

Technology status of hydrogen production from fossil fuels w/CCS

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Chatou France • November 6th 2019

Fabrice Del Corso • R&D

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Agenda

- Air Liquide Climate Objectives & Hydrogen production
- CO₂ Capture from SMR : Technologies Portfolio
- CO₂ Capture from ATR : Technologies Portfolio

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2018 Key Figures



Different Syngas (H₂ / CO / CO₂) Generation Technologies



Syngas (H₂ / CO / CO₂) Generation Technologies



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Greenhouse gas emissions within Air Liquide



Air Liquide GHG emissions in 2018

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CLIMATE OBJECTIVES



Contribute to a new low-carbon society

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Air Liquide Group CO₂ & Climate Objectives

• Active projects underlining Air Liquide's ambition in the Energy Transition:

0	Liquid hydrogen production from biomethane SMR, US West Coast	Press release November 28, 2018
0	Long term purchase agreement for 50 MW renewable electricity in Texas	Press release November 30, 2018
0	20.5 M\$ Strategic investment in electrolysis technology (Hydrogenics)	Press release January 28, 2019
0	Investment in 20 MW water electrolysis plant in Canada	Press release February 25, 2019
0	Steel industry - hydrogen injection to blast furnace with ThyssenKrupp	Press release July 19, 2019
0	Steel industry - CCU on blast furnace with ArcelorMittal	Press release October 17, 2019
0	Hydrogen mobility - more than 120 Hydrogen refueling stations (HRS) installe	ed by Air Liquide in the world

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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 CO₂ 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 CO₂ capture, liquefaction, and transportation to Norway

Air Liquide joins innovative large scale Carbon Capture and Storage project in Norway





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Air Liquide Carbon Capture Processes Portfolio

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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% H₂ production <u>OR</u> -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 CO₂

2) Range in capture cost is dependant on Opex drivers (power, steam pricing) and CO₂ utilization (quality, pressure)

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Selected References Amine (Syngas) - Northern Alberta, Canada



• Syngas Treatment with BASF OASE White

- Designed and constructed by Air Liquide
- \circ Start-up in 2016 161,000 Nm³/h H₂ SMR Train
- Entire plant including Amine is modularized
- Over 1,200 mtpd CO₂ captured from syngas
- CO₂ intended for alkaline wastewater treatment
- Flexible operation with or without CO₂ capture
- Air Liquide references include:
 - Design or construction of over 80 units
 - Own and operating over 20 units

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Selected References Cryocap[™] - Port Jerome, France



- Retrofit of an AL SMR
 - SMR supplying 50,000 Nm³/h H₂ to **Exxon refinery**
 - PSA off gas treated: 17,000 m3/h
 - **300 tons/day** food-grade liquid CO₂ (99.9% purity)

Start up in H₁ 2015

- Integration to an existing SMR without impact on SMR operations
- **Reliable** operation of the compressor, cold box and membranes
- Increase of H₂ production flow
- Centrifugal compression scalable for large plants
- Additional module for food grade liquid CO₂

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

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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
- CO₂ product can be directly pumped or produced liq
- High level of CO₂ recovery
- High level of modularization with membranes
- Possibility to integrate heat of compression

Air Liquide patented technology











Example of ATR Based Hydrogen Production + CCS



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



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AL CO₂ Capture Technologies Air Liquide Lurgi Rectisol[™]

- Applicable for very large scale, high pressure H₂ production from Autothermal Reforming (ATR) or gasification
- Patented Air Liquide technology
- 85 units in operation worldwide
- Achieves five steps in one unit
 - Bulk CO₂ removal
 - \circ CO₂ purification

and in gasification application:

- Trace contaminant removal
- Desulfurization
- Acid Gas Enrichment

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Shenhua Rectisol Plant in Ningxia, China Four Trains: 1.12MM Nm³/h each Startup: June 2016

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