TO ALL OUR CUSTOMERS,

We are pleased to share with you our new Technology Handbook. It provides a comprehensive overview of our portfolio of advanced technologies designed to provide sustainable solutions to your business.

Our ambition is to be the partner of choice for the design, engineering and construction of state-of-the-art production units worldwide. We work continuously to increase the value of our technologies and expand our knowledge to serve our customers better. Innovation is vital, and our internal technology experts and research networks work closely with our development teams and plant operators to develop ideas and new approaches that meet our clients’ needs. We stay close to the markets and customers we serve, allowing us to develop our technological leadership for our customers’ benefit.

A fundamental goal at Air Liquide Engineering & Construction is to provide our customers with competitive solutions that are safe and reliable. Our aim is to make sure that our customers can secure the best possible performance from their operations and make the most efficient use of natural resources that support the transition to a low-carbon society.

We are helping to reduce carbon emissions, developing new technologies and skills to support energy transition.

We encourage you to contact us through our regional offices or one of our technology groups. Our experts and project leaders will be at your disposal and ready to offer additional information to help your business grow and prosper.
We are present in 78 countries with approximately 64,500 employees, serving more than 3.8 million customers and patients.

Oxygen, nitrogen and hydrogen are essential small molecules for life, matter and energy. They embody Air Liquide’s scientific territory and have been at the core of the company’s activities since its creation in 1902.

Air Liquide’s ambition is to be a leader in its industry, deliver long term performance and contribute to sustainability - with a strong commitment to climate change and energy transition at the heart of its strategy. The company’s customer-centric transformation strategy aims at profitable, regular and responsible growth over the long term. It relies on operational excellence, selective investments, open innovation and a network organization implemented by the Group worldwide. Through the commitment and inventiveness of its people, Air Liquide leverages energy and environment transition, changes in healthcare and digitization, and delivers greater value to all its stakeholders.
Air Liquide Engineering & Construction, the engineering and construction business of the Air Liquide Group, builds the Group’s production units – mainly air gas separation and low carbon or renewable hydrogen production units – and supplies external customers with its portfolio of technologies. Its industrial gas, energy conversion and gas purification technologies enable customers to optimize the use of natural resources.

We cover the entire project life-cycle: from license engineering services / proprietary equipment, high-end engineering and design capabilities, as well as project management, commissioning and execution. Our exclusive and innovative technologies are contributing to the transition of the energy sector.

We are at work, connecting people and ideas everywhere to create advanced technologies to solve customer issues and deliver innovation for a sustainable world.
Inventiveness, open-mindedness, sharing, agility and entrepreneurial mindset are fundamental features of our innovation approach.

Our Group’s innovation network is built on science, technologies, and dedicated investments. It is focused on developing new approaches and services for customers and patients, accelerated by digital transformation. It is part of an open ecosystem in which advances are rapidly shared across Air Liquide and with our external scientific partners and start-ups.

Innovation improves our customers’ experience, contributes to growth and to the creation of a more sustainable world.

We innovate across all our areas of activity, balancing the drive for innovation with a commitment to preserve and maintain core products. By combining this pragmatic approach with technical creativity, our teams deliver unique solutions that make a real difference to our customers. Here are just a few examples of recent innovations.
Innovation for sustainability

**Electrolyzers for sustainable hydrogen production**
We supported the construction of the world’s largest PEM (Proton Exchange Membrane) electrolyzer operating in the world today. Located in Becancour, Canada, it has a capacity of 20 MW and a production of up to 8.2 tons of hydrogen per day. We also signed a Memorandum of Understanding with Siemens Energy, with the objective to combine our expertise in PEM and AEM (Anion Exchange Membrane) electrolysis technologies.

**SMR-X, a zero steam hydrogen plant solution**
SMR-X enables zero steam hydrogen production, with 4% natural gas fuel savings and 4% reduced CO₂ emissions compared to conventional installations.

**Hydrogen production unit with Cryocap™, CO₂ cold capture system**
Cryocap™ enables the capture of CO₂ released during hydrogen production via a cryogenic process. The first industrial deployment of this technology was made in Port-Jérôme, France, at the largest steam methane reforming hydrogen production unit operated by Air Liquide.

**World’s largest plants for industrial gas production**
We have designed and assembled the largest single train air separation unit ever built. With a total capacity of 5,800 tons of oxygen per day (at mean sea level), the unit will supply industrial gases to the Secunda site for Sasol in South Africa. By 2030, Air Liquide will reduce the CO₂ emissions of the plant by 30-40% through the sourcing of 600 MW of renewable energy.

**Hydrogen Liquefaction**
With growth in hydrogen mobility and the transition to low carbon societies, we are supporting the construction of the largest hydrogen liquefaction plant in the world in South Korea which will have a production capacity of 90 tons per day of liquid hydrogen and will be operational by July 2023.
Our commitment to safety

We execute all our activities across the globe by ensuring the Health, Safety, Environmental Protection and Security (HSES) of our employees and stakeholders. This responsibility is deeply anchored in our culture and HSES is the core value providing us with the licence to operate.

WITH THE ACTIVE INVOLVEMENT OF THE LOCAL MANAGEMENT TEAMS WE ARE:

• Providing a healthy & safe work environment for our employees and other stakeholders;
• Continuously enhancing employee knowledge and skills;
• Protecting travelling employees and sites against security related risks and threats;
• Complying with applicable laws and regulations, and with our internal Standards and Policies, where the higher standard will prevail;
• Identifying and reducing industrial risks and exposure to hazards of our employees and stakeholders;
• Educating and recognizing HSES performance to improve awareness;
• Reporting, analyzing and communicating HSES related events to avoid any recurrence and to capitalize best practices.

Our safety commitment applies not only to our employees, but also to our contractors, customers, adjacent facilities and local communities. We ensure that safety is the responsibility of everyone and is a part of the Air Liquide Engineering & Construction culture driven by our behavioral-based ACT (Actively Caring Together) program. In this way, we are all safety leaders, and all share a commitment to the golden rule of safety first.

Our occupational HSES goal is simply stated “to achieve zero injuries, work-related illnesses and incidents”.

Air Liquide Engineering & Construction
Our commitment to sustainability

It is time to ACT for a sustainable future.
In full support of the 2015 Paris agreement, Air Liquide commitments for sustainability address the urgency of climate change and energy transition.

Air Liquide Engineering & Construction will also deploy a broad range of low-carbon solutions for its clients to help them decrease their CO₂ footprint:
• Carbon capture
• Hydrogen liquefaction
• Low carbon or renewable hydrogen
• Sulfur recovery
• Green chemicals
• Renewable fuels

Supporting sustainability also involves actions in our own activities in engineering, manufacturing or on our sites to minimize environmental impact, leveraging new ways of digital transformation.

Targeting carbon neutrality by 2050 with key intermediary milestones in 2025 and 2035:
• to start reducing its absolute CO₂ emissions around 2025
• to reach a 33% decrease of its Scope 1 & 2 CO₂ emissions by 2035 compared to 2020
TABLE OF CONTENTS
We are pushing technology limits in the design and delivery of low carbon solutions for industry and offer fully integrated technology solutions for the production of Hydrogen and Syngas, providing our customers with the flexibility to meet their industrial needs.
Large Electrolyzer

**Description**
Large Electrolyzer solutions are fully integrated Hydrogen plants including the electrolyzer system, the electrical power distribution within the plant and harmonics filtration, the gas purification system (Hydrogen and optionally Oxygen), the downstream compression if necessary, the de-ionized water generation unit and the necessary utilities and site infrastructures for operation of the plant.

The electrolyzer technology is selected among the best-in-class Proton Exchange Membrane (PEM) and Alkaline technologies, and optimized according to specific project requirements such as power cost, footprint, project scale.

**Main features:**
- Optimization of Plant Total Cost of Ownership by selection of the most relevant technology
- Valorization of Oxygen and/or heat as a by-product
- Indoor solutions for ease of maintenance
- Full integration with various processes (Ammonia synthesis, Methanol synthesis, H₂ Liquefaction)

**References**
3 (> 10 MW)

**Contact**
electrolyzers@airliquide.com

**Application**
“Low-carbon Hydrogen” production for refining, chemicals, steel making, mobility

**Feedstock**
Water, renewable/low-carbon electricity

**Product**
Hydrogen

**Co-product**
Optionally Oxygen, heat

**Capacity**
Electrolyzer plants > 2,000 Nm³/h H₂

**Economics**
Opex:
Approx. 5.0 kWh/Nm³ H₂, depending on H₂ delivery pressure
Capex:
Available upon inquiry

**Diagram**
![Electrolyzer PFD](image)

**Process**
Water -> Electrolyzer Stack -> O₂ and H₂ Conditioning section (Purification, Compression...) -> O₂, H₂ Gas Separator -> AC/DC -> Electric Power -> H₂ Conditioning section (Purification, Compression...) -> H₂ Gas Separator -> Process Water

Electrolyzer Stack

**Economics**
Opex:
Approx. 5.0 kWh/Nm³ H₂, depending on H₂ delivery pressure
Capex:
Available upon inquiry

**Application**
“Low-carbon Hydrogen” production for refining, chemicals, steel making, mobility

**Feedstock**
Water, renewable/low-carbon electricity

**Product**
Hydrogen

**Co-product**
Optionally Oxygen, heat

**Capacity**
Electrolyzer plants > 2,000 Nm³/h H₂

**Economics**
Opex:
Approx. 5.0 kWh/Nm³ H₂, depending on H₂ delivery pressure
Capex:
Available upon inquiry
Onsite Electrolyzer

Description
Onsite Electrolyzer solutions are fully packaged Hydrogen plants including the electrolyzer system, the Hydrogen purification system, the de-ionized water generation unit and the necessary utilities for operation of the plant. Optionally oxygen purification, downstream compression and storage can be included. The onsite electrolyzer plants are standardized and delivered in containers (electrolyzer and utilities) for easy and fast outdoor installation.

Main features:
• Standard electrolyzer solutions for short lead-time
• Outdoor solutions for fast installation
• Optional integration with compression and storage solutions for H₂

References
> 30 (< 5 MW)

Contact
electrolyzers@airliquide.com

Application
“Low-carbon Hydrogen” production for onsite Hydrogen generation, mobility

Feedstock
Water, KOH (for alkaline), renewable/low-carbon electricity

Product
Hydrogen

Co-product
Optional: Oxygen

Capacity
Alkaline electrolyzer units < 100 Nm³/h H₂
PEM electrolyzer units between 100 to 500 Nm³/h H₂

Economics
Opex:
approx. 5.0 kWh/Nm³ H₂
Capex:
Available upon inquiry
Hydrogen Liquefier (small to mid scale)

**Application**
Liquefaction of all kinds of H₂ streams to optimize the H₂ logistics chain (Liquid hydrogen is 850 times denser than gaseous hydrogen at atmospheric pressure): storage, transport by trailers and ships, to final-users for mobility markets and for industrial applications

**Feedstock**
Many energy sources: natural gas, biomass, renewables with different production technologies, Electrolysis or Steam Methane Reforming, with carbon capture. Industry off-gases

**Product**
Liquid hydrogen (>95% Para)

**Co-product**
None

**Capacity**
0-100 tpd

**Economics**
Opex:
7-10 kWh/kg LH₂
Capex:
20 - 100 MEUR

**Description**
Hydrogen to be liquefied may come from different sources. A warm purification upstream of the liquefier may be requested in addition to the cold purification in the liquefier itself, which is dedicated to the removal of the last traces of impurities. H₂ is first precooled from ambient temperature to 80K (-190° C) with a close nitrogen refrigeration loop and the use of a turbo-expander together with cryogenic exchangers.

H₂ is then cooled down to 20K and liquefied thanks to a H₂ cycle and the use of cryogenic expanders together with a highly optimized cryogenic exchangers’ arrangement. Once liquid, H₂ is expanded to reach the storage pressure through a JT valve or a liquid turbine for more efficiency.

The two steps of the liquefier use brazed aluminium heat exchangers (widely used in Cryogenics).

The particularity of hydrogen liquefaction is the use of a catalyst to convert ortho-hydrogen into para-hydrogen in order to reduce boil-off in storage and the logistic chain.

Boil-off from LH₂ storage and trailers can be sent back to the liquefier in order to recover H₂ molecules. Downstream infrastructures (storage, loading bays, etc.) can also be supplied.

Main features:
- Highly efficient technologies, relying on decades of operational experience
- High quality design and manufacturing (in-house)
- In-house hydrogen expansion turbines (gas and liquid)
- Low maintenance costs & high reliability

**References**
10 units in operation by Air Liquide or third party (1 to 10 tpd)
3 units under construction (5, 30 and 90 tpd)

**Contact**
hydrogenliquefaction@airliquide.com
Hydrogen Liquefier (large scale)

**Description**

Hydrogen to be liquefied may come from different sources. A warm purification upstream of the liquefier may be requested in addition to the cold purification in the liquefier itself, which is dedicated to the removal of the last traces of impurities. H₂ is first precooled from ambient temperature to 80K (-190°C) with a close Mixed Refrigerant refrigeration loop, derived from our liquefaction expertise, and the use of a JT valve together with cryogenic exchangers.

H₂ is then cooled down to 20K and liquefied thanks to a H₂ cycle and the use of cryogenic expanders together with a highly optimized cryogenic exchangers’ arrangement. Once liquid, H₂ is expanded to reach the storage pressure through a liquid turbine.

The two steps of the liquefier use brazed aluminium heat exchangers (widely used in Cryogenics).

The particularity of hydrogen liquefaction is the use of a catalyst to convert ortho-hydrogen into para-hydrogen in order to reduce boil-off in storage and the logistics chain. Boil-off from LH₂ storage and trailers can be sent back to the liquefier in order to recover H₂ molecules. Downstream infrastructures (storage, loading bays, etc.) can also be supplied.

**Main features:**
- Highly efficient technologies, relying on decades of operational experience
- High quality design and manufacturing (in-house)
- In-house hydrogen expansion turbines (gaz and liquid)
- Low maintenance costs & high reliability

**Application**

Liquefaction of all kinds of H₂ streams to optimize the H₂ logistics chain (Liquid hydrogen is 850 times denser than gaseous hydrogen at atmospheric pressure): storage, transport by trailers and ships, to final-users for mobility markets and for industrial applications

**Feedstock**

Many energy sources: natural gas, biomass, renewables with different production technologies: Electrolysis or Steam Methane Reformer with carbon capture

**Product**

Liquid hydrogen (>95% Para)

**Co-product**

None

**Capacity**

>60 tpd per train

**Economics**

Opex:

<7 kWh/kg LH₂

Capex:

From 50 MEUR

**References**

10 units in operation by Air Liquide or third party (1 to 10 tpd)

3 units under construction (5, 30 and 90 tpd)

**Contact**

hydrogenliquefaction@airliquide.com
Small-Scale Standard Hydrogen Plant

Description

The small-scale standard H₂ plant product is based on hydrogen production via steam reforming of hydrocarbon feedstocks. Additionally a CO-shift and PSA unit are included to maximize the H₂ yield and purify the H₂. For more details regarding the process technology reference is made to the description of Steam Methane Reforming (SMR).

The small-scale standard H₂ plant product includes four different plant sizes with pre-defined equipment, piping arrangement and lay-out.

Its design is optimized for minimum total cost of ownership, but nevertheless allows for considerable process flexibility.

The product is suitable for receiving different types of feedstocks, its configuration may be selected for high or low steam co-product ratios with an option for high export steam quality. A pre-reformer may be included as well, particularly in combination with liquid feedstocks.

Main features:
- Design of standard plant allows for considerable process flexibility
- High degree of modularization to limit exposure during construction
- Compact plant layout and small foot-print
- Delivery time < 15 month FOB from project award

References
>20 (6 in last 10 years)

Contact
hydrogen-syngas@airliquide.com

Application
Hydrogen production by steam reforming in a highly standardized and modularized plant

Feedstock
Natural gas, refinery off-gas, LPG, naphtha

Product
Hydrogen

Co-product
Steam

Capacity
15,000 - to 45,000 Nm³/h H₂

Economics
Opex:
Feed+Fuel: 14.5 to 15.0 MJ/Nm³ H₂ (Figures based on nat. gas feed & fuel)

Capex:
25 to 60 mm USD

Application
Hydrogen production by steam reforming in a highly standardized and modularized plant

Feedstock
Natural gas, refinery off-gas, LPG, naphtha

Product
Hydrogen

Co-product
Steam

Capacity
15,000 - to 45,000 Nm³/h H₂

Economics
Opex:
Feed+Fuel: 14.5 to 15.0 MJ/Nm³ H₂ (Figures based on nat. gas feed & fuel)

Capex:
25 to 60 mm USD
SMR-X™ – Zero Steam Hydrogen Production

**Description**
SMR-X technology is based on a new generation steam methane reformer furnace with additional heat recovery of the reformed gas leaving the reaction zone back to the catalyst bed. To achieve this, the reformed gas passes via heat exchange tubes, located inside the main reformer tubes, before leaving the reformer.
Geometry and material of the internal heat exchange system is optimized for high efficiency and reliability. Consequently, utilization of SMR-X allows for a H₂ plant design with balanced steam production and consumption at superior overall process efficiency compared to conventional SMR technology. Also, highly efficient H₂ plant designs with very low steam co-export ratios are possible.
Furthermore, the plant’s steam system is simplified and the reformer size of SMR-X is reduced compared to a conventional furnace, because approximately 20% of the required process heat is supplied by internal heat exchange.

**Main features:**
- H₂ plant de-coupled from steam host
- Highest efficiency of all available zero steam solutions
- >5% reduction of CO₂ emissions compared to conventional SMR based zero steam design
- Attractive plant Capex due to compact reformer design

**Application**
Production of hydrogen in a radiative heat exchange steam methane reformer (SMR) without co-export of steam

**Feedstock**
Natural gas, refinery off-gas, LPG, naphtha

**Product**
Hydrogen

**Co-product**
None (optionally steam at low co-export ratio)

**Capacity**
Up to 100,000 Nm³/h hydrogen

**Economics**
**Opex:**
Feed+Fuel: Appr. 13.6 MJ/Nm³ H₂  (Figures based on nat. gas feed & fuel)

**Capex:**
25 to 135 mm USD

**Contact**
hydrogen-syngas@airliquide.com

Air Liquide Engineering & Construction Technology Handbook

Technology Handbook
**Application**
Generation of syngas by steam reformation of methane rich hydrocarbon

**Feedstock**
LPG, naphtha, natural gas, refinery off-gas

**Product**
Hydrogen, carbon monoxide, syngas or a combination thereof

**Co-product**
Steam, optionally carbon dioxide

**Capacity**
Per SMR train:
- 15,000 - to 200,000 Nm³/h H₂ plant
- 3,500 - 40,000 Nm³/h CO plant

**Economics**

- **Opex:**
  - H₂ plants (based on nat. gas feed & fuel):
    - Steam co-export ratio: 0.4 to 1.1 kg/Nm³ H₂
    - Feed+Fuel: 14.5 to 15.3 MJ/Nm³ H₂
  - HyCO plants (based on nat. gas feed & fuel):
    - H₂/CO product ratio: 1.8 to 4.2
    - Steam co-export ratio: 0.3 to 0.7 kg/Nm³ [H₂+CO]
    - Feed+Fuel: 14.2 to 14.8 MJ/Nm³ [H₂+CO]

- **Capex:**
  - H₂ and HyCO plants (incl. purification): 25 to 370 mm USD

**Description**
Feedstocks are desulfurized, mixed with steam and pre-heated.

Optionally a catalytic pre-reforming step may be foreseen to convert the feed/steam mixture to a methane rich gas to improve efficiency of the SMR.

The main reforming reaction takes place in the proprietary top-fired steam reformer in which the feed/steam mixture is converted while passing catalyst filled and heated tubes at temperatures of 800 to 940 °C and pressures of 15 to 45 barg. Reformed gas leaving the reformer contains H₂, CO, CO₂ and unreacted components.

Efficiency of the process and composition of the reformed gas can be adjusted via the process parameters reforming pressure, temperature and steam to feed ratio.

In case H₂ yield should be increased or maximized a catalytic shift reactor may be added and fed with reformed gas to convert CO and steam to additional H₂ and CO₂.

In case a high CO yield is targeted CO₂ may be separated from reformed gas and recycled to the SMR. Additional import CO₂ may be added if available.

Suitable product purification technologies include: PSA and membrane for H₂, amine wash (aMDEA) for CO₂ removal and methane wash Cold Box for CO.

**Main features:**
- Flexibility in process design to optimize for best efficiency, lowest Capex or lowest total cost of ownership
- Optimized integration of refinery off-gases for H₂ production and recovery
- Best in class plant reliability and operability through operational feedback from Air Liquide’s own plants.

**References**
> 140 (> 40 in last 20 years)

**Contact**
hydrogen-syngas@airliquide.com
Low Carbon H₂ Solutions

**Application**
Production of low carbon hydrogen from a hydrocarbon feedstock

**Feedstock**
Natural Gas, LPG, Refinery Off Gas, Light Naphtha

**Product**
Hydrogen

**Co-product**
Steam, CO₂

**Capacity**
10,000 - 1,000,000 Nm³/hr

**Economics**
Economics are highly dependent on feedstock and CO₂ requirements. It is recommended to perform a plant specific total cost of ownership investigation and optimization to meet the client’s needs. Contact us for more information

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**Description**

Pretreated feedstock is processed to raw synthesis gas by using one of the Air Liquide’s proprietary syngas generation technologies such as Steam Methane Reforming (SMR), Autothermal Reforming (ATR) or Partial Oxidation (POX).

To increase the hydrogen yield of the raw synthesis gas, a CO-Shift conversion step is considered.

Hydrogen is purified by using a Pressure Swing Adsorption (PSA) technology.

Depending on the carbon capture requirements, CO₂ can be separated from the process at three different locations:

- CO₂ Removal from syngas upstream the PSA unit using Amine Wash, or Air Liquide proprietary Rectisol™ or Recticap™ technology
- CO₂ Removal from PSA off gas using Air Liquide proprietary Cryocap™ H₂ technology
- CO₂ Removal from flue gas at fired heater stack using Amine Wash or Air Liquide proprietary Cryocap™ FG technology.

**Contact**
hydrogen-syngas@airliquide.com
Autothermal Reforming for low carbon hydrogen

**Application**
Large scale production of hydrogen from natural gas. Hydrogen may be used for fuel and chemical applications. Side product CO₂ is at high purity and both gases are at pressure for easy processing. The CO₂ stream may be captured, stored or re-used to produce low carbon Hydrogen.

**Feedstock**
Natural gas

**Product**
Hydrogen, Carbon dioxide

**Co-product**
High pressure steam

**Capacity**
From 200 kNm³/h hydrogen to 900 kNm³/h hydrogen

**Economics**
Capex: between $ 200 mil and $ 700 mil (excl. ASU)

**Description**
The Lurgi ATR is combining the reforming of natural gas to syngas and the production of required energy in one reactor. Required oxygen for the reaction is provided through an ASU. All products from natural gas use are in one stream at a pressure of 35 bar or higher. The resulting syngas mixture is treated in a shift reactor in order to convert all CO to CO₂. Depending on the site specifics, CO₂ is separated and purified in a Cryocap™ or Recticap™ plant. Hydrogen can be purified in a PSA. Clean CO₂ under pressure is ready for capturing and storage. Liquefaction of CO₂ is also available.

**Main features:**
- Entire technology portfolio (ATR, ASU, Shift, Cryocap™, Recticap™, PSA, CO₂ liquefaction) available from Air Liquide
- ATR is a large-scale solution for the production of low carbon hydrogen
- The CO₂ side product is easily separated and purified and ready for capturing/use.

**References**
Air Liquide has licensed >40 ATR units

**Contact**
chemicals@airliquide.com
Gas POX – Natural Gas Partial Oxidation

**Application**
Production of CO, oxogas and syngas by partial oxidation of hydrocarbon feed in a refractory lined reactor

**Feedstock**
Natural gas, refinery offgas

**Product**
Syngas (H₂/CO < 1), oxogas, carbon monoxide

**Co-product**
Steam

**Capacity**
Up to 150,000 Nm³/h syngas

**Economics**
- Oxygen consumption: 0.32 to 0.38 kg/Nm³ syngas (dry)
- Capex: 10 to 100 mm USD

**Description**
Feed gas is desulfurized, mixed with steam and preheated in a fired heater.
Feed, steam and oxygen are fed from the proprietary burner to a refractory lined reactor operating at up to 100 barg, where H₂, CO and CO₂ are produced via partial oxidation.
Reformed gas is cooled down producing high pressure steam. CO₂ is removed from the syngas in an amine wash unit.
In case a high CO yield is targeted CO₂ may be separated from syngas and recycled to the POx. Additional import CO₂ may be added if available.
Suitable product purification technologies include: PSA and membrane for H₂, oxogas, amine wash (aMDEA) for CO₂ removal and partial condensation Cold Box for CO.

**Main Features:**
- Efficient technology for products with low H₂/CO ratio or for pure CO production
- Revamp of residue POx reactors allows for switching to more economic nat. gas feed
- Low CO₂ footprint

**References**
6

**Contact**
hydrogen-syngas@airliquide.com
Lurgi MPG™ – Multi-Purpose Gasifier

**Description**

The feedstock together with oxygen and steam is fed via the proprietary MPG-burner into the refractory lined entrained flow reactor operating at 30 to 100 barg, where it reacts in a non-catalytic partial oxidation at typically 1,200 to 1,500 °C to form syngas. The syngas leaving the bottom of the reactor is cooled by quench or in a waste heat boiler, depending on feedstock characteristics and downstream usage.

The proprietary MPG-burner design allows a wide variety of feedstock properties to be handled safely and reliably, covering high viscosity and even occasional particles up to millimeter size. The pressurized water cooling of the burner insures safe operation under all conditions. The technology may also be adapted to the usage of slurries with solid content or bio-based syn crude.

**Main Features:**

- Valorization of residues capable of converting almost any liquid feedstock
- Highly tolerant to impurities
- High pressure

**Application**

Utilization of all kinds of liquid hydrocarbon residues from refinery or chemical processes for the production of syngas by non-catalytic partial oxidation

**Feedstock**

Typical feedstocks are residue from oil refining like: asphalt, bitumen, tar, visbreaker residue, hydrocracker residue, FCC residue, vacuum residue, coal tar, oil sand tar, etc.

**Product**

Syngas (H₂ + CO)

**Co-product**

None

**Capacity**

Up to 200,000 Nm³/h dry syngas per gasifier

**Economics**

Individual costs vary significantly depending on feedstock, size, location, integration in refinery, etc.

**Oxygen consumption:**

0.7 Nm³ O₂/kg feed

**Capex:** 180 to 400 mm USD

**Contact**

hydrogen-syngas@airliquide.com
**Pressure Swing Adsorption (PSA) Hydrogen Purification**

**Description**
Pure H₂ product is delivered at a pressure close to feed pressure (pressure drop across PSA could be as low as 0.5 bar) and impurities are removed at a lower pressure (typical PSA offgas pressures range from 1.1 to 10 bara).

The PSA tail-gas, containing impurities, can be sent back to the fuel system (SMR burners or refinery fuel network) with or without the need of a tail-gas compressor. Operation is fully automatic.

PSA units use the most advanced adsorbents on the market and patented high efficiency cycles to provide maximum recovery and productivity. Typical on-stream factors are >99.9%.

Turndown can be as low as 25%.

PSA units are compact, fully skid-mounted and pre-tested units designed for outdoor and unmanned operation.

**References**
>70 (in operation or under construction)

**Contact**
hydrogen-syngas@airliquide.com
Hydrogen Separation Membranes

**Description**

Our membranes operate on the basis of selective permeation. Each membrane is composed of millions of polymeric hollow fibers similar in size to the diameter of a human hair. The “fast gases,” or gases with a higher permeation rate, permeate through the membrane into the hollow interior and are channeled into the permeate stream. Simultaneously, the “slower gases” flow around the fibers and into the residue stream. As a result, the fibers have the ability to selectively separate a fast gas like hydrogen from carbon monoxide, methane, heavier hydrocarbons and other slower gases.

The process begins when pressurized feed gas is routed to the coalescing filter to remove contaminants and protect the membranes’ fiber from liquid aerosols and particulates. Feed gas is then preheated before entering the membranes. The membranes then separate the feed into the hydrogen-rich permeate and hydrogen-lean residue. The separation of permeate and residual gas is driven by the hydrogen partial pressure difference between the feed gas and permeate gas, as well as our advanced polymer material. The non-porous hollow fiber membranes selectively allow faster molecules to permeate the membrane wall while slower, bulkier molecules remain on the high pressure side.

**Main Features:**
- No moving parts
- Skid mounted systems cartridge design for simple installation
- Estimated payback period of less than a year
- High permeability membranes for compact, low capital system design
- Unrestrained turndown capabilities
- Linear scale up for all size systems
- Hollow fiber membranes offer higher area to volume efficiency resulting in better packing efficiency, smaller footprint and reduced weight and module count.

**Contact**

hydrogen-syngas@airliquide.com

**Application**

Recovery of hydrogen in refinery or chemical plants purge gas
H₂ / CO ratio adjustment

**Feedstock**

Any purge gas streams with hydrogen concentrations >20% (vol).

**Product**

Hydrogen (>99% vol achievable)

**Co-product**

None

**Capacity**

Membrane systems are truly scalable with virtually no upper capacity limit. Largest system referenced by Air Liquide: 124 membrane cartridges.

**Economics**

**Opex:**
- Dependant on feedstock quality
- Hydrogen recovery > 98%
- 50% + turndown capabilities

**Capex:**
1 mm to 10 + mm USD

**Feed Gas**

**Coalescing Filter**

**Preheater**

**Hydrogen Rich Permeate**

**Permeator**

**Hydrogen Lean Residual**

**Application**

Recovery of hydrogen in refinery or chemical plants purge gas
H₂ / CO ratio adjustment

**Product**

Hydrogen (>99% vol achievable)

**Co-product**

None

**Capacity**

Membrane systems are truly scalable with virtually no upper capacity limit. Largest system referenced by Air Liquide: 124 membrane cartridges.

**Economics**

**Opex:**
- Dependant on feedstock quality
- Hydrogen recovery > 98%
- 50% + turndown capabilities

**Capex:**
1 mm to 10 + mm USD

**Feed Gas**

**Coalescing Filter**

**Preheater**

**Hydrogen Rich Permeate**

**Permeator**

**Hydrogen Lean Residual**

**Application**

Recovery of hydrogen in refinery or chemical plants purge gas
H₂ / CO ratio adjustment

**Product**

Hydrogen (>99% vol achievable)

**Co-product**

None

**Capacity**

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**Feed Gas**

**Coalescing Filter**

**Preheater**

**Hydrogen Rich Permeate**

**Permeator**

**Hydrogen Lean Residual**
Hydrogen Extraction from Natural Gas Pipelines

**Application**
Separation of Hydrogen and Natural Gas in Natural Gas Pipeline Grids

**Feedstock**
Hydrogen-enriched natural gas with hydrogen concentrations up to 20% (vol)

**Product**
Hydrogen (up to 99.999%)

**Co-product**
Natural Gas (Hydrogen < 0.5% vol)

**Capacity**
5,000 to 200,000 Nm³/h

**Economics**
- **Opex:** Dependant on feedstock pressure and hydrogen content in the feedstock
- **Capex:** Dependant on capacity and hydrogen content in the feedstock

**Description**
A unique combination of Air Liquide's Hydrogen Separation Membranes and Pressure Swing Adsorption designed for extracting or rejecting hydrogen injected into the natural gas pipeline grid. As hydrogen enriched natural gas becomes an important component of logistics in growing hydrogen economies, Air Liquide’s pioneering solution helps closing the value chain by allowing separation of H₂ and NG at the end user’s site.

Air Liquide’s membranes ensure removal of hydrogen upstream of natural gas consumers to a residual content of <0.5 vol% while keeping the natural gas product close to feed pressure.

The permeate, which is enriched in hydrogen may be either reinjected into the natural gas grid or further purified. After a compression step and depending on the degree of enrichment, the permeate is either sent to a 2nd stage membrane with a subsequent purification step in a Hydrogen PSA or is sent directly to the PSA to achieve a hydrogen purity of up to 99.999%.

For details regarding technologies used in this application see their respective pages.

**Main Features:**
- One-Stop-Shop: Air Liquide’s solution effectively combines its in-house membrane and PSA technologies
- In-house optimization of hybrid systems consisting of membranes, PSA and compression in terms of technological solution, Capex and Opex
- Skid-mounted, compact systems for simple installation
- Easily scalable for variations in feed hydrogen content and feed pressure

**Contact**
hydrogen-syngas@airliquide.com
Blue and Green Ammonia

**Application**

**Blue Ammonia:** Production of low carbon ammonia from hydrocarbon feedstock

**Green Ammonia:** Production of renewable ammonia from renewable feedstock

**Feedstock**

**Blue Ammonia:** Natural Gas, LPG, Refinery Off Gas, Light Naphtha

**Green Ammonia:** Renewable Electricity (REN), water

**Product**

Ammonia

**Co-product**

**Blue Ammonia:** CO₂ for sequestration or utilization

**Green Ammonia:** O₂

**Capacity**

> 50 MTPD Ammonia

**Economics**

Economics are highly dependent on feedstock and CO₂ requirements. It is recommended to perform a plant specific total cost of ownership investigation and optimization to meet the client’s needs.

Contact us for more information

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**Description**

**Blue Ammonia (low carbon ammonia)**

Pretreated feedstock is processed to raw hydrogen by using one of the Air Liquide’s proprietary syngas generation technologies such as Steam Methane Reforming (SMR), Autothermal Reforming (ATR) or Partial Oxidation (POx).

A CO-shift conversion shift is applied to increase the hydrogen yield.

CO₂ is removed from the raw hydrogen and captured for sequestration or utilization by one of Air Liquide’s proprietary carbon capture technologies Rectisol™, Recticap™, PSA + Cryocap™ or in an Amine wash.

In a final step, the gas is conditioned and nitrogen is added by utilizing one of Air Liquide’s Air Separation Unit (ASU) or Nitrogen Generation Unit products.

The blue hydrogen and N₂ will be converted to blue ammonia using a renowned third party ammonia licensor technology.

**Green Ammonia (renewable ammonia)**

Hydrogen is split from water by electrolysis and nitrogen is separated from air in an Air Liquide proprietary Nitrogen Generation Unit. For the ammonia synthesis, Air Liquide is able to team up with renowned ammonia synthesis technology providers.

**Contact**

hydrogen-syngas@airliquide.com
At Air Liquide, we are committed to making a difference through the abatement of CO₂ emissions for our own production facilities and for our customers. Our innovative suite of carbon capture and sulfur recovery technologies are helping customers to decarbonize their industrial facilities.
Acid Gas Removal – Amine Wash

**Application**
Removal of acid gases (CO₂, H₂S, COS) from natural gas, associated gases and unconventional gas sources

**Feedstock**
Natural gas

**Product**
Sweet natural gas, pipeline natural gas, LNG

**Co-product**
Acid gases

**Capacity**
Up to 1,500,000 Nm³/h per train

**Economics**
Economics are highly dependent on feedstock and requirements. It is recommended to do a plant specific TCO optimization to meet client’s needs. Contact us for more information

**Description**
Acid gases contained in raw gases are removed by absorption with an amine-based solvent. The rich solvent leaving the contactor is regenerated by flashing and stripping. The process configuration and solvent selection will be tailored according to feedstock and sweet gas application.

Air Liquide Engineering & Construction can offer very energy-efficient processes such as the BASF OASE® purple or OASE® yellow as well as other proprietary or generic amines for pipeline or liquefied natural gas specifications.

This process presents the advantage of very low hydrocarbon co-absorption. With selective processes deep H₂S removal with low to moderate CO₂ co-absorption can be achieved for pipeline specifications.

**References**
> 30 OASE references
> 80 total amine references

**Contact**
gas-treatment@airliquide.com
**CO₂ Removal from Flue Gas**

**Amine Wash**

**Application**
Removal of CO₂ from oxygen containing feed stock such as flue gas

**Feedstock**
Flue Gas with 3% to 25% CO₂

**Product**
Decarbonized Flue Gas, CO₂

**Capacity**
Up to 1,500,000 Nm³/h feed per train
Up to 4,000 tpd CO₂ per train

**Economics**
Economics are highly dependent on feedstock and requirements. It is recommended to do a plant specific TCO optimization to meet client’s needs. Contact us for more information.

**Description**
CO₂ contained in the flue gas is removed by absorption with an amine-based solvent. The rich solvent leaving the contactor is regenerated by flashing and stripping. Trace components such as particles and SOx are handled in the upstream pretreatment.

Air Liquide offers energy efficient solutions with highly stable, low maintenance solvents based on proprietary second generation amines. The process configuration will be tailored according to specific process requirements and optimized CAPEX and OPEX.

CO₂ capture rates of up to 95% can be reached irrespective of the feed’s CO₂ content.

Since the process has a very low co-absorption, CO₂ product specifications with CO₂ > 99.9% are achievable.

**Contact**
gas-treatment@airliquide.com
**CO₂ Removal from Flue Gas**

**Cryocap™ FG**

**Description**

The flue gas is first compressed, dried and sent to a PSA (Pressure Swing Adsorption). The PSA pre-concentrates the CO₂ in the offgas. It is compressed then sent to a cold process. There, the CO₂ is recovered by combination of partial condensation and distillation(s), which allow the removal of the heavy compounds such as NOx and the light elements such as O₂, Ar, N₂, NO and CO. The CO₂ product is compressed, condensed and pumped up to supercritical pressure or directly produced under liquid.

The pressurized nitrogen from the PSA is expanded to recover energy.

**Main features:**

- Cryocap™ FG allows very high CO₂ recovery (up to 95%) and near zero-emission to the atmosphere (SOx, particulate matter, NOx, Hg).
- Cryocap™ FG is a solvent free solution that runs on electricity rather than thermal energy. It can run on renewable energy to further reduce the environmental footprint of the sites equipped on.

**Reference**

Multiple Pre-FEEDs/FEEDs/PDP under execution

**Contact**

cryocap@airliquide.com
**CO₂ Removal from Syngas Amine Wash**

**Application**
Removal of CO₂ from syngas or other feed gases irrespective of pressure level or CO₂ content.

**Feedstock**
Syngas

**Product**
Syngas with low CO₂ specification and/or CO₂, Blue Hydrogen

**Capacity**
- Up to 500,000 Nm³/h feed per train
- Up to 5,000 tpd CO₂ per train

**Economics**
- Opex + Capex: -35 to 45 USD/tonne of CO₂
- Economics are highly dependent on feedstock and requirements. It is recommended to do a plant specific TCO optimization to meet client’s needs.
- Contact us for more information

**Description**
CO₂ contained in the raw gas is removed by absorption with an amine-based solvent. The rich solvent leaving the contactor is regenerated by flashing and stripping.

Air Liquide Engineering & Construction offers very energy-efficient processes such as BASF OASE® white.

The process configuration will be tailored according to treated gas requirements and CO₂ product specification as well as optimized CAPEX and OPEX. To this end, this process can be heat-integrated with the upstream gas generation.

CO₂ specifications in the treated gas < 20 ppm are achievable, making this process ideal for CO₂ removal upstream of any coldbox or ammonia process. Similarly, CO₂ capture rates from syngas of more than 99% can be achieved to produce a decarbonized hydrogen product (Blue Hydrogen).

Since the process has a very low CO-absorption even at higher feed gas pressures, CO₂ product specifications with CO₂ > 99% are achievable.

**References**
- > 30 OASE references
- > 80 total amine references

**Contact**
gas-treatment@airliquide.com
CO₂ Removal from Syngas
Cryocap™ H₂

**Description**

The PSA offgas is compressed, dried and sent to a cryogenic unit, where the CO₂ is separated from the other components by a combination of partial condensation and distillation. A pure and pressurized CO₂ flow is produced from the cold process.

The non condensed gases are recycled through a membrane system to recover H₂ and CO₂. Residual gas is sent to the burners of the H₂ production plant.

The CO₂ product is compressed up to supercritical pressure or liquefied and stored in liquid storage.

Liquid CO₂ can also be directly withdrawn from the cold process at marginal costs.

Cryocap™ H₂ can be installed for greenfield as well as brownfield H₂ plants.

**Main features:**

- More than 98% of CO₂ recovery from syngas
- Cryocap™ H₂ is a solvent free solution that runs on electricity rather than thermal energy. It can run on renewable energy to further reduce the environmental footprint of the sites equipped on.
Rectisol™ – Syngas Purification

**Description**

Harmful acid gases contained in raw gases from any gasification are removed by absorption with a physical solvent (cold methanol). The rich solvent leaving the contactor is regenerated by flashing and stripping. Different process configurations are available to deliver a tailored solution optimized for Capex and Opex for a given syngas specification. Rectisol™ is the leading process when it comes to the purification of gasification-based syngas for catalytic applications (production of SNG, methanol, ammonia, or Fischer-Tropsch) as well as hydrogen and syngas for power production. Using inexpensive solvent in combination with optimized heat integration, the Rectisol™ process has extremely low operating costs and high availability.

**Main Features:**

- Highest level of purity for all contaminants in treated syngas
- Low Capex and Opex when compared to other purification process
- Low cost solvent
- CO₂ offgas & CO₂ product meeting most stringent emission requirements as well as product specifications for downstream processing & utilization
- Special setups for removal of mercaptans, metal carbonyls and BTX available
- Accumulation of all harmful contaminants within the acid gas to be safely processed in a SRU

**Application**

Selective removal of acid gases (CO₂ and H₂S+COS) and of nearly all trace components (carbonyls, mercaptans, HCN...) from syngas produced by gasification of any type of feedstocks (coal, petcoke, waste, residue, heavy oil...) to meet highest syngas specification requirements for catalytic processes, hydrogen, CO and ammonia production or power applications.

**Feedstock**

Raw syngas deriving from gasification of any carbon containing feedstock

**Product**

Clean/high purity syngas (H₂+CO) for catalytic processes, clean hydrogen (e.g. total sulfur < 100 ppb)

**Co-product**

H₂S rich gas for sulphur recovery units (SRU), e.g. Claus units, CO₂ rich offgas ready for storage/utilization

**Capacity**

50,000 - 1,000,000 Nm³/hr per train (feed gas)

**Economics**

Individual costs vary significantly depending on feedstock, size, purity request, etc.

**Capex:** 35 to 200 mm USD

**References**

> 110 (> 35 since 2005)

**Contact**

hydrogen-syngas@airliquide.com

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**Lurgi Rectisol® - The “5 in 1” Solution:**

1. Trace contaminant removal
2. Deep Desulfurization (total S < 80 ppb)
3. Bulk CO₂ removal (up to 100%)
4. CO₂ purification (total S < 5 ppmv)
5. Acid Gas Enrichment (S > 25 vol%)

**CO₂ suitable for compression, synthesis or venting**

**CO₂ CAPTURE**

Air Liquide Engineering & Construction

Technology Handbook
**Application**
Production of decarbonized hydrogen (Blue Hydrogen) and hydrogen-rich syngases

**Feedstock**
Raw sulfur-free hydrogen rich gases from natural gas reforming or partial oxidation, downstream of CO shift units

**Product**
Fuel grade hydrogen

**Co-product**
Dry CO₂ (> 98 vol-% possible), up to 98% carbon capture rate possible

**Capacity**
Preferably > 300,000 Nm³/hr (feed gas)

**Economics**
Individual costs vary significantly depending on size, carbon capture rate and purity request.

Opex: 20 - 35 kWh / t CO₂ electricity
< 0.05 t steam / t CO₂
Capex: 35 - 100 mm USD

**Description**
Recticap™ is AL-Lurgi’s Rectisol™ tailored for carbon capture from natural gas reforming to produce low cost blue hydrogen in large capacities (>300,000 kNm³/hr) at moderate to high pressures (>25 bar).

In contrast to a Rectisol™, Recticap™ removes only CO₂ from the raw hydrogen/syngas and has hence a simplified process setup with reduced capital expenditures.

**Main feature:**
• Large capacities can be built in a single train
• High partial pressure of CO₂ reduces specific capture cost
• Low steam consumption
• Production of dry CO₂
• Methanol solvent is cheap and very robust (no degradation)
• Significantly decreased Capex and Opex compared to a Rectisol™

**References**
>110 (Rectisol™)

**Contact**
hydrogen-syngas@airliquide.com
**CO₂ Removal – Membranes**

**Application**
CO₂ removal from natural gas

**Feedstock**
Natural gas with moderate to high acid gas content

**Product**
Sweet natural gas

**Co-product**
Acid gases

**Capacity**
Up to 500,000 Nm³/h

**Economics**
Economics are highly dependent on feedstock and requirements (high efficiency or low Capex). Contact us for more information.

**Description**
Air Liquide Engineering & Construction offers a vast portfolio of gas separation membranes for natural gas treatment: the natural gas product is recovered as a high-pressure retentate while the impurities are concentrated in the low pressure permeate. This includes bulk CO₂ removal with the highly selective MEDAL™ NG, as well as HC dewpointing, bulk CO₂ removal and dehydration with PEEK-SEP™ suite of products.

**Main Features:**
The hollow-fiber type offers more compact and robust membrane solutions to meet pipeline specifications. Air Liquide membrane technology is characterized by higher resistance to hydrocarbons and higher selectivity, compared to cellulose acetate products, offering higher methane recovery, lower investment and operating costs.

**Contact**
gas-treatment@airliquide.com
CO₂ Removal from Acid Natural Gas

Cryocap™ NG

**Application**
Removal of CO₂ from natural gas, associated gases and unconventional gas sources

**Feedstock**
Natural gas with high CO₂ content (> 35%)

**Product**
Natural gas

**Co-product**
CO₂ (under pressure)
NGL (possible)

**Capacity**
Up to 1,000,000 Nm³/h

**Economics**
Separation cost: less than 1 USD/MMBTU
Capex savings: > 50% vs. amine absorption (at high CO₂ content)

**Description**
The CO₂ rich natural gas is first dried and sent to a cold process where the CO₂ is separated from the other components by a combination of partial condensation and distillation.
High CO₂ partial pressure favors the CO₂ partial condensation and thus makes its separation from natural gas even easier.
The non-condensable gas is enriched in methane and sent to a membrane for final purification.
The CO₂ purity of the product corresponds to pipeline specifications, generally 1 to 10 mol%.
The permeate stream of the membrane enriched in CO₂ is sent back to the cold process. The CO₂ and heavy hydrocarbons condense in the cold process and are collected at high pressure. NGL recovery is possible with almost no additional cost.

Cryocap™ NG is tolerant to a few % H₂S.
Cryocap™ NG also allows for H₂S bulk removal from NG.

**Contact**
cryocap@airliquide.com
**Cryogenic CO₂ Separation for Oxycombustion Cryocap™ Oxy**

**Description**

The flue gas issued from the cement or lime or power plant is first treated in a pre-treatment unit, which aims to cool the gas and remove the SOx, HF, HCl, most of the NOx, and the dust. Then the gas is compressed and dried before entering the cryogenic purification unit.

In the cold process, CO₂ is recovered by combination of partial condensation and distillation, which allow the removal of the heavy compounds such as NOx and the light elements such as O₂, Ar, N₂, NO and CO.

The CO₂ product is compressed, condensed and pumped up to supercritical pressure or directly produced under liquid state.

**Main feature:**
- Cryocap™ Oxy allows very high CO₂ recovery and near zero-emission to the atmosphere (SOx, particulate matter, NOx, Hg). 98+% of CO₂ recovery from flue gas.
- Cryocap™ Oxy is a solvent free solution that runs on electricity rather than thermal energy. It can run on renewable energy to further reduce the environmental footprint of the sites equipped on.

**Application**
- CO₂ capture from cement, lime or power plants

**Feedstock**
- Oxycombustion flue gas

**Product**
- CO₂ (gaseous under pressure or directly liquid)

**Co-product**
- None

**Capacity**
- From 1,000 to 15,000 tpd

**Economics**
- 30 to 50 €/tCO₂ captured

**References**
- 3 demonstration plants (from 25 000 to 1.2 million t/y) and multiple FEEDs

**Contact**
- cryocap@airliquide.com
**Cryocap™ Steel**

**Description**

The gas is first compressed, dried and sent to a PSA (Pressure Swing Adsorption). The PSA pre-concentrates the CO₂ in the offgas while producing a CO rich stream.

The pre-concentrated CO₂ stream compressed then sent to a cold process. There, the CO₂ is recovered by combination of partial condensation and distillation, which allow the removal of the light elements such as, Ar, N₂, H₂ and CO₂. The CO₂ product is compressed, condensed and pumped up to supercritical pressure or directly produced under liquid state at a marginal cost.

The pressurized CO rich stream is either recycle to the Blast Furnace or used to produce fuels.

**Main feature:**
- Cryocap™ Steel is a solvent free solution that runs on electricity rather than thermal energy. It can run on renewable energy to further reduce the environmental footprint of the sites equipped on.

**References**

For PSA part, 2 (10 & 800tpd)

**Contact**

cryocap@airliquide.com
**Application**
CO₂ liquefaction for CCUS

**Feedstock**
Gaseous CO₂ at concentration higher than 95%v (dry basis)

**Product**
Liquified CO₂

**Co-product**
None

**Capacity**
From 800 to 10 000tpd+

**Economics**
5-25€/tCO₂ liquefied

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**CO₂ Large Liquefiers**

**Cryocap™ XLL**

**Description**
The Cryocap™ XLL process is proposed as an industrial solution to compress, liquefy, and purify the raw CO₂ stream resulting from upstream units.

The CO₂ feed gas is compressed in the feed/recycle compressor, dried at an intermediate pressure and then compressed again.

The compressed gas is cooled down and then routed to the cold process.

In the cold process, the high-pressure, dry CO₂ is cooled down and split into various streams. One of these streams is purified by distillation in the Stripping Column to produce the liquid CO₂ product, which is routed to the unit's battery limits.

The remaining streams are expanded to different levels and vaporized in the main heat exchanger, providing the refrigeration load required for the liquefaction of the CO₂. Once vaporized, these streams are recycled at ambient temperature to the feed / recycle compressor.

This configuration makes it possible to handle the compression of the feed gas and the refrigeration with a single compressor (so called self-refrigerated cycle).

**Main feature:**
- Cryocap™ XLL is a HSE friendly solution that does not involve the use of any toxic or flammable external refrigerant (such as ammonia or propane). As a single compressor is used for both feed and cycle, it is also a very compact and Capex attractive solution.

**Contact**
cryocap@airliquide.com
**Oxynator™ / OxyClaus™ for Sulfur Recovery Units (SRU)**

### Description

In a conventional Sulfur Recovery Unit ambient air is used to oxidize part of the hydrogen sulfide (H₂S) in the acid gases to sulfur dioxide (SO₂). By enriching the combustion air to the Claus unit with pure oxygen more feed gas can be processed in the SRU without violation of pressure drop or residence time constraints. Air Liquide Engineering & Construction provides the most suited oxygen enrichment technology depending on client’s requirements.

**Oxynator™ for low-level enrichment (<28% O₂ in air)**

Low-level oxygen enrichment is a very cost effective option to increase SRU capacity up to 125% as there is usually no modification required on existing SRU equipment. Air Liquide uses its patented Oxynator™, a compact swirl type mixer, for safe and efficient oxygen mixing. The oxygen is injected into the combustion air upstream of the Claus burner.

**OxyClaus™ for high-level enrichment (<60% O₂ in air)**

Capacity increase to 200% can be achieved by using the well known Lurgi OxyClaus™ process that can safely handle high levels of oxygen. In the specially designed Lurgi OxyClaus™ burner the oxygen is directly injected into the flame via dedicated oxygen lances. The hot oxygen flame is surrounded by a cooler acid gas – air flame shielding the refractory from exposure to high temperature.

### Main Features:

- Integration with ASU
- Low power consumption
- Pre-assembled packages or skid units to ease the erection

### References

>40

### Contact

sulfur@airliquide.com
Emission-Free Sulfur Recovery Unit

**Description**

Raw gas is desulfurized in an AGR and the removed acid gas is sent to the emission-free SRU for sulfur recovery. The oxygen based Claus process is employed to recover sulfur from the acid gas in elemental form. The recovered sulfur is degassed and is then available as a sellable product.

Claus tail gas is hydrogenated and cooled before being compressed and routed back to the AGR. Here it is desulfurized and the H₂S is recycled together with the acid gas back to the Claus unit. Other valuable components inside the tail gas, like H₂ and CO end up in the purified gas. With this recycle a sulfur recovery rate of 100% is achieved. The sulfur emissions to the atmosphere in the overall complex are significantly reduced.

OxyClaus™ is used in this concept because this reduces the process gas volume and therefore lowers not only investment cost plus operating cost but also the amount of inert gas sent to AGR.

**References**

3 emission-free SRUs have been designed, two are in operation.

**Contact**

sulfur@airliquide.com
**Sulfur Recovery Unit**

**Description**

The acid gases are burnt sub-stoichiometrically with air in a refractory lined furnace. Resulting mixture of H₂S and SO₂ reacts to form elemental sulfur which is removed from the process through condensation. In subsequent catalytic stages, typically two or three, the conversion to sulfur is promoted further yielding a sulfur recovery of 94.5% – 97.5% for the Claus unit. Two tail gas treatment (TGT) options are available to boost the sulfur recovery further.

1) **Sulfreen™**: A sub-dewpoint; catalytic purification of the Claus tail gas for an overall sulfur recovery of up to 99.5%.

2) **LTGT™**: Claus tail gas is purified in the amine based Lurgi Tailgas Treatment (LTGT™) process. Due to the recycling of the H₂S rich stream to the Claus unit, total sulfur recovery can be increased to 99.9%. By using specialty amines, the sulfur recovery can be further increased to 99.9+% while reducing the SO₂ flue gas emissions to less than 150mg/Nm³ SO₂.

**References**

>170 Claus plants (4 to 1000 tpd)
>60 tail gas treatment processes
>50 Aquisulf™ in operation

**Contact**
sulfur@airliquide.com
We have the experience, flexibility and capacity to provide a wide range of air separation units through standard plants, customized offerings and other cryogenic liquefaction technologies. Our strength lies in our ability to adapt our plants performances, safety and construction design philosophy to each project and customer’s specifications.
Sigma – Standard Air Separation Unit

Description
Sigma units are based on air separation with the following steps: air compression, adsorption, purification, cryogenic distillation of main components, internal compression. Several process schemes are available to optimize both Capex and Opex depending on customer product requirements. The Sigma units are designed to reduce construction and time to production with a highly packaged architecture. Some liquid co-production could be available to refill backup liquid storages.

References
>40

Contact
airgases@airliquide.com

Application
Steel making (oxygen boosting, electric arc furnace), chemicals (ethylene oxide, etc.), glass, non-ferrous metals, waste water treatment, pulp and paper

Feedstock
Air + Energy (electrical)

Product
Oxygen up to 99.8% purity

Co-product
Nitrogen, liquid oxygen, liquid nitrogen, liquid argon, compressed dry air

Capacity
110 to 380 tpd

Economics
Specific energy: 280 to 460 kWh/t
Capex: 5 to 9 mm USD
**Yango™ – Standard Air Separation Unit**

**Application**
Steel making (basic oxygen furnaces, blast furnaces, electric arc furnaces), chemicals (ethylene oxide, ammonia, etc.)

**Feedstock**
Air + Energy (electrical or steam)

**Product**
Oxygen from 99.6% to 99.8% purity and up to 50 bar

**Co-product**
Nitrogen, liquid oxygen, liquid nitrogen, liquid argon, compressed dry air

**Capacity**
330 to 770 tpd

**Economics**
Specific energy: 400 to 600 kWh/t
Capex: 22 to 30 mm USD

**Description**
The Yango™ air separation unit is based on air compression, adsorption purification, cryogenic distillation of main components and internal compression of high pressure products. Yango is a standardized, highly packaged ASU solution to support short-time-to-start-up projects.

Several process schemes are available to optimize both Capex and Opex depending on customer product requirements, energy cost and customer process integration potential.

Air Liquide Engineering & Construction offers optimized solutions in terms of construction strategy, operating philosophy and reliability.

**References**
>20

**Contact**
airgases@airliquide.com
Vacuum Swing Adsorption (VSA)
On-Demand Oxygen Generation

Description

VSA uses the process of air separation by adsorption. The basic principle of air separation by adsorption relies on the use of specific zeolite adsorbents for the selective adsorption of nitrogen over oxygen and argon.

Main features:
- Compact design layout
- Fully packaged and pre-tested skids
- Minimized schedule, erection and start-up times
- Automatic and unattended operation
- Capitalization of more than 30 years of operating and maintenance experience.

References

>100

Contact

argases@airliquide.com

Application
Steel making, glass, pulp and paper, waste water treatment, mining

Feedstock
Air + Energy (electrical)

Product
Oxygen from 90% to 93% purity

Co-product
None

Capacity
40 to 130 tpd

Economics
Specific energy: 265 kWh/t
Capex: 1 to 6 mm USD
**APSA – Nitrogen Generation System**

**small capacity**

**Description**

This nitrogen generation system is based on air separation with the following steps: air compression, adsorption, purification, cryogenic distillation of main components. Several process schemes are available to optimize both Capex and Opex depending on customer product requirements. Some liquid co-production could be available to refill backup liquid storages. Systems often include backup vaporizers and storages designed as per customer’s requirements (availability and reliability). These systems are safe, reliable and easy-to-operate and maintain.

**References**

> 100

**Contact**

airgases@airliquide.com

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**Application**

LNG terminal, crude oil refinery, electronics

**Feedstock**

Air + Energy (electrical)

**Product**

Nitrogen (gaseous, liquid) with 100 ppm to 1 ppb O₂

**Co-product**

LOX high purity

**Capacity**

500 Nm³/h to 9,000 Nm³/h of nitrogen

**Economics**

Specific energy: 175 to 280 KWh/t

Capex: 1.5 to 4 mm USD
TCN™-BE – Nitrogen Generation System
large capacity

**Application**
Electronics, Chemical (Green Ammonia, etc.), Oil & Gas

**Feedstock**
Air + Energy (Electrical)

**Product**
Nitrogen (gaseous and liquid)
100 ppmO₂ to 1 ppbO₂ at 7.5-10 bar G

**Co-product**
With additional module:
- Ultra Pure Oxygen 50 ppbAr
- Oxygen 99.8%O₂

**Capacity**
4,000 to 51,000 Nm³/h

**Economics**
Specific Energy: ~160 kWh/tons of Nitrogen
Capex: 5 to 13 mm USD

**Description**
TCN™ is a standard product for nitrogen generators. BE Stands for “Best Energy”. This nitrogen generator offers the best-in-class efficiency for high pressure nitrogen production. The process is composed of the following steps: air compression, purification, cryogenic distillation. These systems are safe, reliable and easy-to operate and maintain.

**Main features:**
- Low Nitrogen Specific Energy Consumption
- Single column, Single Machine process.

**References**
> 50

**Contact**
airgases@airliquide.com

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**Diagram**

- **Air Compression**
- **Precooling & Front End Purification**
- **Cold Production**
- **Heat Exchange & Distillation**

- Main Air Compressor
- Adsorbers
- Aftercooler
- Expander Booster
- Main exchanger
- Distillation Column
- 1st Condenser
- 2nd Condenser
- Cold Box
- Liquid Nitrogen
- Gaseous Nitrogen
- Waste Gas vent
Large Air Separation Unit

**Description**
Large air separation units are based on adsorption purification, cryogenic distillation of main components and internal compression of high pressure products. From the small standard of a few hundred tonnes per day to Mega ASU complexes (multi-train) of more than 15,000 tonnes per day, Air Liquide Engineering & Construction offers optimized solutions in terms of construction strategy, operating philosophy and reliability.

**References**
>4000

**Contact**
airgases@airliquide.com
Krypton / Xenon

Description
Liquid oxygen from ASU(s) is first treated in a primary module, named “Extraction cold box,” which aims to remove contaminants such as N₂O and partially CnHm before entering in a first set of cryogenic separation to produce a pre-concentrated mixture.

The secondary module, named “Krypton-Xenon upgrader,” treats the pre-concentrated mixture through a hydrocarbons purifier before entering into the final concentrated cryogenic separation in order to produce a krypton-xenon mixture enriched at > 98% (rest is oxygen).

This concentrated cryogenic mixture (typically Kr 91%, Xe 7%, O₂ 2%) is then compressed and vaporized to fill gas cylinders at 150 barg.

Final separation (pure Kr, pure Xe) is done outside the ASU plant in a dedicated laboratory.

Note: Krypton-Xenon production is economically favored for large ASU (>4000 tpd) or for multi ASUs due to the low Krypton and Xenon content in the air (resp. 1.1 ppm, 0.086 ppm).

Main features:
- Integration with ASU
- Low power consumption
- Pre-assembled packages or skid units to ease the erection

References
> 10

Contact
raregases@airliquide.com
Leveraging on our vast technology portfolio, we have the means to combine various patented processes to address any Hydrogen & Syngas separation challenge. Our customers benefit from continuous improvements due to Air Liquide’s own track record in its operational experience of such processes - from cryogenics to permeation to adsorption.
CO Cold Box – Methane Wash

**Description**
Methane Wash process is based on cryogenic separation technology using the difference in boiling points of the main components from the synthesis gas. Feed gas is pretreated to remove impurities which will freeze at cryogenic temperatures encountered in the process. It is then cooled down in heat exchangers and washed with liquid methane before being purified step by step through distillation columns. Every cryogenic process is tailor-made to fit the customer’s specifications and other requirements on co-products.

**Main Features:**
- Greatest number of references in CO/N₂ separation
- Highest safety standards for all Cold Boxes
- In-house technology for highly safe, highly reliable & highly efficient CO expander
- High CO recovery

**References**
34 (latest 2021)

**Contact**
hydrogen-syngas@airliquide.com
**CO Cold Box – Partial Condensation**

**Application**
Carbon monoxide (CO) production or ratio-adjusted synthesis gas production from synthesis gas for use in chemical industry.

**Feedstock**
Synthesis gas from natural gas/naphtha or coal/residue gasification.

**Product**
CO up to 99.99% purity

**Co-product**
Hydrogen, oxogas, methane, LNG

**Capacity**
Up to 55 000 Nm³/h (1 650 tpd) CO

**Economics**
**Opex:** Specific energy: 18 to 100 kWh/tonne
**Capex:** Economics are highly dependent on the type and quality of feedstock (coal, Naphtha or natural gas), as well as of the required CO purity and pressure (MDI/TDI, PC, AcAc, MEG, etc.) and of the required scope of supply.

**Description**
Partial Condensation process is based on cryogenic separation technology using the difference in boiling points of the main components from the synthesis gas. Feed gas is pretreated to remove impurities which will freeze at cryogenic temperatures encountered in the process. It is then partly condensed in heat exchangers and flashed in a syngas drum before being purified step by step through distillation columns.

Every cryogenic process is tailor-made to fit the customer’s specifications and other requirements on co-products.

**Main Features:**
- Greatest number of references in CO/N₂ separation
- Highest safety standards for all cold boxes
- Low specific energy consumption for wide range of feedstock

**References**
23 (latest 2021)

**Contact**
hydrogen-syngas@airliquide.com

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**SYNGAS SEPARATION**

**CO Compressor**

**Heat Exchanger**

**Fuel**

**N₂**

**CO**

**CO/N₂ Column**

**Wash Column**

**Stripping Column**

**Application**
Carbon monoxide (CO) production or ratio-adjusted synthesis gas production from synthesis gas for use in chemical industry.

**Feedstock**
Synthesis gas from natural gas/naphtha or coal/residue gasification.

**Product**
CO up to 99.99% purity

**Co-product**
Hydrogen, oxogas, methane, LNG

**Capacity**
Up to 55 000 Nm³/h (1 650 tpd) CO

**Economics**
**Opex:** Specific energy: 18 to 100 kWh/tonne
**Capex:** Economics are highly dependent on the type and quality of feedstock (coal, Naphtha or natural gas), as well as of the required CO purity and pressure (MDI/TDI, PC, AcAc, MEG, etc.) and of the required scope of supply.

**References**
23 (latest 2021)

**Contact**
hydrogen-syngas@airliquide.com

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**Air Liquide Engineering & Construction Technology Handbook**
Liquid Nitrogen Wash

**Description**
Raw hydrogen and high pressure nitrogen are fed to the liquid nitrogen wash unit. Both streams are cooled down against product gas.

Raw hydrogen is fed to the bottom of the nitrogen wash column and condensed nitrogen liquid is fed to the top. Trace impurities, like methane, argon and carbon monoxide, are removed and recycled as fuel gas.

To establish the desired H₂/N₂ ratio, high pressure nitrogen is added to the process stream.

**Main Features:**
- Highest safety standards for all Cold Boxes
- Low specific energy consumption for Methane / LNG co-production

**References**
49 (latest 2015)

**Contact**
hydrogen-syngas@airliquide.com
Raw natural gas needs to be treated to meet pipeline and liquefaction specifications. We offer a full range of technologies to remove any kind of contaminant, as well as extensive experience equipping plants of all sizes with our range of LNG technologies, providing our customers with reliable and cost-effective solutions tailored to their needs.
Acid Gas Removal – OmniSulf™

**Description**
The OmniSulf™ technology encompasses the following proprietary key processes:
Acidic components are removed using BASF’s OASE® technology and the cleaned gas is routed to a dehydration and mercaptan removal unit (DMR) that removes moisture and mercaptans with multi-layered bed of specialized zeolitemolecular sieves. If necessary, mercury is removed from the sweet gas with impregnated activated carbon. Mercaptans are recovered from the regeneration gas with the Lurgi Purisol™ technology. All gas streams containing sulfur are routed to a sulfur recovery unit (SRU). Elemental sulfur is produced in the Claus process (equipped with a Lurgi Multi-Purpose Burner) followed by a Lurgi tail gas treatment (LTGT™) unit combined with an acid gas enrichment system to boost sulfur recovery and reduce SO₂ emissions. The liquid sulfur product is degassed to H₂S concentrations below 10 ppm by applying the Aquisulf™ technology. Offgases are incinerated before being released to the atmosphere.

The OmniSulf™ technology can be tailored for gas reinjection.

**Contact**
gas-treatment@airliquide.com
Acid Gas Removal – Purisol™

**Description**

The Purisol™ process uses a highly selective, non-toxic, non-corrosive, easily available solvent (N-Methyl-2-Pyrrolidone, NMP) for the physical absorption of the undesired acidic components of a feed gas or process gas, like H₂S and mercaptans. The process requires very low Opex due to several features. Taking advantage of the very high selectivity towards H₂S and mercaptans compared to CO₂ and hydrocarbons allows a low circulation rate. The process is operated at ambient temperature and thus does not need high cooling duty. Regeneration of the solvent is done by flashing and heating. Because of the high boiling point of the solvent, losses are extremely low.

A typical application is the cleaning of periodically released regeneration gases of natural gas treatment to a clean fuel gas. Here an additional feature is to provide a continuous flow of sulfur rich gas to the Claus process by using the buffering function of the set up.

The process can be modularized and also easily be integrated into existing plants.

**Main Features**:

- Non-toxic, non-corrosive solvent, easily available solvent
- Smooth and peakless gas to Claus process

**Contact**

gas-treatment@airliquide.com
Nitrogen Rejection Unit

**Description**

Natural gas feed is partially condensed, then methane and nitrogen are separated into a system of distillation column(s). Depending on the feed composition and pressure, the system can include one to three distillation columns. The process scheme selection is done according to project-specific parameters such as feed evolution with time and product specifications. Air Liquide Engineering & Construction offers a wide range of solutions, such as the ability to treat any N₂/CH₄ mixtures (5-90%), high efficiency, flexibility and recovery (>99% methane), minimization of greenhouse gas emissions to the atmosphere (methane in N₂ vent << 1%). Capex optimization and operation flexibility are allowed thanks to proprietary design and Air Liquide operational feedback.

**References**

>15

**Contact**

gas-treatment@airliquide.com
Turbofin™ (Nitrogen Refrigerant Cycle)

Description
The process consists of three main modules: pre-treatment of natural gas (NG), liquefaction, and LNG storage and loading (truck, trailer, bunkering barge, etc.).

1) The pre-treatment consists mainly of CO₂ and H₂O removal. It is either a simple Temperature Swing Adsorption (TSA) cycle or a combination of amine wash with TSA depending on the CO₂ content in the feed gas.

2) The liquefaction process is based on a nitrogen cycle (closed loop): N₂ is first compressed and boosted. After being cooled down through a Brazed Aluminum Heat Exchanger, it is expanded releasing N₂ at low pressure and low temperature. Cold N₂ (T<-165°C) is then re-injected into the main Heat Exchanger to cool down the NG and convert it to LNG which is sent to storage. Warm N₂ is then recycled through the cycle compressor.

3) Storage can either be fabricated for small volumes (vacuum insulated) or site erected flat bottom tanks for larger needs, depending on the applications considered.

The loading station can be adapted to truck, trailer, or maritime. Regasification is added downstream of the storage for peak shaving facilities.

Main Features:
- Cost effective especially for small scale plant
- Non-hydrocarbon refrigerant improving safety
- Simplicity of operation

References
90

Contact
lng@airliquide.com
**Smartfin™ (Single Mixed Refrigerant Cycle)**

**Description**

Smartfin™ is a single mixed refrigerant type of process optimized with the use of Brazed Aluminium Heat Exchangers (BAHX).

The refrigeration cycle is filled with a mixture of hydrocarbons and nitrogen.

The refrigerant is compressed and separated in liquid and gaseous streams. Lightest fractions of the refrigerant are sent to the cold end of the main heat exchanger, cooled down and sent back to the compressors after being vaporized through the main BAHX. Heaviest fractions are let down and vaporized at an intermediate level in the main BAHX.

The optimization of the mixed refrigerant cycle consists of taking advantage of the vaporization temperature difference between generated refrigerant streams to optimize the natural gas liquefaction heat exchange profile. In addition, the heavy hydrocarbons removed from the process can be recovered and sold as NGL.

**Main Features:**
- Efficient Process
- Reduced number of rotating machines
- Flexibility of Operation

**References**

5

**Contact**

lng@airliquide.com
Helium Extraction and Liquefaction

Description
The impure helium feed gas is purified in a first section, where N₂, CH₄, H₂, CO, Ar, O₂, water and CO₂ are separated from helium. It is composed of a cryogenic partial condensation unit, a hydrogen removal system and a Pressure Swing Adsorber (PSA) unit. Then, the pure gaseous helium is cooled and liquefied via a helium cycle and the use of cryogenic expanders with a highly optimized cryogenic exchanger arrangement. Expanders are based on a proprietary technology using static gas bearing, ensuring high reliability and efficiency.

Liquid helium is continuously produced and stored in tanks. The unit is equipped with loading bays to fill ISO containers. All helium vapors from the containers are collected and recycled within the unit.

Contact
raregases@airliquide.com
Our range of leading Lurgi™ technologies for chemicals and fuels spans from Methanol production, through to the pretreatment and production of green chemicals and renewable fuels. Our experience and continuous development of our products ensures well referenced, safe and reliable technology for our customers that can be tailored to meet their specific needs.
ATR – Autothermal Reforming for syngas production

**Application**
Production of syngas by partial oxidation of gaseous hydrocarbon feed followed by a catalytic reforming conversion.
The syngas can be used as feedstock for different synthesis processes such as methanol or Fischer-Tropsch synthesis.
Syngas components can be also separated to pure products (H₂, CO, CO₂)

**Feedstock**
Natural gas, refinery offgas, pre-reformed gas, Fischer-Tropsch tail-gas, LPG, Naphtha

**Product**
Syngas (H₂+CO)

**Co-product**
None

**Capacity**
Up to 1,000,000 Nm³/h (dry) per reactor

**Economics**
Yield: 2.5 - 4.0 Nm³ syngas / Nm³ natural gas (including fuel for fired heater)
Oxygen consumption: 0.15 - 0.25 kg O₂ / Nm³ syngas
Capex: 160 to 280 mm USD

**Description**
Desulfurized feed gas is preheated and optionally pre-reformed prior to entering the ATR reactor. The gas is fed via the proprietary burner into a refractory lined reactor operating at 30 to 100 barg, where it reacts with oxygen and steam to form syngas. The syngas is further reformed via a Ni-based catalyst bed located in the same reactor. The syngas is cooled in a waste heat boiler producing high pressure steam.
Depending on the needed syngas properties of the downstream process this technology can be applied as stand-alone ATR or as a combination of SMR and ATR known as Combined Reforming.

**Main Features:**
- Provide large quantities of H₂-rich gas at lowest cost
- Compact reactor
- High pressure (up to 100 bar)

**References**
Air Liquide has licensed >40 ATR units

**Contact**
hydrogen-syngas@airliquide.com
**Lurgi™ Methanol**

**Description**

In the LP methanol unit (either with integrated gas generation based on natural gas or downstream of a coal gasification unit) syngas is converted over a copper catalyst in a water-cooled reactor to produce raw methanol. Unconverted synthesis gas is recycled back to the synthesis loop to enhance yield and carbon efficiency.

Raw methanol leaving the synthesis loop is further distilled to meet the required specification.

**Main Features:**
- Simple to operate over full catalyst life time
- Optimized heat transfer preventing temperature peaks in the methanol reactor
- Flexible integration with any syngas generation

**References**

>40

**Contact**

chemicals@airliquide.com

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**Application**

Medium-scale production (< 1 million tpa) of methanol from synthesis gas derived from all kinds of carbonaceous material

**Feedstock**

Natural gas or synthesis gas (H₂+CO)

**Product**

Methanol in the required specification (AA, IMPCA, etc.)

**Co-product**

None

**Capacity**

Up to 3,500 tpd

**Economics**

Natural gas consumption: 29 MM BTU (LHV)/tonne (this includes energy for the process, all utilities and the ASU that produces 0.4 - 0.5 tonne O₂/tonne methanol)

Capex: 250 to 500 mm USD
Lurgi MegaMethanol™

Description
Syngas production can be fully integrated in the methanol synthesis. Available syngas can be converted to methanol.

Syngas Production
Natural gas is converted in a combination of SMR (Steam Methane Reformer) and ATR (Auto-Thermal Reformer) to Synthesis gas (carbon monoxide and hydrogen). The Synthesis gas is compressed and fed into the methanol reactor system. Alternatively, natural gas can be converted in an ATR at higher pressure, reducing the size of the synthesis gas compressor or even avoiding it. This is especially beneficial for large methanol capacities above 7,000 tpd.

Biomass or Coal is treated in a gasifier in presence of oxygen. The resulting synthesis gas is converted in a shift reactor in order to install the right carbon monoxide to hydrogen ratio. Sour gases (CO₂ and H₂S) are removed.

MeOH Synthesis
In the Lurgi MegaMethanol™ unit syngas is converted over a copper catalyst in a two-stage reactor system (water-cooled followed by gas-cooled) to produce raw methanol. Unconverted syngas is recycled back to the synthesis in order to enhance yield and carbon efficiency. However, this stream is small due to a methanol interstage condenser between the water cooled and the gas cooled reactors. Raw methanol leaving the synthesis loop is further distilled to meet the required specification. Due to the high energy integration of the unit and the low recycle ratio in the synthesis loop, Lurgi MegaMethanol™ yields the lowest production cost. The most recent design (GigaMethanol) can produce up to 10,000 tpd in a single train.

Main features:
- Syngas production with efficient combined reforming
- ATR only with elevated pressure resulting in lower capex
- Methanol loop with minimized recycle ratio through interstage condensation, resulting in reduced piping and equipment size
- Best referenced technology in the 5000 metric tpd class.

References
12 units in operation

Contact
chemicals@airliquide.com
**Lurgi MTP™ – Methanol-to-Propylene**

**Application**
This on-purpose production of propylene from methanol is a way to produce propylene independently from crude oil and/or natural gas liquids. Hence, it supports the utilization of land-locked coal or natural gas reserves as feedstock for petrochemical processes.

**Feedstock**
Methanol

**Product**
Polymer-grade propylene

**Co-product**
Gasoline and LPG

**Capacity**
500 to 1,500 tpd

**Economics**
**Yield:**
3.5 tonnes methanol/tonne propylene

**Capex:**
250 to 500 mm USD

**Description**
In a first step, methanol is converted into dimethyl-ether (DME) which is, together with recycled hydrocarbon streams, the feedstock for the fixed-bed MTP reactor filled with proprietary zeolite catalyst. The effluent from the MTP reactor is cooled and enters a separation sequence similar to the one applied in steam-crackers. During this sequence, the effluent is separated into different hydrocarbon streams which are partially recycled to the reactor in order to maximise the propylene yield. The last step of the separation sequence yields polymer-grade propylene.

Compared to crude-based processes (naphtha cracking, metathesis, PDH) the MTP process has the lowest cash cost.

**Main Features:**
- Focus on propylene product
- Lowest cash cost
- High integration potential with methanol and other technologies

**References**
3 in operation (all coal based), first natural gas based plant in engineering stage.

**Contact**
chemicals@airliquide.com
Butadiene Extraction (BASF NMP Licensed)

**Description**

In the pre-distillation tower methyl acetylene, propadiene and other light components are separated from the C4 cut feedstock which then enters the bottom section of the main washer column while NMP solvent enters at the top. C4 raffinate consisting of butanes and butenes is drawn off as overhead product. The loaded solvent is sent to the rectifier. In the first compartment of the divided wall column, the less soluble butenes are separated and recycled to the main washer while C4 acetylenes are separated from crude butadiene in the second compartment. The solvent from the rectifier is sent to the degassing tower where hydrocarbons are stripped from the solvent and then recycled to the rectifier by a compressor. The side stream of the degassing tower containing diluted C4 acetylenes is fed into a scrubber to recover NMP solvent. After further dilution with raffinate or other suitable materials, the C4 acetylene stream is discharged to battery limits for further processing. The crude butadiene withdrawn as overhead product from the second compartment of the rectifier is sent to the butadiene column for final purification. The butadiene product is withdrawn as liquid side product.

**Ecology:** NMP biodegrades readily and has low toxicity to aquatic life. Compared to other technologies, this process is much more eco-friendly.

In addition the BASF SELOP selective hydrogenation process can be offered for further treatment of the C4 Acetylene stream to increase the 1,3 Butadiene yield.

**References**

>36

**Contact**

chemicals @airliquide.com
CO₂ to Methanol

**Application**
Conversion of CO₂ to methanol requires significant volumes of hydrogen. This will valorize CO₂ off gases and may use hydrogen from regenerative sources. The technology is optimized for small capacities.

**Feedstock**
CO₂ and H₂ to be used in a 1:3 volume ratio (1 t of MeOH requires 1.4 t of CO₂ and 0.19 t of H₂)

**Product**
Co-product

**Capacity**
Plant sizes start at 25 tpd (from $ 10 mil installed cost) and may be build up to 1000 tpd

**Economics**
Opex:
Capex:

**Description**
A single stage synthesis loop is combining the reverse water-gas-shift reaction for the CO production with the forming of methanol. The reactor uses a Clariant catalyst developed for such conversions. This catalyst is especially designed to handle the higher water output from the reaction compared to a classical methanol production.

Methanol is distilled to grade AA or IMPCA quality.

**Main Features:**
- Two reaction steps (water-gas-shift from CO₂ to CO and CO to methanol) in one reactor;
- Optimized distillation set-up for specific by-product spectrum;
- Optimized capex and opex for small scale plants

**Contact**
chemicals@airliquide.com
**Acrylic Acid**

**Application**
The combined Lurgi/Nippon Kayaku technology produces ester-grade acrylic acid (EAA). Main uses are adhesives, paints and coatings (acrylic esters).

**Feedstock**
Propylene

**Product**
Ester-grade acrylic acid

**Co-product**
None

**Capacity**
Up to 25 t/h (single train)

**Economics**
Capex: 200 to 300 mm USD

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**Description**

**Reaction**: Acrylic acid (AA) is produced by catalyzed oxidation of propylene in a two-stage tubular fixed-bed reactor system. The reactors are cooled by circulating molten heat transfer salt. The heat of reaction is used to produce steam.

**Quench**: The AA is recovered from the reactor product gas in a quench tower. The AA solution is routed to an extractor. Uncondensed gases are sent to an offgas treater to recover the remaining AA. A side draw from the offgas is sent to incineration. Overhead gas is recycled to the first reactor.

**Solvent extraction**: Liquid-liquid extraction is used to separate water and AA. The solvent is recovered and recycled. In the first step, water and acetic acid are removed to achieve a crude AA to be further purified in the next process steps. The extractor bottom is sent to the raffinate stripper to recover remaining solvents.

**Crude AA recovery**: In this section, solvent and acetic acid are removed from crude AA using two columns.

**Raffinate stripping**: The raffinate stripper recovers solvents from the wastewater streams. The Lurgi/Nippon Kayaku technology combines high performance catalysts with highest acrylic acid yields and outstanding catalyst longevity with an optimized process. With low raw material and energy consumption, low environmental impact and high onstream time, this technology exhibits competitive production costs.

**Acrylic acid purification**: Crude AA is purified in the ester grade AA column. To maximize AA recovery, dimer is converted to AA in a dedimerizer.

**References**
2

**Contact**
chemicals@airliquide.com
Acrylates (Synthomer Licensed)

**Application**
Production of acrylates by the esterification of acrylic acid with alcohol. Use mainly for adhesives, paints and coatings.

**Feedstock**
Acrylic acid, alcohol (methanol, ethanol, butanol or 2-ethyl-hexanol)

**Product**
- **Light acrylates:** Methylacrylate, Ethylacrylate
- **Heavy Acrylates:** Butylacrylate, 2-Ethylhexylacrylate

**Co-product**
None

**Capacity**
Typically 2 t/h up to 20 t/h depending on the product

**Economics**
Process configuration is optimized resulting in low material and utility consumption, high degree of energy integration and minimized environmental impact. On stream times exceeding 8,000 h per year could be achieved.

**Capex:** in the range of 25 and 115 Mio Euro depending on product and capacity

**Description**
The technologies for light and heavy acrylates production differentiate mainly in the reactor section and the catalytic system applied. The light acrylates are produced in a fixed bed reactor catalysed by means of an acidic ion exchange resin whereas the reaction to form heavy acrylates takes place in the liquid phase catalysed by means of para toluene sulfuric acid (PTSA).

The separation of the reactor effluents comprises similar unit operations for all four technologies. The unreacted acrylic acid, process water and alcohol are removed from the crude acrylate by means of extraction and distillation steps to finally meet the required purified product specification. In case of heavy acrylates using PTSA an additional neutralization step is required. Unreacted feedstock and parts of the process water are recycled. Remaining part of the process water and heavy ends are discharged to battery limit for further treatment. High boiling components are routed to a decomposer where they could partly be converted back to alcohol, acrylate and acrylic acid to be recycled resulting in yield increase.

Acrylates are prone to polymerization. In order to minimize polymerization effects, an inhibitor injection system is foreseen at critical locations within the plant.

**References**
1 reference for each acrylate product

**Contact**
chemical@airliquide.com

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Figure: Example Heavy Acrylate Butylacrylate (BA)
Bio Propylene Glycol (BASF Licensed)

**Application**
Production of bio propylene glycol (1,2-propanediol, MPG) from glycerin as alternative to petrochemical route

**Feedstock**
Pharma grade glycerin

**Product**
Pharma grade propylene glycol

**Co-product**
Technical grade propylene glycol

**Capacity**
50 to 300 tpd

**Economics**
Contact us for more information

**Description**
In this process, licensed from BASF, glycerin is hydrogenated in liquid phase using a copper catalyst. The reaction takes place in two serial fixed bed reactors at a temperature between 175 to 195 °C and pressures between 75 and 200 bar. The crude product is purified in a two-column distillation unit to yield pharma grade propylene glycol.

**References**
1 commercial plant
1 plant under construction
1 plant in engineering phase

**Contact**
green-chemicals-fuels@airliquide.com
HVO-Solutions: (Crushing & Extraction, Pretreatment, Oil Refining & Splitting)

**Application**
Feedstock Pretreatment with patented oil splitting option for HVO

**Feedstocks**
Various Veg. oils, Tallows, UCO, waste/ recycle oils and fats

**Product**
Purified feed matching HVO unit’s licensor’s specification

**Co-product**
Glycerin water (crude Glycerin) in case of Splitter: Feed either for pure Glyc. or further value-addition, e.g.Bio-PG

**Capacity**
300 - 6000 MTPD

**Opex**
30-40 USD/tonne, Pretreatment
30-35 USD/tonne, Splitting
Depending upon feed type

**Description:**

**HVO-Pretreatment**
The HVO Pretreatment basic solutions offered by Air Liquide Engineering and Construction cover all process steps to provide treated oil suitable for hydrotreating to all licensors’ requirements and limitations associated with refinery retrofits. The basic pretreatment solution covers ultra-degumming, bleaching and filtration. Optional solutions like PE (polyethylene)-Removal, FFA (free fatty acid)-stripping and Enzymatic Degumming can be added on a case by case basis, providing the flexibility to operate with a very broad spectrum of feedstock, including low quality waste oils and fats. The HVO-Pretreatment solutions provide many advantages including reduction of total cost of ownership, a complete range of feedstocks and a broad range of technology options to meet customer’s needs.

**Patented Oil Splitting**
Reducing overall OPEX and upgrading coproducts is a proven way to improve refining economics. The incorporation of Air Liquide’s patented Oil Splitting (Hydrolysis) solution allows customers to achieve this goal. Hydrolysis advantages include improvement of the HVO-catalyst lifetime through further removal of impurities, and considerable savings in OPEX due to the reduction of hydrogen consumption in the HVO process by approximately 25-30%. The hydrolysis solution also provides the valuable by-product, premium Glycerin, instead of propane. Glycerin can add further value in terms of producing refined glycerin or green chemicals like Bio-PG (Propylene Glycol) from any existing HVO plan.

**Crushing & Extraction**
The integrated solution is a key factor to reduce the general carbon footprint of renewable fuels. Among various synergies within the AL Technology portfolio, AL and its partner JJ-Lurgi offer solutions from the preparation of various types of oilseeds to the extraction of the oil.

**References:**
> 25 in Pretreatment; incl. 4 nos. Pretreatment for HVO
> 20 in Splitting
> 300 in Crushing & Extraction

**Contact**
green-chemicals-fuels@airliquide.com
Supercritical Biodiesel (Inventure Licensed)

**Application**
Conversion of various low quality oils and fatty acids to Biodiesel

**Feedstock**
Used Cooking Oil, Corn Oil, Acid Oil, Tallow, Yellow Grease, Fatty Acids and other oils

**Product**
Distilled Biodiesel

**Co-product**
Premium crude Glycerin (free of salts), Distillation bottoms

**Capacity**
50 tpd to 750 tpd

**Economics**
Opex: 70 USD/tonne

**Description**
Unpretreated low quality oils and fatty acids are directly converted with Methanol to Biodiesel (FAME) without usage of any catalyst. The esterification and transesterification is conducted under supercritical conditions. Glycerin is separated and dried to give premium crude Glycerin, which is free of salts. The Biodiesel is distilled to achieve ASTM and EN specifications. The distillation bottoms contains unsaponifiable components separated and can be used as fuels. This technology is licensed from Inventure Renewables, Inc.

**References**
1 commercial plant
1 plant engineered

**Contact**
green-chemicals-fuels@airliquide.com
Soap Carbonate Technology
(Inventure Licensed)

**Description**

The Soap Carbonate Technology is able to harvest all free or bound Fatty Acid molecules present in the soapstock, regardless of their source (phospholipids, mono-, di-, triglycerides, soaps). Fatty Acids are released from glycerides by thermal hydrolysis followed by acidulation of soaps using CO₂ avoiding sulfuric acid. Distillation is the final step for the production of high quality Fatty Acids. Water soluble organics and carbonate salts are recovered from the Process Water Recovery section, which also provides process water for reuse.

This technology is licensed from Inventure Renewables, Inc.

**References**

1 commercial plant under construction

**Contact**

green-chemicals-fuels@airliquide.com

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**Application**
Conversion of soapstock to distilled Fatty Acids utilizing Carbon Dioxide

**Feedstock**
Soapstock from Chemical Refining in Edible Oil Refineries

**Product**
Distilled Fatty Acids

**Co-product**
Meal Additive, Distillation Bottoms, Process Water

**Capacity**
20 tpd to 200 tpd

**Economics**
Opex: 125 USD/tonne
Glycerin Distillation and Bleaching

**Application**
Purification of glycerin to pharma and technical grade

**Feedstock**
Crude glycerin from biodiesel or oil splitting (fatty acid) plants

**Product**
Pharma grade glycerin (purity > 99.7%)

**Co-product**
Technical grade glycerin (purity 85-90%)

**Capacity**
10 tpd to 600 tpd

**Economics**
Opex: 35 USD/tonne

**Description**
Vacuum distillation is used to separate glycerin from organic components and salts at temperatures up to 175°C. The residue from the column bottom is sent to a thin film evaporator to increase glycerin yield. Salt can be separated from the residue by a decanter to reduce the amount of waste and to increase glycerin recovery even further.

Pharma grade glycerin as main product is polished by bleaching, i.e., adsorption at fixed beds of activated carbon. Light impurities end up in the by-product, technical grade glycerin.

**References**
> 45

**Contact**
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**Application**
Sorbitol is produced by batchwise hydrogenation of aqueous glucose solution. This technology is also suitable for different sugar alcohols, e.g., Mannitol, Xylitol.

**Feedstock**
Glucose from wet milling plants

**Product**
Technical, food or pharma grade sorbitol

**Co-product**
None

**Capacity**
30 to 200 tpd

**Economics**
**Opex:** 130-165 USD/tonne w/o feedstock and fixed cost.
**Capex:** 4 to 7 mm USD

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**Sorbitol**

**Description**
The glucose solution is hydrogenated in a batch reactor using nickel or ruthenium catalysts. Reaction takes place at 110°C and 40 bar pressure. After reaction, the product slurry is filtered to recover the catalyst. Makeup catalyst compensates catalyst loss and deactivation. The crude sorbitol solution is purified by ion exchange and evaporated to the final concentration. Optionally, sorbitol powder can be obtained by melt crystallization.

**References**
>10

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Air Liquide Engineering & Construction offers its engineering and operational experience to customers through a growing range of Services. Our goal is to be your one-stop service provider allowing customers to gain full visibility of their total cost of ownership and allowing the optimization of each process on the short and long term.
A growing range of services developed for the plants of the group

Our offer is organized in the following categories:

**Engineering Services**
Conversions, modifications, upgrades: from conceptual and feasibility studies to project execution for the improvement of operating plants; design for third parties and validation, performance improvement programs.

**Remote Support Services**
Customer training, safety studies and recommendations, technical assistance, monitoring and diagnostics from our technology centers and front-end offices.

**On-Site Services**
Deployment of our experts to site for issue resolution, performance checks, installation of components, supervision of planned or unplanned shut-down events.

**Spare Parts Services**
Customers’ spares management, supply of parts through custom lists, safety stocks, interchangeability studies, compliance with regulations.

**Customer Service Agreements (CSA)**
To strengthen the partnership with our Customers, Air Liquide Engineering & Construction also offers its Services through tailored CSAs. These CSAs are customized and adjusted to a Customer’s specific needs of support and can include services from the above categories as well as premium Services such as dedicated technical support, definition and optimization of maintenance plans, extension of guarantees. The CSA is the ideal tool to manage the Total Cost of Ownership.

**Contact**
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Engineering Services: pre- and post-sales solutions

Air Liquide Engineering & Construction offers a full range of pre- and post-sales solutions, from feasibility studies to upgrading of operating plants for performance improvement purposes. A typical, comprehensive project includes detailed design work, procurement, supervision of installation and restart, performance validation tests to verify the effectiveness of the implemented solutions.

Engineering Services are central to Customer Service Agreements, where regular product or process improvement options are evaluated.

Engineering Services:
- Revampings
- Design validation
- Debottlenecking
- Studies (Screening/Feasibility/Permitting)
- Process optimization studies
- Performance improvement programs (PIP)
- Modifications / Conversions / Upgrades
- Plant life cycle assessments and extensions
- Design for third party organizations
- Project development and cost estimates

Contact

customer-services@airliquide.com

Case Study: Unit lifetime extension

Mission Oxygen plant – Europe -2013:

Our Customer wanted to revamp their plant to bring it up to date and extend its life.

Intervention:

We identified the need to replace:
- Front end purification
- Electrical room
- Main heat exchanger of the cold box

Revamping planned to take place during planned shutdown.

We supervised the re-start of the ASU.

Results:
- + 15 years’ life plant
- Full compliance with more stringent safety regulations.
- Excellence of Execution
- Efficient intervention in a complex environment meeting customer requirements.
Remote Support Services: monitoring and analyses for prompt assistance

Air Liquide Engineering & Construction specialists can perform plant data analysis, carried out in our product/process centers of excellence to provide reliable, effective solutions using on-line, connectivity-based services. Remotely conducted predictive analyses support:

• Prevention of potential incidents or problems;
• Avoidance of costly unplanned downtime;
• Life extension programs through plant obsolescence management

To further assist operations, members of our Remote Support Services team are available to hold customized training courses for your personnel on safety, equipment, processes, operations and maintenance (O&M).

Remote Support Services:

• Plant diagnoses
• Vulnerability studies
• Accident risk analyses
• Energy efficiency assessments
• Remote monitoring and diagnostic reports
• Customer training (O&M, HSE) and upgrades
• Health, Safety and Environment (HSE) studies
• Operations and maintenance optimization studies

Case Study: Process optimization

Mission LNG Terminal, UK:

The needs of our client have changed. He wanted advice to re-optimize.

Intervention:

Experts mobilized in order to fully audit their processes:

• Detailed diagnostic with recommendations for plant optimizations in the short and long term
• Combination of Remote On-Site Support with back office analysis

Results:

• Significant reduction of OPEX:
  Optimization of common header system 30% energy reduction, Payback < 6 months
• Improved equipment lifetime
• Reduced stop and go operation of units

Contact

customer-services@airliquide.com
On-Site Services: expertise in assessments, operations, repairs

Our experienced field service engineers, the same as deployed at Air Liquide Group facilities, are at Customer’s disposal for site interventions, troubleshooting and fixes. Prompt dispatch of experts is also provided to root cause incidents and restart reliable operations after unplanned shutdown events. On-Site repair activities, executed by our qualified team, will ensure reliable plant operations for the long term to follow.

On-Site Services:
• Repairs
• Troubleshooting and fixes
• Support upon emergency call
• Performance / Efficiency checks
• Supervision for:
  - Plant operations
  - Supplier interventions
  - Planned maintenance events
  - Installation, commissioning, start-up
• Execution of plant relocation activities

Contact

customer-services@airliquide.com

Case Study: ASU relocation and uprating project to meet higher production demand

Mission ASU – Asia - 2010:
A customer asked us to plan and complete the ASU relocation, and propose a solution to increase significantly gaseous nitrogen production.

Intervention:
To address the uprating, we provided our Customer with two detailed proposals for increasing production: adding a new ASU or upgrading an existing unit. Our Customer opted for the upgrade.

Results:
• Flexible approach to evolving needs
Our well-structured proposals and sound technical support enabled our Customer to make a well-informed decision with confidence.
• Cost-effective major production increase
Upgrading was the best solution, in CAPEX terms, while our efficient execution made for reliability and a doubling of N2 production.
Spare Parts Services: competent support from our supply chain

Thanks to strong relationships with selected suppliers, our E&C specialists will support you at best with custom spare part lists, specifying everything needed to respect fit, form and function of installed parts. We insure interchangeability and offer assistance related to change of suppliers, obsolescence and upgrading of parts and provide assistance in case of certification requirements to comply with the latest regulations and local jurisdictions. We also carry out our consultative studies on safety and capital stocks needed to maximize the availability of your plant.

**Spare Parts Services:**
- Standard supply
- Emergency supply
- Site inventory audits
- Spare parts installation
- Safety and capital stocks
- Inspection and expediting
- Interchangeability studies
- Storage recommendations
- Obsolescence management
- Compliance with updated regulations
- Lists for planned and unplanned maintenance

**Case Study:** Sourcing and procurement of an update for a 30-year-old bundle

**Mission Chemical plant – South Africa – 2015:**

Our client had to change three 30+ years old bundles in order to increase plant's reliability and comply with local regulations. They had no equipment documentation and the equipment was tailor made.

**Intervention:**
As the initial manufacturer didn’t exist anymore, we searched for vendors able to manufacture the bundles based on the technical documents from our archives.
Several components had to be upgraded so as to comply with current local regulations.
Finally, the ready to install equipment was handed to the client’s transporter together with the requested documents to apply for local certifications.

**Results:**
- Ready to install: the bundles were made to fit the plant’s design
- Performance consistency: a 12 months’ performance guarantee of the equipment

**Contact**
customer-services@airliquide.com
Customer Service Agreements (CSA): Easy ongoing access to our broad range of services and expertise

Customer Service Agreements (CSA) are the most comprehensive way to benefit from our Customer Services. By simplifying your access to the expertise of Air Liquide, a CSA makes for a close partnership between your team and ours. This includes regular on-site meetings. A single CSA provides you with the ongoing support of as many of our Customer Service as you require, enabling you to optimize plant performance and maximize cost control over time.

The CSA can be customized to fit your specific needs and circumstances, with options to renew or modify the subscribed services. The duration of the agreement is variable, keeping up with your requirements.

Customer Service Agreements:
- Easy and effective access to Air Liquide specialists and expertise:
  - Single renewable contract
  - Single contact person
  - First reply guaranteed timing
  - Practical answers with clear and easy operating instructions
  - Regular on-site meetings
- Maintenance programs
- Continuous technical support
- Extended performance guarantees
- Customer tailored terms on any selected Service

Contact

customer-services@airliquide.com

Mission ASU plants – Middle East - 2017:

Our customer wanted to increase its production, optimize the related energy consumption and sustain a good knowledge of its units.

Intervention:

We first assessed the current status of the units and their energy consumption:
- Off-site preparation and information gathering
- On-site visual inspection and report-out

Results:

A long term Service Agreement has been signed including ‘on demand’ specific diagnostics (feasibility studies, risk analysis, remote troubleshooting,…), site services, spare parts services, guaranteeing the customer the best follow-up and ensuring him with support whenever requested.
With extensive experience, the core technology of Air Liquide Turbo has been well proven for over 50 years. During that time, with an installed base of well over a thousand turbo expanders, our technology has steadily grown and improved to be a leaders in both overall efficiency as well as reliability.
Dual Turboexpander - Compressor TC Series
TC2000, TC3000, TC4000, TC6000, TC9000, TC12000

Available options
- Inlet screens
- Inlet trip valves
- Surge control system
- Low hysteresis high cycle inlet guide vanes
- Cable trays or conduit
- Safe area or hazardous area location
- International code compliance (HPGSL, PED, GOST, etc.)
- Cryogenic performance testing
- Spare cartridge with nozzle assembly

Application
Industrial Gas Production - Air Separation & Liquefaction

Feedstock - Fluids Handled
Air, Nitrogen, Waste Gas (high oxygen content), Carbon dioxide and carbon monoxide

Cross Section: Tc-4000

Compressor Loaded Expanders – Dual Machines

Rugged Rotor Design

Self-Aligning Wheel Attachment
**Description**

**“Zero Leakage” Inlet Guide Vanes**
- Adjustable inlet guide vanes provide optimum flow patterns as well as precise and continuous control across the machine’s full operational spectrum.
- Self-energizing back plate maintains zero sidewall clearance for maximum expander efficiency.
- Zero backlash variable guide vane configuration provides smooth turn-up capability to 125% of design flow.

**Rugged Rotor Design**
- Stiff rotor shaft and high capacity tilt pad bearings assure maximum stability at all operating loads and speeds.
- High capacity tilt pad thrust bearings provide the extra margin necessary to handle transients.
- Numerous bearing designs available to accommodate specific process applications, including hydrodynamic (journal and tilt pad) bearings, ball bearings, ceramic bearings, and air/foil bearings.
- Sealing design offers robust construction and reliable performance.

**Dual Independent Labyrinth Shaft Seal**
- Reliable teeth-on-shaft design is precision machined to ultra close clearances, minimizing seal gas consumption.
- Dual port, atmospheric center vent prevents process steam contamination.

**Self-Aligning Wheel Attachment**
- Tapered bore and stretch rod design automatically compensates for thermal and mechanical changes to maintain alignment under all operating conditions.
- Precision machined tapered bore/shaft attachment allows independent balancing of turbine wheel and shaft to facilitate.

**Main features:**
- Common lube oil system and controls support two expanders/compressors.
- “Zero leakage” inlet guide vanes.
- Components individually balanced for ease of field replacement.
- Tapered shaft wheel attachment for field interchangeability.
- Labyrinth shaft seal design minimizes seal gas consumption and prevents process stream contamination.
- Shaft-driven boost compressor reduces power consumption, increasing plant efficiency.
- Easily upgraded for future plant changes e.g. improved aero for higher efficiency/capacity.

**Contact**

turboexpanders@airliquide.com
Hydrobrake Cryogenic Compressor (THC)
Series THC-3000, THC-4000, THC-6000

Application
Industrial Gas Production - Air Separation & Liquefaction

Feedstock - Fluids Handled
Air, Nitrogen, Waste Gas (high oxygen content), Carbon dioxide and carbon monoxide

Available options
- Inlet screens
- Inlet trip valves
- Surge control system
- Low hysteresis high cycle inlet guide vanes
- Cable trays or conduit
- Safe area or hazardous area location
- International code compliance (HPGSL, PED, GOST, etc.)
- Cryogenic performance testing
- Spare cartridge with nozzle assembly

Performance
- Expander Ns Range: 40 – 140
- Expander Efficiency: up to 88%
- Expander Pressure Ratio: up to 24:1
- Tip Speed: up to 1,200 ft/sec (366 m/s)
- Rotor Speed: up to 55,000 RPM
- Refrigeration Production: up to 200 HP (150 kW)
Description

“Zero Leakage” Inlet Guide Vanes
• Adjustable inlet guide vanes provide optimum flow patterns as well as precise and continuous control across the machine’s full operational spectrum
• Self-energizing back plate maintains zero sidewall clearance for maximum expander efficiency
• Zero backlash variable guide vane configuration provides smooth turn-up capability to 125% of design flow

Rugged Rotor Design
• Stiff rotor shaft and high capacity tilt pad bearings assure maximum stability at all operating loads and speeds
• High capacity tilt pad thrust bearings provide the extra margin necessary to handle transients
• Numerous bearing designs available to accommodate specific process applications, including hydrodynamic (journal and tilt pad) bearings, ball bearings, ceramic bearings, and air/foil bearings
• Sealing design offers robust construction and reliable performance

Dual Independent Labyrinth Shaft Seal
• Reliable teeth-on-shaft design is precision machined to ultra close clearances, minimizing seal gas consumption
• Dual port, atmospheric center vent prevents process stream contamination
• Self-Aligning Wheel Attachment
• Tapered bore and stretch rod design automatically compensates for thermal and mechanical changes to maintain alignment under all operating conditions
• Precision machined tapered bore/shaft attachment allows independent balancing of turbine wheel and shaft to facilitate field repair

Main features:
• Compact footprint
• “Zero leakage” inlet guide vanes
• Rugged rotor design
• Components individually balanced for ease of field replacement
• Tapered shaft wheel attachment for field interchangeability
• Dual vibration probes
• Coalescing mist eliminator
• Labyrinth shaft seal design minimizes seal gas consumption and prevents process stream contamination
• Easily upgraded for future plant changes e.g. improved aero for higher efficiency/capacity

Contact
	turboexpanders@airliquide.com
Turboexpander - Hydrobrake (TH)
Series TH-3000, TH-4000, TH-6000

Application
Industrial Gas Production - Air Separation & Liquefaction

Feedstock - Fluids Handled
Air, Nitrogen, Waste Gas (high oxygen content), Carbon dioxide and carbon monoxide

Available options
- Inlet screens
- Inlet trip valves
- Surge control system
- Low hysteresis high cycle inlet guide vanes
- Cable trays or conduit
- Safe area or hazardous area location
- International code compliance (HPGSL, PED, GOST, etc.)
- Cryogenic performance testing
- Spare cartridge with nozzle assembly

Performance
- Expander Ns Range: 40 – 140
- Expander Efficiency: up to 88%
- Expander Pressure Ratio: up to 24:1
- Tip Speed: up to 1,200 ft/sec (366 m/s)
- Rotor Speed: up to 55,000 RPM
- Refrigeration Production: up to 200 HP (150 kW)
**Description**

**“Zero Leakage” Inlet Guide Vanes**
- Adjustable inlet guide vanes provide optimum flow patterns as well as precise and continuous control across the machine’s full operational spectrum.
- Self-energizing back plate maintains zero sidewall clearance for maximum expander efficiency.
- Zero backlash variable guide vane configuration provides smooth turn-up capability to 125% of design flow.

**Rugged Rotor Design**
- Stiff rotor shaft and high capacity tilt pad bearings assure maximum stability at all operating loads and speeds.
- Sealing design offers robust construction and reliable performance.
- Uniformly loaded drive tangs provide the high torque capacity necessary to handle upset conditions.

**Self-Aligning Wheel Attachment**
- Tapered bore and stretch rod design automatically compensates for thermal and mechanical changes to maintain alignment under all operating conditions.
- Precision machined tapered bore/shaft attachment allows independent balancing of turbine wheel and shaft to facilitate attachment allows independent balancing of turbine wheel and shaft to facilitate field repair.

**Main features:**
- Compact footprint
- “Zero leakage” inlet guide vanes
- Rugged rotor design
- Tapered shaft wheel attachment for field interchangeability
- Components individually balanced for ease of field replacement
- Externally adjustable power absorption control
- Labyrinth shaft seals with oil-free design
- Manual or automatic oil brake flow control valve for adjustment
- Easily upgraded for future plant changes e.g. improved aero for higher efficiency/capacity

**Contact**

[Contact at turboexpanders@airliquide.com](mailto:turboexpanders@airliquide.com)
Compressor TC - Series
TC2000, TC3000, TC4000, TC6000, TC9000, TC12000

Application
Industrial Gas Production - Air Separation & Liquefaction

Feedstock - Fluids Handled
Air, Nitrogen, Waste Gas (high oxygen content), Carbon dioxide and carbon monoxide

Available options
• Inlet screens
• Inlet trip valves
• Surge control system
• Low hysteresis high cycle inlet guide vanes
• Cable trays or conduit
• Safe area or hazardous area location
• International code compliance (HPGSL, PED, GOST, etc.)
• Cryogenic performance testing
• Spare cartridge with nozzle assembly

Performance
• Expander Ns Range: 40 – 140
• Expander Efficiency: up to the low 90%s
• Expander Pressure Ratio: up to 24:1
• Tip Speed: up to 1,500 ft/sec (457 m/s)
• Rotor Speed: up to 115,000 RPM
• Refrigeration Production: up to 10,000 HP (7,457 kW)

Compressor Loaded Expanders – Dual Machines
Rugged Rotor Design
Self-Aligning Wheel Attachment

Cross Section: Tc-4000
Description

“Zero Leakage” Inlet Guide Vanes
• Adjustable inlet guide vanes provide optimum flow patterns as well as precise and continuous control across the machine’s full operational spectrum
• Self-energizing back plate maintains zero sidewall clearance for maximum expander efficiency
• Zero backlash variable guide vane configuration provides smooth turn-up capability to 125% of design flow

Rugged Rotor Design
• Stiff rotor shaft and high capacity tilt pad bearings assure maximum stability at all operating loads and speeds
• High capacity tilt pad thrust bearings provide the extra margin necessary to handle transients
• Numerous bearing designs available to accommodate specific process applications, including hydrodynamic (journal and tilt pad) bearings, ball bearings, ceramic bearings, and airfoil bearings
• Sealing design offers robust construction and reliable performance

Dual Independent Labyrinth Shaft Seal
• Reliable teeth-on-shaft design is precision machined to ultra close clearances, minimizing seal gas consumption
• Dual port, atmospheric center vent prevents process stream contamination

Self-Aligning Wheel Attachment
• Tapered bore and stretch rod design automatically compensates for thermal and mechanical changes to maintain alignment under all operating conditions
• Precision machined tapered bore/shaft attachment allows independent balancing of turbine wheel and shaft to facilitate

Main features:
• Compact footprint
• “Zero leakage” inlet guide vanes
• Components individually balanced for ease of field replacement
• Tapered shaft wheel attachment for field interchangeability
• Labyrinth shaft seal design minimizes seal gas consumption and prevents process stream contamination
• Shaft-driven boost compressor reduces power consumption, increasing plant efficiency
• Easily upgraded for future plant changes e.g. improved aero for higher efficiency/capacity

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Or contact us online: www.engineering-airliquide.com/contact-us
Our other locations’ contact information can be found at www.engineering-airliquide.com
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tbody>
<tr>
<td>DMR</td>
<td>Dehydration and mercaptan removal unit</td>
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<tr>
<td>DRI</td>
<td>Direct reduction of iron ore</td>
</tr>
<tr>
<td>DTDC</td>
<td>Desolventizer, toaster, dryer and cooler</td>
</tr>
<tr>
<td>E&amp;C</td>
<td>Engineering and construction</td>
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<tr>
<td>EA</td>
<td>Ethylacrylate</td>
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<tr>
<td>EAA</td>
<td>Ester-grade acrylic acid</td>
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<tr>
<td>EOR</td>
<td>Enhanced oil recovery</td>
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<tr>
<td>EtOH</td>
<td>Ethanol</td>
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<tr>
<td>FAD</td>
<td>Fatty acid distillate</td>
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<tr>
<td>FAME</td>
<td>Fatty acid methyl ester</td>
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<tr>
<td>FBD</td>
<td>Block flow diagram</td>
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<tr>
<td>FBF</td>
<td>Boiler feedwater</td>
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<tr>
<td>BOG</td>
<td>Boil-off gas</td>
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<td>BTU</td>
<td>British thermal unit</td>
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<tr>
<td>BuOH</td>
<td>Butanol</td>
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<tr>
<td>C2+</td>
<td>Hydrocarbons with 2 or more carbons</td>
</tr>
<tr>
<td>C4</td>
<td>Mixture of 4-carbon hydrocarbons (butane, butylenes and butadienes)</td>
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<tr>
<td>Capex</td>
<td>Capital expenditures</td>
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<tr>
<td>CCR</td>
<td>Continuous catalytic reforming</td>
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<td>CDU</td>
<td>Crude distillation unit</td>
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<td>Claus</td>
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<td>CO</td>
<td>Carbon monoxide</td>
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<td>CO₂</td>
<td>Carbon dioxide</td>
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<td>COS</td>
<td>Carbonyl sulfide</td>
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<td>CSFT</td>
<td>Cold soak filtration test</td>
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<tr>
<td>Cu</td>
<td>Copper</td>
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<td>CW</td>
<td>Cooling water</td>
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<td>DEA</td>
<td>Diethanolamine</td>
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<td>DME</td>
<td>Dimethyl ether</td>
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<td>FAME</td>
<td>Fatty acid methyl ester</td>
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<td>FBD</td>
<td>Fixed bed dry bottom gasifier</td>
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<td>FEED</td>
<td>Front-end engineering design</td>
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<td>FFA</td>
<td>Free fatty acid</td>
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<td>FOB</td>
<td>Free on board</td>
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<td>F-T</td>
<td>Fischer-Tropsch</td>
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<td>G2G</td>
<td>Gas-to-Gasoline</td>
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<tr>
<td>GAN</td>
<td>Gaseous nitrogen</td>
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<td>GAR</td>
<td>Gaseous argon</td>
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<td>GNG</td>
<td>Gaseous natural gas</td>
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<td>Gaseous oxygen</td>
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<tr>
<td>HCN</td>
<td>Hydrogen cyanide</td>
</tr>
<tr>
<td>HDS</td>
<td>Hydrodesulfurization</td>
</tr>
<tr>
<td>He</td>
<td>Helium</td>
</tr>
<tr>
<td>HF</td>
<td>Hydrofluoric acid</td>
</tr>
<tr>
<td>Hg</td>
<td>Mercury</td>
</tr>
<tr>
<td>HHC</td>
<td>Heavy hydrocarbon</td>
</tr>
<tr>
<td>HP</td>
<td>High pressure</td>
</tr>
<tr>
<td>HT</td>
<td>High temperature</td>
</tr>
<tr>
<td>IgCC</td>
<td>Integrated gasification combined cycle</td>
</tr>
<tr>
<td>IMPCA</td>
<td>International methanol producers and consumers association</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>JT</td>
<td>Joule-Thomson</td>
</tr>
<tr>
<td>Kr</td>
<td>Krypton</td>
</tr>
<tr>
<td>LNG</td>
<td>Liquefied natural gas</td>
</tr>
<tr>
<td>LOX</td>
<td>Liquid oxygen</td>
</tr>
<tr>
<td>LP</td>
<td>Low pressure</td>
</tr>
<tr>
<td>LP3</td>
<td>Low pressure fatty alcohols production</td>
</tr>
<tr>
<td>LPG</td>
<td>Liquefied petroleum gas</td>
</tr>
<tr>
<td>LTGT</td>
<td>Lurgi tailgas treatment</td>
</tr>
<tr>
<td>MA</td>
<td>Methylacrylate</td>
</tr>
<tr>
<td>MDEA</td>
<td>Methyl diethanolamine</td>
</tr>
<tr>
<td>MDI</td>
<td>Methylene diphenyl disocyanate</td>
</tr>
<tr>
<td>MEA</td>
<td>Monoethanolamine</td>
</tr>
<tr>
<td>MEG</td>
<td>Monoethylene glycol</td>
</tr>
<tr>
<td>MeOH</td>
<td>Methanol</td>
</tr>
<tr>
<td>MP</td>
<td>Medium pressure</td>
</tr>
<tr>
<td>MPG</td>
<td>Multi-purpose gasifier</td>
</tr>
<tr>
<td>MTG</td>
<td>Methanol-to-Gasoline</td>
</tr>
<tr>
<td>MTP</td>
<td>Methanol-to-Propylene</td>
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<tr>
<td>NaOH</td>
<td>Soda</td>
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<tr>
<td>Ne</td>
<td>Neon</td>
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<tr>
<td>NG</td>
<td>Natural gas</td>
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<tr>
<td>NGL</td>
<td>Natural gas liquids</td>
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<tr>
<td>NH₃</td>
<td>Ammonia</td>
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<tr>
<td>Ni</td>
<td>Nickel</td>
</tr>
<tr>
<td>NMP</td>
<td>N-methylpyrrolidone</td>
</tr>
<tr>
<td>NO</td>
<td>Nitrous oxide</td>
</tr>
<tr>
<td>NOx</td>
<td>Nitrous oxides</td>
</tr>
<tr>
<td>NRU</td>
<td>Nitrogen removal unit</td>
</tr>
<tr>
<td>Opex</td>
<td>Operating expenditures</td>
</tr>
<tr>
<td>PAH</td>
<td>Polycyclic aromatic hydrocarbon</td>
</tr>
<tr>
<td>PC</td>
<td>Polycarbonate</td>
</tr>
<tr>
<td>PDH</td>
<td>Propane dehydrogenation</td>
</tr>
<tr>
<td>PDP</td>
<td>Preliminary design package</td>
</tr>
<tr>
<td>PIMS</td>
<td>Proprietary simulation software</td>
</tr>
<tr>
<td>PIP</td>
<td>Performance improvement program</td>
</tr>
<tr>
<td>POX</td>
<td>Partial oxidation</td>
</tr>
<tr>
<td>PSA</td>
<td>Pressure swing adsorption</td>
</tr>
<tr>
<td>PSD</td>
<td>Prevention of significant deterioration</td>
</tr>
<tr>
<td>PTSA</td>
<td>Para-toluene sulfuric acid</td>
</tr>
<tr>
<td>RBD</td>
<td>Refined, bleached and deodorized</td>
</tr>
<tr>
<td>RSH</td>
<td>Carbon-bonded sulfhydryl or thiol</td>
</tr>
<tr>
<td>SMR</td>
<td>Steam methane reforming or reformer</td>
</tr>
<tr>
<td>SNG</td>
<td>Synthetic natural gas</td>
</tr>
<tr>
<td>SO₂</td>
<td>Sulfur dioxide</td>
</tr>
<tr>
<td>SOx</td>
<td>Sulfur oxides</td>
</tr>
<tr>
<td>SRU</td>
<td>Sulfur removal unit</td>
</tr>
<tr>
<td>TDI</td>
<td>Toluene disocyanate</td>
</tr>
<tr>
<td>USD</td>
<td>United States dollar</td>
</tr>
<tr>
<td>VDU</td>
<td>Vacuum distillation unit</td>
</tr>
<tr>
<td>VSA</td>
<td>Vacuum Swing Adsorption</td>
</tr>
<tr>
<td>WHRS</td>
<td>Waste heat recovery system</td>
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<tr>
<td>Xe</td>
<td>Xenon</td>
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Technology Handbook

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**Economic hypothesis and definitions:** Unless otherwise specified, Opex calculations include variable operating costs (utilities, feedstock...) and fixed costs (labour...). Natural gas cost is assumed to be $4/mmBTU HHV. In addition, unless otherwise specified, Capex is calculated either: a) including all EPC costs (process units, offsite and utilities) but excluding owner’s costs for a plant built on the USGC; or, b) using 1.8xEP costs (process units, offsite and utilities). Price base is 2017. Opex and Capex are indicative and can vary according to the basis of design, such as: product(s) yield and quality, site conditions, feedstock quality, utilities, project scope and plant capacity. Units are metric. Gallons (gal) are US Gallons (3.785 liters). Barrel (bbl) refers to oil barrel (42 gal). Heating value shall be understood as Lower Heating Value (LHV). Exchange rate used is: 1 Euro = 1.1 US Dollar.

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**Contact information for suggestions, improvements... email at editorth@airliquide.com**

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