PRE-COMBUSTION CCS TECHNOLOGY – PROCESS DIAGRAM DESIGN

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CO-OPERATION IN RESEARCH AND DEVELOPMENT OF CARBON CAPTURE AND STORAGE TECHNOLOGIES
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INPUT REQUIREMENTS

- Location: **Prunerov II. Power Plant are (North-West Bohemia)**
- Design power output : => around **250 MWe**
- Fuel: **czech lignite – mine ČSA**
- Projected period of probable implementation : short time period (5 year) = > **focus on using of proven technologies** (gasification unit etc.)

Parameters	Unit	Fuel - raw
LHV - Q_i^r	MJ/kg	16.50
W_t^r	% wt.	**31.00**
A^d	% wt.	**13.00**
Volatile matter		
C^{daf}	% wt.	70.40
H^{daf}	% wt.	6.10
N^{daf}	% wt.	1.00
O^{daf}	% wt.	20.89
S^{daf}	% wt.	**1.61**

Parameter	Name	Temperature
DT	Deformation point	1 325 °C
ST	Softening point	1 425 °C
HT	Hemisphere temperature	1 525 °C
FT	Flow temperature	1 550 °C

INPUT REQUIREMENTS – CO2 Capture

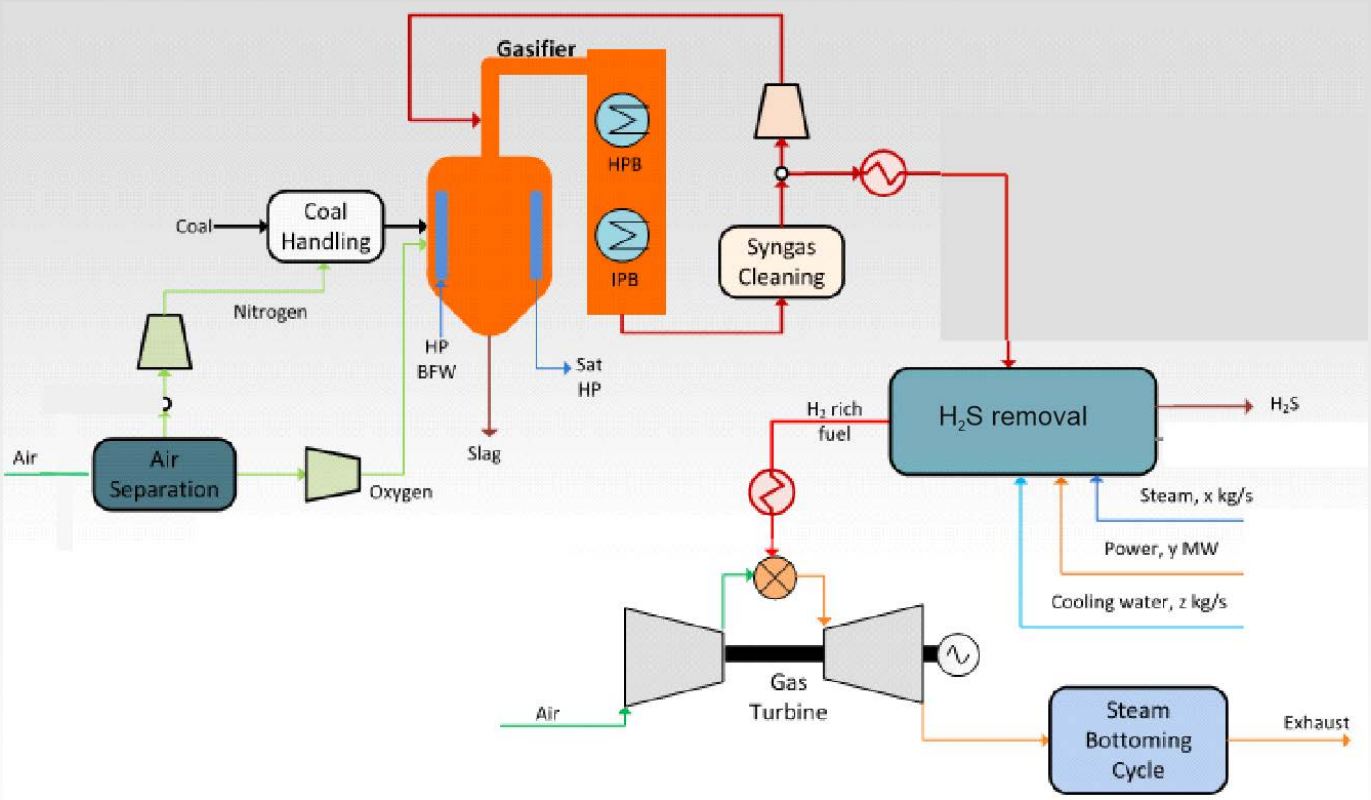
- Carbon Capture ratio (CCR)= 85%
- CO_2 transport mixture:

Parameter	Unit	Gas phase – pre-combustion	Liquid phase – FR-TI/379
CO_2	vol%	> 95	
H_2+Ar+O_2+N_2	vol%	<3	
H_2O	ppm	300	
CO	ppm	<2000	
H_2S	ppm	100	
temperature	°C	40/50	-50.3
pressure	MPa	11	0.65

- H_2 rich fuel: H_2 >80 vol%, H_2S < 30 ppm

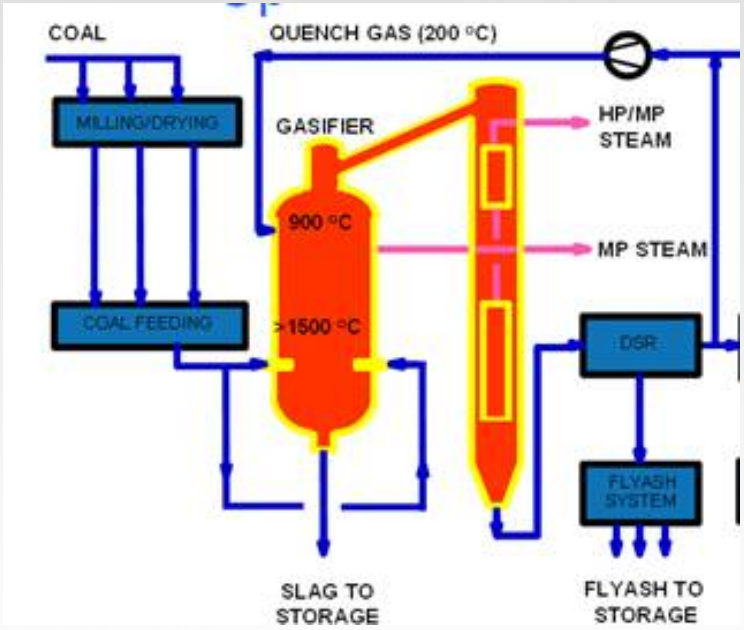
IGCC POWER PLANT – Basic FLOW DIAGRAM

- IGCC power plant without CCS is based on similar realizations in the world and according to the recommendations derived from the operation experience of IGCC Vresova power plant



GASIFICATION UNIT INCLUDING QUENCH

- Shell gasification unit
  - entrained flow single stage with membrane wall cooling by water/steam (LP steam) and gas quench after solids removal
  - syngas convective cooler is used – produced saturated HP (12 MPa) and IP (4.5 MPa) steam and reheated IP steam
  - gasifier design parameters:
    - pressure is 3 MPa
    - temperature is 1600°C
    - conversion efficiency 98.5 %
  - Oxygen
    - 95% purity
    - pressure 0.4 MPa above gas. press.
  - Steam (if needed)
    - 0.5 MPa above gasification (sat.)
  - Nitrogen
    - 99.9% purity
    - pressure 4.5 MPa gas. press.



Sources: http://www.nios.com.cn/c/index_en/cleancoal/jjmsub/3401.html

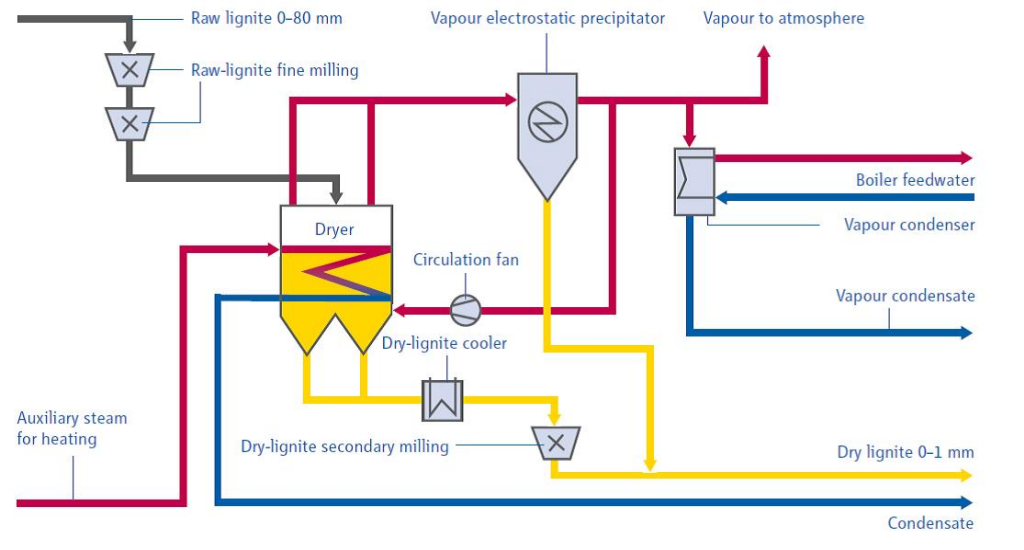
SYNGAS
- VRESOVA GAS. / SHELL GAS.

Parameter	Unit	Vresova gas. unit	Shell gas. unit
H_2	vol%	18.5 / 16	24.5
CO_2	vol%	2.5 / 13	5.5
CO	vol%	18.5 / 5.5	48.98
CH_4	vol%	0 / 4.5	0
H_2O	vol%	60 / 60	11.29

FUEL TREATMENT

- Granulometry for gasification unit >**200 μm**
- Water content for gasification unit is **11%**

- Fuel treatment – three steps
  1. Crushing coal – input 0–40 mm, output 0–2 mm (Roll crusher)
  2. Coal drying – input water content 31 %, output water content 11% (WTA dryer)
  3. Coal milling – input 0–2 mm, output below the 200 μm (Rod mill)



Sources: RWE

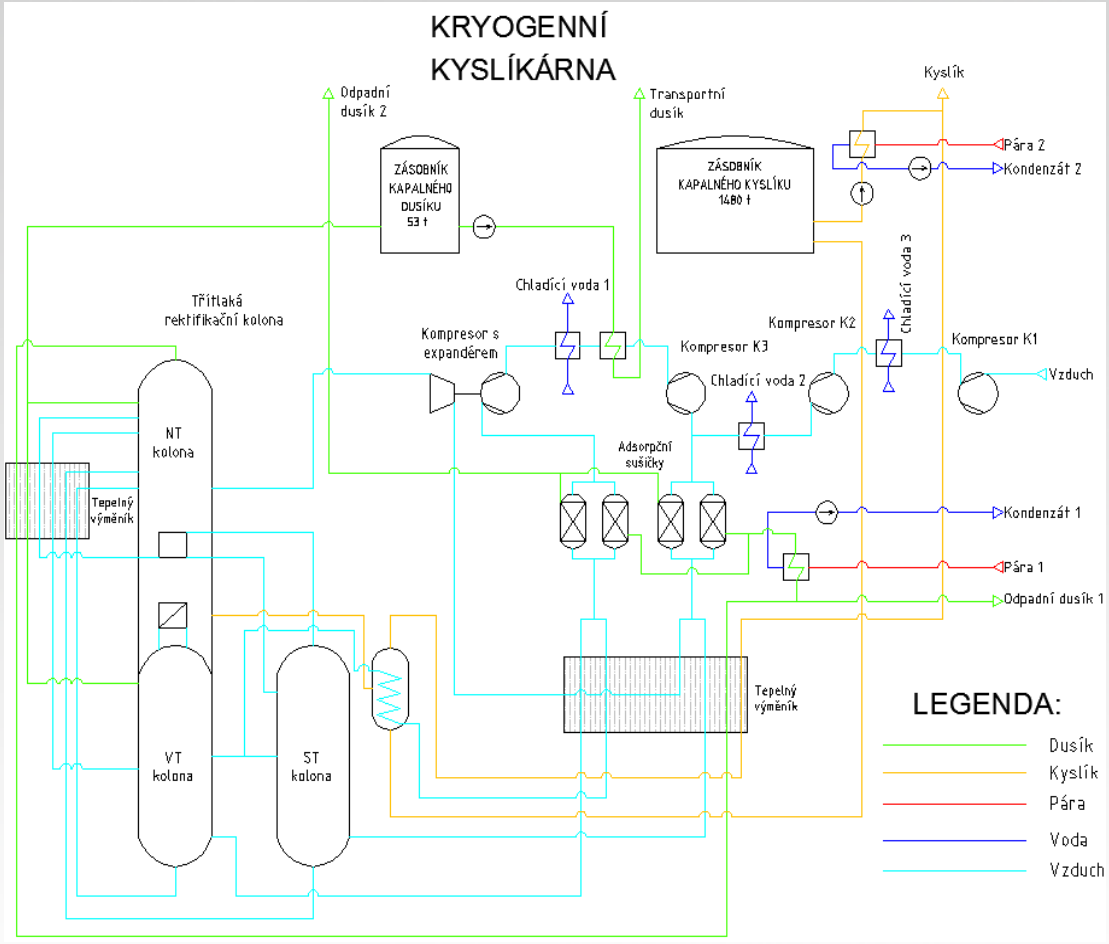
ASU UNIT

Cryogenic air distillation will be used for oxygen production.

Basic requirements of the technology for the media (O_2 and N_2) are:

- O_2 Purity:
- **<u>95 %</u>** (exit of ASU and input to gasifier)

- N_2 purity
- 99.9% for coal transport
- 99% for turbine dilution gas,



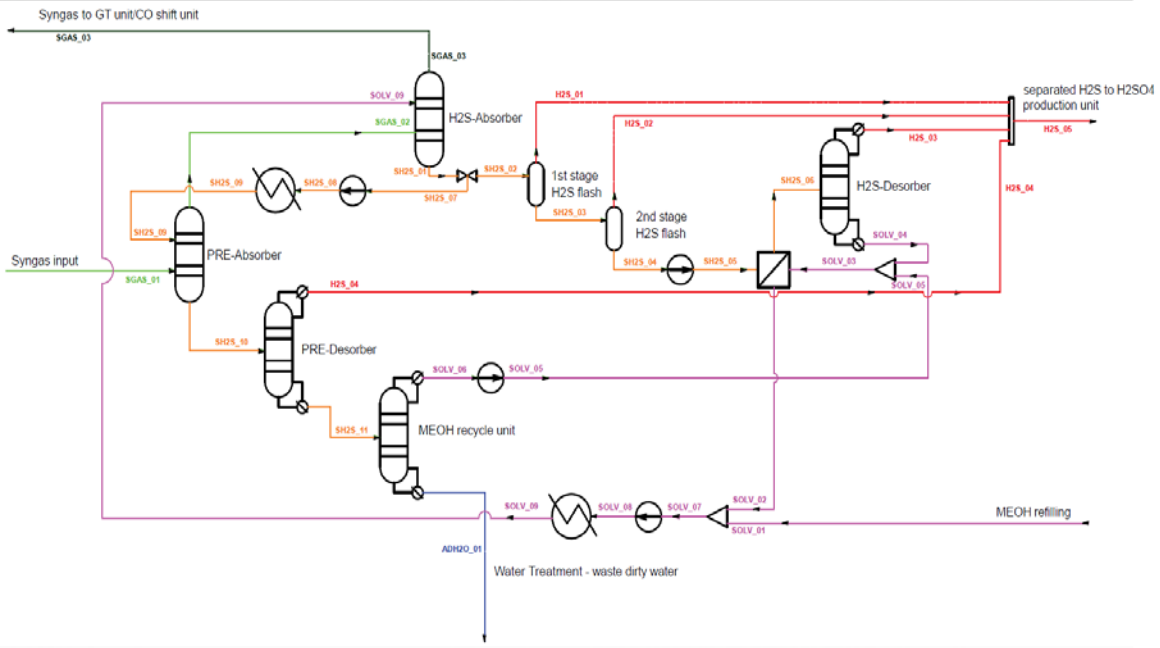
ASH and AGR units

AGR unit is designed by Rectisol process in accordance with reference unit from IGCC power plant Vresova. Flow and process diagram is inspired by real application in this power plant.

- Rectisol wash operational temperature is around **-20°C**
- Limit of H_2S in cleaned syngas is **5 mg/m³**
- Separated H_2S is then used for H_2SO_4 production in WSA unit.

Ash separator will be designed as a bank of ceramic filters

- Operational temperature 250°C
- Solid removal **< 5 mg/m³**



GAS TURBINE

- FUEL – syngas
- **SGT-2000E**
  - 187 MWe design output (new data for 2015)
  - 17 stage compressor
  - 8 hybrid burners (dry low NO_x)
  - IGCC design application

Source: Siemens

Turbine main parameters	current	by 2006/2011
ISO base power output (MW)	172	166-168
Heat rate (kJ/kWh)	10 190	10 375
Gross Efficiency (%)	35.3	34,7
Pressure Ratio	12,1	12
Exhaust Mass Flow (kg/s)	531	525
Turbine Speed (rpm)	3 000	3000
Exhaust Temperature (C°)	537	541
Firing temperature	*	1080 [13]
Gas Turbine Physical Dimensions		
Approx. Weight (ton)	216	234
Length (m)	14,0	10
Width (m)	12,5	12
Height (m)	8,5	7,5
Combined cycle 1x1 parameters		
Net Plant Power Output (MW)	253	250
Net Plant Efficiency (%)	52.5	52,4
Heat Rate (kj/kWh)	6,857	6,869
Gas Turbine Gross Power (MW)	168	-
Steam Turbine Gross Power (MW)	89	-
Impurities, contaminants, hydrogen fuel		
max ash content (w/o film cooling) (% / $g \cdot s^{-1}$)	0,05-0,1 / 6-12	
max H2S content (ppm)	10 000	
Allowable hydrogen content (%, diluted by N2)	35	
Allowable hydrogen content (%, diluted by steam)	50	
Allowable hydrogen content (%, max current plant)	31,3	
Fuel inlet temperature (°C, approx.)	150-300	

* since 2013 available TIT increase also for old models as upgrade, but temperature is not specified

Steam power plant

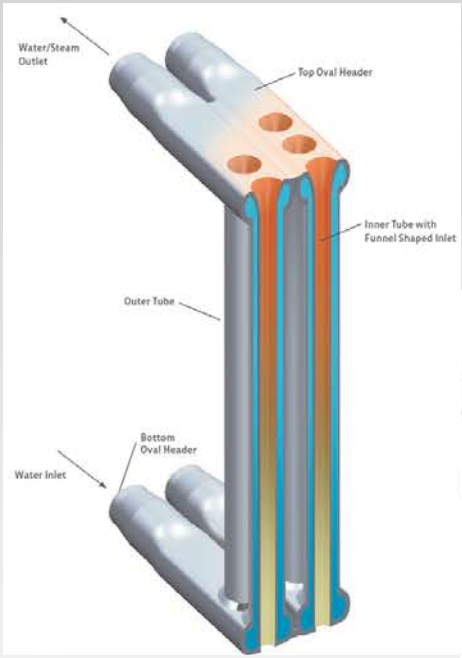
⇒ dual pressure simple steam cycle with reheating of IP steam power plant and steam extractions for
- feedwater tank (LP steam)
- WTA dryer (LP MPa steam)
- ASU unit (LP MPa steam)
- „WGS“ (IP MPa steam)

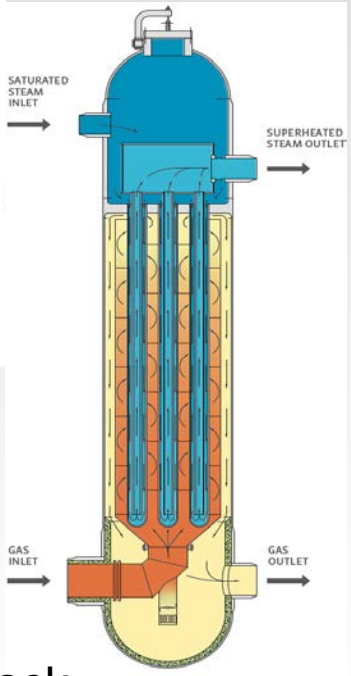
⇒ design steam parameters:
- HP steam (12.5 MPa/525 °C)
- IP steam (4 MPa/525 °C)
- LP steam (0.5 MPa)
- condensing pressure (4.3 kPa)

Waste Heat exchanger design

- **syngas cooling**
  (900 –> 400/250 °C, app. 120 MWt)
  - double-wall tubes cooler - SCHMIDTSCHE SCHACK
    - **saturated HP steam evaporator (max. 14 MPa)**
    - **saturated IP steam evaporator (4 MPa)**

- **WGS cooling**
  (450 -> 200 °C, app. 40 MWt)
  - helically wound tubes reheater / Schmidtsche schack design reheater
    - **IP steam reheater (4 MPa)**
    - **saturated IP steam evaporator and reheater (4 MPa)**





Source: Schmidtsche schack

IGCC with CCS technology (pre-combustion)

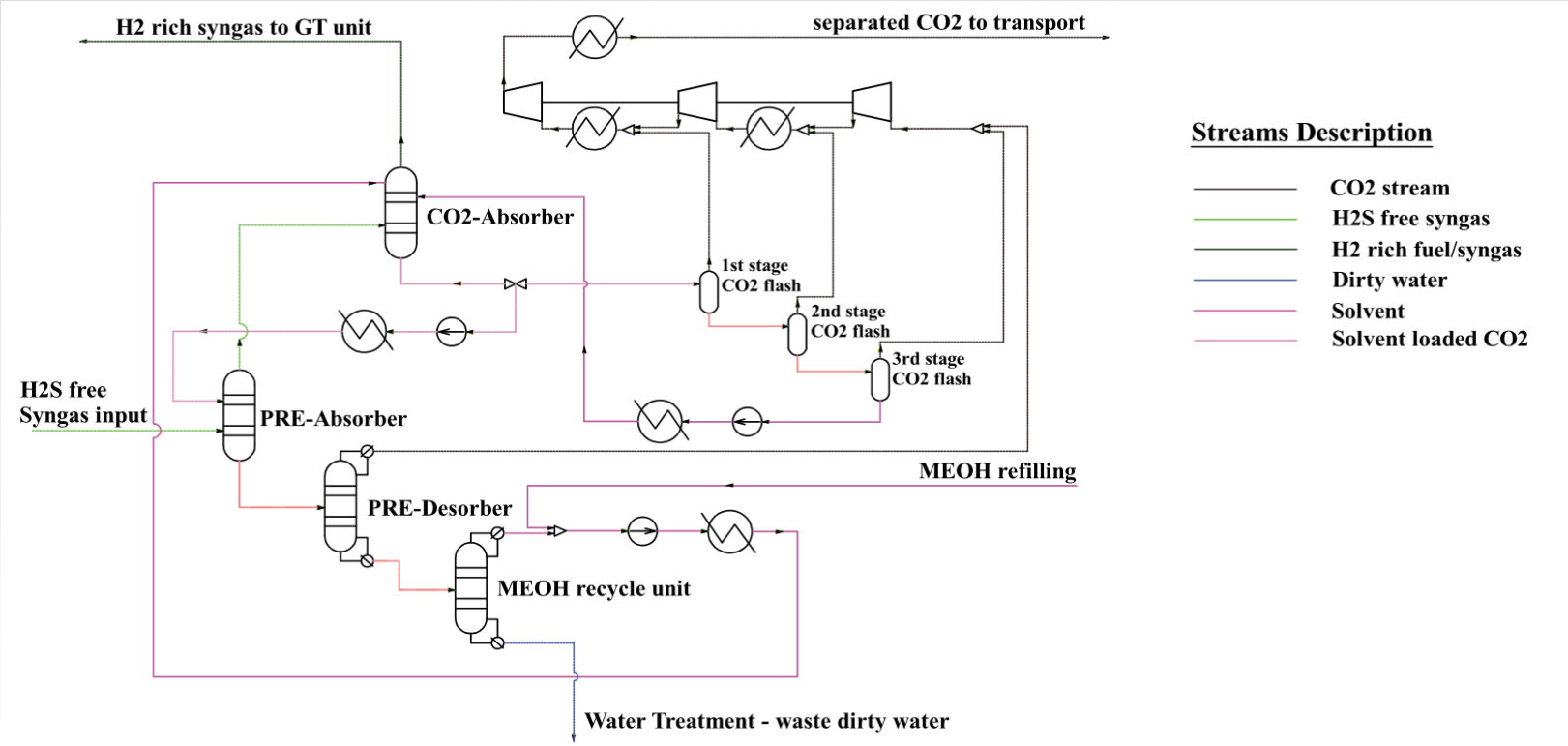
- Integration new systems/units:
  - CO_2 capture units
    - CO_2/H_2 membrane, Low-temperature, Rectisol wash
  - CO shift reactors (2 stage 300/500)
  - $DeNO_x$
- Modification/Upgrade systems
  - gas turbine
    - Air compressor update and nitrogen compressor integration
  - heat recovery system (HRSG, CO shift)
  - increase process steam consumptions

Unit	process steam	IGCC w/o CCS	IGCC w CCS
Fuel treatment	0.35 MPa/160 °C	9.67 kg/s	9.67 kg/s
AGR unit	0.35 MPa/160 °C	4.59 kg/s	-
AGR + CO2 capture unit	0.35 MPa/160 °C	-	**7.05 kg/s**
CO shift unit	3 MPa/370 °C	0	**36.42 kg/s**

Rectisol CO_2 capture

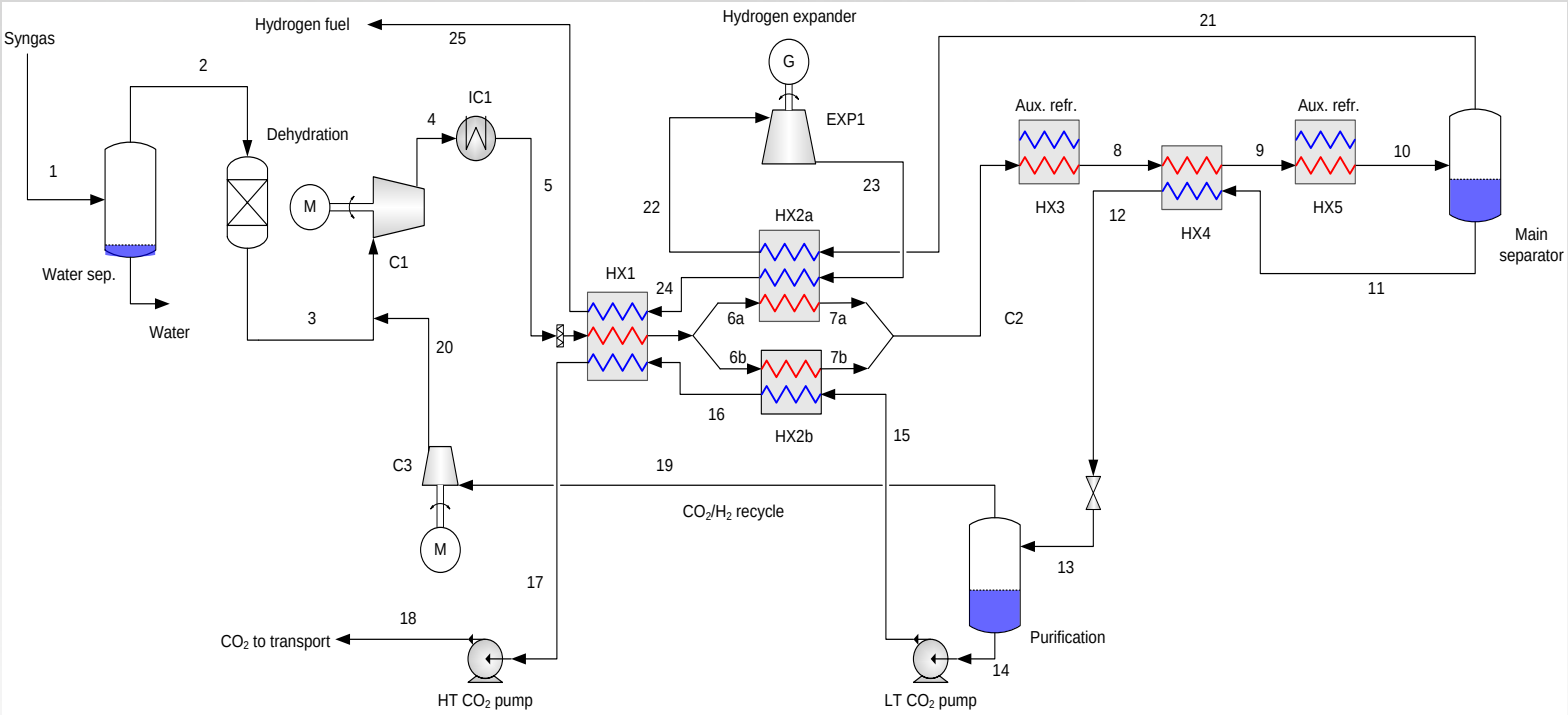
Process flow diagram of CO_2 capture based on Rectisol wash with design parameters - 85% CCR_T:

- pressure: 3.1 MPa
- temperature: - 20 °C



Low-temperature CO_2 capture

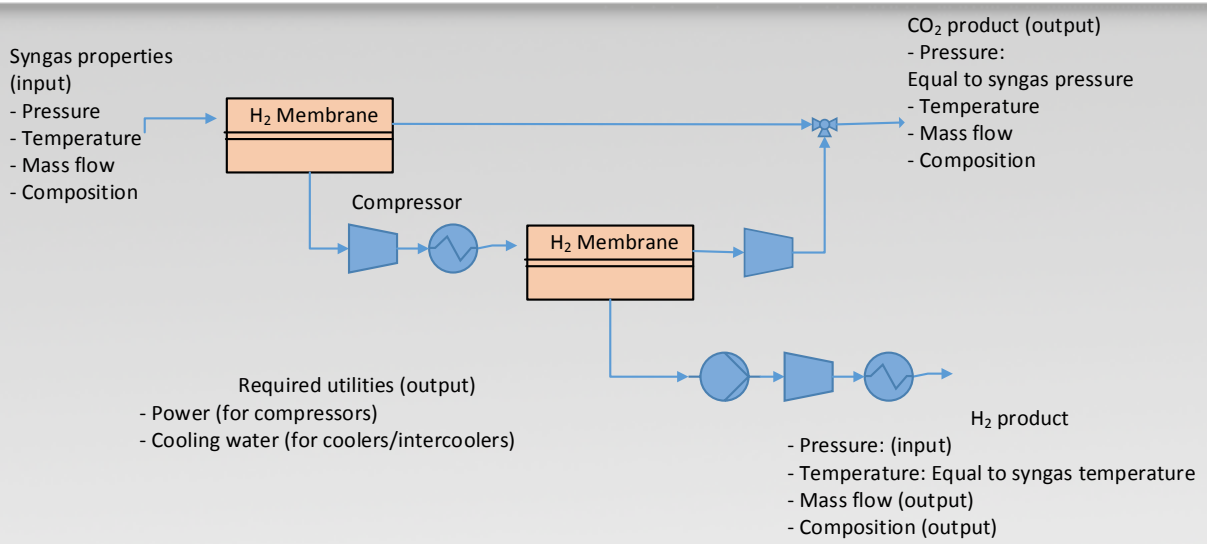
- Process flow diagram of cryogenic technology with design pressure = 7.9 MPa (CCR_T 85%)

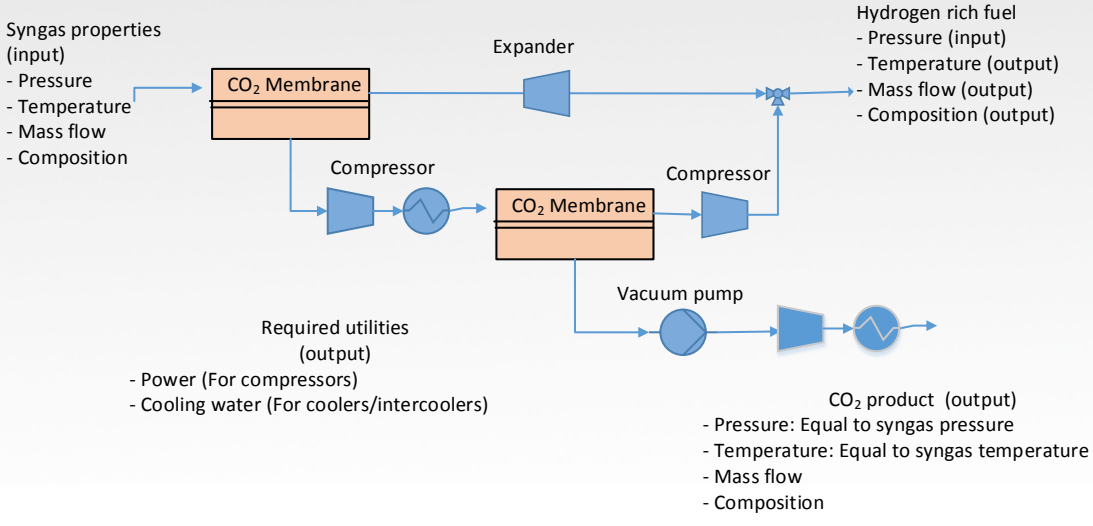


Separation pressure [MPa]	3.75	7.9	8.8	9.8	11.4
CCR_T	72%	85%	86%	87%	88%

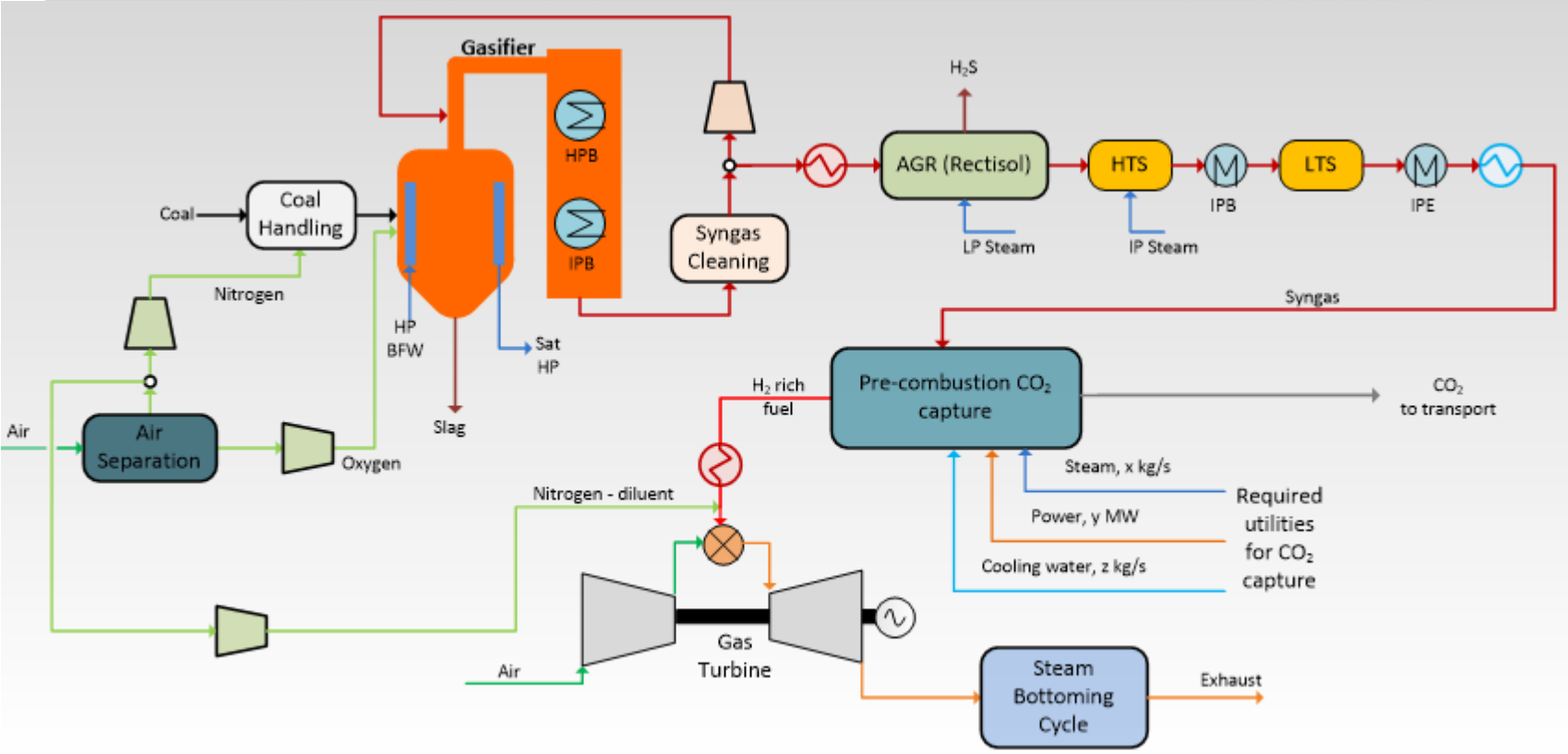
Berstad D.(2015) „ Norway Grants – WP3 – CCS separation proces Cryogenic “ presentation on IV. Bilateral Workshop of NF-CZ08-OV-1-003-2015 project, Prague, November 2015

CO_2/H_2 membrane CO_2 capture





IGCC with pre-combustion – design flow diagram



Var. I.

Var. II.

Var. III.

Var. IV.

THANK YOU FOR YOUR ATTENTION

More information about project:

- **project website:**
  - www.czech-norway-pilotccs.cz
- **project facebook:**
  - https://www.facebook.com/Czech-Norway-Pilot-CCS-1664816420432846**/**
- **project email:**
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