M J

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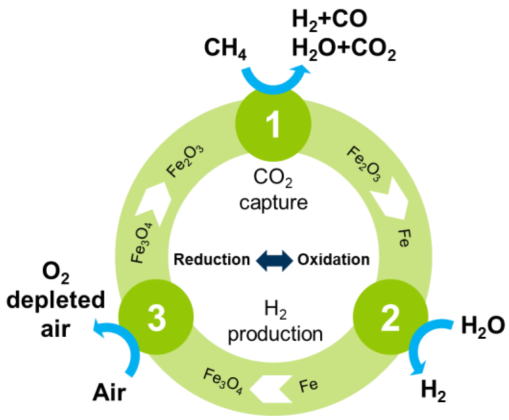
WP1: Oxygen carrier development for Gas Switching water splitting



<u>Requirements</u>:

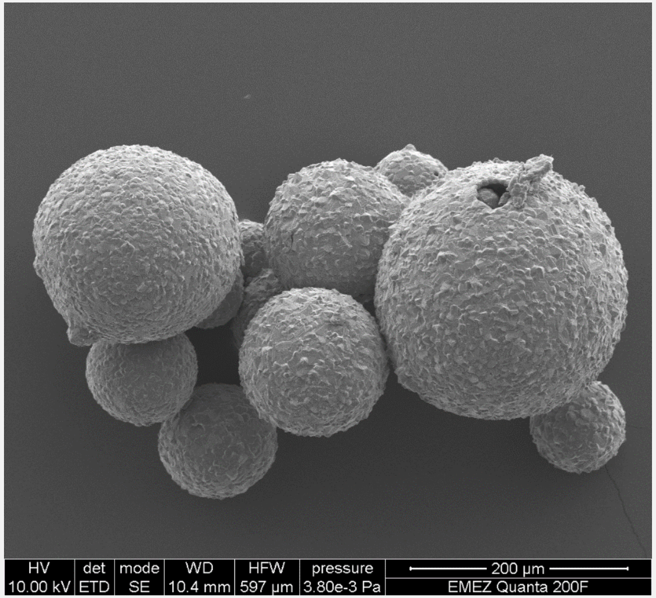
- High conversion of CH_4 at 800-850°C
- High iron contact (>70 wt%) for separation performance
- Prevention of formation of coke on the OC for high-purity H_2
- Relatively cheap materials
- Synthesis via spray-drying is feasible (Euro Support BV)

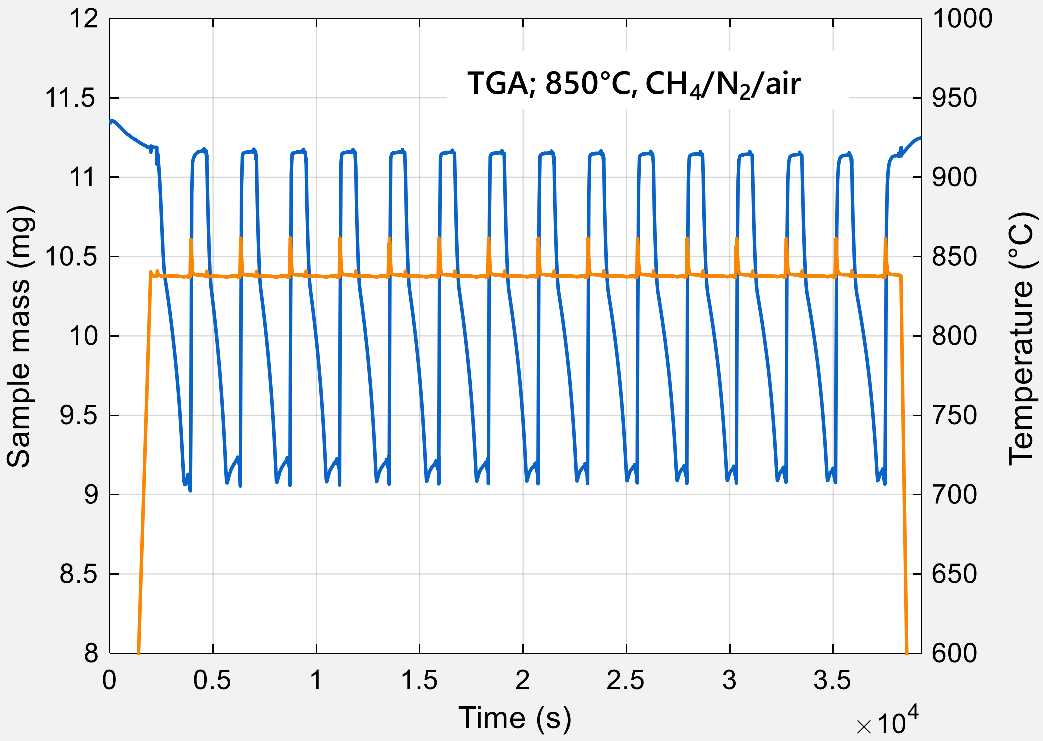
→ Material selection based on results reported in the literature

- <u>Performance evaluation:</u>
- TGA, fixed bed, fluidised bed, (in-situ) XRD, SEM/TEM, compression strength

euro support

- **Synthesis and investigation of > 30 different Fe-based materials in TGA (Fe-, Mg-, Al-, Zr-, Cu-, Ce-, La-, Ca-, Ti-, Si-oxides)**



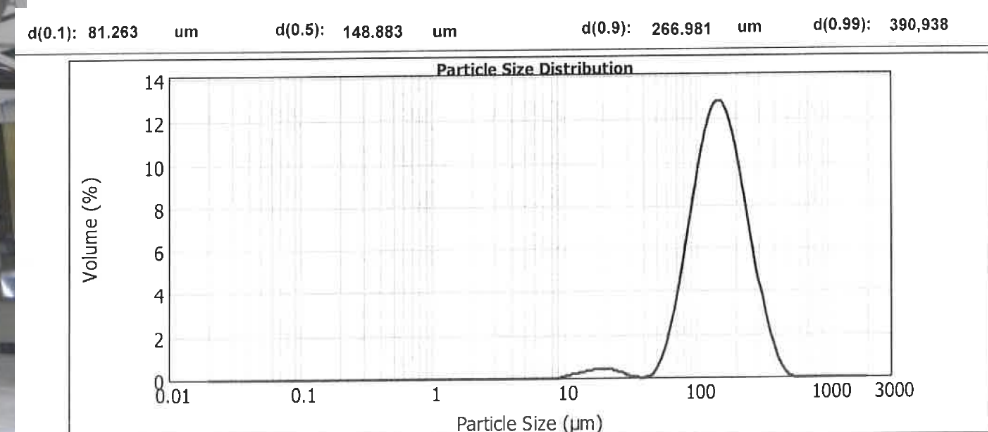


euro support

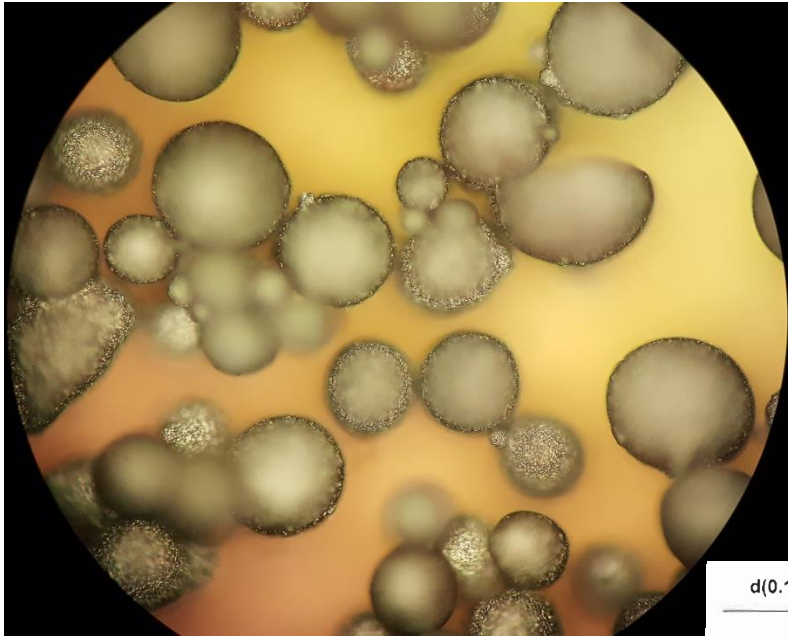
Oxygen carrier production for GSWS

Mass production on spray drier

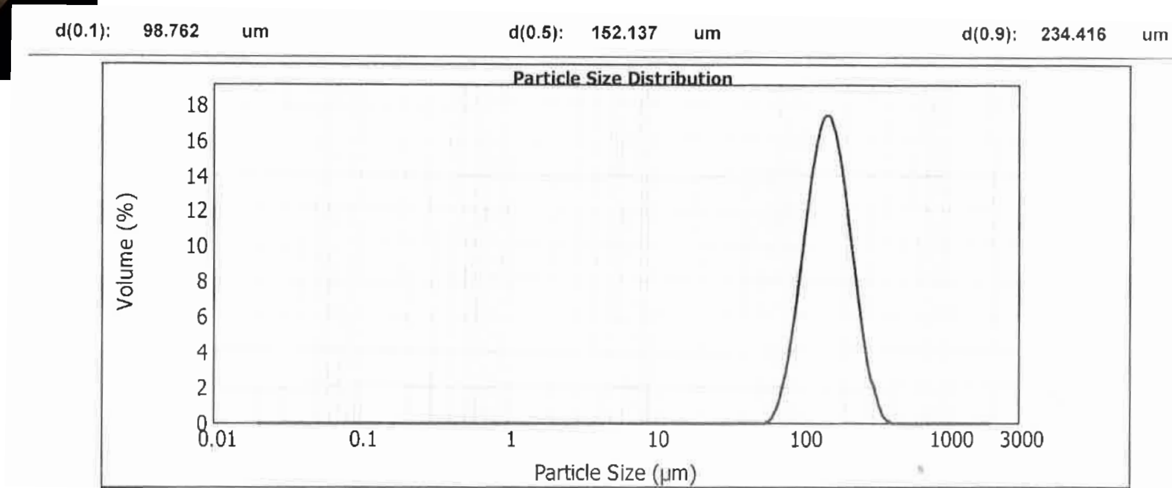
- Optimization of proces conditions for maximum sphere size



Oxygen carrier production for GSC



- Carrier and process developed in SUCCESS project
- Process optimized for improved particles strength
- Narrow PSD
- 50kg of material send for testing of GSC cluster at SINTEF



WP1: Oxygen carrier development for GS water splitting

Conclusions

- **Sintering and agglomeration are severe problems**
- **Prevention of coking on Fe-based materials not feasible when reducing the material to metallic iron**
  - GSWS by far the most challenging Chemical looping process – currently under optimisation
  - Upscaled material for GSC
  - Screening materials for GSR

Project plan for the next year – materials

- Materials production
  - Development and testing of oxygen career materials for GSR, scale up by ESAM
  - Development and testing of oxygen career materials for GSOP, scale up by ESAM

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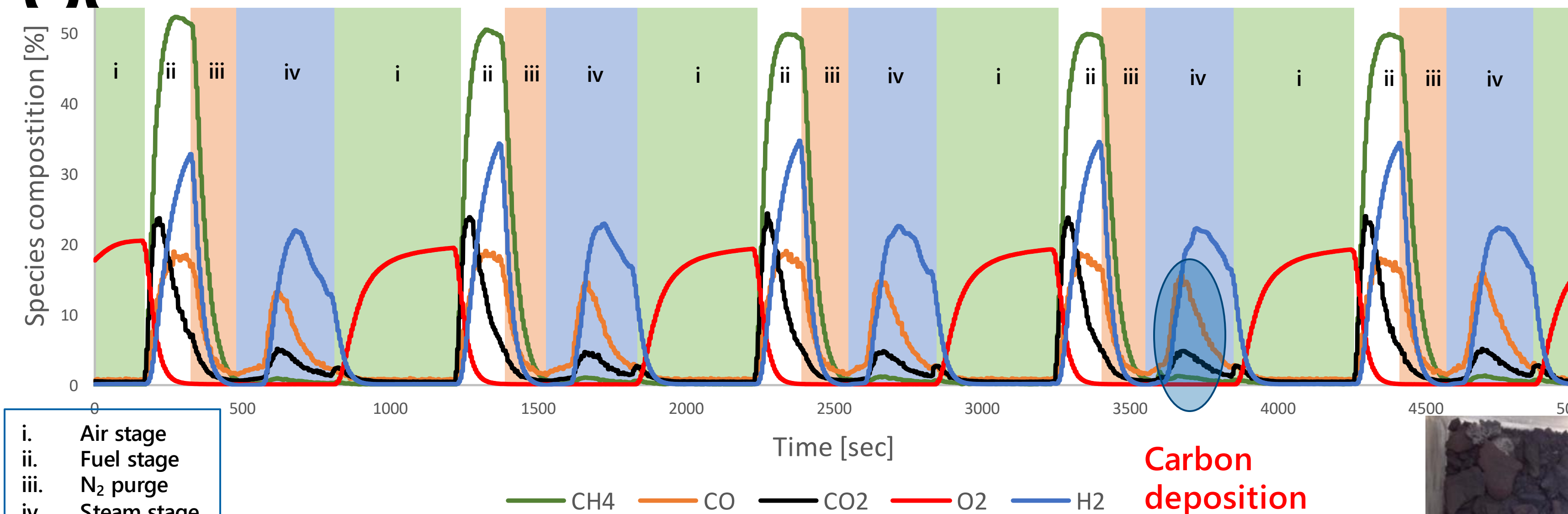
WP2: Demonstration of pressurized GasTech

- Demonstration of Gas Switching Water Splitting (GSWS)
- Construction of GasTech cluster

GSWS with CH_4 and 70% iron loading OC



i. Air stage
ii. Fuel stage
iii. N_2 purge
iv. Steam stage

Carbon deposition

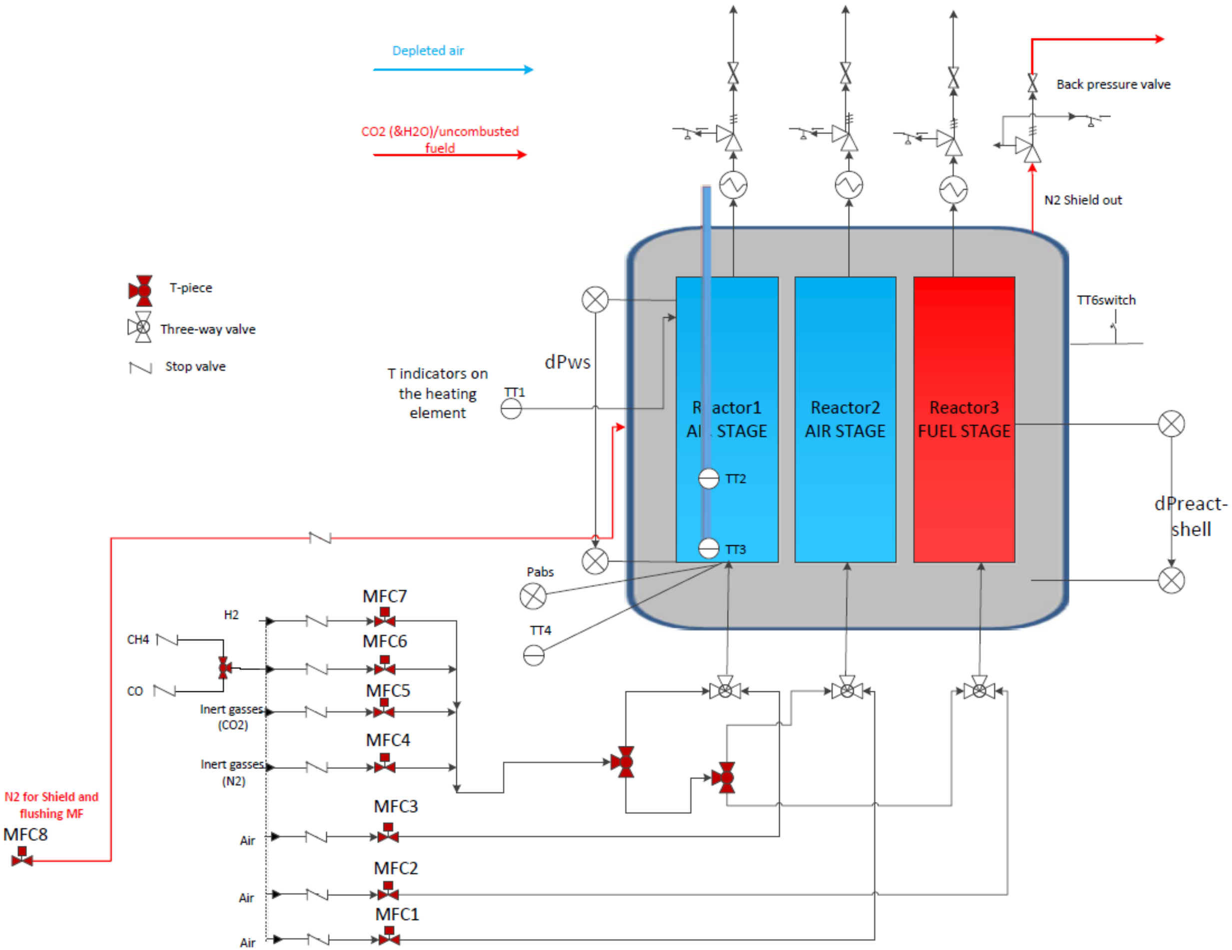
Conditions:

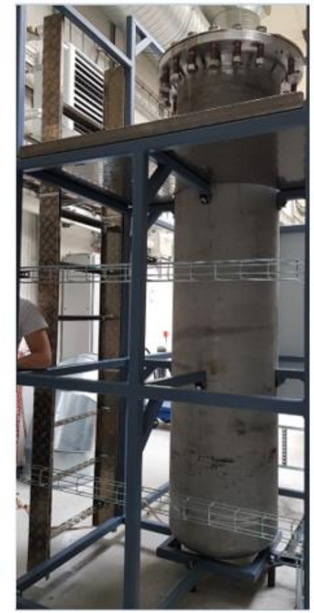
- *Fuel stage: 5nl/min for 3min (Reduction to FeO)*
- *Steam stage: 1.6g/min for 5minutes.*
- *Steam stage: 1.6g/min for 5minutes.*

Result

- Over 10 repeated cycles (stable)
- Hydrogen produced in the steam stage but mixed with CO due to gasification of deposited carbon deposition
- Further optimization to the oxygen carrier is required

WP2: Construction of GasTech cluster





- *Three reactors of 10 cm ID and 2 m height*
- *20 bar operating pressure*
- *1100 °C operating temperature*
- *Reactors are placed in a pressure shell*

Work packages

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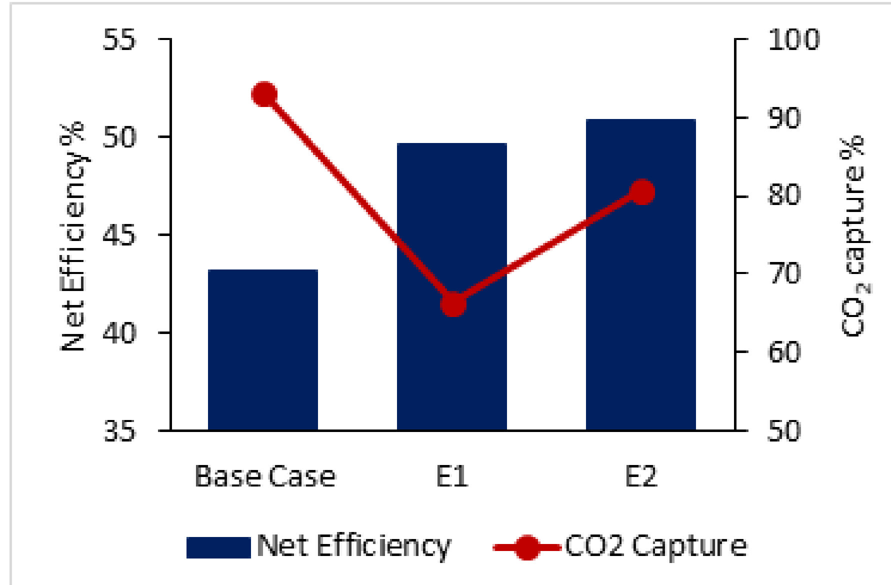
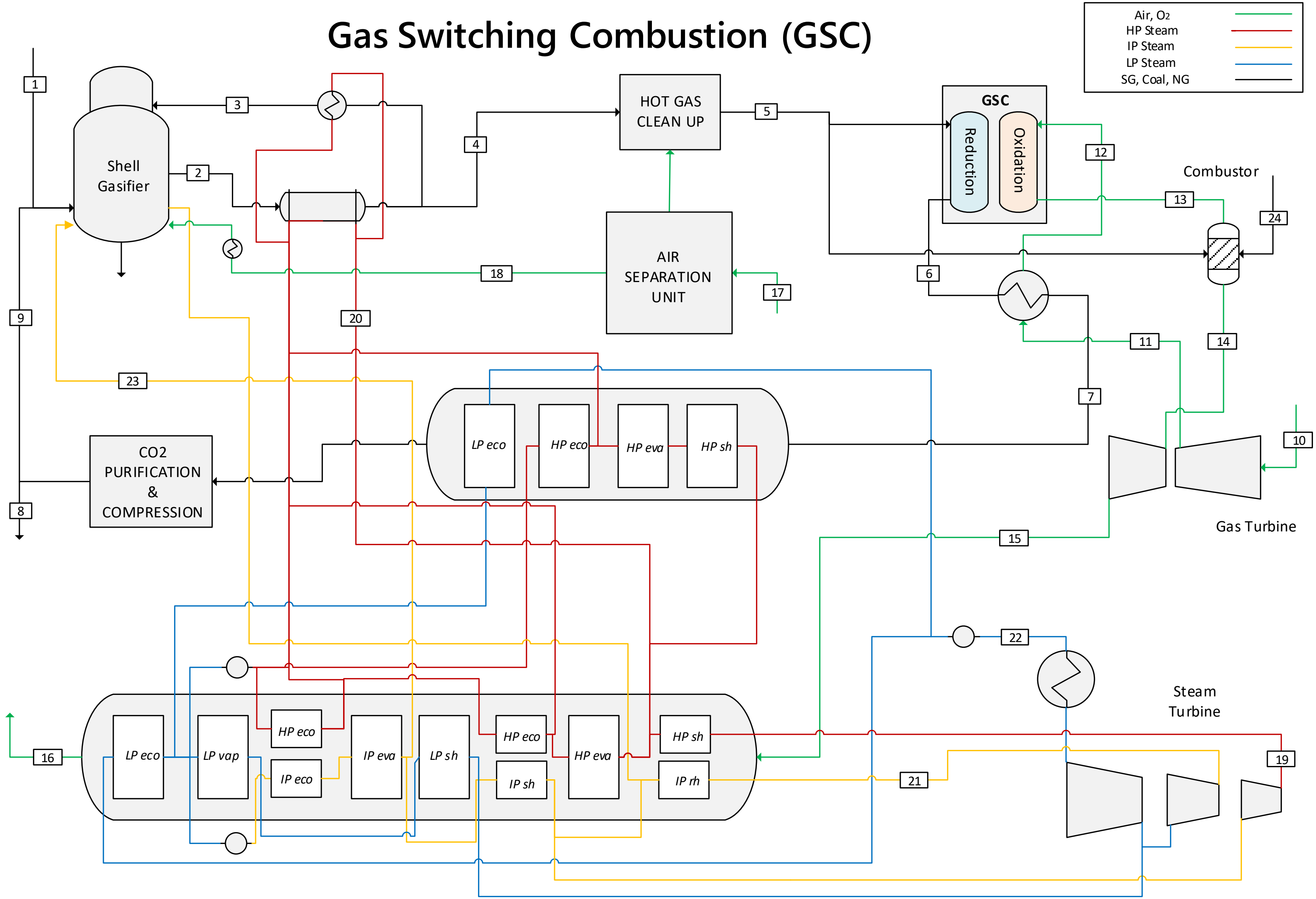
WP3: High efficiency Gas Switching Combustion (GSC)

- GSC with added combustor to raise turbine inlet temperature and increase efficiency
- Potential to eliminate gas clean-up
- Extra firing with natural gas achieves very high 50.9% efficiency and 80.7% CO_2 capture in IGCC configuration



Base case: GSC-IGCC with hot gas clean-up
E1: GSC-IGCC with added combustor fired by syngas and no gas clean-up
E2: GSC-IGCC with added combustor fired by natural gas and no gas clean-up


Gas Switching Combustion (GSC)
Air, O2
HP Steam
IP Steam
LP Steam
SG, Coal, NG
Shell
Gasifier
HOT GAS
CLEAN UP
GSC
Reduction
Oxidation
Combustor
AIR
SEPARATION
UNIT
CO2
PURIFICATION
&
COMPRESSION
LP eco
HP eco
HP eva
HP sh
Gas Turbine
Steam
Turbine
LP vap
IP eco
IP eva
LP sh
IP sh
IP rh
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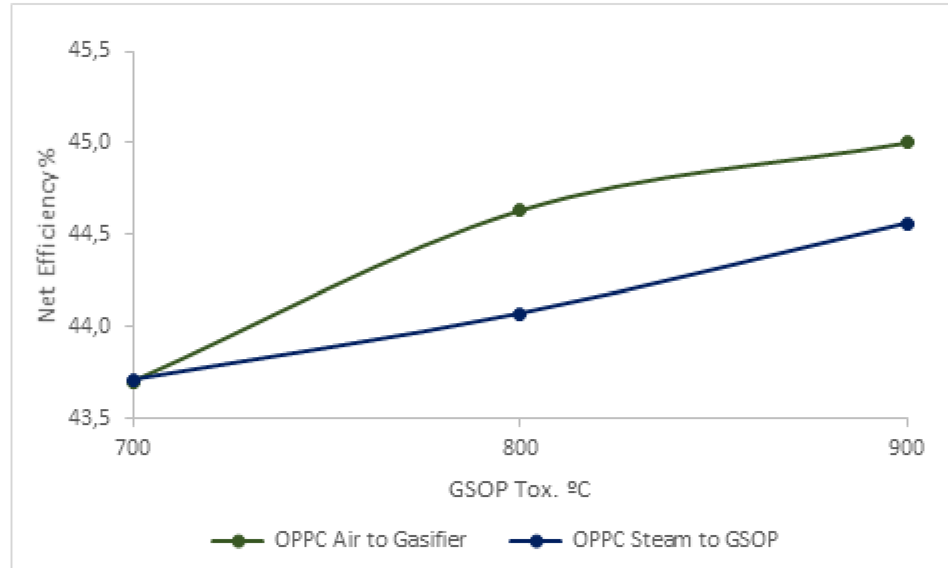
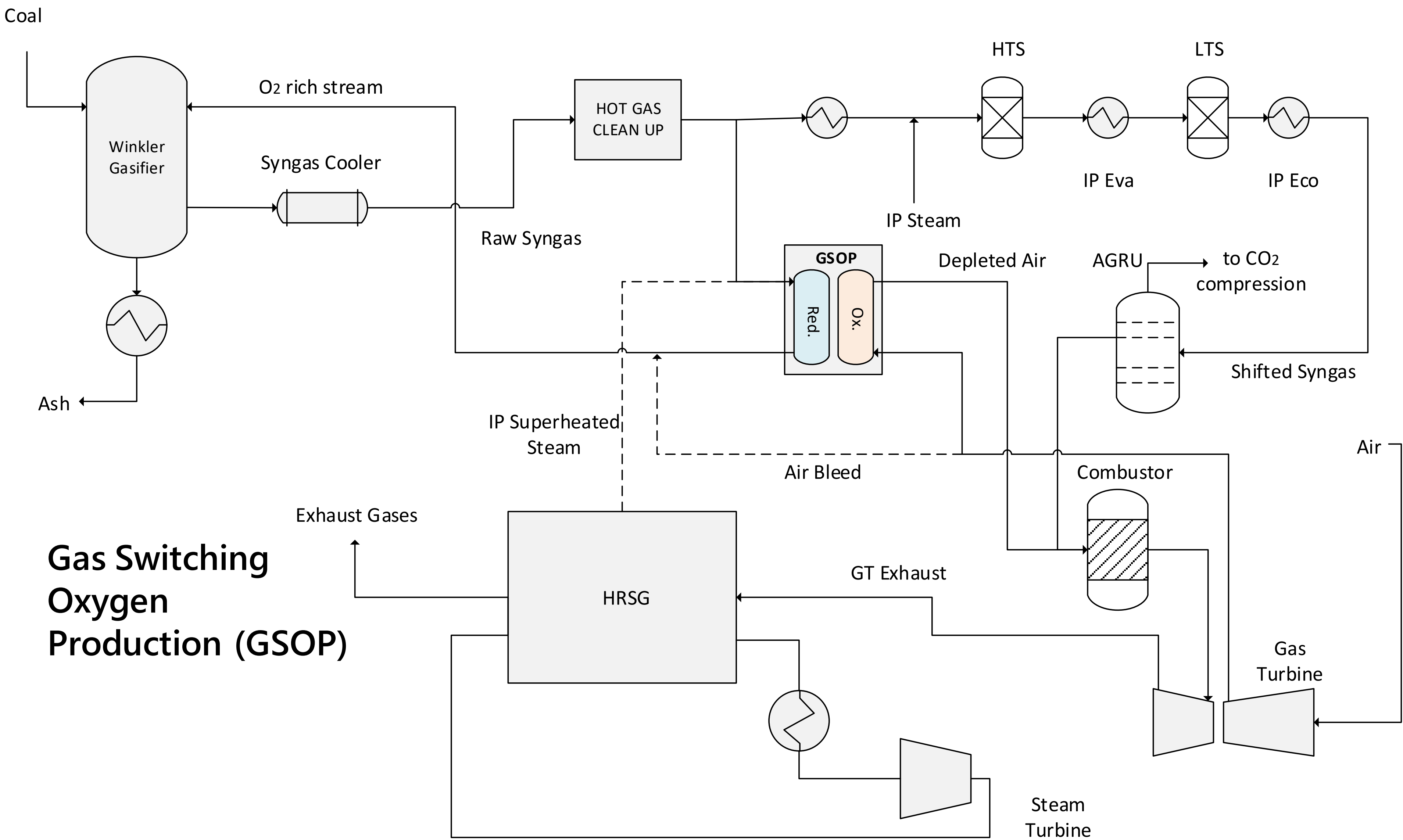
WP3:
Simplified Gas Switching Oxygen Production (GSOP)

- GSOP replaces ASU in IGCC plant
- Eliminates challenge with high-temperature valves and filters in GSC
- Much higher efficiency than conventional pre-combustion IGCC plant (~38%)

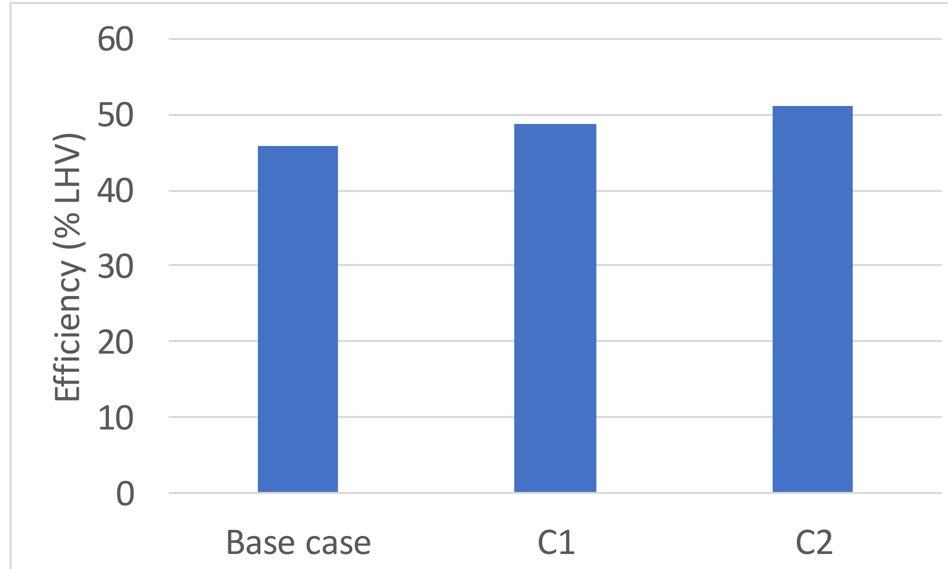


Efficiency increases with GSOP operating temperature because more fuel is combusted in GSOP, leaving less to be converted to H_2.


Coal
Winkler Gasifier
O2 rich stream
Syngas Cooler
Raw Syngas
HOT GAS CLEAN UP
HTS
LTS
IP Eva
IP Eco
IP Steam
GSOP
Red.
Ox.
Depleted Air
AGRU
to CO2 compression
Shifted Syngas
Ash
IP Superheated Steam
Air Bleed
Air
Combustor
Exhaust Gases
GT Exhaust
HRSG
Gas Turbine
Steam Turbine
Gas Switching Oxygen Production (GSOP)

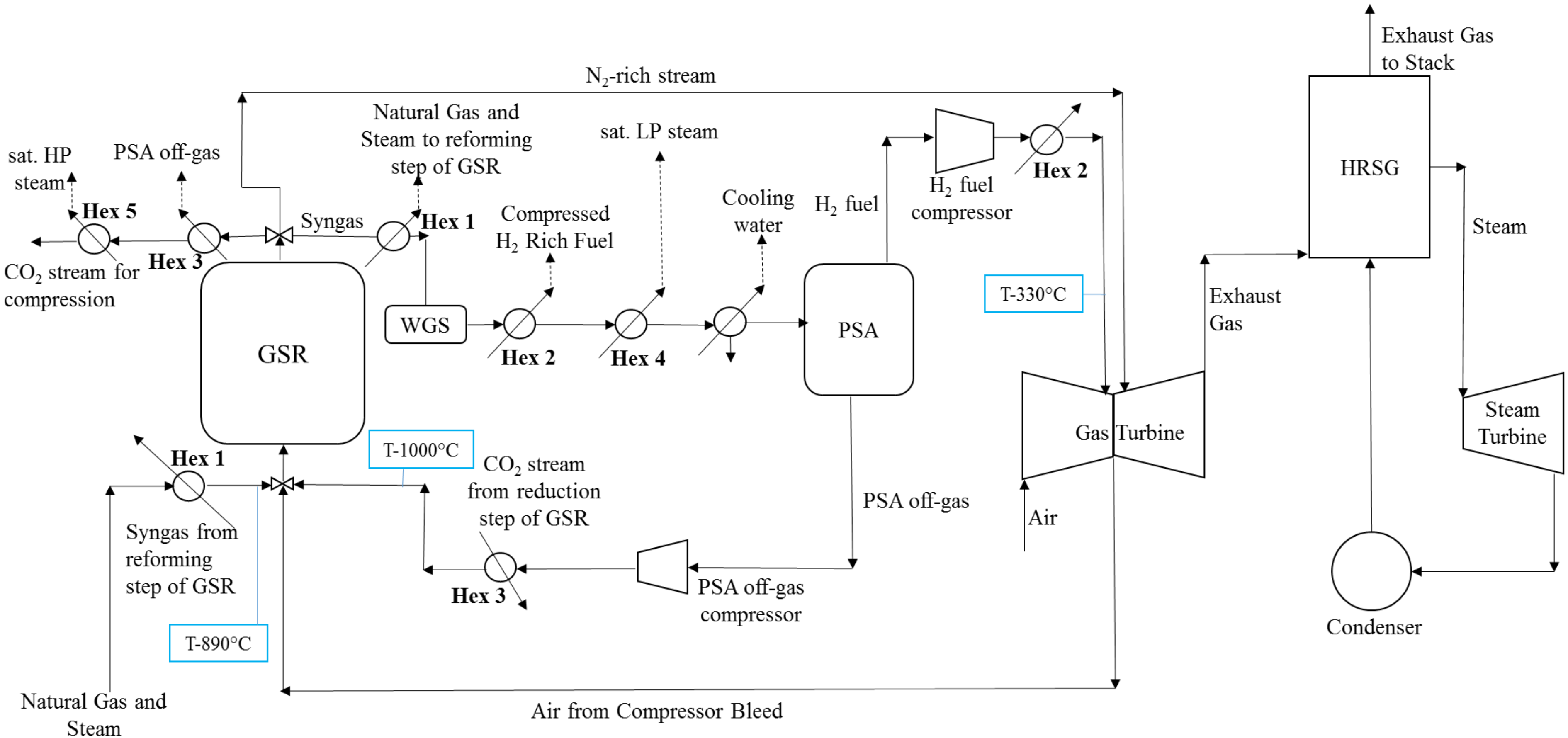
WP3: Improved GSR-Combined Cycle (CC)

- GSR-CC can lower the energy penalty to 7 %-points in natural gas plants
- Main advantage: flexible output:
  - Electricity when electricity price is high
  - Pure H_2 when electricity price is low
- Very high 98% CO_2 avoidance



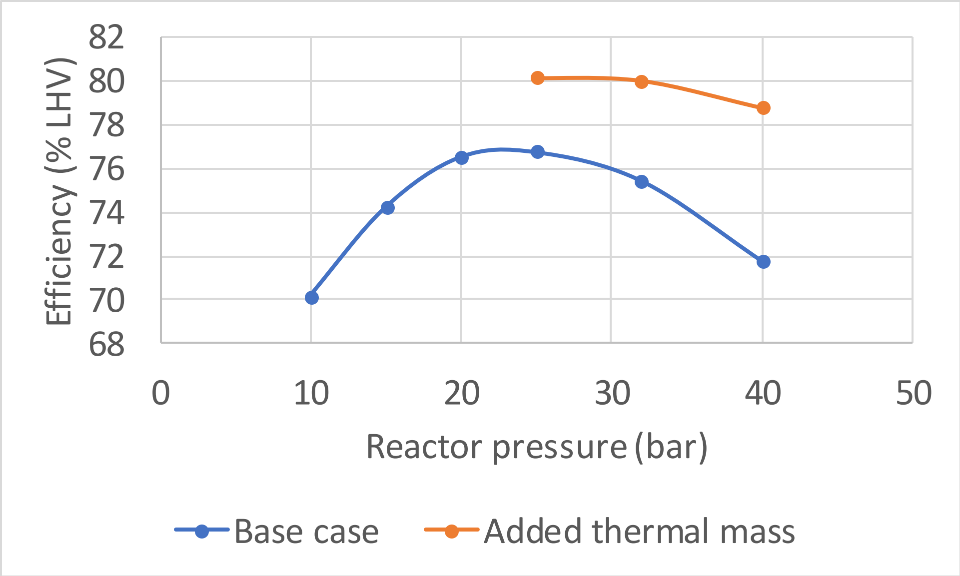
Base case: Conventional GSR-CC plant
C1: GSR-CC with improved lean pre-mixed combustion turbine
C2: GSR-CC with improved turbine and improved heat integration

GSR-Combined Cycle (CC)



WP3: GSR H_2 plant

- GSR for pure H_2 production with 96% CO_2 capture can match the efficiency of conventional methods without CO_2 capture (~80%)
- More thermal mass to reduce the temperature drop during reforming was important



Added thermal mass adds some inert material into the reactor to reduce the transient temperature variation across the GSR cycle.

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Benckmark cases

- GSC: IGCC
- GSR: NGSR
- GSWS: -
- GSOP: -

Economic assessments of gas switching technologies

Capital costs
- Plant size
- Fuel type
- Oxygen carrier types
- CO_2 storage

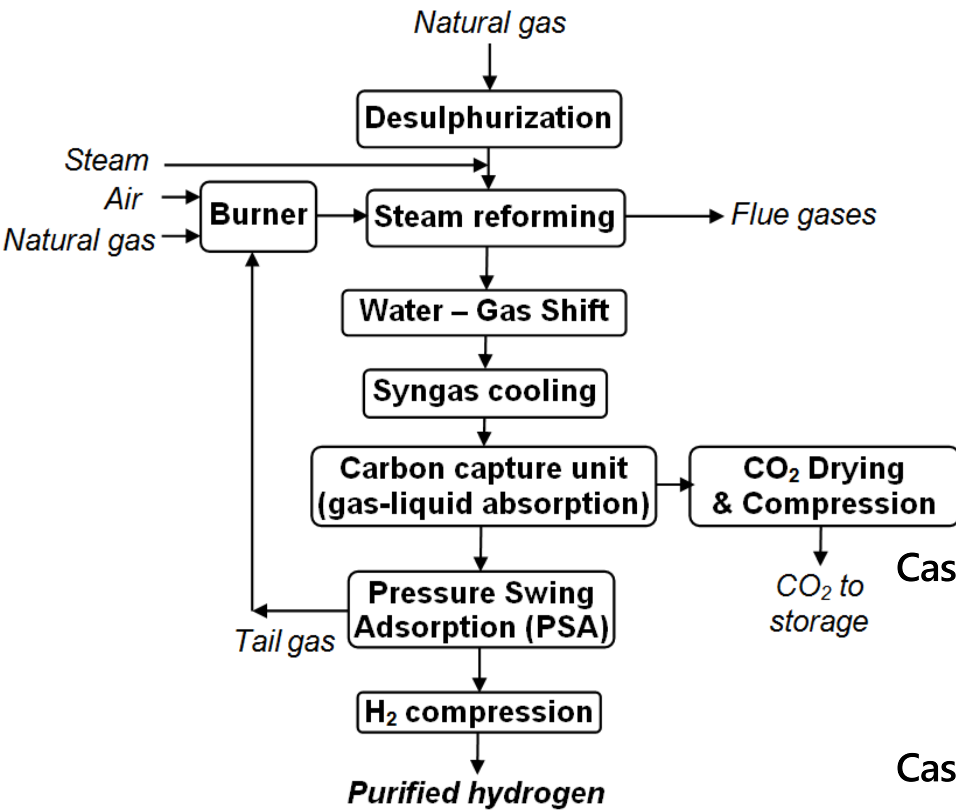
Operational and mentenance costs
- Mass and energy balance
- Fuel cost
- Material cost
- Utility cost

Production costs
- Production costs of power/ hydrogen/ oxygen

Economic assessments of gas switching technologies

Connection between WP4 and other WPs	
Reactor operating parameters (size, temperature, pressure, etc.)	WP 2-3 SINTEF, UPM, NTNU
Information about the production cost of the involved oxygen carrier	WP1 ESAM, ETH
Detailed flow sheet diagrams for the gas switching technologies	WP3 SINTEF, UPM
Mass and energy balance data for gas switching technologies	WP3 SINTEF, UPM
Other technical details	WP1-3 ESAM, SINTEF, UPM, NTNU

Economic assessments of gas switching technologies



Benckmark study case:
Natural gas reforming technologies

Case 1 - the conventional steam methane reforming
- Case 1a: No carbon capture scenario
- Case 1b: MDEA-based pre-combustion CO_2 capture
- Case 1c: Selexol™-based pre-combustion CO_2 capture

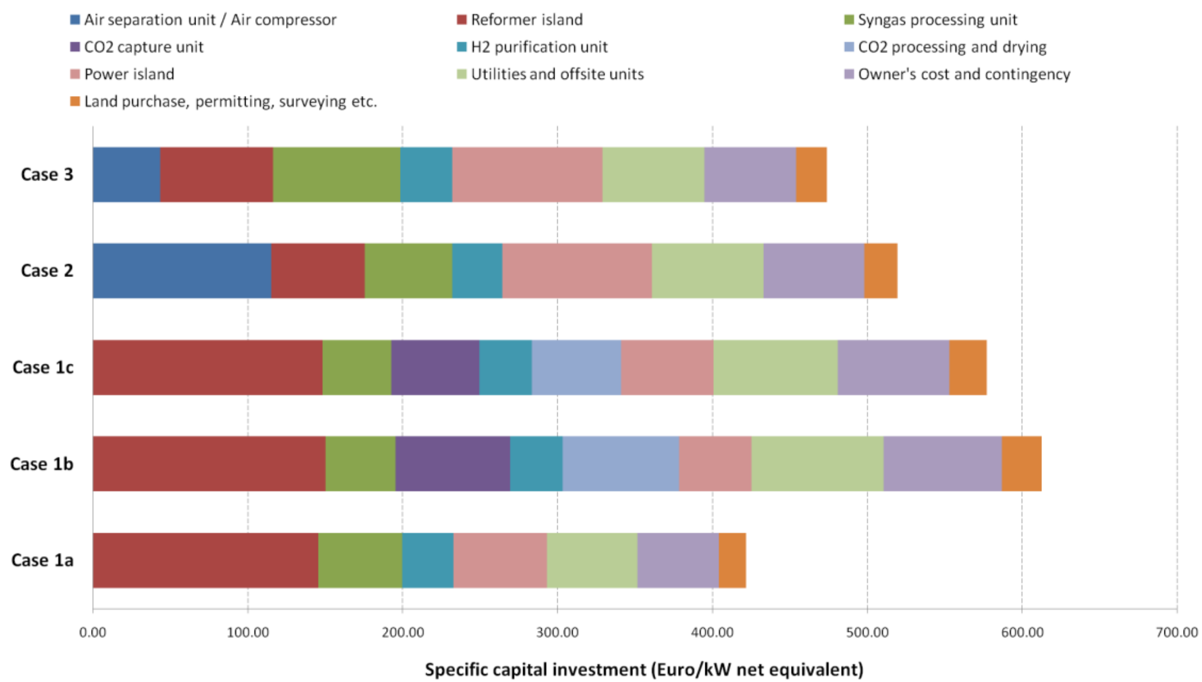
Case 2 - the oxygen autothermal reforming

Case 3 - the air autothermal reforming

Cormos et al., PRES 2018 Conference (Chem Eng.Trans. 70, pp 1231 -1236)

Economic assessments of gas switching technologies

Benckmark study case: Natural gas reforming technologies



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Economic assessments of gas switching technologies

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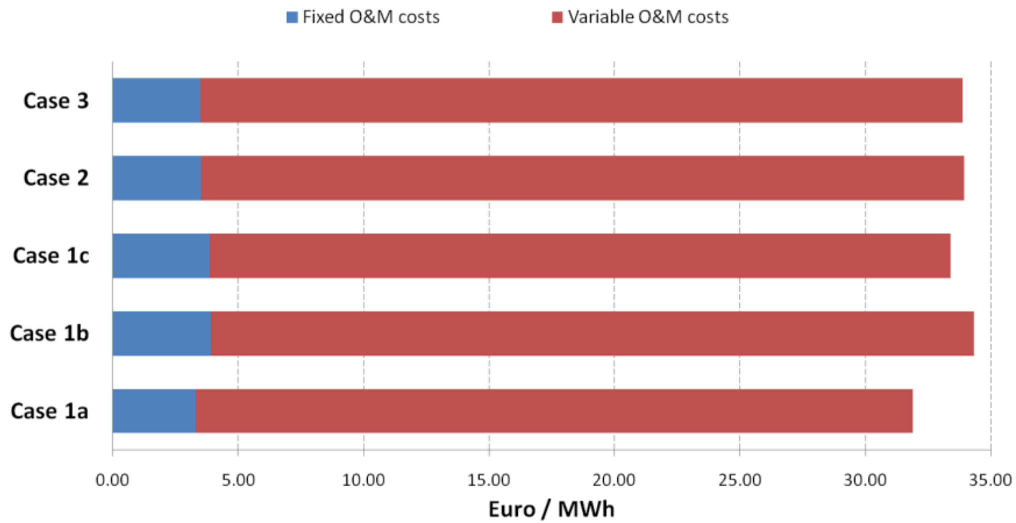

Costs of hydrogen & electricity and CO_2 capture costs

Main plant data	Units	Case 1a	Case 2	Case 3	Case 1b	Case 1c
Levelised cost of hydrogen (LCOH)	€ / MWh	**37.72**	41.10	39.63	43.03	41.64
Levelised cost of electricity (LCOE)	€ / MWh	**38.15**	40.90	38.55	43.20	41.77
CO_2 removal cost	€ / t	-	-	-	27.40	30.59
CO_2 avoided cost	€ / t	-	-	-	29.85	21.86

Economic analysis - reference

- The conventional steam reforming and air autothermal reforming (both without CCS) have similar specific investment costs (about 420 Euro/kW net equivalent).
- If pre-combustion CO_2 capture is applied for conventional steam reforming, the specific capital investment cost increases by 45 % for MDEA process (Case 1b) and 37 % for Selexol™ process (Case 1c) compared to the case without CCS.
- The economic indicators show better performances for the conventional steam reforming in comparison to the autothermal reforming technologies in term of specific capital investment cost (about 24 % lower).
- The variable cost component is significantly higher than the fixed one; this is because the fuel (natural gas) cost is having a major cost influence.
- For conventional steam reforming design, the introduction of pre-combustion CO_2 capture implies an increase of hydrogen production cost by about 14 % for MDEA process (Case 1b) and 10 % for Selexol™ process (Case 1c).
- The CO_2 avoidance cost is lower for the Selexol™ case than for the MDEA case by about 36 %.

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WP5: Business Case: Cost and Benefit Analysis

➢ **Part-1: investigation of current system and technology**

- Analysis of operating costs of the gasifier process with ORC at HAYAT
- Monitoring energy, personnel overtime, material, maintenance, and other miscellaneous operating cost are being monitored on a weekly and monthly basis
- Monitoring power output: electricity and steam production per day.
- Monitoring composition of syngas on a weekly basis to identify whether there is an abrupt change in the feedstock content

WP5: Business Case: Cost and Benefit Analysis

- **Part-2: investigation of market reports**
  - Investigating which market reports should be obtained in 2019 to assess more reliable information about CO_2 capture and utilization
  - Aacquiring reports for state of the art on how to utilize CO_2 and methanol/formaldehyde process and market economics.

WP5: Business Case: Cost and Benefit Analysis

- **Part-3: selection of suitable feasibility analysis method**
  - GSC system process economics plus CO_2 capture benefits will be compared with the ORC system process economics
  - For GSR, HAYAT will come up with a financial model to assess a 100k TPY methanol production facility investment
  - HAYAT will consider the output methanol with 2019 market value and try to put a value on the feed stream of CO_2 + H_2 by deducting all Capex and Opex costs from cash flow out of methanol sales. In this way, HAYAT will be able to compare the cost of H_2 with that of coming from traditional hydrogen techniques like steam reforming.

Reach out

- How does the project contribute to accelerating CCS by reach-out to industry, to decision makers, to the general public, to the scientific community?
  - Scientific publications in journals
  - Popular science publications in different channels
  - Linkedin
  - Twitter
  - Plan for Youtube (plan to be made)
  - Plan to run a mini-symposium workshop ideally with other ACT projects as a part of next GHGT conference in 2020
  - Creating brochures for policy makers at the end of the project

GaSTech - Demonstration of Gas Switching Technology for Accelerated Scale-up of Pressurized Chemical Looping Applications

GASTECH   Objectives   Partners

Introduction

Gas switching technology offers a promising alternative to chemical looping applications for highly efficient power or hydrogen production with integrated CO_2 capture. Highly efficient oxygen production for oxyfuel CO_2 capture is also possible. In order to maximize efficiency, these processes need to operate at elevated pressures, creating serious scale-up challenges for interconnected chemical looping reactors. Gas switching reactors, on the other hand, utilize simple standalone bubbling/turbulent fluidized beds that are alternatively fed with oxidizing and reducing gases. This simple reactor configuration can be scaled up and pressurized without facing unforeseen challenges

Collaboration within project

- How do you collaborate/communicate in your transnational project. What works well, what could be improved?
  - Monthly telecons
  - Workshops in each consortium meeting (every 6 months)
  - Bi lateral telecons between partners in each WP

Synergies with other project

- Are there any results? Should this be taken forward?
  - Plan to work with other ACT projects
  - Open to discuss with other project (face to face or through websinars)

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