

# Air Liquide - The Technology Powerhouse for Low-Carbon Syngas Production

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Air Liquide

A world leader  
in industrial  
gases and  
related  
services

A unique  
model

## Our profile

~66,400  
committed employees  
in 75 countries

**Extensive scientific  
& technical expertise**  
in industrial gases (oxygen,  
nitrogen, hydrogen, etc.)

>3.8 million  
customers & patients

4,500  
employees contributing  
to innovation

5 Innovation Campuses  
1 Campus Technologies

13,500  
patents

### 2 industrial gases production modes

Centralized production  
On-site production at  
customers'

### 3 industrial gases distribution networks

>9,700 km of pipelines for  
large quantities

~ 20 million cylinders for  
small quantities

~ 9,900 trucks for medium  
quantities

## Our business model

**Long-term  
vision and sustainable  
growth strategy**

**A wide range  
of customers  
and applications**

**Major ability  
to innovate**

**Long-term  
customer contracts,  
indexed to energy  
prices**

**Management  
and optimization  
of production and  
distribution chain**

**Active involvement  
in new markets**

**Global presence  
and local activity**

## Our activities



## To support almost all economic sectors

### LARGE INDUSTRIES

Industrial gases in large  
quantities in the framework  
of long-term partnerships



Chemicals  
Refining  
Metals

### INDUSTRIAL MERCHANT

Industrial gases in small and  
medium quantities, application  
technologies, small equipment  
and related services serving a  
wide range of customers



Materials & energy  
Automotive & fabrication  
Food & pharmaceuticals  
Technology & research  
Entrepreneurs & distributors

### ELECTRONICS

Ultra-pure gases in large  
quantities and development  
of new molecules



Semiconductors  
Photovoltaic  
Flat panels

### HEALTHCARE

Medical gases, products  
and services to support  
patients and customers  
in hospital and at home



Hospitals  
Home healthcare  
Specialty ingredients

### GLOBAL MARKETS & TECHNOLOGIES

Molecules, equipment and services  
to support of energy transition and  
deep tech<sup>(2)</sup>



Energy transition  
Deep tech<sup>(2)</sup>

### ENGINEERING & CONSTRUCTION

Plants and equipment  
for industrial gas production



Customers choosing  
to insure their  
industrial gas needs

<sup>(1)</sup> Percentage of 2021 Group revenue.

<sup>(2)</sup> Disruptive technologies based on scientific breakthroughs that can fundamentally change design and production methods.



# HYDROGEN as a cornerstone of the energy transition... ...and a tremendous growth potential

2050

>20%  
of final world  
energy  
demand<sup>(1)</sup>

Power  
generation,  
buffering



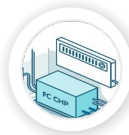
Transportation



Industry  
energy



Building  
heating and  
power



Industrial  
feedstock  
(CCU, DRI)



## Our ENGAGEMENT

➤ **Decarbonize our production assets** to develop a competitive low-carbon H<sub>2</sub> offering at large scale.

➤ **Create value by decarbonizing our customers' processes**, leveraging our long-term relationships.

➤ **Be a key enabler of the Hydrogen society** thanks to our assets, technology, and expertise.

(1) [Hydrogen for net zero](#)



# AL Electrolyzer ramp-up

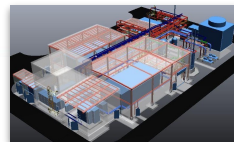
**Towards 100+MW scale**

Air Liquide's 200 MW electrolyzer project in the Netherlands enters the final selection round of European Innovation Fund



Air Liquide transforms its network in Germany by connecting a large electrolyzer producing renewable hydrogen

Paris, France, July 29, 2021



**OBERHAUSEN**  
Phase 1 20 MW  
Phase 2 10 MW  
Siemens PEM  
**Under execution**

Air Liquide completes the first phase of ultra-high purity low-carbon H<sub>2</sub> electrolyzer plants in Taiwan



**2020**

**25 MW in Taiwan**  
Alkaline  
**Start-up**

**2019**

**BECANCOUR 20 MW**  
Largest PEM project  
**In operation**

Air Liquide inaugurates the world's largest low-carbon hydrogen membrane-based production unit in Canada



With a capacity of 20 megawatts

**2018**

**< 2017**

more than 35 electrolyzers in operation worldwide usual range:  
**50 - 100 Nm<sup>3</sup>/h H<sub>2</sub>**  
Mainly Alkaline technology

**ONSITE**

**HYBALANCE 1.25 MW PEM**  
**In operation**



**2023**

**Giga-Factory start-up**  
Up to 3 GW/yr by 2025  
**Under construction**

Air Liquide and Siemens Energy form a joint venture for the European production of large-scale renewable hydrogen electrolyzers



**SIEMENS**  
energy



**Joint Venture**

**2025**

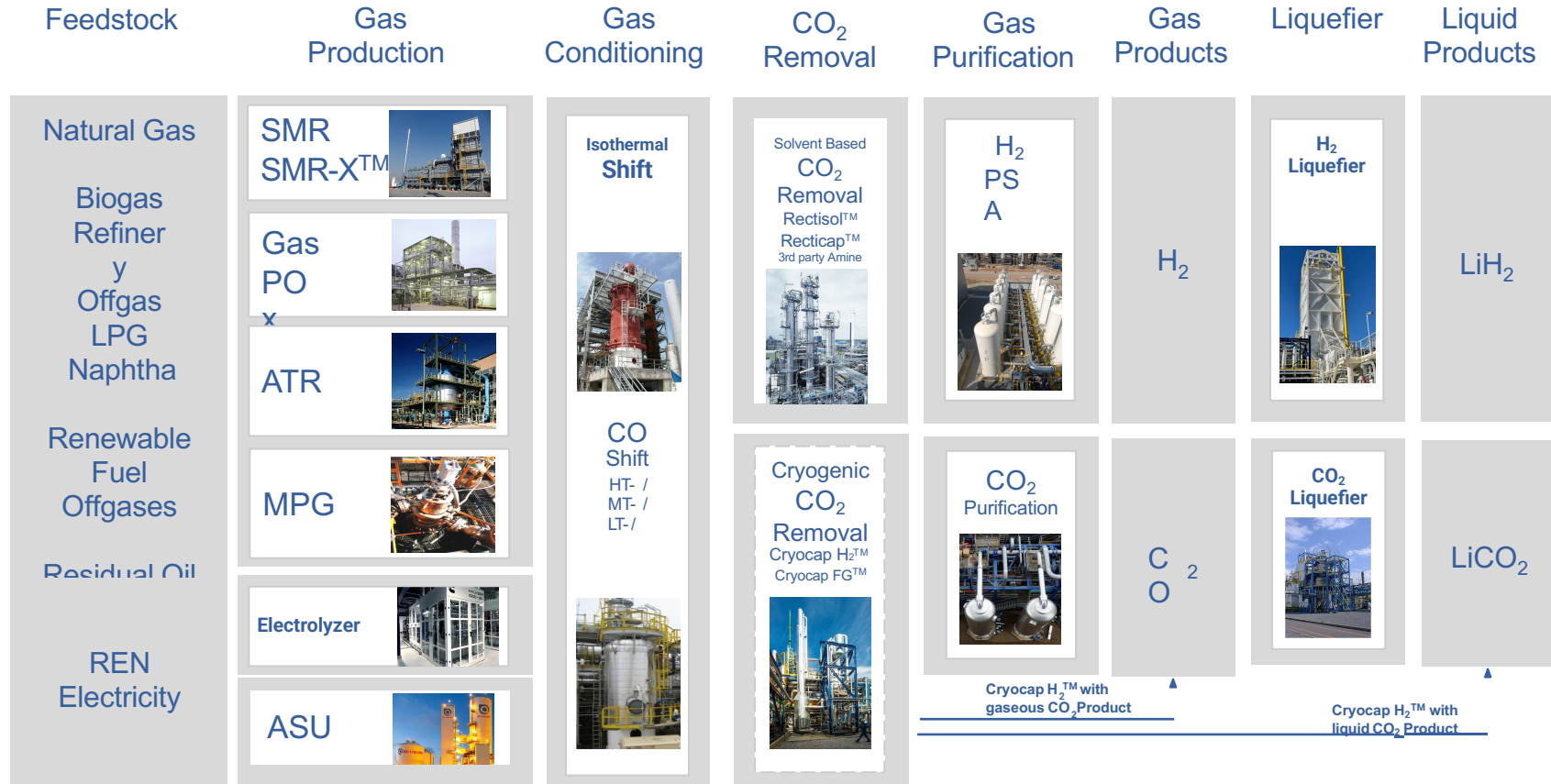
**NORMAND'HY 200 MW**  
Largest ELY project  
**Under conception**

Air Liquide accelerates its large scale renewable hydrogen production flagship project in France

Paris, France, October 20, 2021



# Technology Portfolio for Low Carbon Hydrogen





# Update of Air Liquide Oxygen based Syngas Production

## ATR

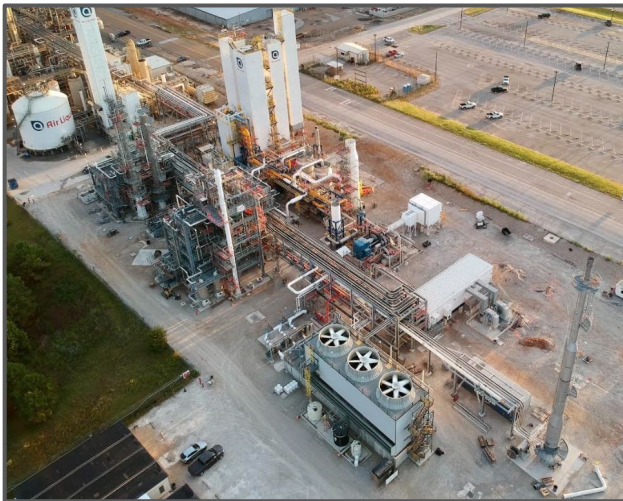
33 ATR built, and 6 ATR awards under execution



- After Natgasoline (2018) the **second Megamethanol Plant with 5000 MTPD production for Koch Industries is successfully in operation USA**. Lurgi Combined Reforming Technology comprising a SMR & ATR Technology has been applied.
- Process Integration with **ASU and Oxygen Supply** Over the Fence by **Air Liquide Large Industries**

## GasPOX

7 Gasifiers in operation, 2 new under implementation



- **Air Liquide operated GasPOX Plant without any direct CO<sub>2</sub> emissions** - realization of **POXSYN™** concept including elimination of fired heater.
- This is the 7th gasifier operating with “**media cooled**” burner **technology** in GasPOX application. It enables increased burner runtime attributing to elimination of water cooling and avoidance of pressure bearing parts in heat affected burner zone

## MPG

3 Gasifiers in operation



- **Lurgi MPG™ Technology** is used to upgrade a challenging feedstock to low carbon hydrogen. Without further treatment the captured CO<sub>2</sub> is compressed and sequestered through EOR **eliminating approximately 70% of the refinery's total CO<sub>2</sub> footprint**.
- A CO-Shift, Methanation and **Lurgi Rectisol™**, has been applied for gas conditioning and CO<sub>2</sub> Removal

# Update of Air Liquide SMR based Syngas Production

145 Steam Reformer plants built, 9 under implementation

## SMR-X™



- **First Greenfield Standalone Recuperative Reforming plant on the Planet**
- **Commercial Reference** of Technology, successful operation of 2 years
- Performance above expectations; **Lowest intrinsic CO<sub>2</sub> intensity**

## Small SMR's



- 3 highly modularized Small SMR plant in operation
- The West Coast Plant (Nevada) produces 30 TPD renewable hydrogen for the mobility market **based on biomethane feedstock and renewable power**

## HyCO SMR's



- Several **SMR based HyCOs** plants **under implementation.**
- The lead prevails for **high temperature SMR + CO-Cold Box** Technology Combination.
- All plants include **CO<sub>2</sub> capture and recycle** to **ensure wide operating window** for H<sub>2</sub> & CO product.

## Mega SMR's



- **5 large Hydrogen SMR's** **under construction**
- **One fully modularized Mega SMR** under implementation with Samsung Engineering for 5000 MTPD combined reforming based MeOH Plant



# A Complete Portfolio for Carbon Capture and Liquefaction

## MEMBRANES

- CO<sub>2</sub> capture on natural gas or flue gases (10-30% CO<sub>2</sub>)
- Two proprietary brands of Hollow Fiber Membranes: MEDAL™ and Porogen™



## AMINES

- CO<sub>2</sub> Capture on syngas or flue gas
- Air Liquide engineering based on BASF OASE MDEA or OASE White solvents



## RECTISOL™ / RECTICAP™

- CO<sub>2</sub> capture on Pressurized Syngas H<sub>2</sub> production with ATR
- Physical Wash with MeOH Solvent+refrigerant



## CRYOCAP™

H<sub>2</sub> Production



**CRYOCAP™**  
H<sub>2</sub>

Oxycombustion



**CRYOCAP™**  
OXY

Steel Production



**CRYOCAP™**  
Steel

>15% Flue Gas



**CRYOCAP™**  
FG

CO<sub>2</sub> Liquefaction

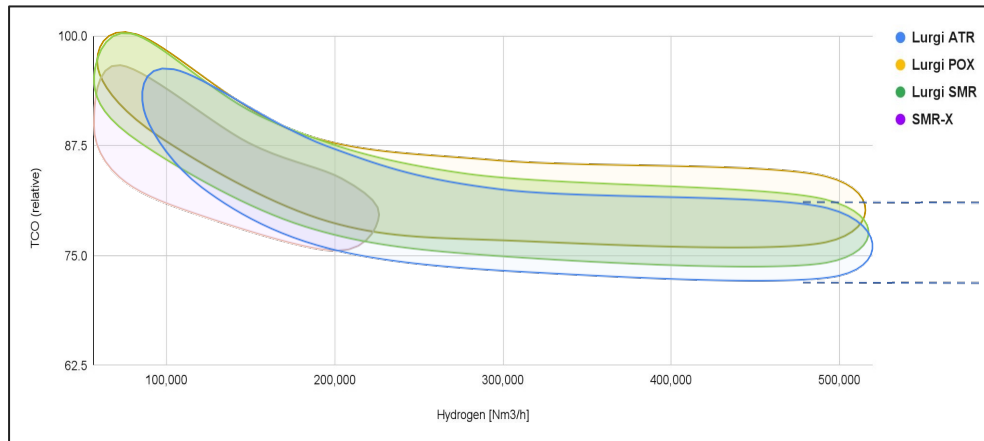


**CRYOCAP™**  
XLL



# Sustainability focused, optimized levelized cost comparison....

- Comprehensive cost map was created for low carbon Hydrogen including performed process studies, proposals and awarded projects - all normalized to a single table (see note)



Impact of process  
optimization and  
selected CO<sub>2</sub>  
Capture  
Technology

- Benefiting from our unique technology portfolio portion all relevant Syngas Generation Technologies and Carbon Capture Technologies were included
- Capacity boundaries of single train limitations were considered

The picture is clear now:

**#1 For the lower end of spectrum: SMR-X™ is the syngas technology of choice**  
**#2 ATR technology is the most suitable route for large scale low carbon hydrogen production**



1. Calculated at carbon pricing of \$100/tonne (\$22m/year over 20 year life of 500k Nm<sup>3</sup>/h plant) and sequestration costs of \$40/tonne. 2. At current EU carbon pricing of \$50/tonne, \$11m/year over 20 year life of plant. 3. Natural gas and electricity costs assumed to be \$5.3/mmBTU and \$0.05/kWh, respectively, with a carbon intensity of electricity import of 200 g/kWh. 4. Every point represent a study, proposal case with flow sheet and closed simulation 5. Capex based on inhouse data leveraging our full EP and EPC capability for each technology brick. 6. Assumed capital charge is 21%.

# Air Liquide SMR-X™ - Next Generation SMR Technology

56,000 Nm<sup>3</sup>/h H<sub>2</sub> production  
Operating since 2020



## High Efficiency Heat Exchange Reforming

- Combined SMR & HER within reformer tubes
- 20% reforming duty from internal HER
- No special catalyst configuration → employs widely conventional referenced SMR catalysts

## Summary of Benefits

- Maximum H<sub>2</sub> yield → 5% increase <sup>1)</sup>
- Minimized CO<sub>2</sub> footprint → 5% reduction <sup>1)</sup>
- 20% less fuel firing <sup>1)</sup>
- Zero steam export
- Lower H<sub>2</sub> cost vs. conventional low steam designs
- Compact, bottom fired furnace → Low CapEx
- Smaller flue gas WHRS → Low CapEx

1) Compared to a conventional SMR plant with zero steam export

**Intrinsic Low Carbon Intensive SMR Process → most efficient low carbon H<sub>2</sub> reforming technology for small / mid size capacities at zero steam**



# Air Liquide's Lurgi ATR Technology

## Design and Process Condition Flexibility

- Natural Gas, Refinery Off Gases, Reformed Gas in Combined Reforming setup
- Outlet temperature 950 -1050°C for plant heat balance optimization
- S/C 0.5 -1.2 mol/mol
- Operating pressure of 80 barg is possible
- Single Train Capacity up to 1,000,000 Nm<sup>3</sup>/hr

## Simple and Robust Equipment Design Features

- 3 layer refractory design
- Robust temperature monitoring
- Safe and reliable reactor controls
- Water Jacket (optional -depending on size, location or customer preference)

## Media Cooled Burner Design

- Proprietary Burner ensures good mixing and temperature distribution
- High lifetime of burner tip (up to 4 years without intermediate inspection)

## ATR Catalyst

- 2 layers concept using ReforMax Product from

**CLARIANT** 



ReforMax<sup>®</sup> 420

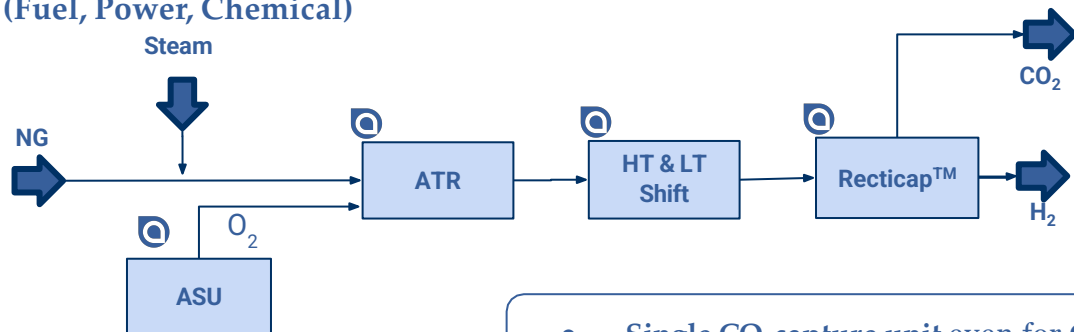


ReforMax<sup>®</sup> 330 LDP



# ATR based Low Carbon Syngas Solution for Hydrogen

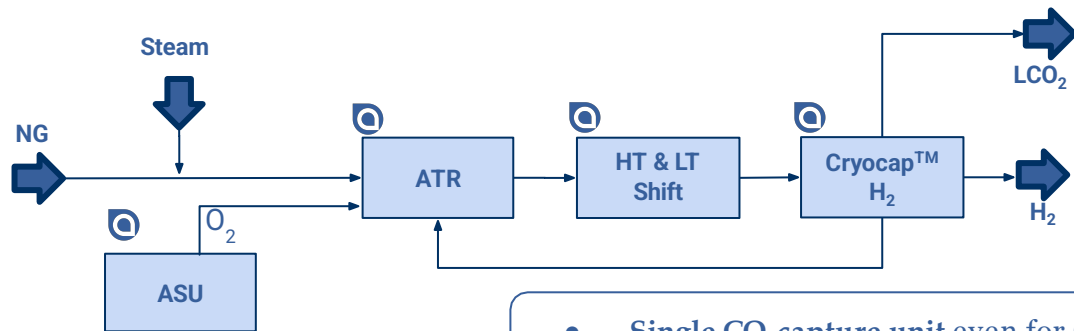
(Fuel, Power, Chemical)



**Preferred configuration for:**

- Fuel grade Hydrogen
- Scheme for gaseous CO<sub>2</sub> supply chain
- Electric power has high cost

- Single CO<sub>2</sub> capture unit even for Carbon Capture rate > 99%
- ATR & Recticap™ at ~60 bar enables single train capacities up to 1,000,000 Nm<sup>3</sup>/h H<sub>2</sub>

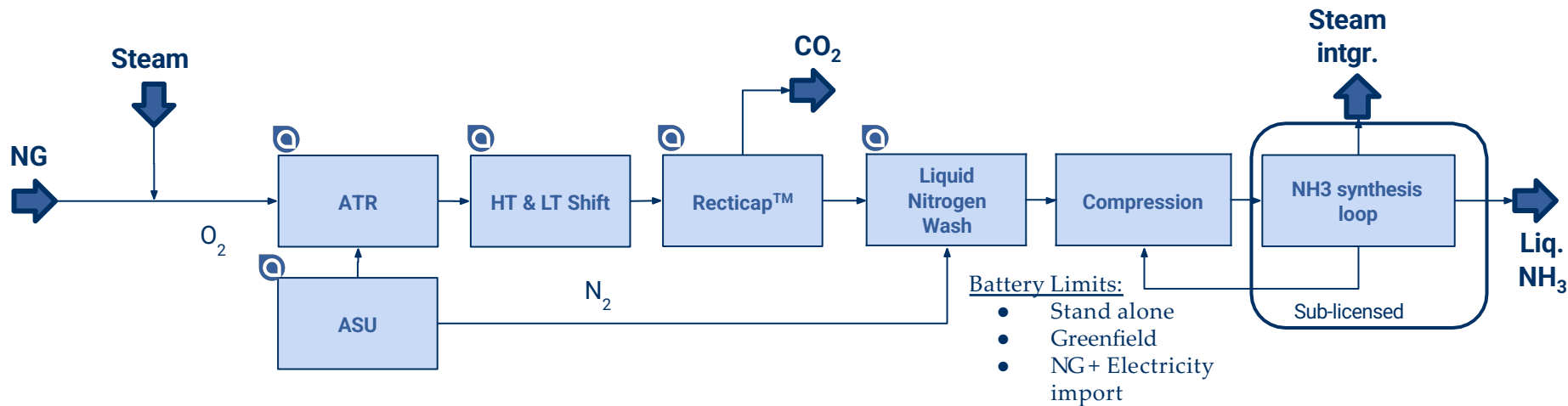


**Preferred configuration for:**

- Chemical grade Hydrogen
- Scheme for liquid CO<sub>2</sub> supply chain
- Electric power has low-medium cost

- Single CO<sub>2</sub> capture unit even for Carbon Capture rate > 99%
- ATR & Cryocap™ H<sub>2</sub> - enables lowest NG footprint and lowest Scope 3 Emissions

# ATR+Recticap™ enables large Low Carbon Ammonia Production



## Single stop technology solution provider for production of decarbonized syngas

- No “dragged” N<sub>2</sub>
- Recticap: energy efficient capture; higher intrinsic capture rate
- ATR + Recticap™ at higher operating pressure → Higher Syngas suction pressure → Lower Syngas Compression duty
- ATR + Recticap™ “The bigger, the better” → Maximum cost effectiveness at larger capacities e.g. 6000 mtpd
  - Best integration possible with referenced large scale ASU (world’s largest) and LNW (world’s largest) from the same technology provider

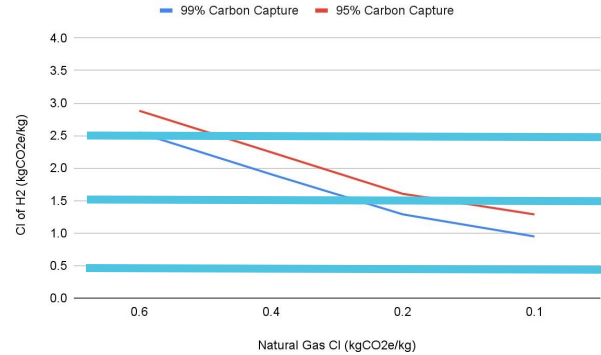
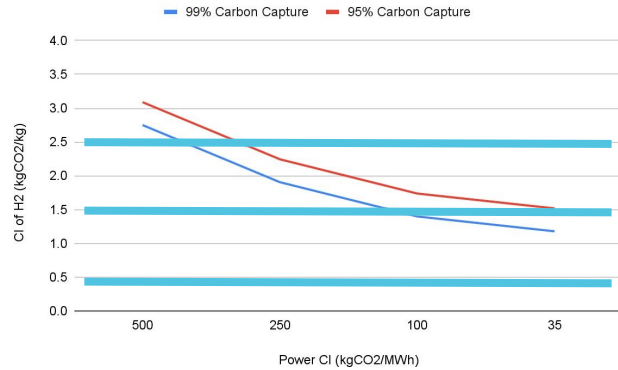
⇒ **Decarbonization of ammonia production happens in the syngas plant!!!**

# Legislations for Low-Carbon Hydrogen

	Australia	European Union	United Kingdom	United States
<b>Legislation</b>	Guarantee of Origin scheme	Renewable Energy Directive	Low-Carbon Hydrogen Standard	Bipartisan Infrastructure Law, Inflation Reduction Act (45Q, 45V)
<b>Key Points</b>	<ul style="list-style-type: none"> <li>- 18-month trial</li> <li>-measure and track emissions from hydrogen production, as well as the type of technology used to manufacture the hydrogen</li> <li>-test the design of a scheme that aims to assure the source of locally-produced hydrogen and its derivatives</li> </ul>	<ul style="list-style-type: none"> <li>-establishes rules to help the EU to meet its greenhouse gas emission reduction commitments under the Paris Agreement.</li> <li>-initiative (which will take the form of a delegated regulation) aims to establish a methodology to assess greenhouse gas emission savings from: renewable liquid and gaseous transport fuels of non-biological origin, and recycled carbon fuels.</li> </ul>	<ul style="list-style-type: none"> <li>-meet a GHG emissions intensity of 20g CO<sub>2</sub>e/MJLHV (~2.4 kgCO<sub>2</sub>e/kg) of produced hydrogen or less for the hydrogen to be considered low carbon</li> <li>-calculate their greenhouse gas (GHG) emissions up to the 'point of production' set out a risk mitigation plan for fugitive hydrogen emissions</li> <li>-meet additional requirements for the use of biogenic inputs, where relevant and as appropriate for the feedstock source and classification</li> </ul>	<ul style="list-style-type: none"> <li>-BIL: \$8 bn funding (from 2022-26) for minimum 4 clean hydrogen hubs.</li> <li>-45Q: tax credit of \$35-85/ton CO<sub>2</sub> sequestered for a period of 12 years.</li> <li>-45V: 4 distinct slabs with max tax credits of \$0.6-3.0/kg H<sub>2</sub> based on carbon intensity (Scope 1+2+3) of H<sub>2</sub> produced. Credits provided for a period of 10 yrs.</li> </ul>



# Economics with IRA 45Q, 45V



~99% Carbon Capture enables reaching top-tier IRA 45V ranges much easier.

With AL's Lurgi ATR combined with Cryocap™ / Recticap™, this is possible without additional hydrogen product firing or post combustion CC !!!

Case1: Power CI Sensitivity

CI of NG	kgCO <sub>2</sub> e/kg	0.4	0.4	0.4	0.4
CI of Power	kgCO <sub>2</sub> e/MWh	500	250	100	35
CI of H <sub>2</sub>	kgCO <sub>2</sub> e/kg	2.8	1.9	1.4	1.2
Credit with 45Q	\$/ton CO <sub>2</sub>	85	85	85	85
Credit with 45V	\$/kg H <sub>2</sub>	0.6	0.75	1	1
TCO with 45Q	Relative	105	100	97	96
TCO with 45V	Relative	118	105	88	87

Case 2: Natural Gas CI Sensitivity

CI of NG	kgCO <sub>2</sub> e/kg	0.6	0.4	0.2	0.1
CI of Power	kgCO <sub>2</sub> e/MWh	250	250	250	250
CI of H <sub>2</sub>	kgCO <sub>2</sub> e/kg	2.5	1.9	1.3	0.9
Credit with 45Q	\$/ton CO <sub>2</sub>	85	85	85	85
Credit with 45V	\$/kg H <sub>2</sub>	0.6	0.75	1	1
TCO with 45Q	Relative	104	100	96	95
TCO with 45V	Relative	117	105	88	86

Case 3: Power+NG CI Sensitivity

CI of NG	kgCO <sub>2</sub> e/kg	0.4	0.2	0.1
CI of Power	kgCO <sub>2</sub> e/MWh	250	0	100
CI of H <sub>2</sub>	kgCO <sub>2</sub> e/kg	1.9	0.4	0.4
Credit with 45Q	\$/ton CO <sub>2</sub>	85	85	85
Credit with 45V	\$/kg H <sub>2</sub>	0.75	3	3

Top-2 tiers in 45V can prove more attractive for project lifetime than 45Q benefits !  
**Design Target:** Low-carbon solution with highest carbon capture rate to minimize CI of H<sub>2</sub>.

With AL's Lurgi ATR + Cryocap™ / Recticap™ we can achieve max. IRA 45V Credit !!

# AL E&C: The Techno Power House

We combine the best low-carbon syngas technologies with EPC capabilities and operation mindset.



ATR and SMR plants at Scale



SMR with World's Largest Hydrogen Liquefier



World's Largest ASU  
5800 mtpd

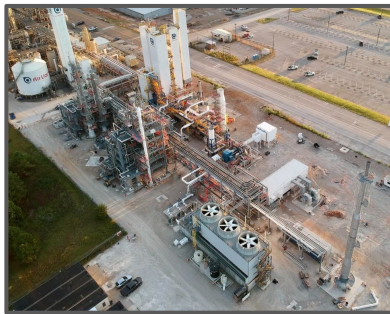


Large Scale MeOH  
Synthesis



Fully integrated Ammonia Plant

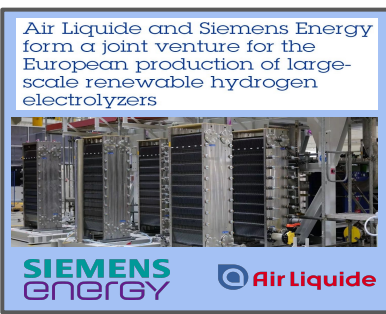
## Thank you for your attention!



GasPOX without direct emissions  
~20,000 Nm<sup>3</sup>/h Syngas



Hydrogen & CO<sub>2</sub> PSAs



Electrolyzer at Scale up



Large Scale Rectisol™  
1,000,000 Nm<sup>3</sup>/h Syngas



Cryocap™ H<sub>2</sub>  
First Commercial Cryogenic CO<sub>2</sub> Separation