# Production of Hydrogen from Natural Gas with Integrated $CO_2$-capture

## Fuel for a Thermal Power Plant

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# Objective of the present study:

**Suggest and describe how the "IFE" $CO_2$-removal process**

$$CaO\,(s) + CH_4\,(g) + 2H_2O\,(g) \rightarrow CaCO_3\,(s) + 4H_2\,(g)$$

**can be integrated in a hydrogen Combined Cycle Power Plant (CCPP) and a hydrogen steam boiler**

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- **Generate a $N_2$-diluted, $H_2$ fuel gas stream for gas turbines fuel ($H_2/N_2$-ratio: 50/50)**
- **Generate a $H_2$-rich fuel (+ 95%) for steam boilers**

# $H_2$-production in one single step

**Steam reforming:**

$$CH_4\,(g) + H_2O\,(g) \rightarrow CO\,(g) + 3H_2\,(g)$$

**Water gas shift:**

$$CO\,(g) + H_2O\,(g) \rightarrow CO_2 + H_2\,(g)$$

**Carbonation:**

$$CaO\,(s) + CO_2\,(g) \rightarrow CaCO_3\,(s)$$

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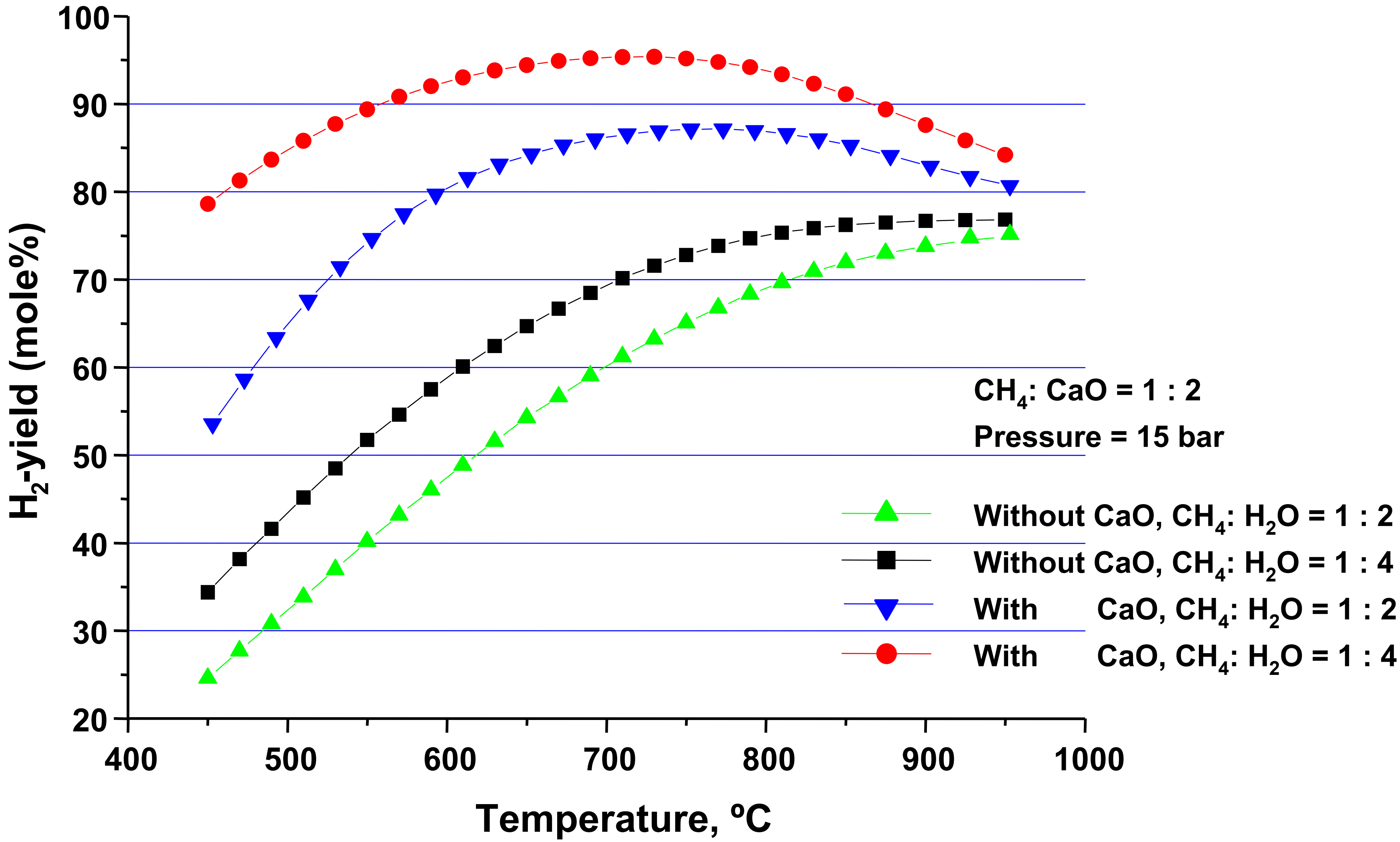
**Overall:**

$$CaO\,(s) + CH_4\,(g) + 2H_2O\,(g) \rightarrow CaCO_3\,(s) + 4H_2\,(g)$$

# Equilibrium hydrogen content

## – thermodynamic analysis



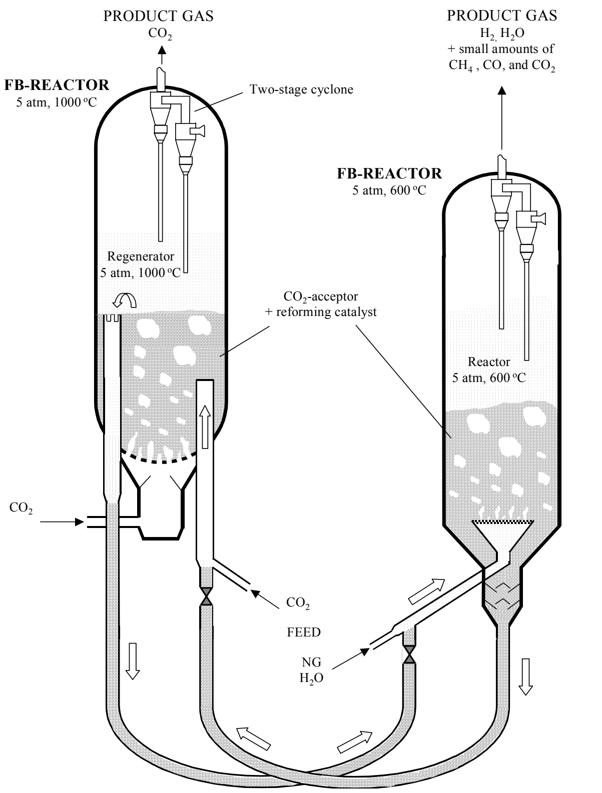
# Integrated reforming and $CO_2$ capture

## Advantages:

- **Process simplification**
  - **Reforming, water gas shift and $CO_2$-separation occur simultaneously in the same reactor**
- **Increased hydrogen yield**
  - **High $H_2$-yield at lower temperatures than in the conventional reforming process**
- **Separation of $CO_2$ as a solid in the process**
  - **No additional costly step for $CO_2$ separation**
  - **Delivered as a pressurised, concentrated $CO_2$ stream for sequestration or utilisation**
- **Recycled CaO represents an important carrier of heat into the reforming stage**

# Challenge: Reactor technology -

## Continuous process; circulation of solids




**Reforming:**

$H_2O : CH_4 = 3.5 / 2$

$CaO : CH_4 = 1.5$

T = 600°C

p = 5 bar

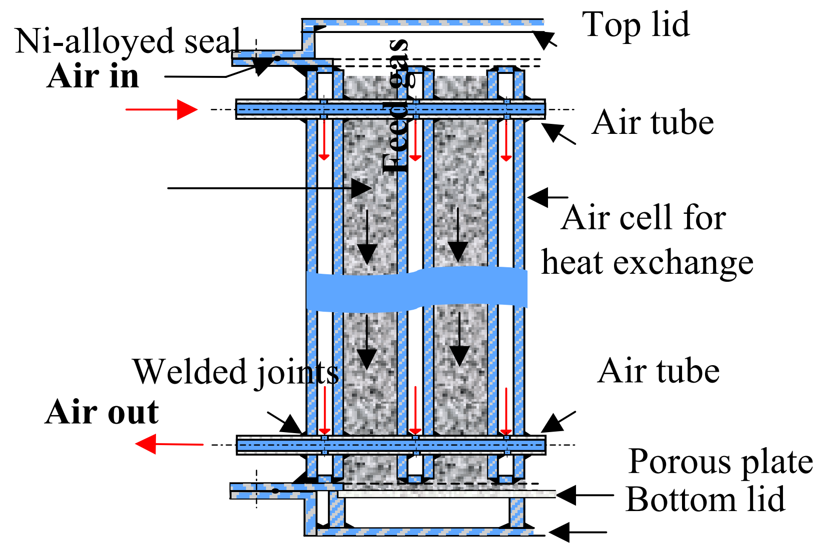
**Calcination:**

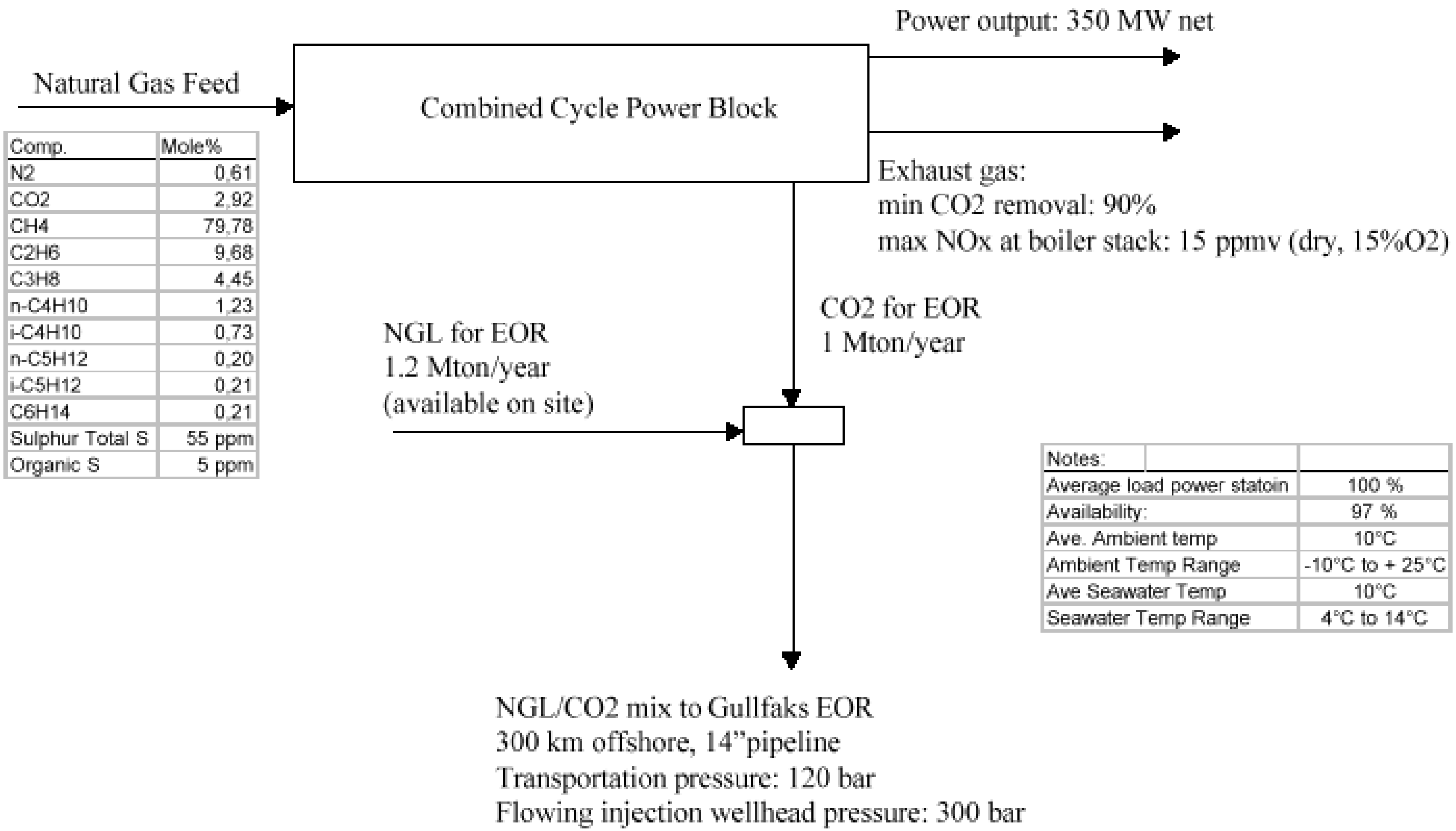
T = 1000°C

p = 5 bar

Atmosphere = $CO_2$

## Batch process; circulation of gases





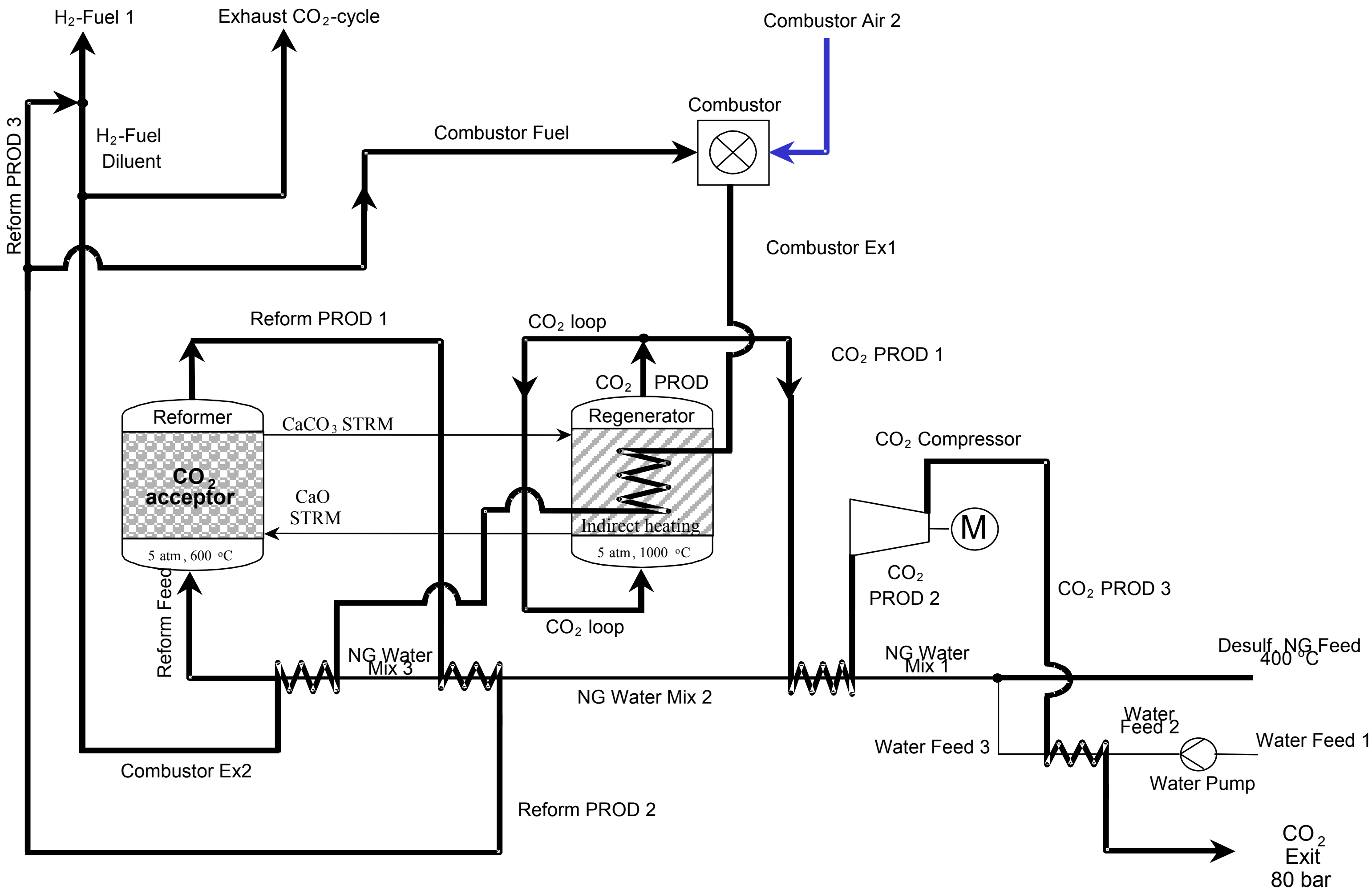

| Comp. | Mole% |
|---|---|
| N2 | 0,61 |
| CO2 | 2,92 |
| CH4 | 79,78 |
| C2H6 | 9,68 |
| C3H8 | 4,45 |
| n-C4H10 | 1,23 |
| i-C4H10 | 0,73 |
| n-C5H12 | 0,20 |
| i-C5H12 | 0,21 |
| C6H14 | 0,21 |
| Sulphur Total S | 55 ppm |
| Organic S | 5 ppm |

| Notes: | | |
|---|---|---|
| Average load power statoin | | 100 % |
| Availability: | | 97 % |
| Ave. Ambient temp | | 10°C |
| Ambient Temp Range | | -10°C to + 25°C |
| Ave Seawater Temp | | 10°C |
| Seawater Temp Range | | 4°C to 14°C |

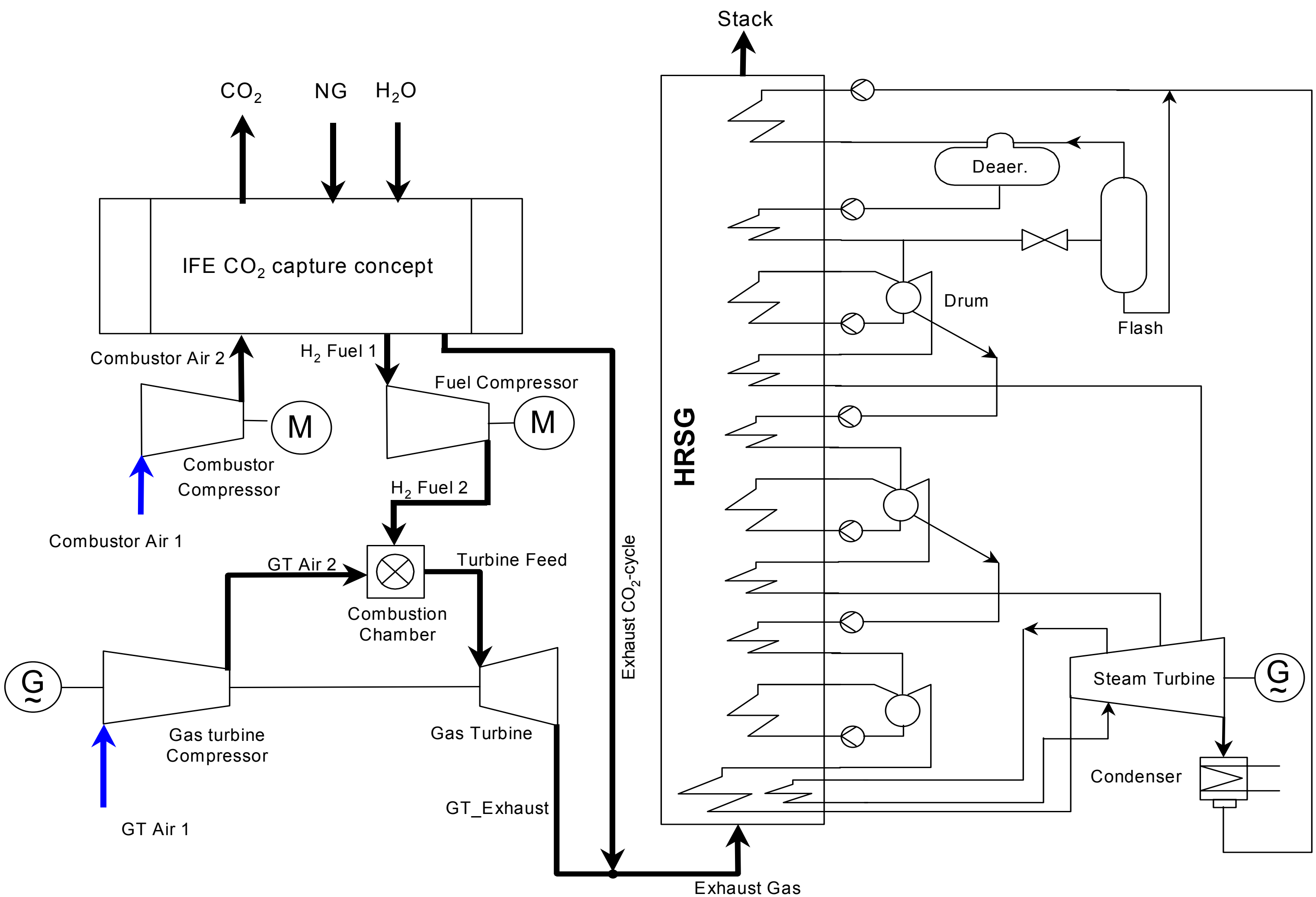
# Norwegian CO2 Capture and sequestration Scenario

STATOIL Rev. 1 January 24, 2001

# IFE $CO_2$-capture concept; CCPP-system

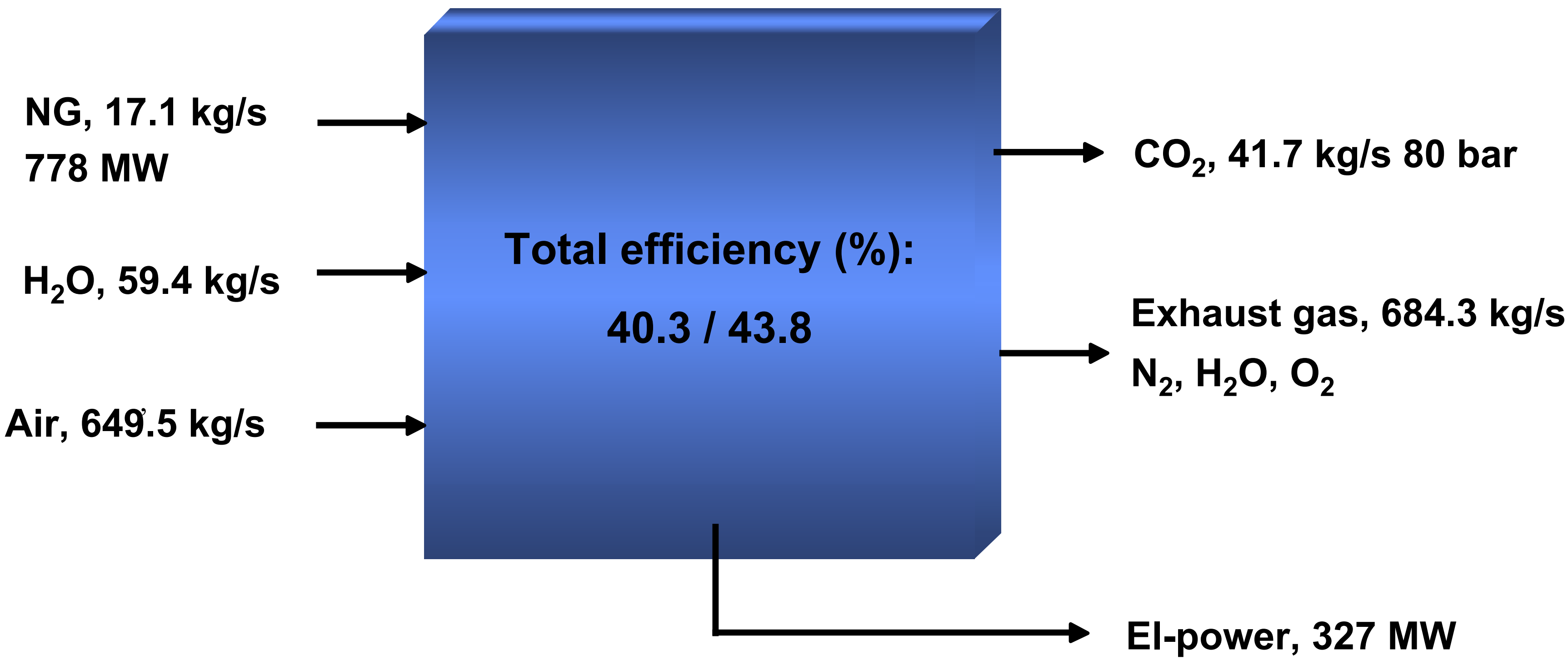


# Process flow diagram, CCPP-system

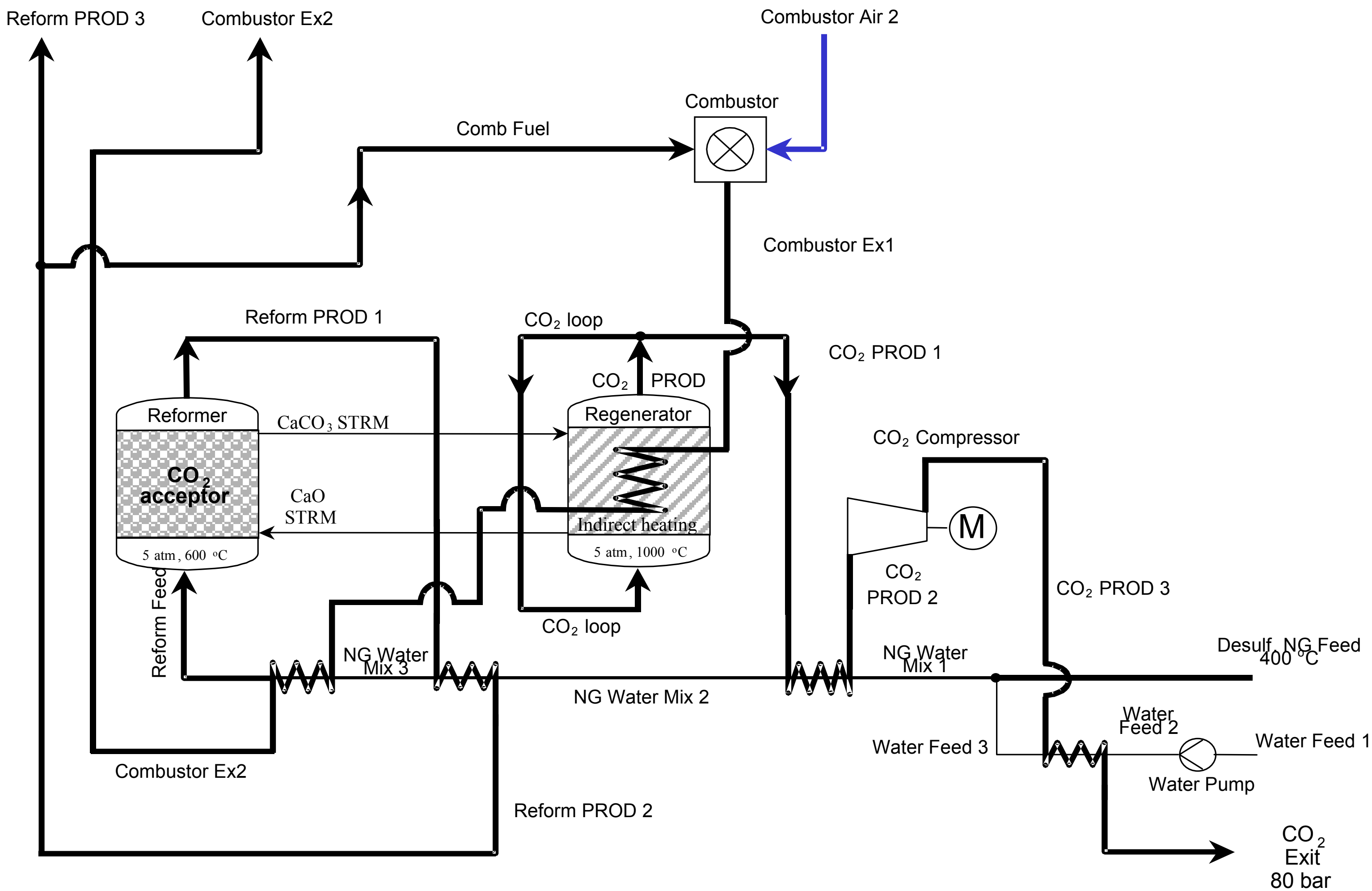


# Production and consumption figures,

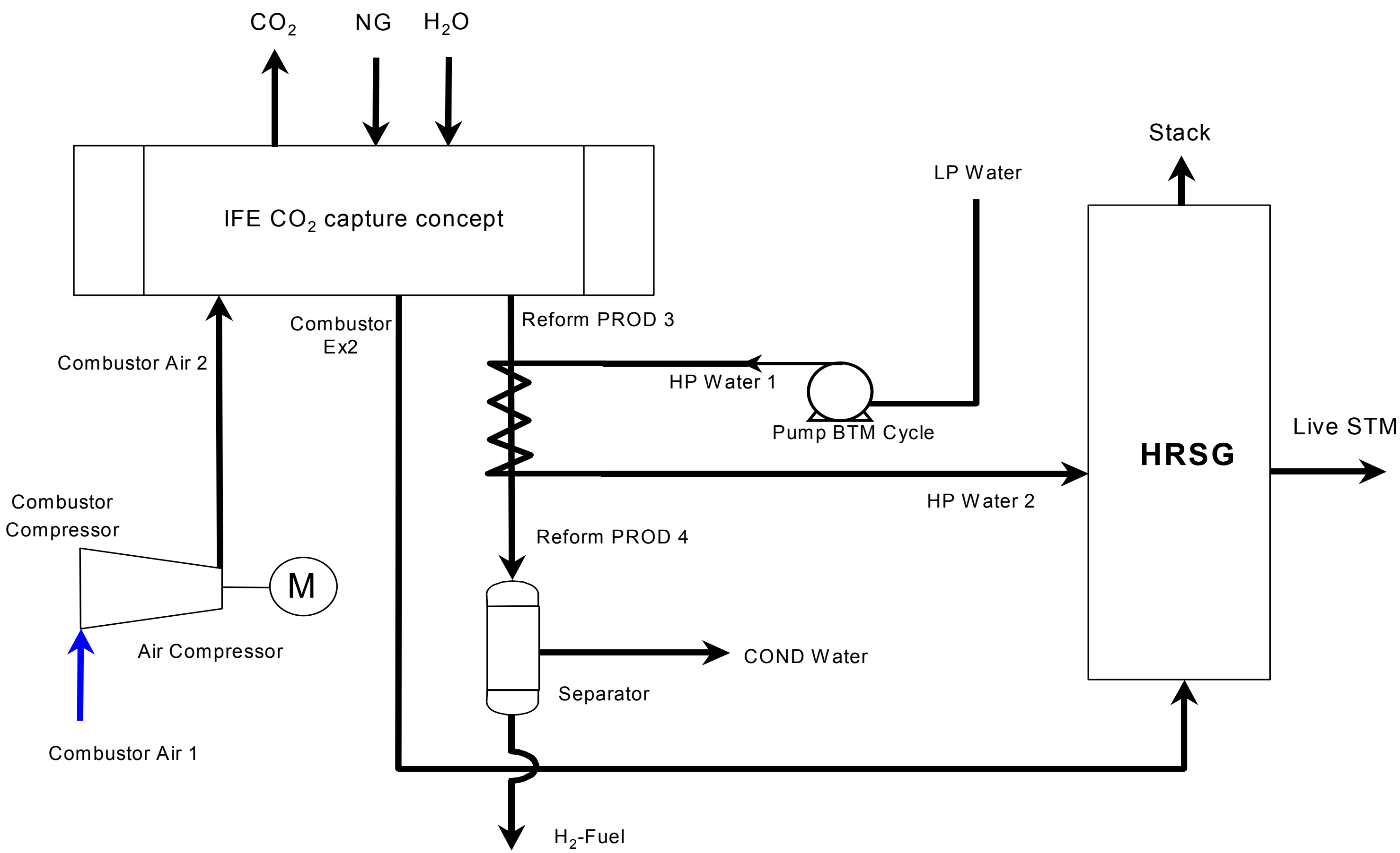
## $H_2$-production with integrated $CO_2$- capture and CCPP-system



# IFE $CO_2$-capture concept; steam boiler-system

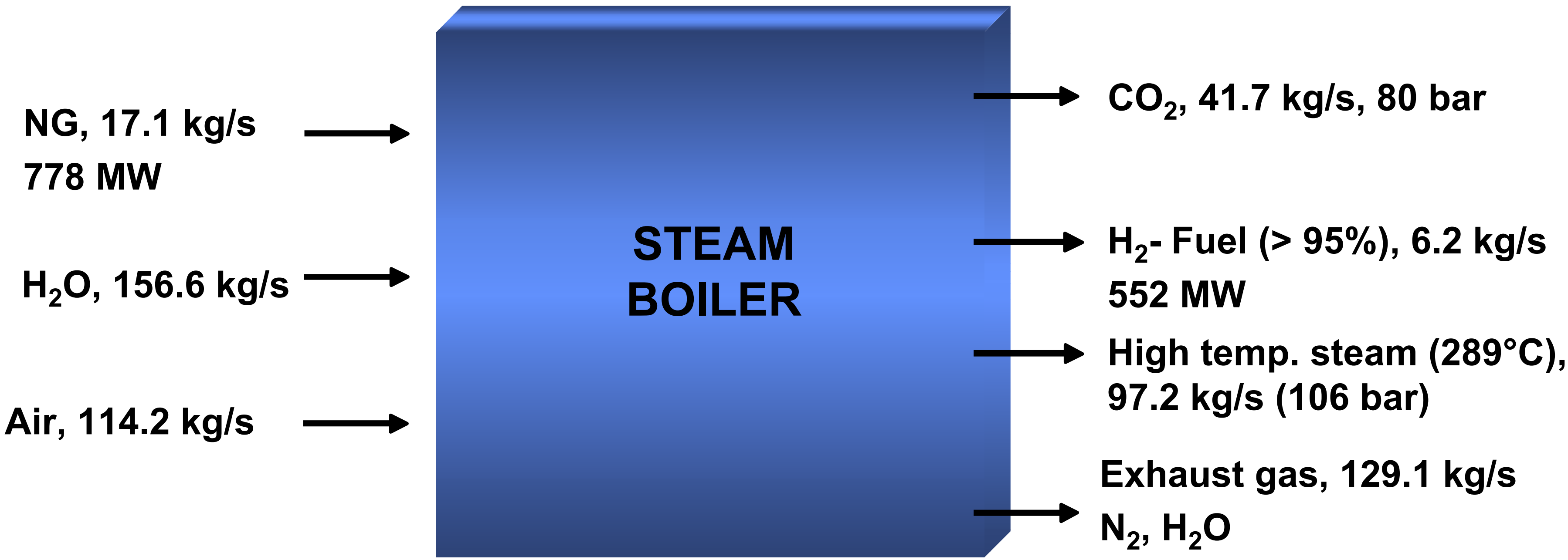


# Process flow diagram, steam boiler-system



# Production and consumption figures,

## $H_2$-production with integrated $CO_2$- capture and steam boiler



# Assumptions and simplifications

- Heat from the desulphuriser is used for production of a natural gas feed at 400˚C and 5.4 bar
- The conversion rate of hydrocarbons heavier than methane is 100 %
- The reformer conversion rate for methane is 93 %
- The $CO_2$-adsorption rate is 95 %
- The $CaCO_3$ conversion in the calcination reaction is 99 %
- A catalyst is not defined in the simulation - the catalyst is not circulating between the reactors and does not affect the heat balance of the system
- The combustion chambers of the regenerator are inside the reaction vessel for maximum heat transfer
- The adiabatic compressor efficiencies are assumed to be 85 %
- Heat loss to the environment from the $CO_2$ removal process reactors and pipes etc. is assumed to be 9.3 % of the heat transferred in the heat exchangers.
- The LHV efficiency of the CCPP is 58 %
- It is assumed that water vapour in the turbine fuel does not affect the firing properties of the combustion chamber. In stead of 50 % dry $N_2$ the simulations allows for steam in the inert fraction as long as 50 % $H_2$ is maintained.

# Summary

- 90% $CO_2$ removal is possible
- CCPP with electrical efficiency 58% (LHV) is reduced to 40 - 44%
  - IFE $CO_2$-capture concept is intended to operate at lower pressures, $H_2$-fuel has to be compressed
  - Need for sulphur removal
- Producing $H_2$ for a steam boiler, waste heat is also generated
  - Heat can be used for preheating the boiler