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Modelling and economic evaluation of carbon capture and storage technologies integrated into coal and biomass MTG plants

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Agenda

- **Introduction**
- **Plant performance evaluation**
  - System modeling
  - Mass and energy balance
  - Efficiency
- **Plant cost analysis**
  - Assumptions
  - Results
- **Conclusions**

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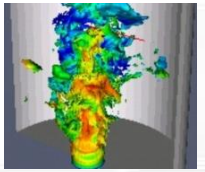

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Introduction: MTG from coal &biomass

MTG-CBTL **Methanol To Gasoline –Coal Biomass To Liquid APPROACH**

Plant performance evaluation

To evaluate the performance of **Methanol To Gasoline from Coal and Biomass plant configuration**

To asses the **performance** with the introduction of Carbon Capture and Storage Technologies

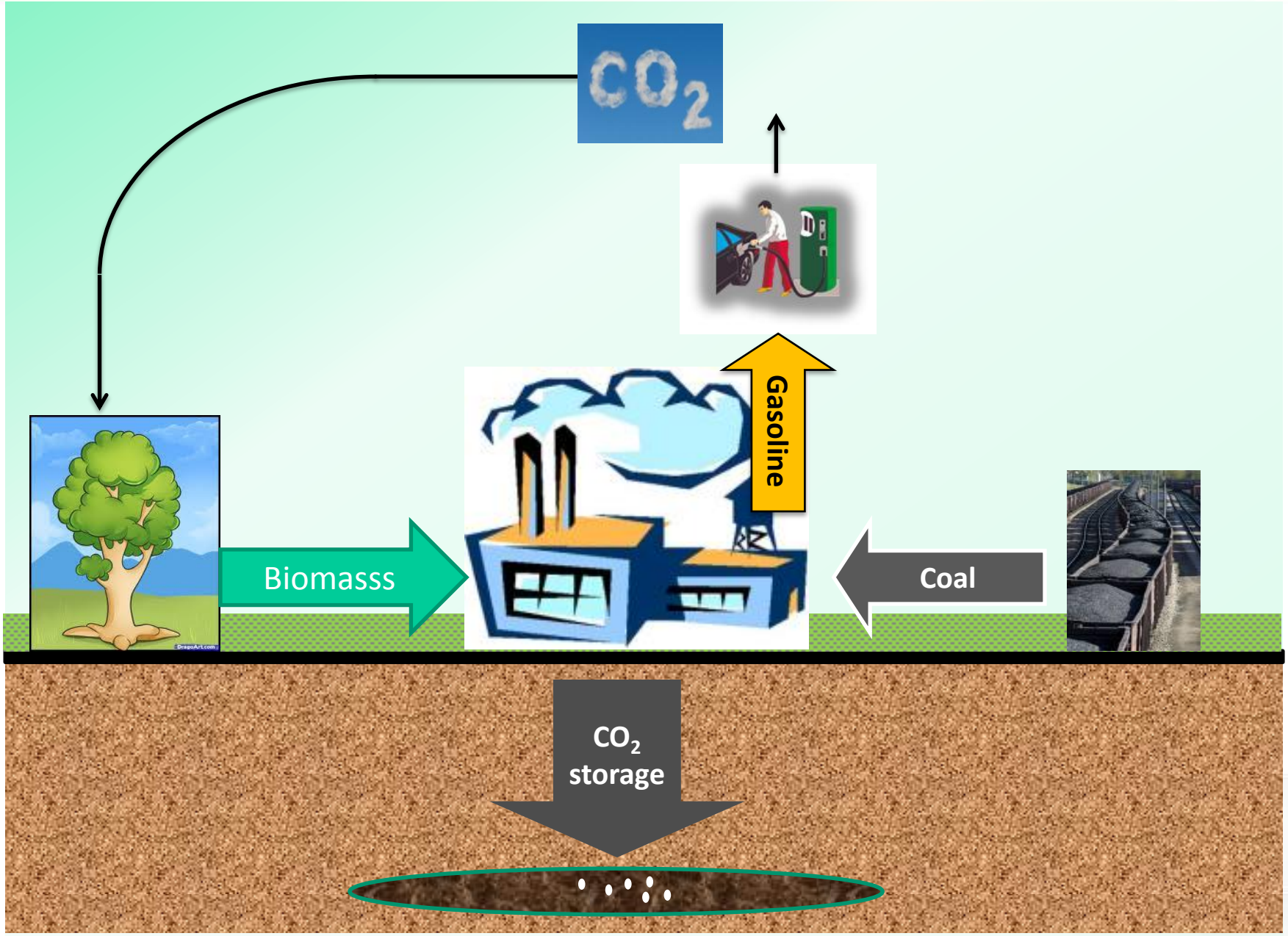
Plant cost analysis

To evaluate the **specific plant cost** w/o CCS

Near zero CO_2 emission

If CCS is applied to a **Methanol To Gasoline from Coal and Biomass** total fuel-cycle emission (included CO2 emission released during liquid fuel combustion) can approach zero or even become negative

Introduction: MTG from coal &biomass
Near zero CO2 emission



System modeling

The simulations were carried out using a commercial software AspenPlus

Mass and Energy Balance

Equilibrium Gibbs Reactors, yeld reactor

Process Integration

The MTG production is based on

Syntesis of methanol

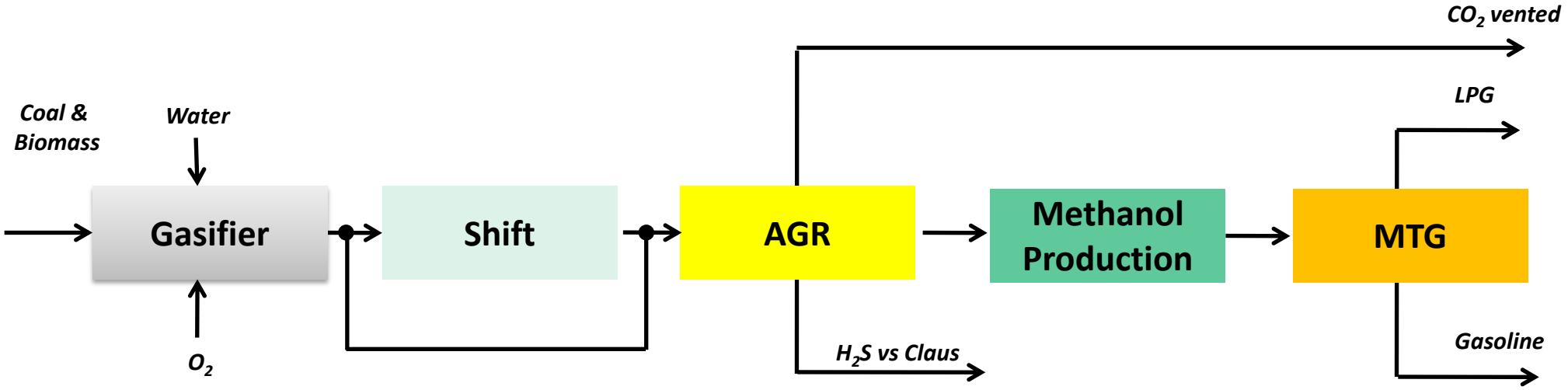
Methanol conversion to gasoline and LPG

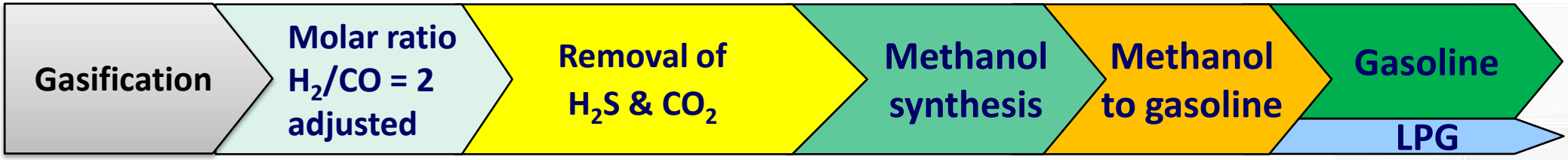
Highly Exothermic Reaction → Heat management is perfomed in two step

Two different plant configurations have been developed:

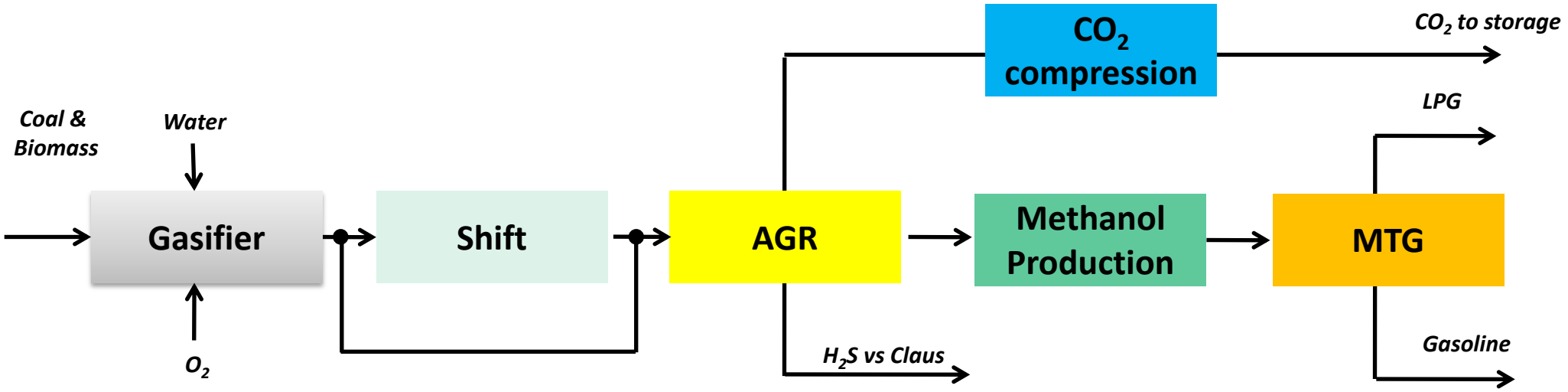
1. Base Case
2. CCS Case

System modeling: BASE CASE



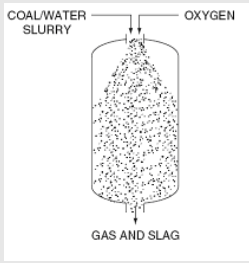


System modeling: CCS CASE



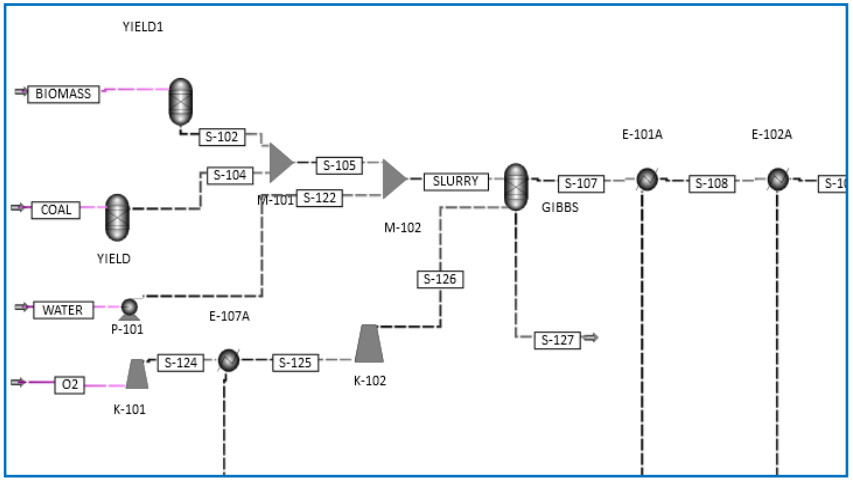
System modeling: assumptions

Gasifier	Entrained flow oxygen-blown gasifier (type GE/Texaco) Pressure = 40 bar Feed: composed of a coal/biomass/water slurry phase ASU section: 175 kWhe/tO_2 O_2 purity of 95% Adiabatic Gibbs reactor Chemical equilibrium Tout=1200° C
WGS section	Two catalytic reactors operating in series HT-WGS T_{HT}=300° C LT-WGS T_{LT}=200° C Adiabatic Gibbs reactor Chemical equilibrium
AGR section	Rectisol L/G=3 kg/kg p design 30 bar Gas clean H_2S= 1 ppm CO_2 =1 % H_2S rich gas H_2S % vol.>20 %
CO_2 compression	3 compressor stages with inter-coolers CO_2 liquid purity CO_2 = 95 % H_2S<200 ppm CO_2 liquid pressure p=150 bar
Methanol synthesis	Lurgi Low-Pressure Methanol (LLPM) process p=75 bar T=220° C , Rstoic reactor isothermal methanol production 96% vol.
Methanol to gasoline	Raw gasoline: Two steps two Ryeld reactor yeld structure by literature Refining: distillation columns RadFrac



System modeling: gasifier results

Gasification pressure	bar	40
Coal and biomass mass flow	t/h	268
O2/coal&biomass mass (daf basis)	α	0.9
$Nm^3_{Syngas}/kg_{coal\&biomass}$ (daf basis)		2
Syngas LHV	MJ/kg	10.2
Cold Gas Efficiency	CGE	0.77



Assumptions and results

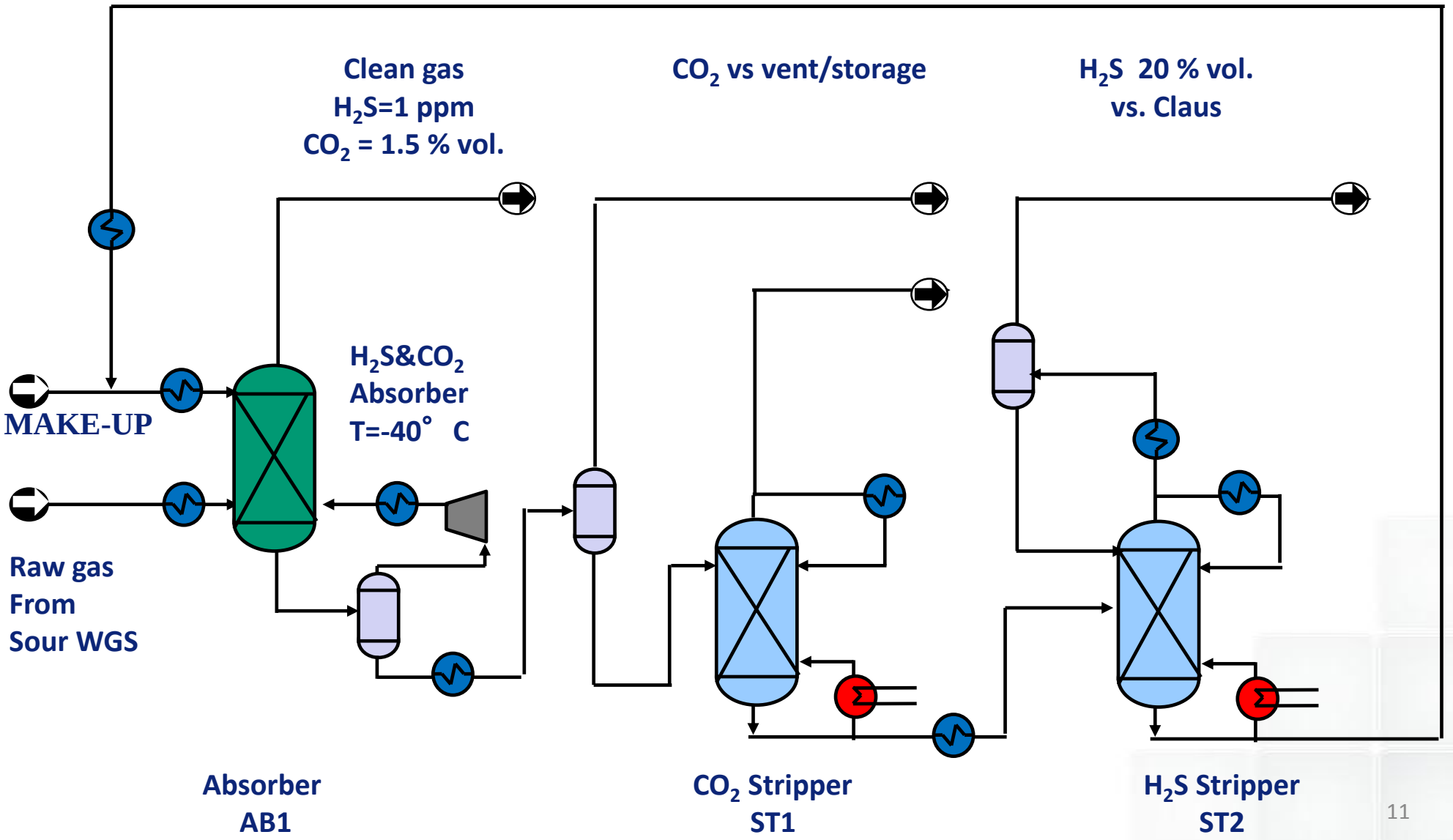
Syngas from Aspen model

Raw gas composition	Aspen model	Literature reference*
	% mol (dry basis)	% mol (dry basis)
H_2	35.1	35.4
CO	44.6	45.0
CO_2	18.3	17.1
CH_4	0.0	0
N_2	1.9	2.5

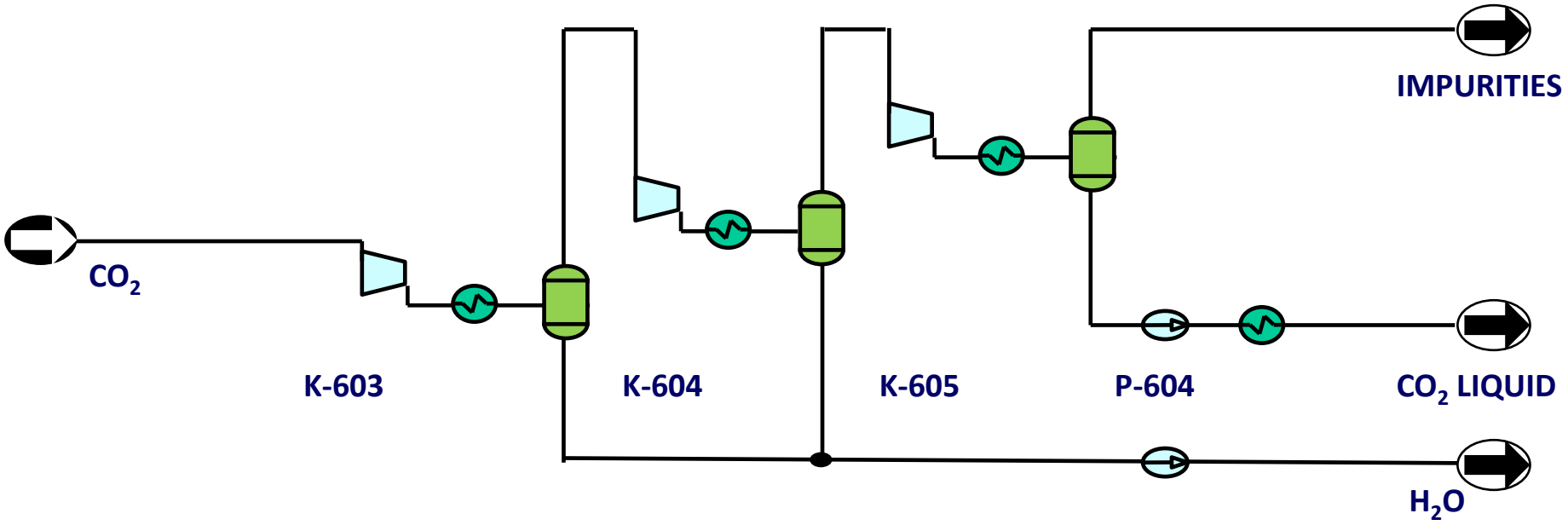
*Source: Brdar, Jones, GE IGCC technology and experience with advanced gas turbine, GE power systems, 2000, page 11

Acid Gas Removal section

Rectisol process



CO_2 compression section

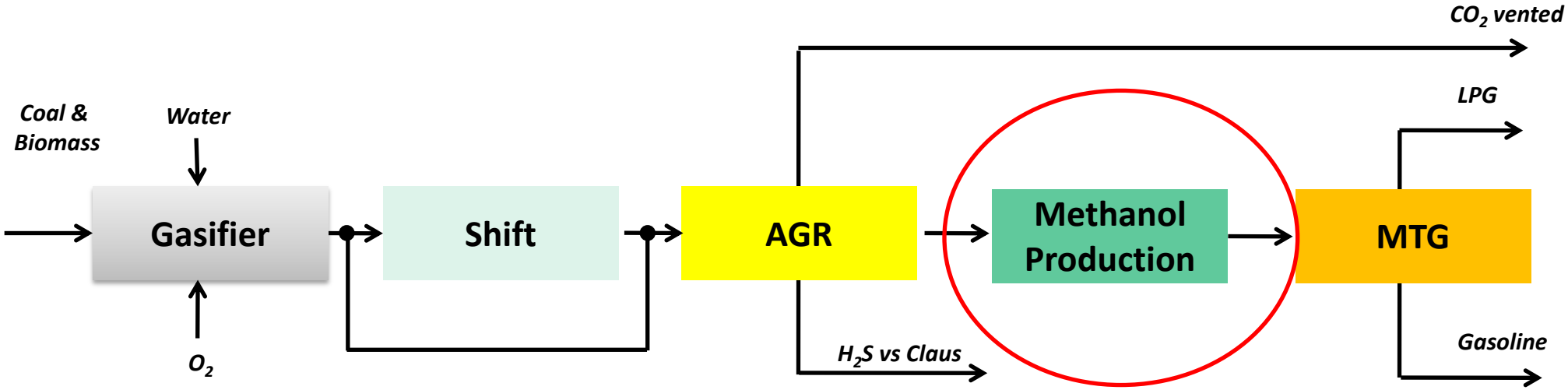


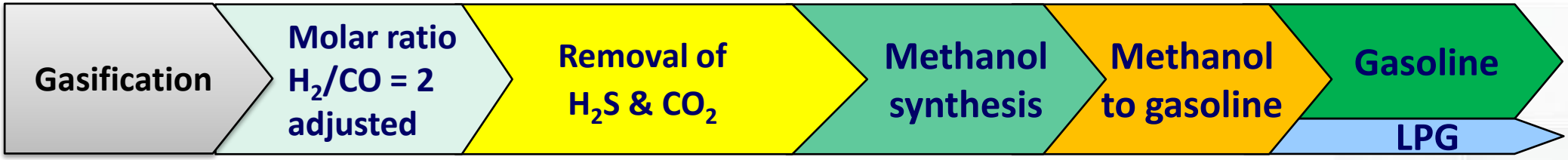
CO_2 compression/liquefaction

1. Three compressor stages

   14 bar, 40 bar, 80 bar
2. inter-coolers T=25 ° C
3. Liquid CO2 is pumped from 80 bar up to 150 bar.
4. CO_2 delivery conditions: 95 % in CO_2, H_2S<200 ppm, H_2O< 300 ppm, defined following the European Best practice Guidelines for assessment of CO_2 Capture Technologies

System modeling: BASE CASE



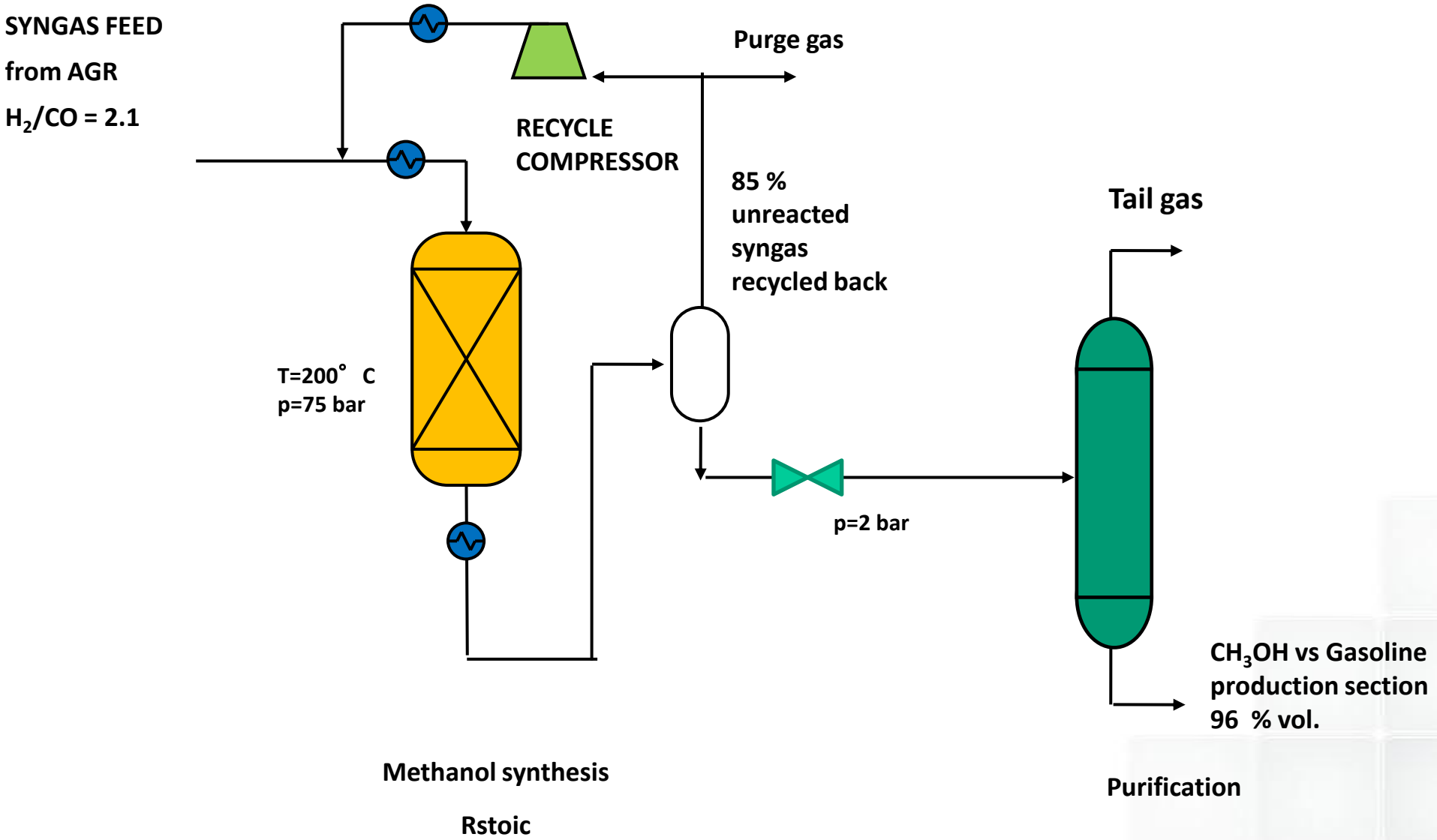


Methanol synthesis section

Lurgi Low-Pressure Methanol process

$CO + 2H_2 \leftrightarrow CH_3OH$

$CO_2 + 3H_2 \leftrightarrow CH_3OH + H_2O$

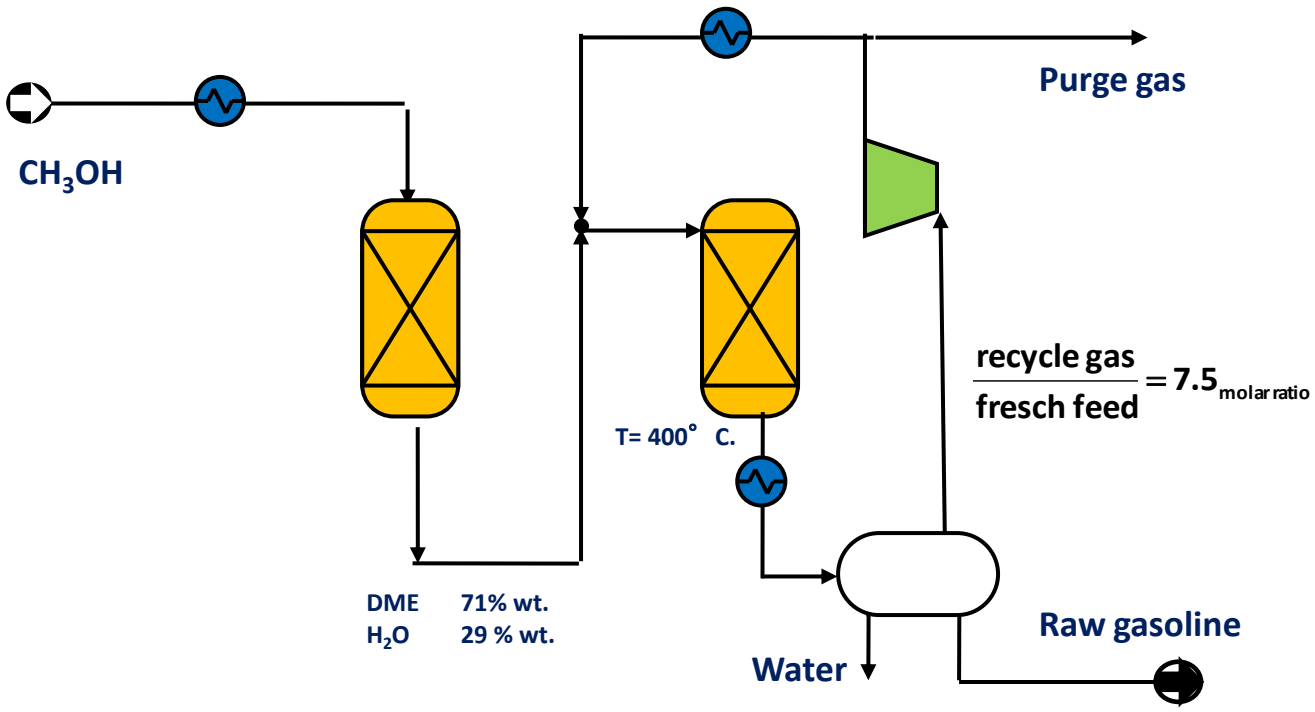


1. MTG synthesis section

The MTG process is highly exothermic → Heat management is performed in two steps

DME Reactor
Ryeld

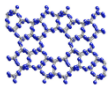
MTG Reactor
Ryeld



2° stage
Converts a mixture of DME and unreacted methanol into:
Water 56 % wt.
Hydrocarbons 44 % wt.

Hydrocarbons composition*		
Light gas	1.4 %	% wt.
Propane	5	% wt.
Propylene	0.1	% wt.
Isobutane	9	% wt.
n-Butane	3.3	% wt.
Butenes	1	% wt.
C5+	80	% wt.

*Source: G. Liu et all. Energy Fuels 2015, 29, 1830–1844

ZSM-5 catalyst 

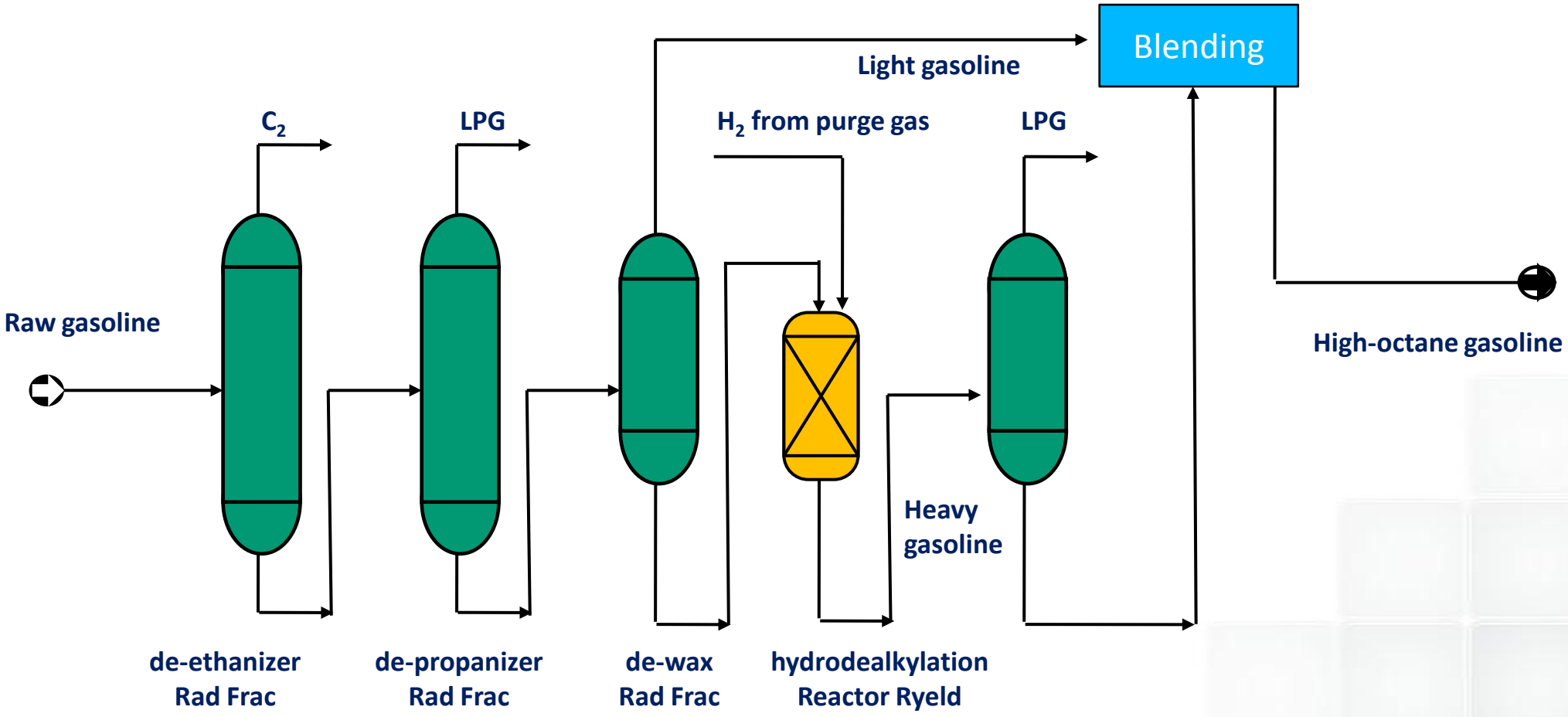
$CH_3OH \leftrightarrow CH_3OCH_3 + H_2O$

$CH_3OCH_3 \rightarrow C_2 - C_5$ alkenes → alkanes, cycloalkanes, aromatics

2. MTG synthesis section

Raw liquid gasoline is purified by:

1. De-ethanizer distillation column: methane, ethane and some propane are removed
2. De-propanizerdistillation column: propane and part of the butane components are removed overhead to produce LPG
3. De-waxing distillation column: a durene-rich heavy stream is taken off as the bottoms product
4. Hydrodealkylation: The durene-rich stream is treated in a hydrodealkylation reactor(Ryeld) to convert it to lighter hydrocarbons more suitable for gasoline

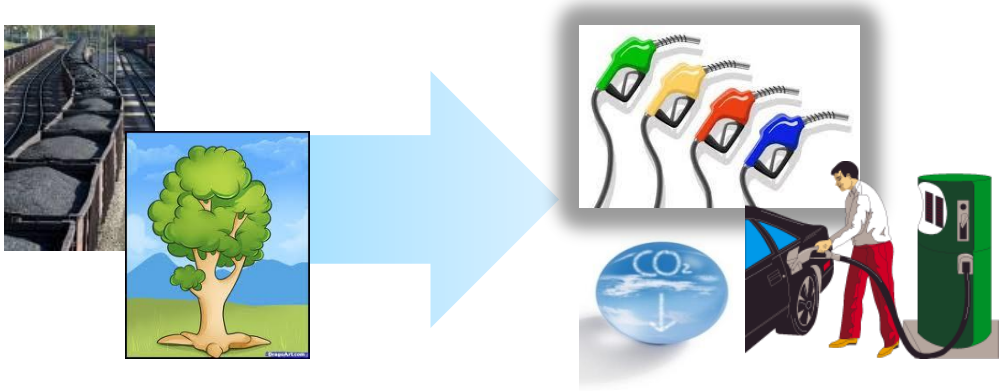


2. MTG synthesis RESULTS

Final composition of the MTG gasoline

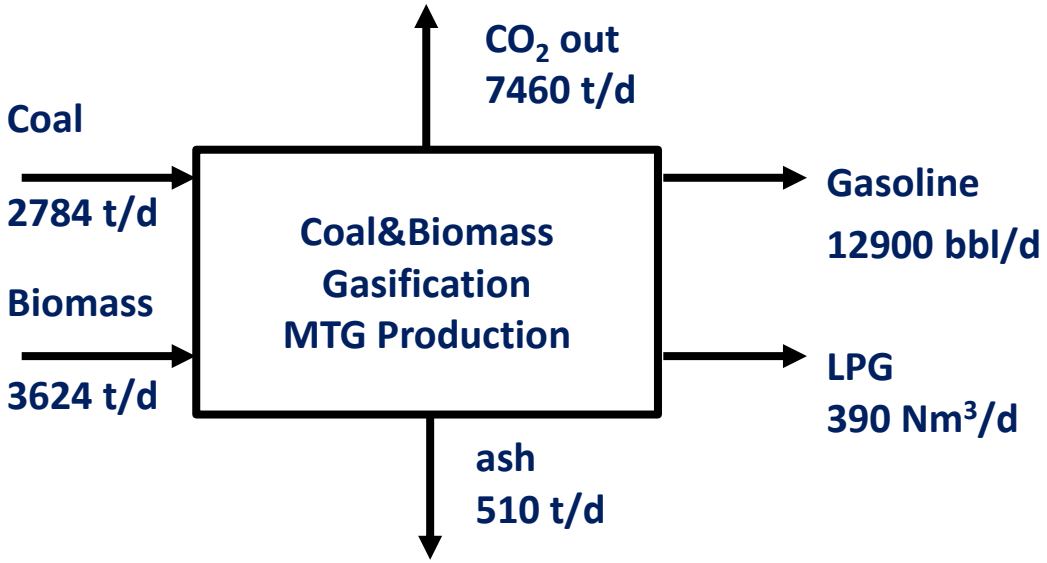
Yield (100 kg of methanol)	Base Case	CCS Case	Reference*
Gasoline	38.5	38.5	38.7
LPG	4.55	4.55	4.6
Fuel gas	0.68	0.68	0.7
Water	56.27	56.27	56

*Source: M Hindman. ExxonMobil

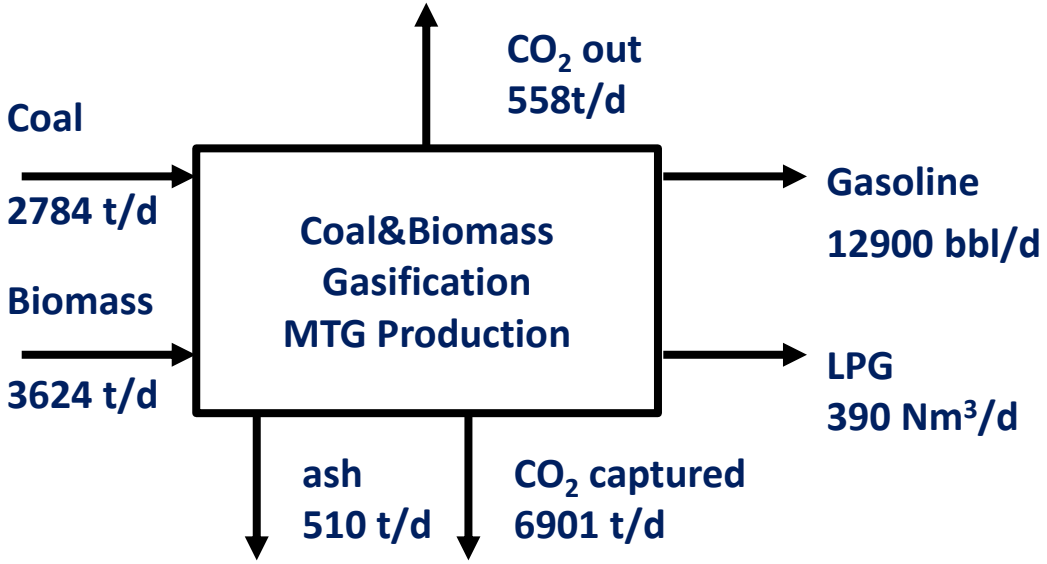


Results

BASE CASE



CCS CASE



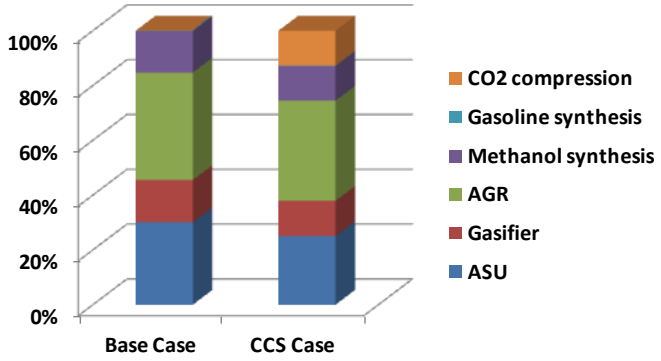
CO_2 removal efficiency = 93 %

Main performance: MTG plant

	Unit	Base Case	CCS Case
Coal & biomass mass flow rate	t/h	268	268
Thermal input	MWth	1603	1603
Gasoline flow rate	bbl/d	12900	12900
LPG flow rate	bbl/d	2450	2450
Gasoline LHV	MJ/kg	43	43
Auxiliary loads	MWe	102	123
Efficiency (η)	%	48.5	47
CO_2 removal efficiency	%		93
Methanol yeld	$kg_{methanol}/kg_{fuel}$	0.64	0.64
Gasoline yield	$bbl/t_{coal\&biomass}$	2	2
CO_2 specific emission	$kgCO_2$ emitted $/MJ_{fuel}$	30	2

The introduction of CCS shows a modest decrease of efficiency

Auxiliary loads

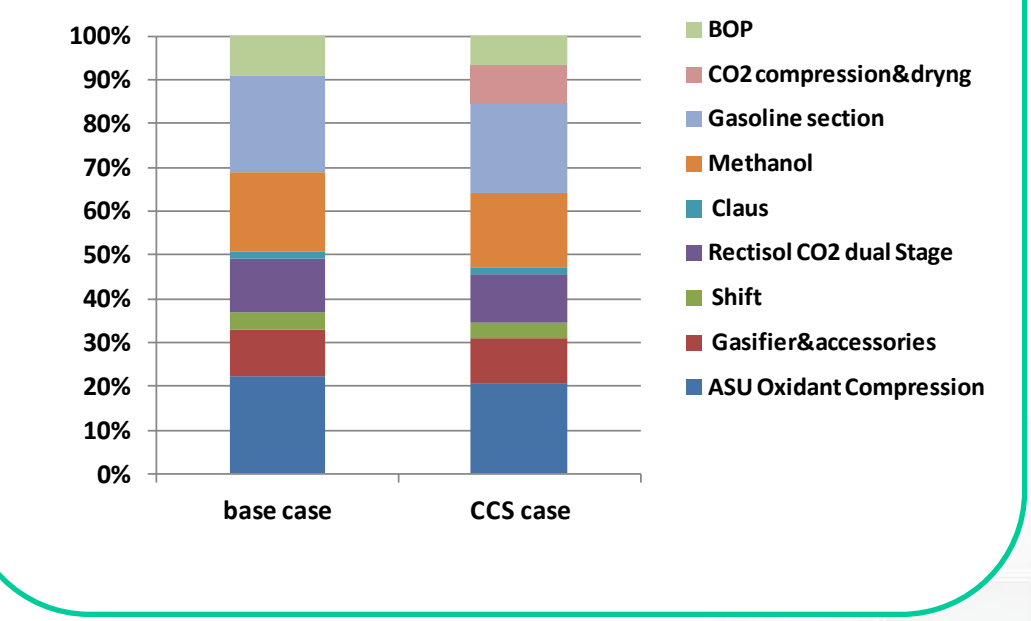


Economic Analysis

Assess the economic impact of the addition of CCS

Method

- **BEC** estimation (Bare Erected Cost) by factored method (CEPCI $\$_{2016}$) data source by literature
- **TPC** estimation(Total Plant Cost) Includes: Engineering, Procurement and Construction Cost, Contingencies.
- Estimation **Total specific plant cost**
- Estimation **specific gasoline production cost**
- Sensitivity analysis on **CO_2 allowances price**



Economic analysis assumptions

Parameter / Assumption	Value
Debt Equity Ratio	40:60
Capacity factor	85%
Plant life time	30 years
Interest rate	8%
Loan interest rate	10%
Annual O&M expenses	5.2 % TCP
Coal Price	100 $/t
Biomass Price	40 $/t
CO_2 storage cost	9 €/t
Electricity price	120 €/MWh
CO_2 price [a]	7 €/t $_{CO2}$

[a] source: EUA is taken from CO2 Exchange Pltaform SENDECO2

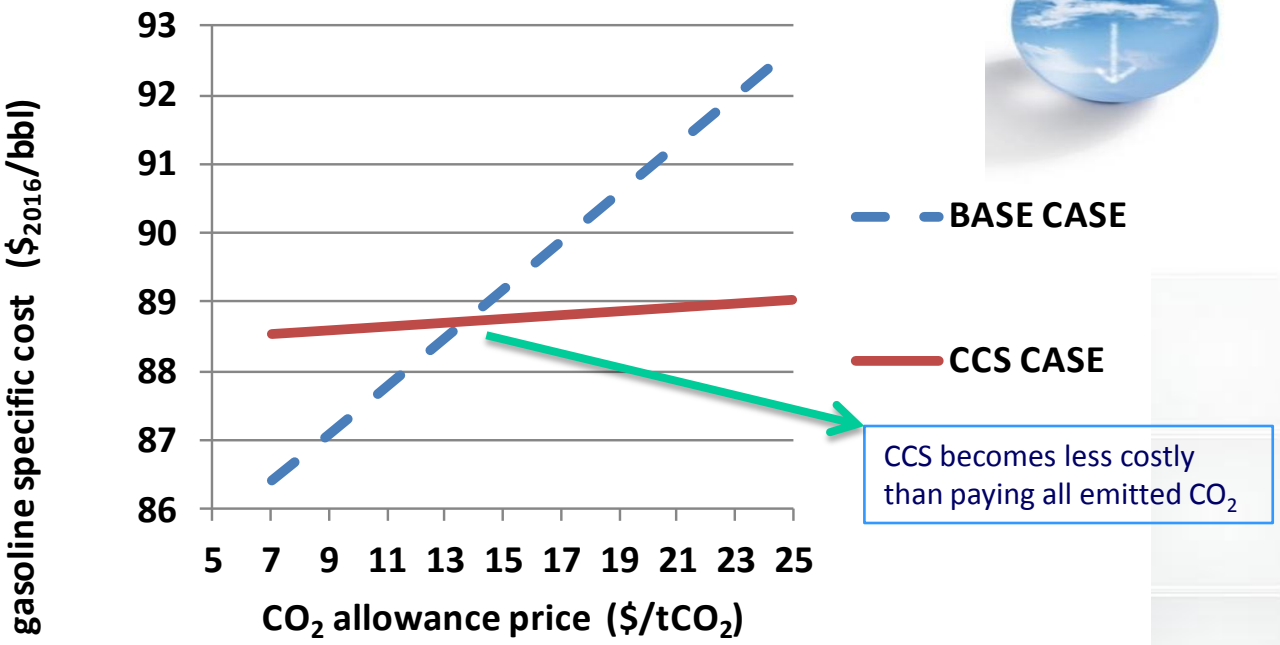
Economic analysis results

Introducing CCS generates **a *slightly increasing of gasoline cost production***, since the only added cost is for the CO_2 compression and storage.

		Base case	CCS Case
Total Specific Capital Cost	$/bbl/day	104000	110000
Incremental cost		-	5
Specific gaoline cost (CO_2 cost 7 $/$t_{CO2}$)	$/bbl	86	88

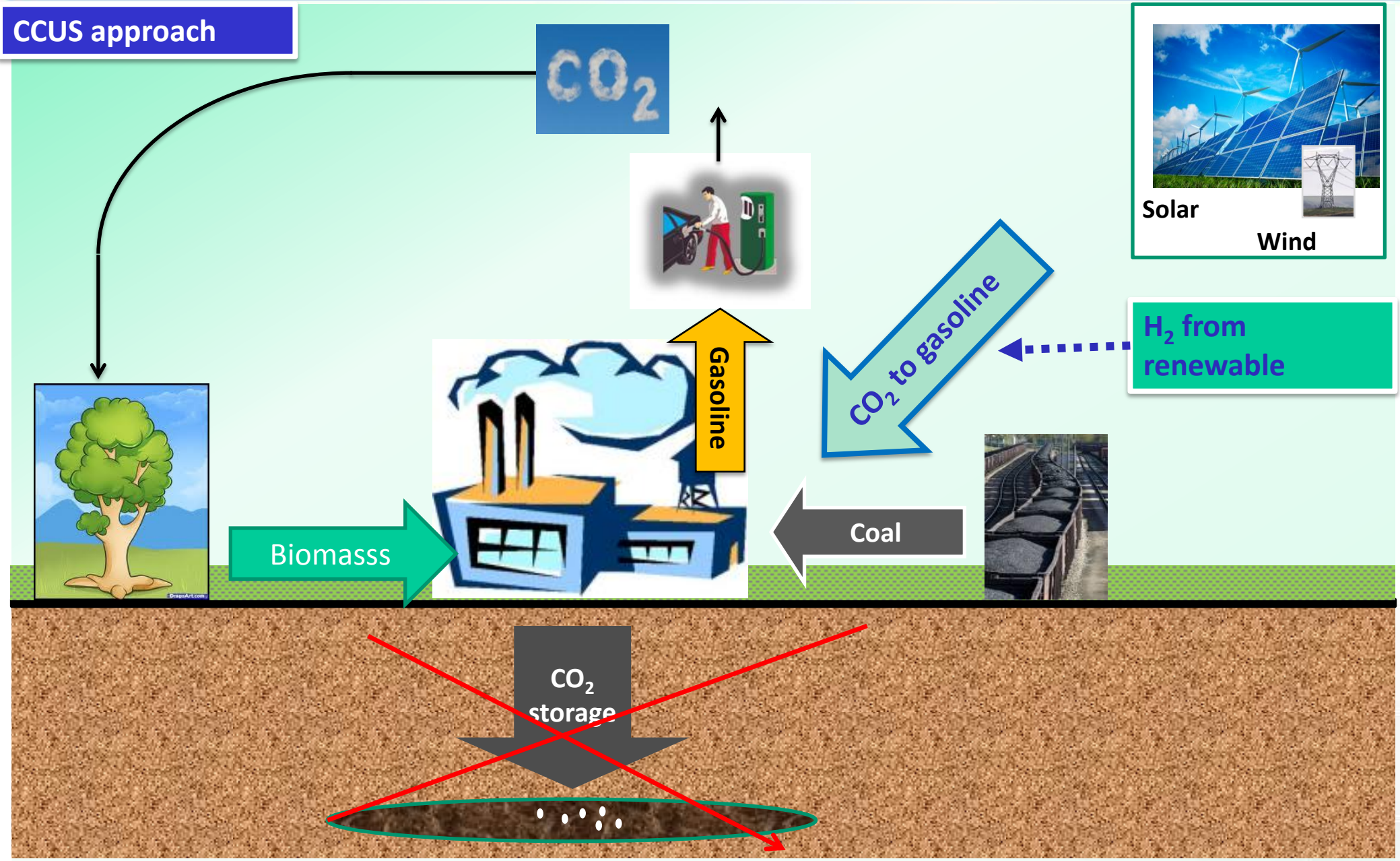
Sensitivity analysis

The CSS option is more or less competitive depending on the **applied price of CO_2 allowance**



Ongoing activities:
MTG from coal &biomass CCUS

CCUS approach



Conclusions

The analysis has made a comparative performance of two MTG plant configurations

1. To evaluate the performance of **Methanol To Gasoline from Coal and Biomass plant configuration and** to asses the **performance** with the introduction of Carbon Capture and Storage Technologies

   The **biomass** was included as co-feed with the goal of obtaining a **near zero lifecycle emissions**.

2. **Energy efficiency**

   Comparative performance analysis shows **similar efficiencies for the two cases**

3. **CCS implementation**
   - ❑ The capture of CO_2 is strictly **integrated into MTG plant**.
   - ❑ This analysis indicates a powerful synergism among MTG plant and CO_2 capture systems.
   - ❑ The introduction of CCS in MTG plant shows a **modest decrease of efficiency** (1.5 %)

Conclusions

4. Economic analysis

- Gasoline specific production cost equal to 86 $/bbl for base case
- Introducing CCS generates a **slightly increasing of gasoline cost production (88 $/bbl)** the only added cost is for the CO_2 compression.

5. Sensitivity analysis

- Sensitivity analysis is performed by changing the value of **CO_2 allowance price**
- Results show that in the case of CO_2 price up to 14 €/tCO_2 the plant configuration without CCS is more competitive than the configuration with CCS.

6 . Future work

Future work will expand technical and economic feasibility analysis with the **integration of power to liquid fuel production (CCUS approach)**

Thank you for your kind attention!

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