Workshop on Operating Flexibility of Power Plants with CCS

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Analysis of flexibility options for electricity generating projects with pre-combustion capture of CO_2

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Introduction to Progressive Energy

- An energy project development company, formed in 1998
- Strengths include knowledge of UK energy scene
- Expertise in ‘clean’ fossil technologies, CO_2 capture & storage
- Co-developing an 850MW clean coal power station with pre-combustion CCS at Teesside
- A further gasification project is being developed in the NE
- Waste-to energy (or hydrogen) projects
- Biomass projects
- Involved in the EC ‘Dynamis’ Programme
- Energy consultancy

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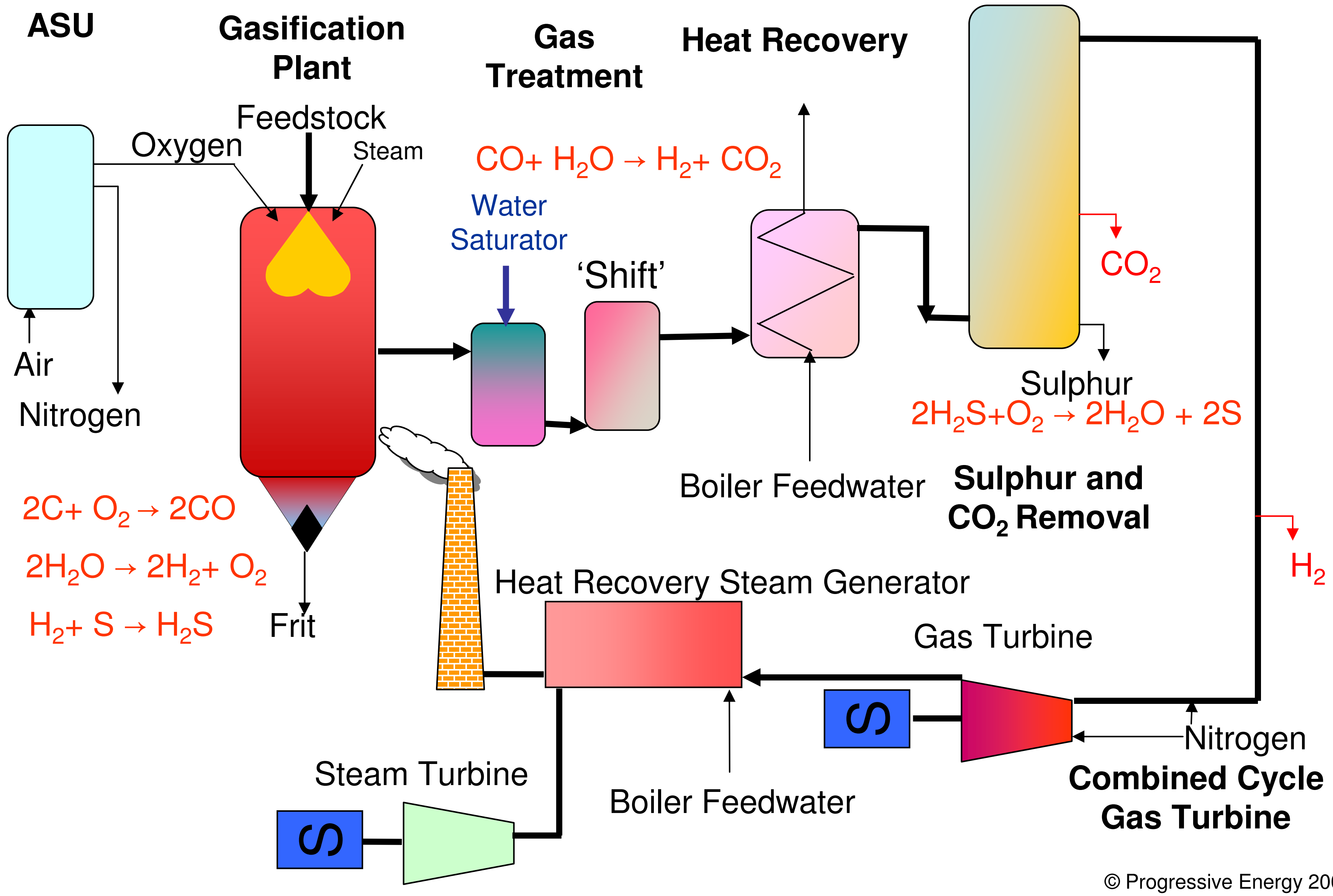
Pre-combustion CO_2 capture and storage

Pre-combustion capture of CO_2 requires processing the feed supply (coal, petcoke, natural gas) to remove the carbon (usually as CO_2) to leave a gas that is mostly hydrogen, which can be used to produce electricity by combustion (in a combined cycle gas turbine or conventional steam-generating boiler), or in fuel cells. The hydrogen can also be utilised in petrochemical and other processing industries.

Since this workshop is on the operating flexibility of power plants with CCS, the focus of this presentation will be on electricity generation, which implies an understanding of IGCC (Integrated Gasification Combined Cycle).



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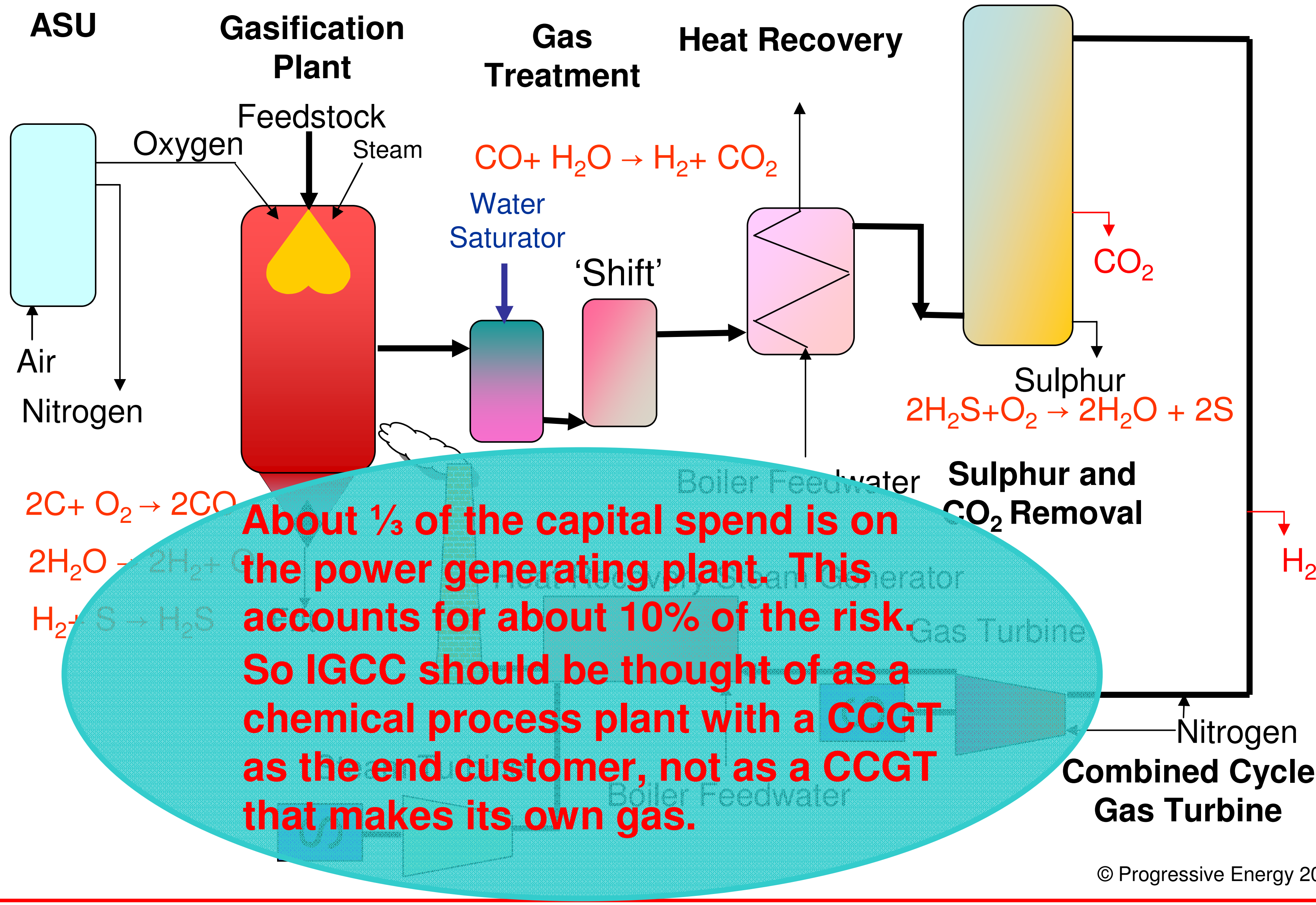
ASU
Gasification Plant
Gas Treatment
Heat Recovery
Feedstock
Oxygen
Steam
CO+ H2O → H2+ CO2
Water Saturator
'Shift'
CO2
Air
Nitrogen
Sulphur
2H2S+O2 → 2H2O + 2S
Sulphur and CO2 Removal
Boiler Feedwater
2C+ O2 → 2CO
2H2O → 2H2+ O2
H2+ S → H2S
H2
Heat Recovery Steam Generator
Gas Turbine
Nitrogen
Combined Cycle Gas Turbine
Boiler Feedwater
About ⅓ of the capital spend is on the power generating plant. This accounts for about 10% of the risk. So IGCC should be thought of as a chemical process plant with a CCGT as the end customer, not as a CCGT that makes its own gas.

Pre-combustion CO_2 capture and storage

Requirements for Power Generation

- Variable output to suit hourly grid demand
- Rapid start-up and shut-down, two-shifting
- Ability to accept wide range of fuels based on the lowest cost
- Most equipment is available as an “off-the shelf” design on a turnkey basis
- Frequent operational and other changes to improve efficiency, flexibility or reliability

Requirements for Process Engineering

- Steady-state operation over long periods of time
- Essential shut-downs only, eg for maintenance
- No changes once process conditions are established
- Most plants are ‘bespoke’ designs, optimised around local conditions
- “If it ain’t broke, don’t fix it”

Flexibility in pre-combustion CCS

Progressive Energy has been working with Sintef and E.ON on the EC Dynamis project. Dynamis responded to the EC target of "Preparing for large scale H_2 production from decarbonised fossil fuels including CO_2 geological storage". The main objective has been to prepare the ground for large-scale European facilities producing hydrogen and electricity from fossil fuels with CO_2 capture and geological storage.

An “Additional Project” was accepted to look at some of the more promising possibilities for operating an IGCC with increased flexibility by investigating the technical issues and evaluating the commercial opportunities.

Six flexibility possibilities were considered.

Flexibility in pre-combustion CCS

The six flexibility possibilities considered were:

1. Load following
2. Diurnal storage
3. ASU interruption
4. AGR/CO_2 turndown
5. Gas substitution
6. Co-production

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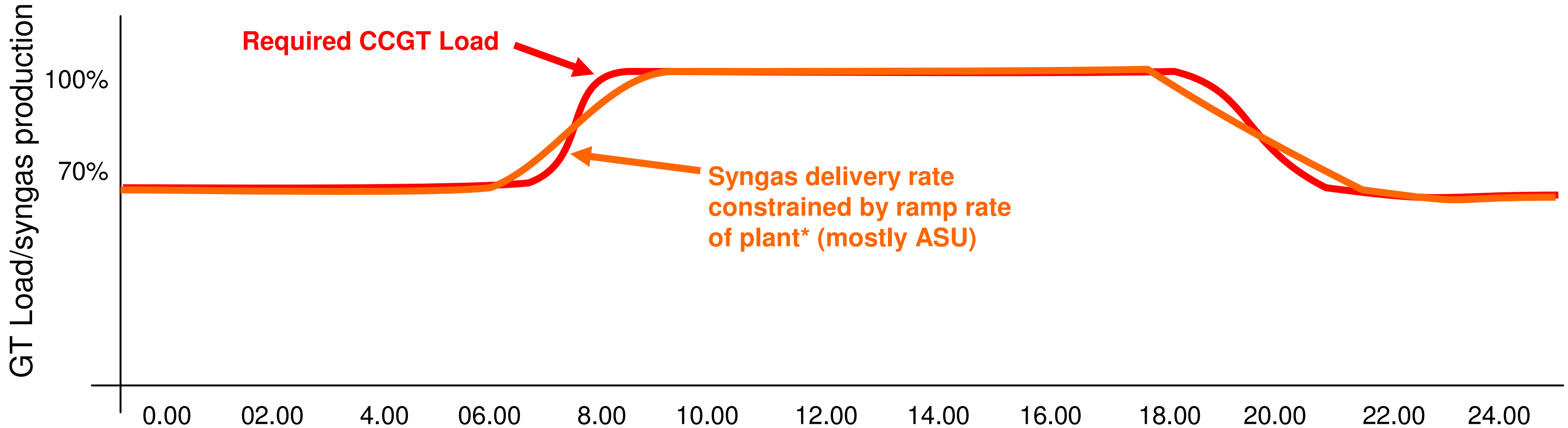
Flexibility in pre-combustion CCS

1. Technical possibilities

1. Load following

Reducing syngas production overnight (and load on the CCGT) and bringing it up to full load during times of high electricity prices.



- Allows the process plant to operate within stable limits permitting some flexibility from the power production plant
- Reduced use of capital invested
- Plant efficiency drops significantly during overnight periods
- **Can we do better than this?**

* NB. Ramp rates are illustrative only

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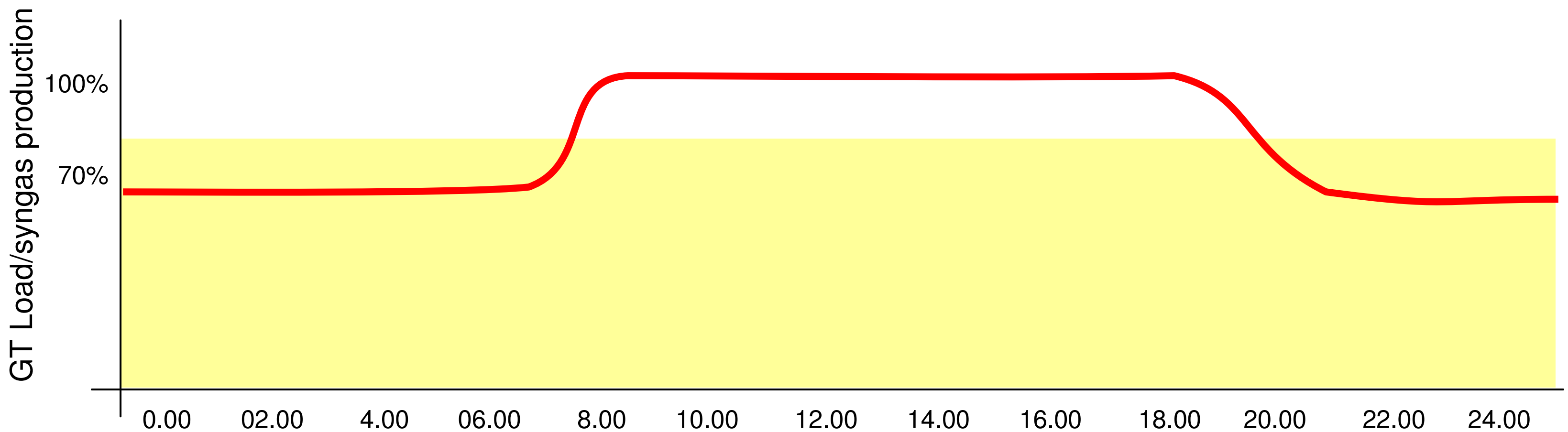
2. Diurnal Storage (1)

Storage of “decarbonised syngas” (eg overnight or at weekends), and subsequent use at times when spot electricity prices are high.



- Allows the process plant to operate “base load”, whilst permitting flexibility from the power production plant
- Possible capex savings, as process plant needs only to be sized for ≈ 80% full load
- Requires significant storage volumes

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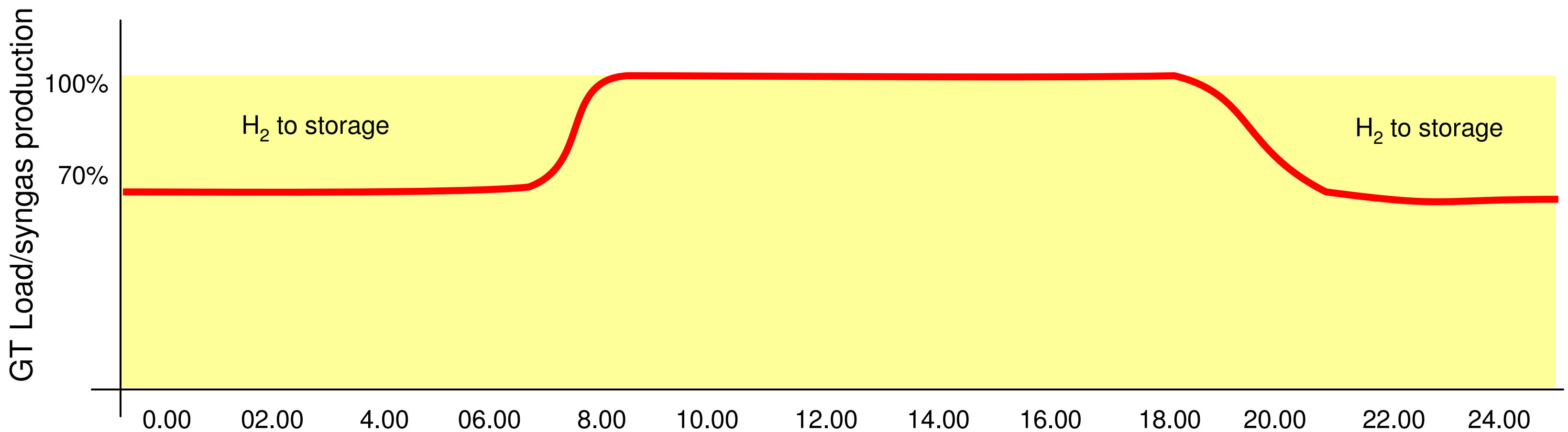
2. Diurnal Storage (2)

Storage of “decarbonised hydrogen gas” (eg overnight or at weekends), and sales to third party.



• Allows the process plant to operate “base load”, whilst permitting flexibility from the power production plant
• Requires significant storage volumes or introduction into NTS as Hythane®
• Requires PSA to separate out hydrogen from syngas
• Requires a customer for 55 tonnes/day of hydrogen

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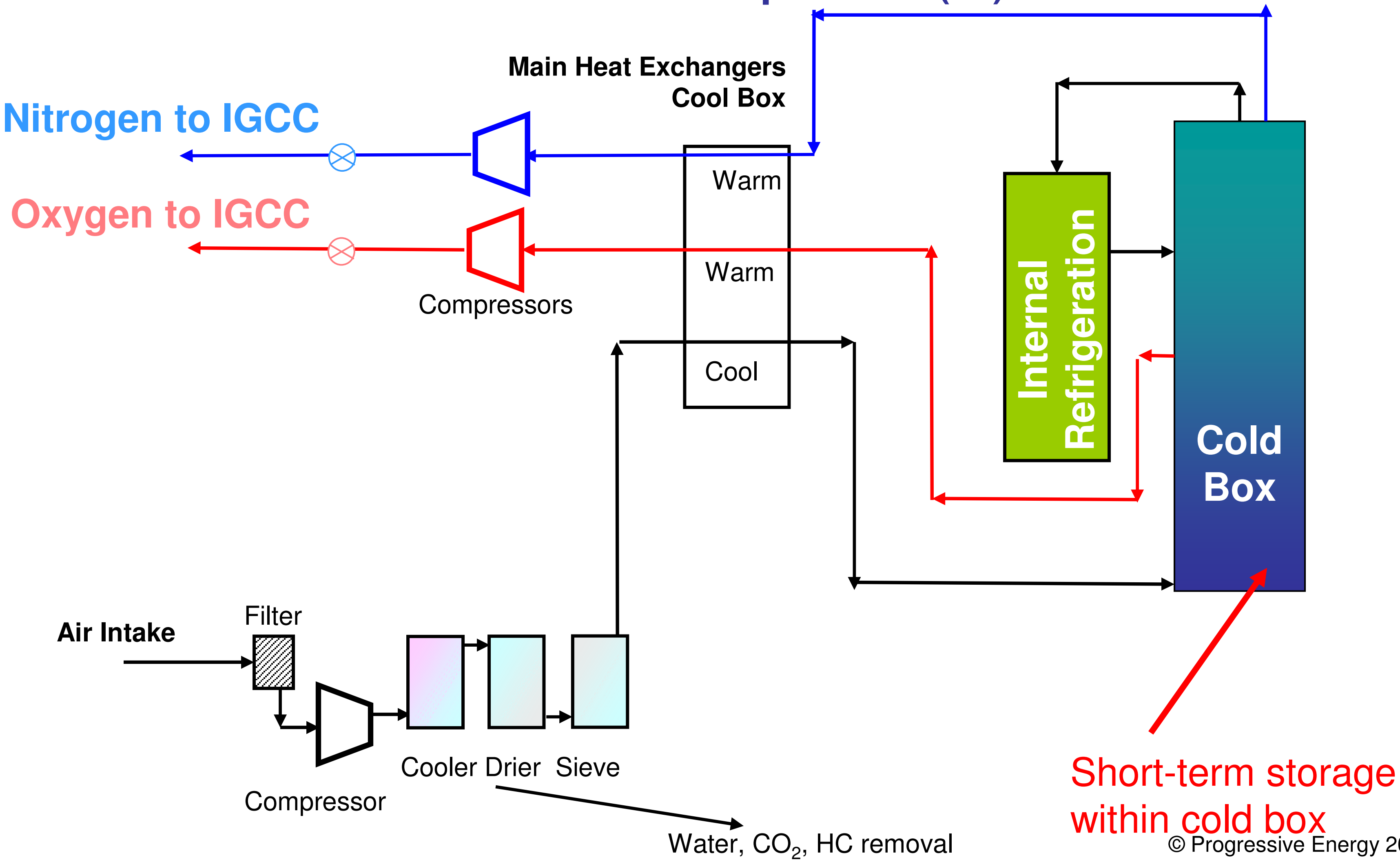
3. ASU Interruption (1)



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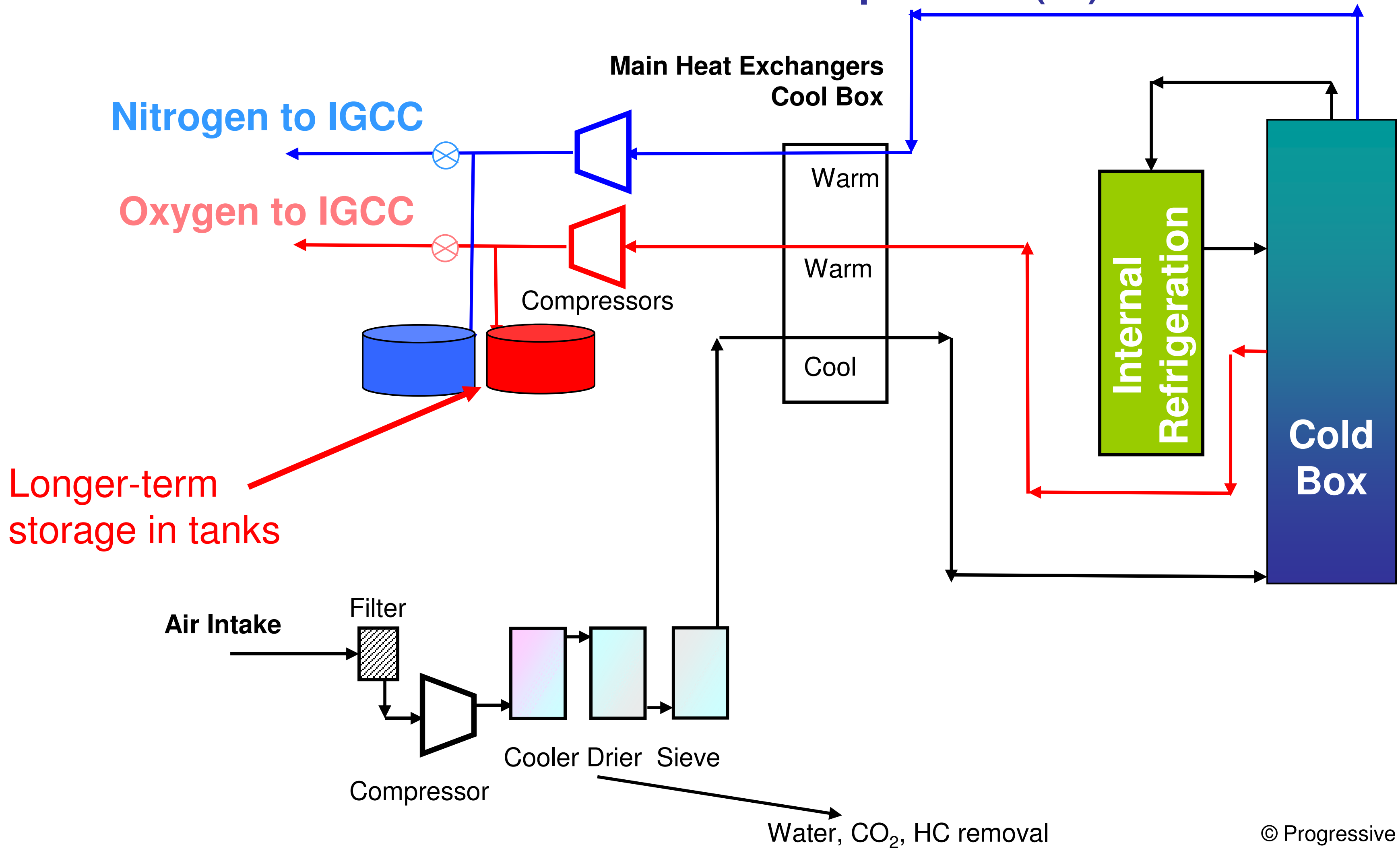
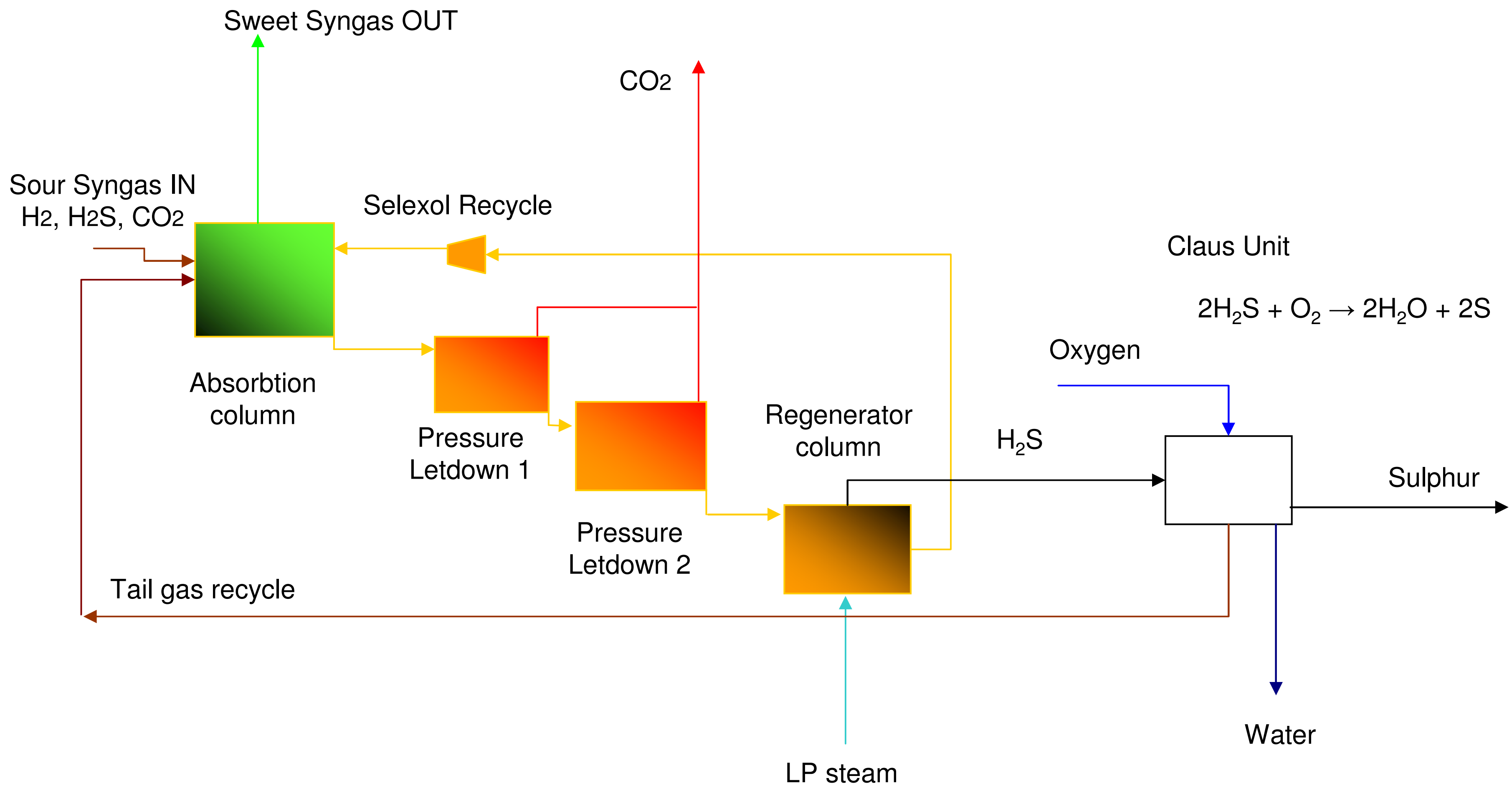
3. ASU Interruption (2)



3. ASU Interruption

- The ASU consumes about 12% of the power, thus tripping it can make this available for export
- The storage tanks could be re-filled overnight by running the ASU at base load and flexing the rest of the plant
- If liquid oxygen or nitrogen is stored in tanks, a gas burner will be needed after about 30 seconds to reheat it to gaseous form.
- Requires significant storage volumes
- Requires capex investment in storage tanks and burners

4. AGR/CO_2 Turndown



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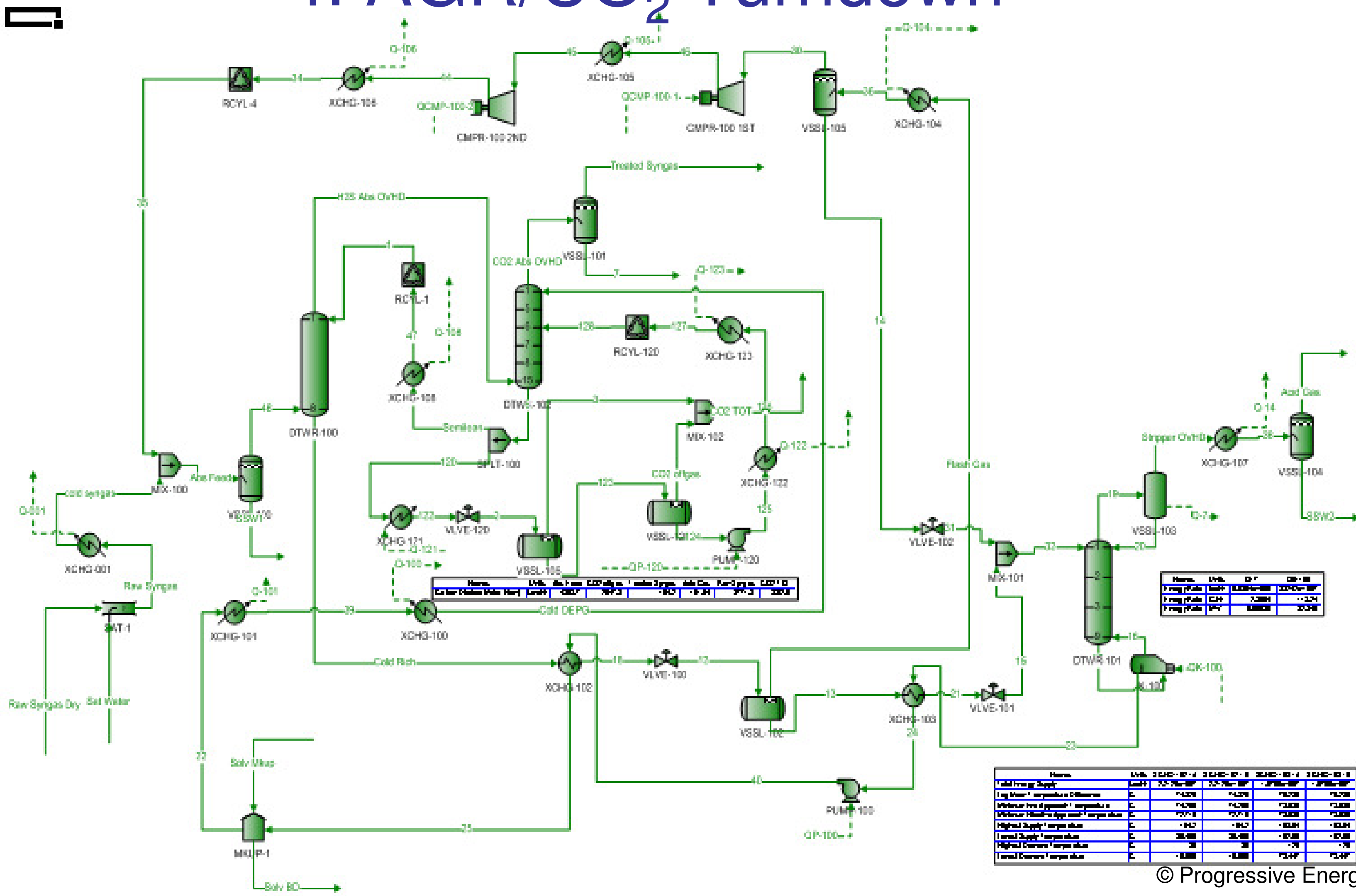
4. AGR/CO_2 Turndown



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4. AGR/CO_2 Turndown

Selexol H_2S and CO2 removal plant, Coffeyville, Kansas

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4. AGR/CO_2 Turndown

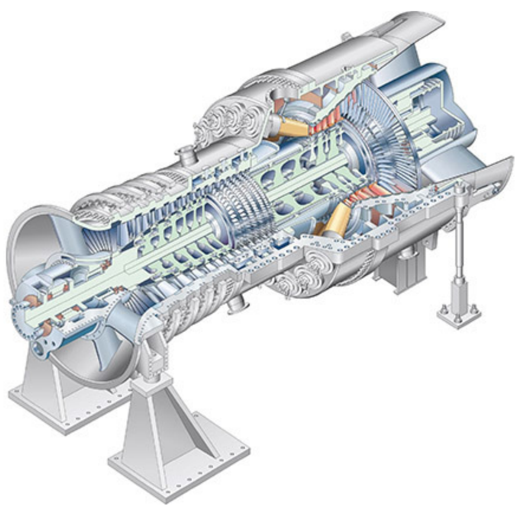
- By not separating out the CO_2 from the syngas, the load on the AGR plant could be reduced.
- The AGR plant could not be shut down completely, as it is needed to remove H_2S from the fuel gas stream
- The CO_2 would be emitted up the CCGT stack (as it would be for a non-CCS IGCC plant)
- Nitrogen diluent would not be required for the gas turbine: tripping the N_2 compressor could release 5% of the CCGT power. The AGR consumes about 3.4% of the CCGT power, and the CO_2 compressor about 4.9% thus not removing the CO_2 can make some of this (about 6.5%) available for export. Total power released about 11.5% of CCGT power.
- The AGR plant will take a while to stabilise. Fuel gas quality will suffer whilst this takes place.
- Emitting the CO_2 will attract financial penalties (€/tonne)
- If the CO_2 is used for EOR applications, there may also be penalties for failure-to supply

5. Gas Substitution

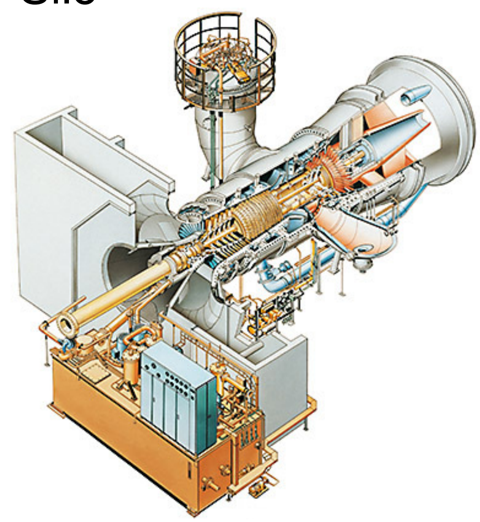
Substituting all of some of the syngas to the gas turbine with natural gas.

There are two types of combustor suitable for burning high hydrogen syngas:

Can-annular



Silo



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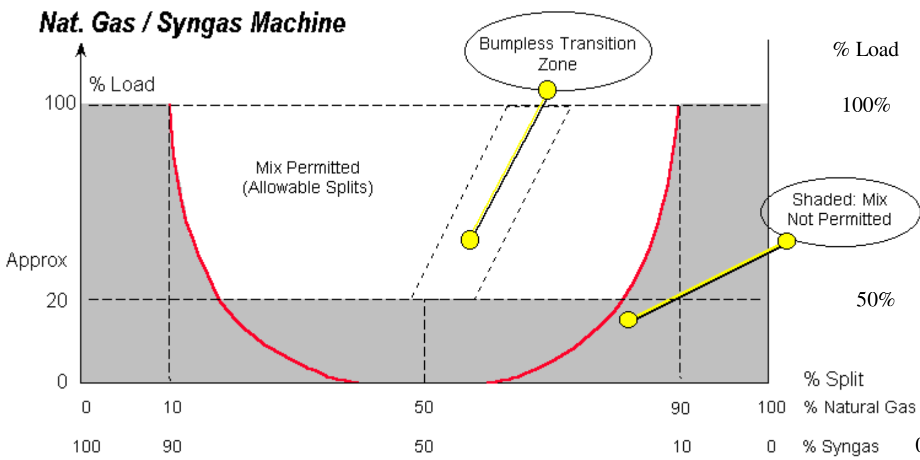
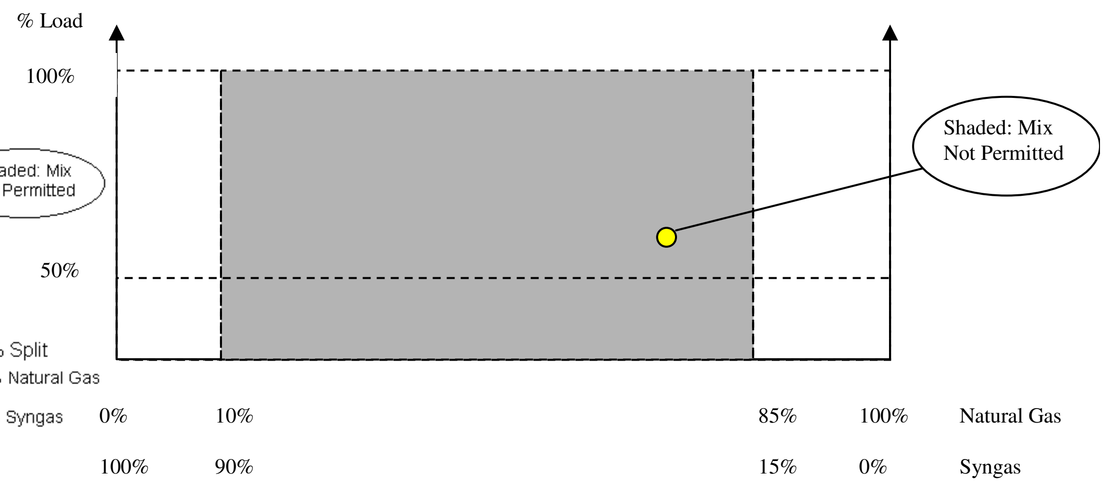
5. Gas Substitution

The two types of combustor have different mixed fuel capabilities:

Can-annular



Silo



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5. Gas Substitution

- Natural gas is necessary to start up the gas turbine, so there will be some compatibility in any case.
- In the event that there were to be a partial plant trip (eg gasifier trip) the energy supply to the gas turbine could be made up by burning natural gas.
- Burning natural gas may require for steam to be injected into the combustor to cool the flame: this robs power from the steam cycle and leads to reduced gas turbine blade life
- The CO_2 from the combustion of natural gas would be emitted up the CCGT stack (as it would be for a non-CCS CCGT plant) attracting financial penalties (€/tonne)
- Syngas is lower in cost than natural gas (p/GJ), so the power price will be higher

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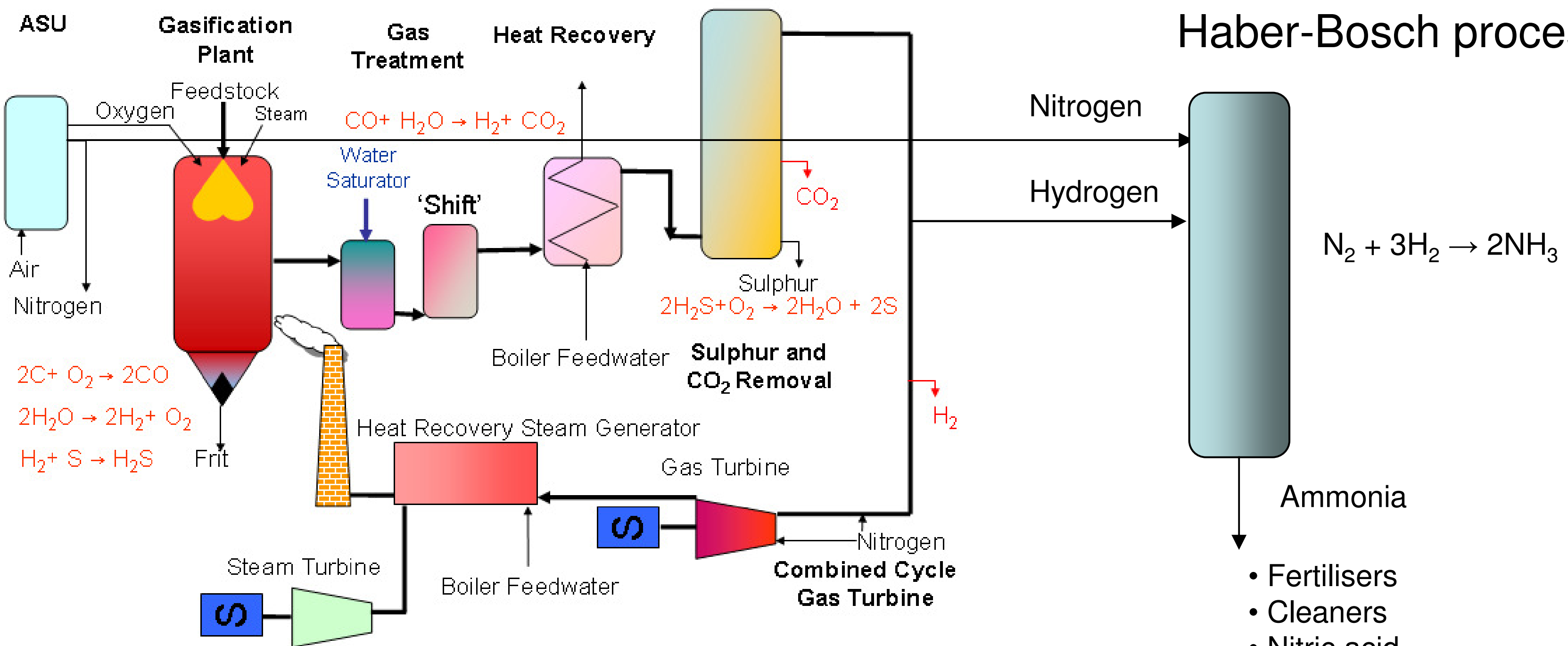
6. Additional Products (Polygeneration)

A) Ammonia.



- Fertilisers
- Cleaners
- Nitric acid
- Refrigerants (R717)

6. Additional Products (Polygeneration)

A) Ammonia.

- Worldwide production (2006) is 146.5 million tonnes, so there is a significant demand.
- The Haber Bosch process is a batch operation, so is suitable for “peak lopping”.
- The H-B process takes place at ≈ 150 bar, thus the gases would need additional compression (and/or very high pressure gasification).
- Additional gas purification stages would need to be added to the N2 and H2 streams (eg to wash out trace amounts of H_2S and CO_2) to <5ppm).
- Ammonia storage is needed under pressure (up to 1500 tonnes at ambient temperature, above this at -33˚C)
- The utilisation of the capex for the H-B process is only about 35% of the time
- Market competition is with ammonia plants operating round-the-clock

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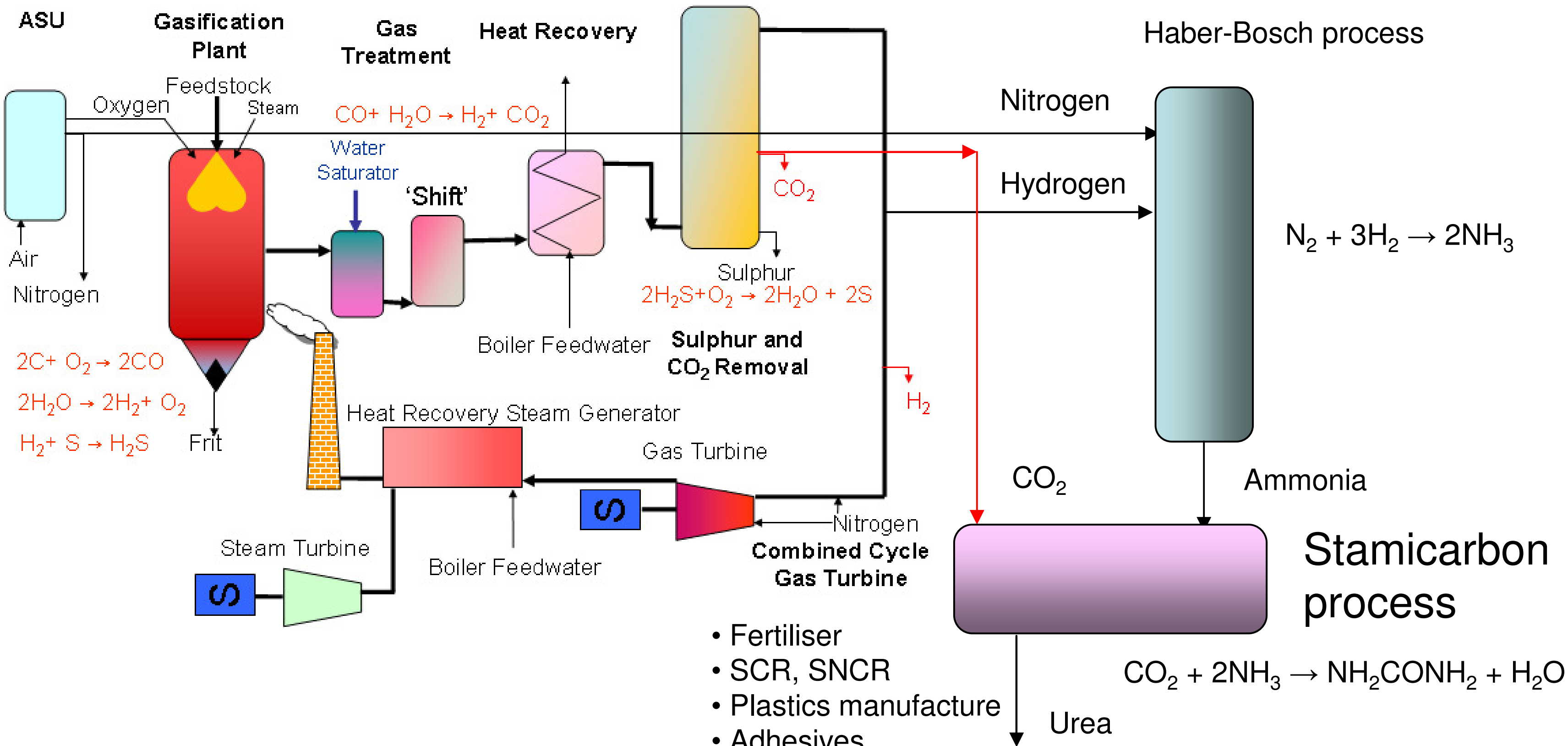
6. Additional Products (Polygeneration)

B) Urea.



$N_2 + 3H_2 \rightarrow 2NH_3$

$CO_2 + 2NH_3 \rightarrow NH_2CONH_2 + H_2O$

- Fertiliser
- SCR, SNCR
- Plastics manufacture
- Adhesives
- Explosives

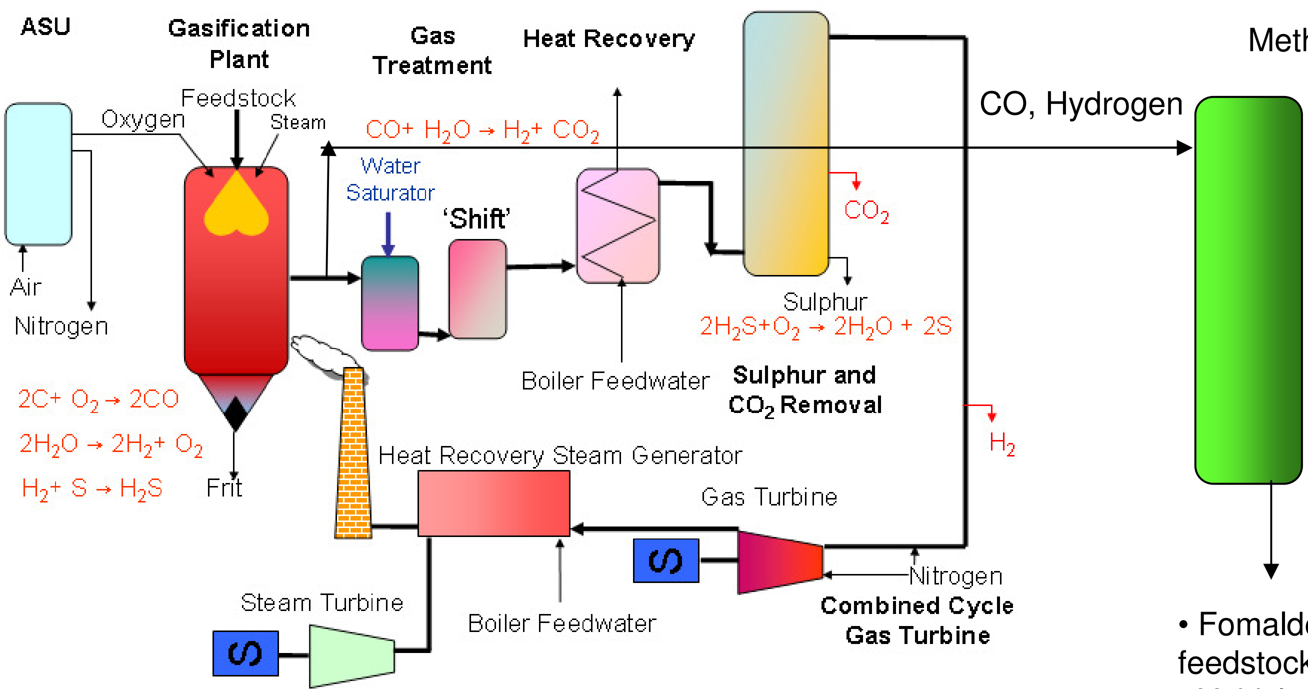
6. Additional Products (Polygeneration)

B) Urea.

• Provides a beneficial use for some of the CO_2 from the plant.
• Potential for beneficial heat integration with the IGCC and H-B plants
• The Stamicarbon process takes place at ≈ 150 bar, thus the CO_2 gas would need additional compression.
• All of the disadvantages from the production of ammonia would apply.
• Significant capital investment in additional process plant would be required
• The utilisation of the capex for the Stamicarbon process is only about 35% of the time
• Market competition is with urea plants operating round-the-clock

6. Additional Products (Polygeneration)

C) Methanol.



$CO + 2H_2 \rightarrow CH_3OH$

$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$

- Fomaldehyde (plastics feedstock, paints etc)
- Vehicle fuel
- Methylated Spirit
- Antifreeze
- Fuel cells

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6. Additional Products (Polygeneration)

C) Methanol.

- Utilises carbon from the syngas.
- The methanation process takes place at 50-100 bar for low-efficiency processes, 100-300bar for high efficiency processes, thus the gases would need additional compression (and/or very high pressure gasification).
- The raw syngas will need downstream processing (COS hydrolysis reactor, sulphur removal to ≈ 0.1 ppmv)
- Balance of gases ex-gasifier is not suitable for full conversion 50% max), thus a use for the mix of unused gases needs to be found (if in the gas turbine, combustion issues will arise). Will influence choice of gasifier, making it sub-optimal for power production with CCS.
- Ammonia storage is needed under pressure (up to 1500 tonnes at ambient temperature, above this at -33˚C)
- Significant capital investment in additional process plant would be required
- The utilisation of the capex for the process is only about 35% of the time
- Market competition is with methanol plants operating round-the-clock

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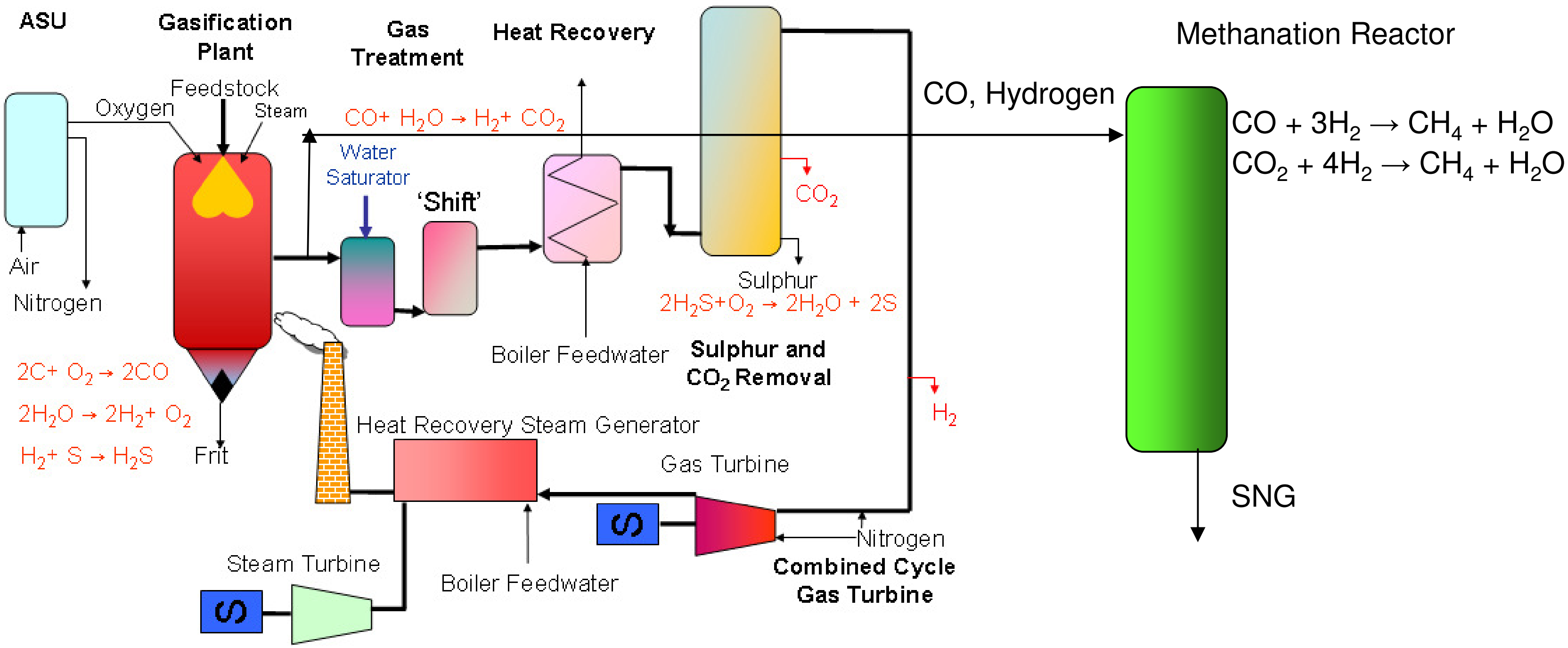
6. Additional Products (Polygeneration)

D) Synthetic Natural Gas (SNG)



6. Additional Products (Polygeneration)

D) Synthetic Natural Gas (SNG)

- Utilises carbon from the syngas.
- The methanation process takes place at 20-25 bar, so no additional syngas compression is needed.
- The raw syngas will need downstream processing (COS hydrolysis reactor, sulphur removal down to ≈0.5ppmv) to be compatible with NTS Standards.
- Balance of gases ex-gasifier is not suitable for full conversion, thus a use for the mix of unused gases needs to be found (if in the gas turbine, combustion issues will arise). Will influence choice of gasifier, making it sub-optimal for power production with CCS.
- A higher oxygen purity than 95% will be needed, so the ASU will need to be of a different design.
- Significant capital investment in additional process plant would be required.
- The utilisation of the capex for the process is only about 35% of the time
- Market competition is with natural gas.

Flexibility in pre-combustion CCS

2. Commercial Issues (1)

Flexing the plant operation

- In all cases some of the IGCC capital investment in under-utilised, and in many instances additional capital (eg PSA for H_2 production, Lox storage with evaporatore) is required
- Emissions of CO_2 can increase, requiring purchase of emissions credits

Polygeneration and hydrogen production

- In all cases for polygeneration, significant capital investment in additional process plant would be required, and the utilisation of the capex for the process is only about 35% of the time.
- In all cases there will be start-up/shut-down energy losses
- In all cases there is market competition with established industries operating continuously.
- There is increased risk associated with operating in multi-markets (eg power/chemicals)

Flexibility in pre-combustion CCS

2. Commercial Issues (2)

Conclusions of Dynamis analysis

• For the price assumptions made (eg coal, power purchase price, natural gas, ammonia, methanol), none of the polygeneration options, gas substitution nor AGR turndown represented attractive commercial propositions.

• ASU interruption and diurnal storage of syngas could be of marginal benefit.

• Given a fertile market for hydrogen, diurnal storage was a possibility worth further investigation.

Other commercial issues

• A different set of conclusions may be drawn for a different set of price assumptions.

• There are project-specific circumstances that may tilt the balance in favour of one or more of the flexibility options (eg. existence of adjacent long-term hydrogen demand).

Flexibility in pre-combustion CCS

Conclusions.

1. There are no technical or engineering reasons why IGCC plants could not provide some degree of operational flexibility.
2. The amount of flexibility possible is likely to be constrained by some items of plant.
3. Options such as diurnal storage may be more attractive where storage facilities are available (eg. salt caverns)
4. The commercial case for enhancing the plant to provide flexibility is less clear: it will depend on specific market conditions at the time.

However, it is possible to provide AFRO, by use of a concept patented by Progressive Energy.