Technology status of hydrogen production from fossil fuels w/CCS

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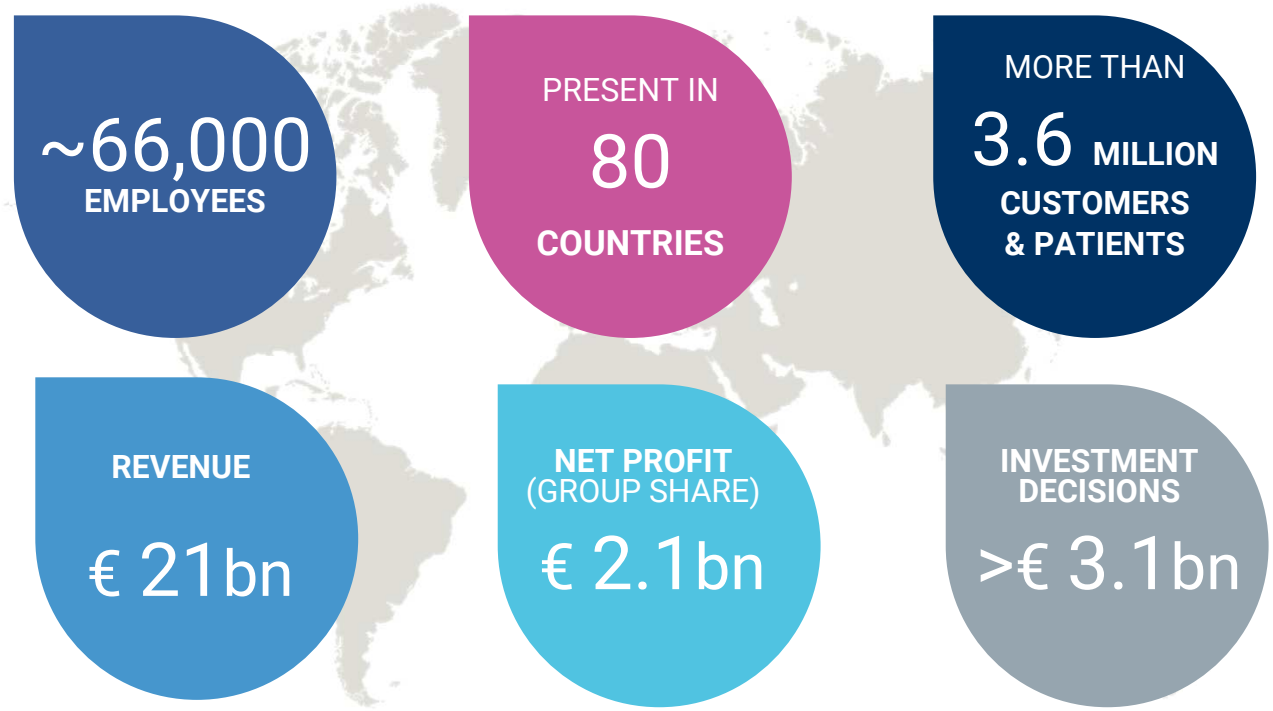
Chatou France • November 6th 2019
Fabrice Del Corso • R&D

Agenda

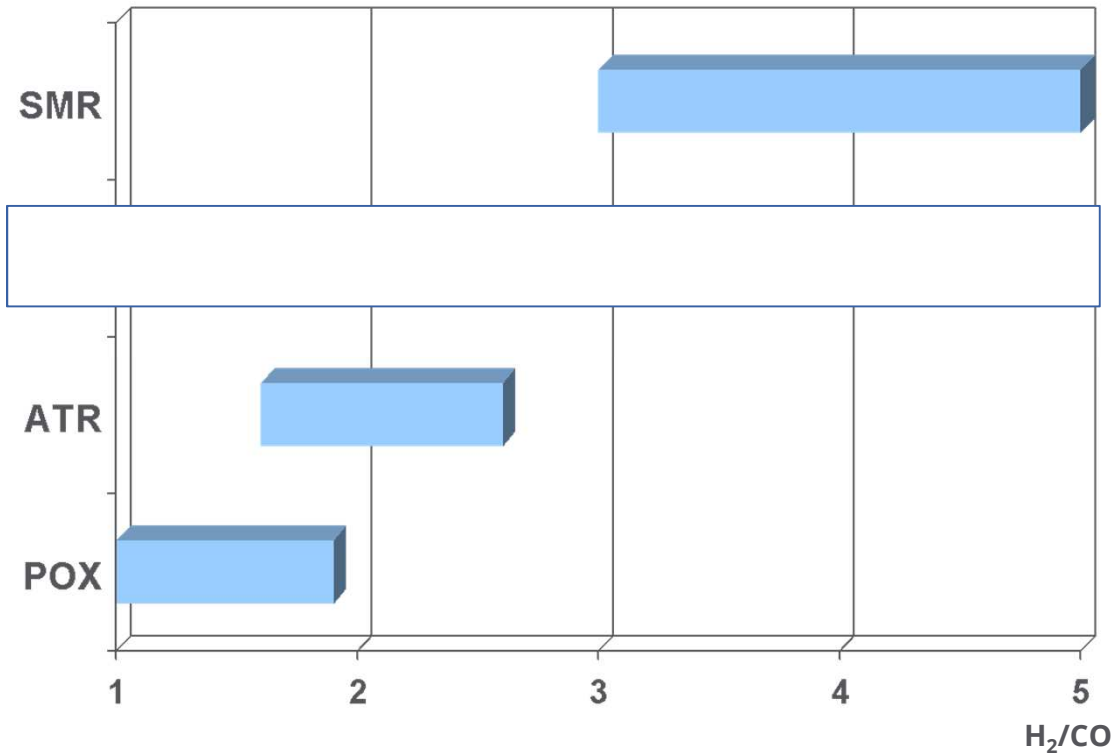
- Air Liquide Climate Objectives & Hydrogen production
- CO_2 Capture from SMR : Technologies Portfolio
- CO_2 Capture from ATR : Technologies Portfolio

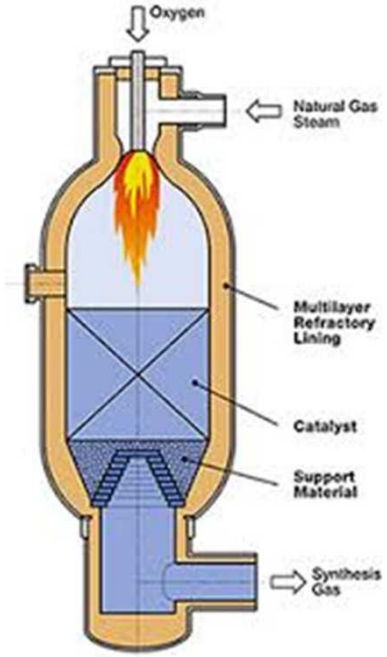
2018 Key Figures



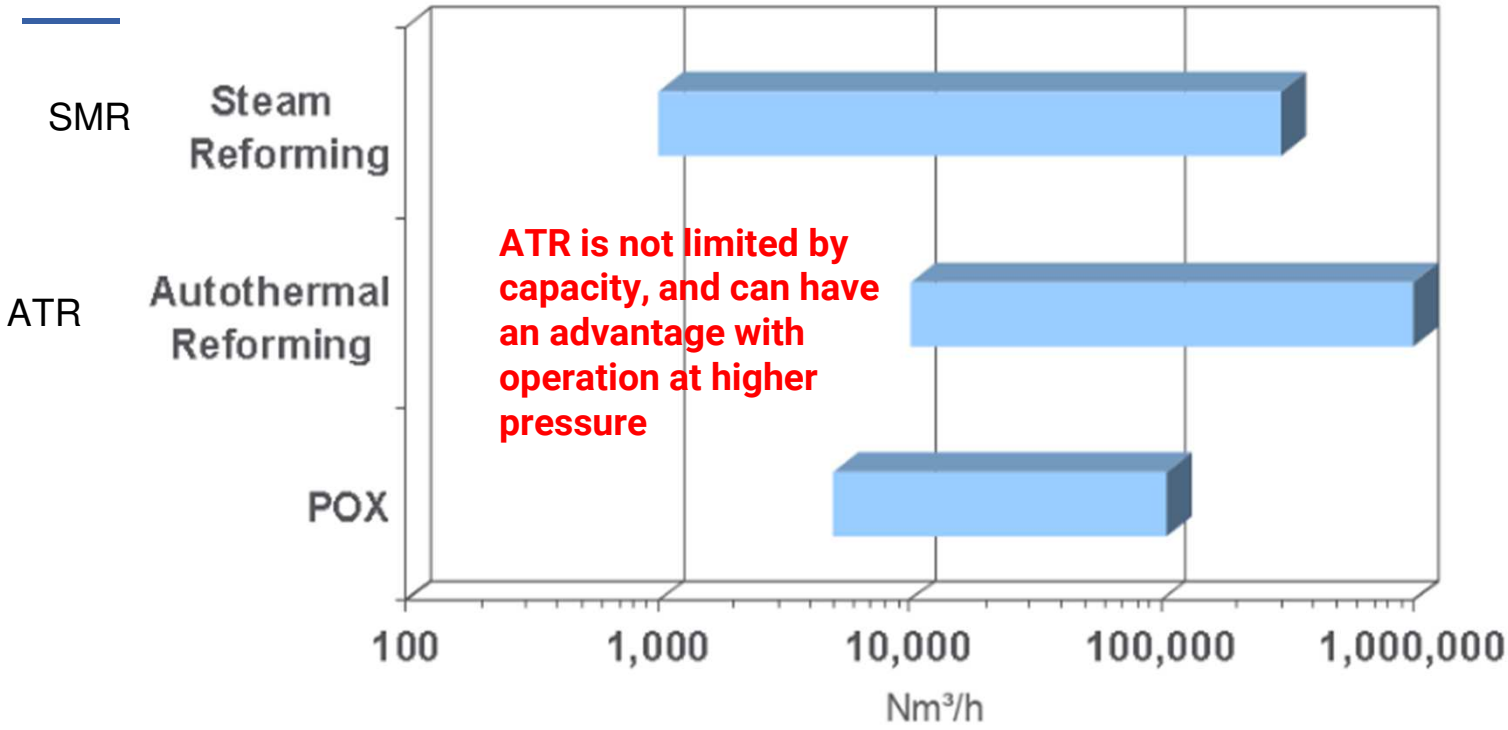
2018 Figures

Different Syngas (H_2 / CO / CO_2) Generation Technologies



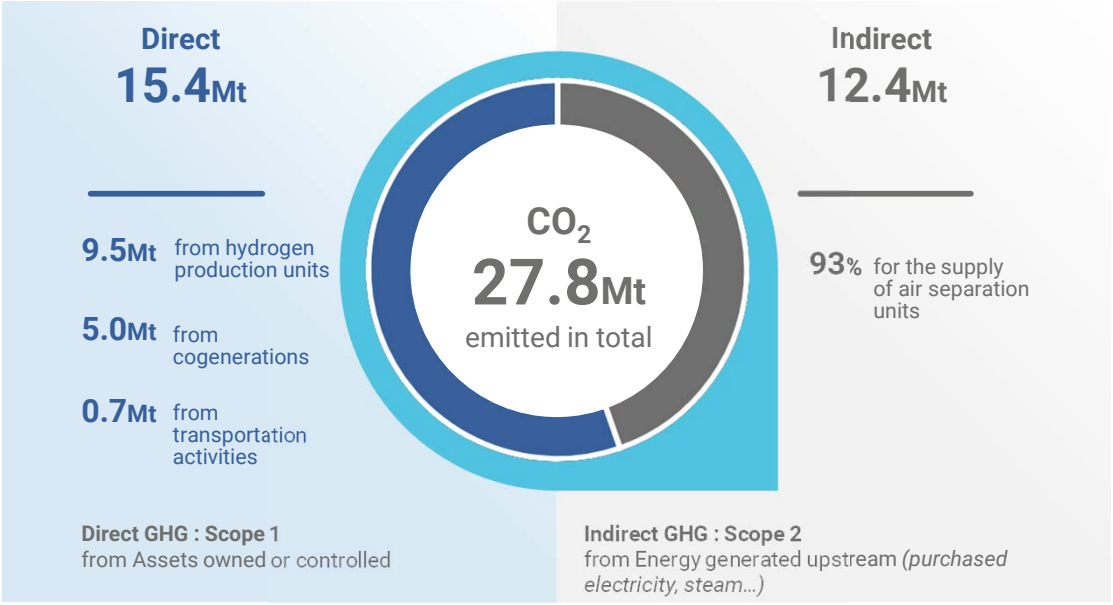


Syngas (H_2 / CO / CO_2) Generation Technologies



Greenhouse gas emissions within Air Liquide

Air Liquide GHG **emissions in 2018**



CLIMATE OBJECTIVES

A global approach

Air Liquide

A
ASSETS

ASSETS

Reduce our carbon intensity in 2025 vs. 2015 by 30%

C
CUSTOMERS

CUSTOMERS

Act for clean industry by developing low-carbon solutions

E
ECOSYSTEMS

ECOSYSTEMS

Contribute to a new low-carbon society

Air Liquide Group CO_2 & Climate Objectives

- **Active projects** underlining Air Liquide's ambition in the Energy Transition:
  - **Liquid hydrogen production from biomethane SMR, US West Coast** — Press release November 28, 2018
  - **Long term purchase agreement for 50 MW renewable electricity in Texas** — Press release November 30, 2018
  - **20.5 M$ Strategic investment in electrolysis technology (Hydrogenics)** — Press release January 28, 2019
  - **Investment in 20 MW water electrolysis plant in Canada** — Press release February 25, 2019
  - **Steel industry - hydrogen injection to blast furnace with ThyssenKrupp** — Press release July 19, 2019
  - **Steel industry - CCU on blast furnace with ArcelorMittal** — Press release October 17, 2019
  - **Hydrogen mobility - more than 120 Hydrogen refueling stations (HRS) installed by Air Liquide in the world**

Air Liquide is actively engaged in development of CCS in the North Sea region

- Porthos CCS project, Port of Rotterdam (PoR), Netherlands
  - Investigation on capture of CO_2 from Air Liquide hydrogen plants
- H-vision study, PoR
  - Technical solution (ATR and Rectisol technologies)
  - Economics of blue hydrogen as means to cut emissions of a large industrial basin
- Northern Lights
  - Exploring cooperation on CO_2 capture, liquefaction, and transportation to Norway

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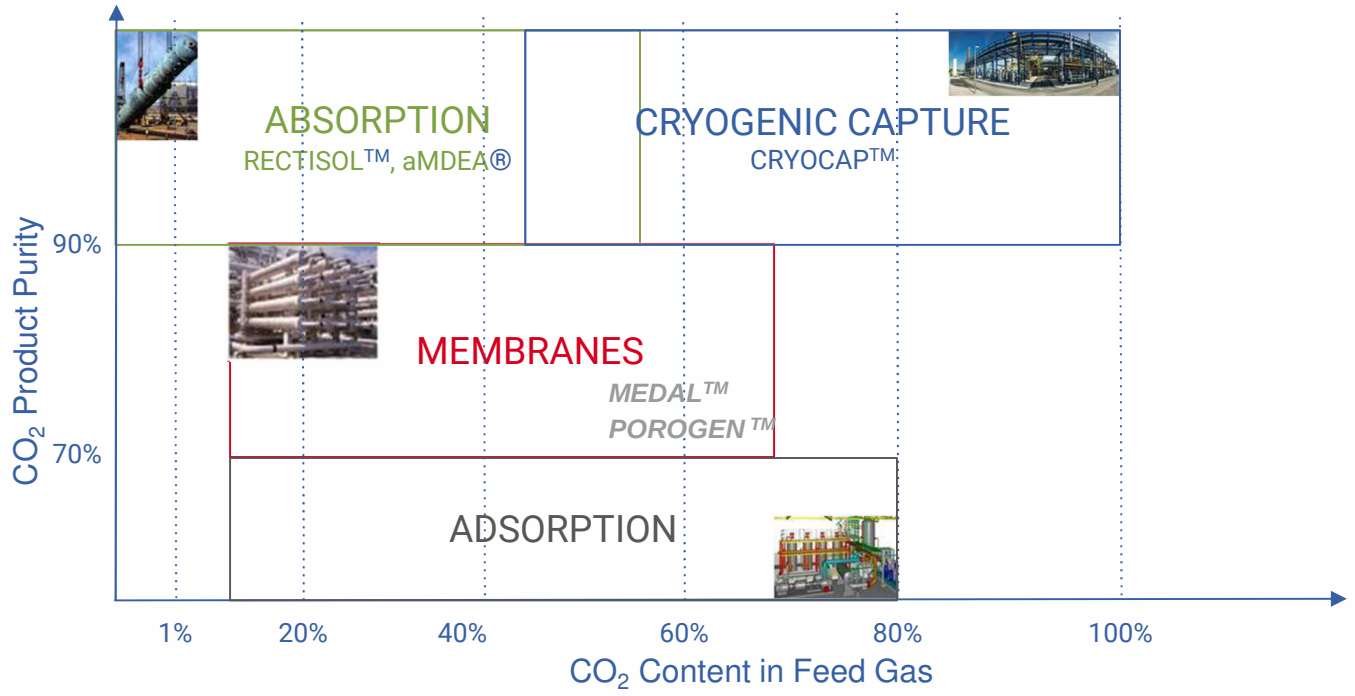
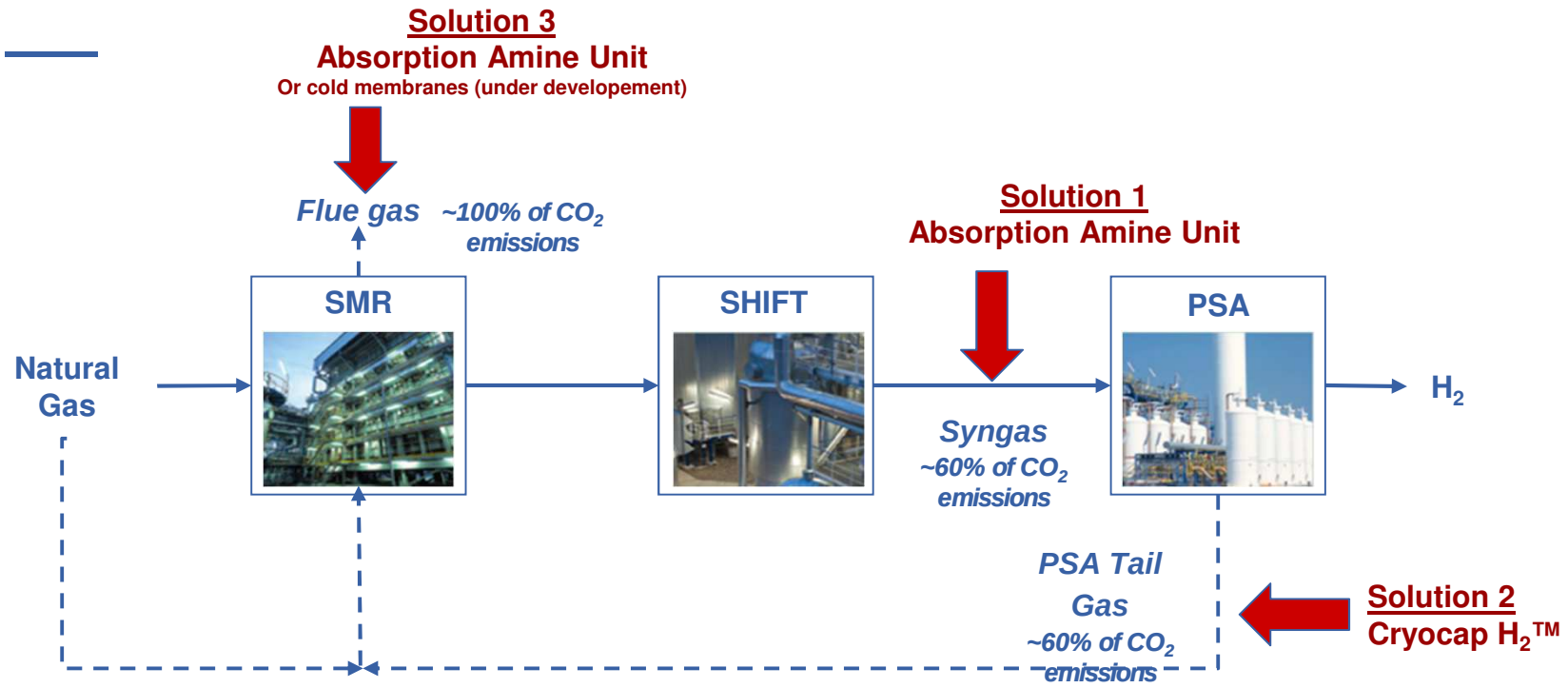
CO_2 Capture from SMR

Air Liquide Carbon Capture Processes Portfolio



Overview of Capture Solutions for SMR Plants



Overview of Capture Solutions for SMR Plants

#	Technology	% CO_2 capture	Other Benefits	Capture Cost (USD / mton) [1) 2)]
1	Amines (syngas)	~60% of total emissions		$30 - 40 / mton
2	Cryocap™	~60% of total emissions	• +13 to +20% H_2 production **OR** • -4% specific NG consumption • -5 to -8% capex, balance of plant	$20 - 40 / mton
3	Amines (flue gas)	~90% of total emissions		$60 - 80 / mton

1) Capture cost defined as TCO delta divided by captured CO_2

2) Range in capture cost is dependant on Opex drivers (power, steam pricing) and CO_2 utilization (quality, pressure)

Selected References

Amine (Syngas) - Northern Alberta, Canada

- **Syngas Treatment with BASF OASE White**
  - Designed and constructed by Air Liquide
  - Start-up in 2016 - 161,000 Nm^3/h H_2 SMR Train
  - Entire plant including Amine is modularized
  - Over 1,200 mtpd CO_2 captured from syngas
  - CO_2 intended for alkaline wastewater treatment
- **Flexible operation with or without CO_2 capture**
- **Air Liquide references include:**
  - Design or construction of over 80 units
  - Own and operating over 20 units

Selected References

Cryocap™ - Port Jerome, France

- **Retrofit of an AL SMR**
  - SMR supplying 50,000 Nm^3/h H_2 to **Exxon refinery**
  - PSA off gas treated: 17,000 m3/h
  - **300 tons/day** food-grade liquid CO_2 (99.9% purity)
- **Start up in H_1 2015**
  - Integration to an existing SMR without impact on SMR operations
  - **Reliable** operation of the compressor, cold box and membranes
  - **Increase of H_2 production** flow
  - Centrifugal compression **scalable for large plants**
  - Additional module for food grade liquid CO_2

World's only referenced cryogenic solution at industrial scale on syngas capture

New Technologies Development

Cold membrane development

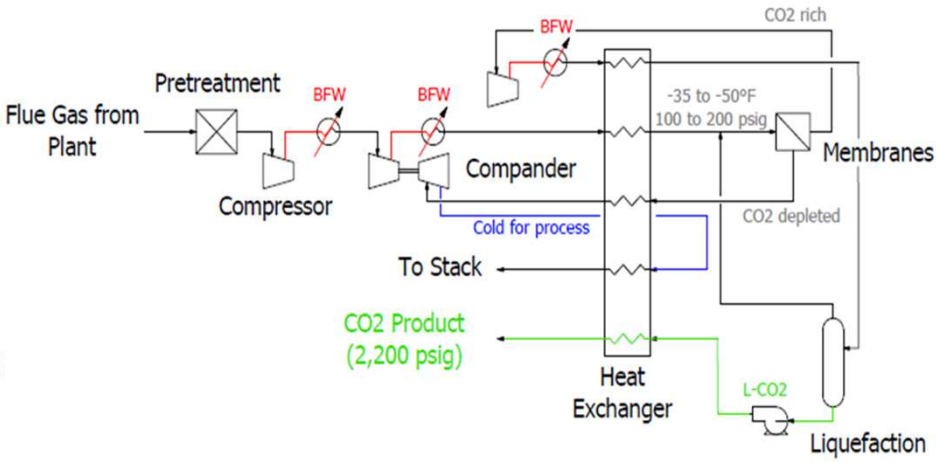
Hybrid Membrane and Cryogenic Technology

Joint development with the DOE
Cold membrane tested at 10tpd scale

Key features

- Integration between flue gas compression and membrane residue expansion
- Membrane operated at mild cryogenic conditions
- CO_2 product can be directly pumped or produced liq
- High level of CO_2 recovery
- High level of modularization with membranes
- Possibility to integrate heat of compression

Air Liquide patented technology



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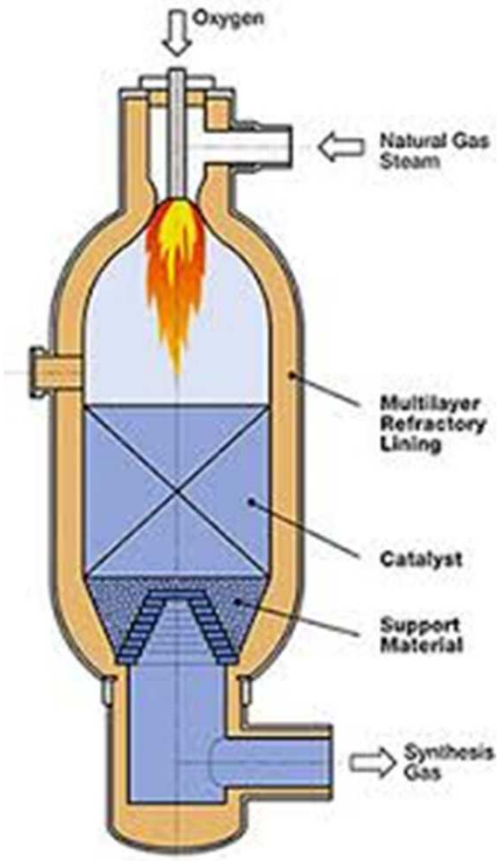
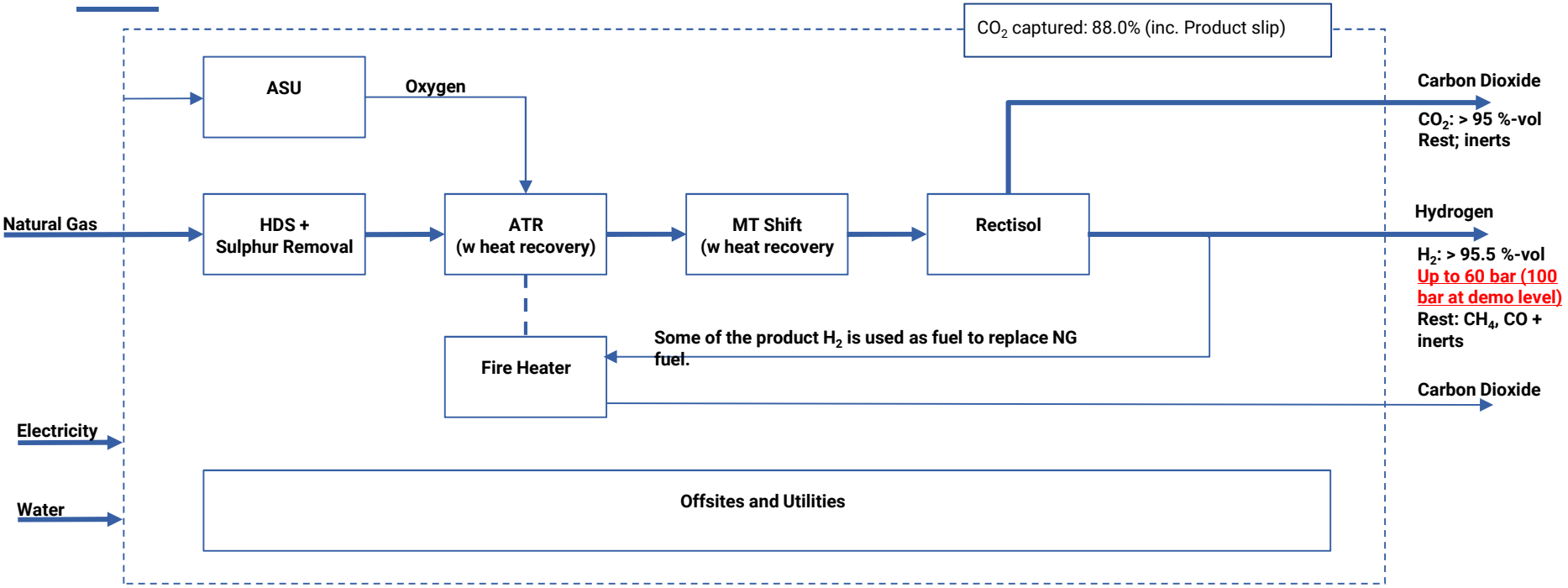
CO_2 capture from ATR

ATR reactor



H_2, CO, CO_2

Example of ATR Based Hydrogen Production + CCS



AIR LIQUIDE Lurgi's Large ATR - World Map of References

AL CO_2 Capture Technologies

Air Liquide Lurgi Rectisol™

- Applicable for very large scale, high pressure H_2 production from Autothermal Reforming (ATR) or gasification
- Patented Air Liquide technology
- 85 units in operation worldwide
- Achieves five steps in one unit
  - Bulk CO_2 removal
  - CO_2 purification

  and in gasification application:
  - Trace contaminant removal
  - Desulfurization
  - Acid Gas Enrichment

Shenhua Rectisol Plant in Ningxia, China
Four Trains: *1.12MM Nm^3/h each*
Startup: *June 2016*

Thank you for your attention