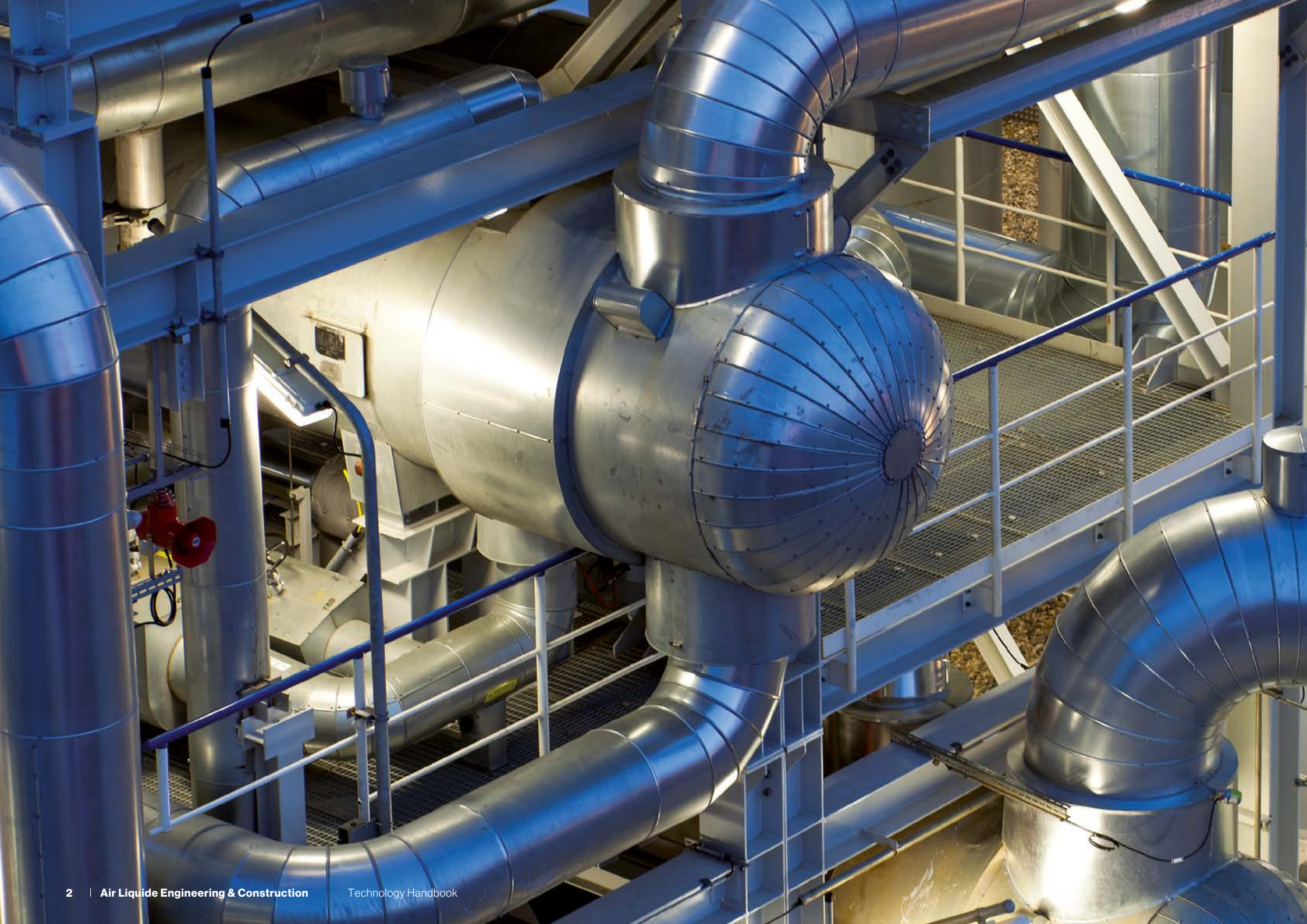




Technology Handbook







Value through technology

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.

Air Liquide

A WORLD LEADER IN GASES, TECHNOLOGIES AND SERVICES FOR INDUSTRY AND HEALTH

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

DELIVERING INNOVATION FOR A SUSTAINABLE WORLD

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.

2500

Employees in
18 countries

15

Operating centers
and front-end offices

3

Manufacturing
centers

347

New patents
filed in 2020

At the heart of innovation

INNOVATION IS ONE PILLAR OF THE AIR LIQUIDE GROUP'S STRATEGY

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 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.



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.

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”.

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.

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

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.



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HYDROGEN & SYNGAS

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.



HYDROGEN & SYNGAS

Application

"Low-carbon Hydrogen" production for refining, chemicals, steel making, mobility

Feedstock

Water, renewables/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

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)

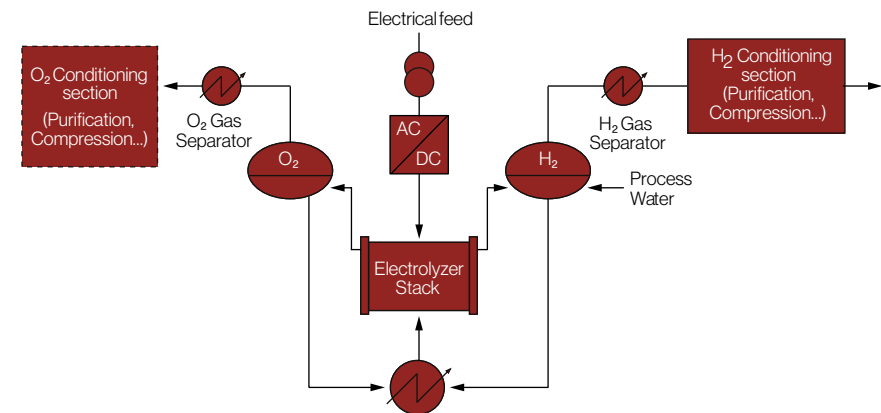
References

3 (> 10 MW)

Contact

electrolyzers@airliquide.com

Electrolyzer PFD





HYDROGEN & SYNGAS

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

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:

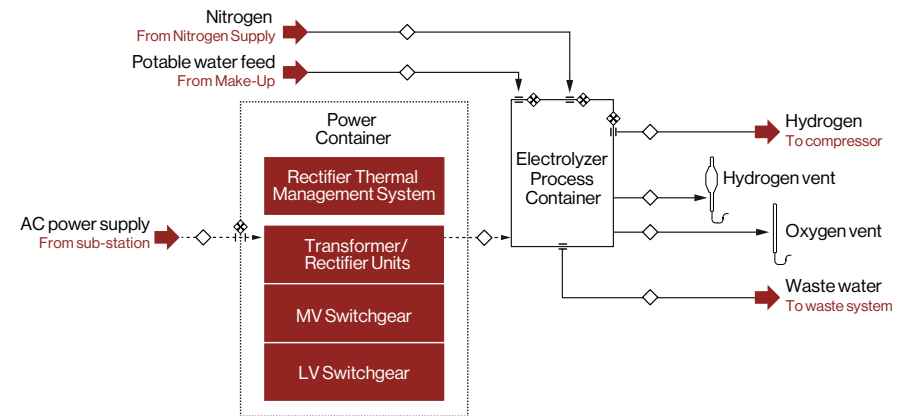
- Standard electrolyzer solutions for short lead-time
- Outdoor solutions for fast installation
- Optional integration with compression and storage solutions for H₂

References

> 30 (< 5 MW)

Contact

electrolyzers@airliquide.com





HYDROGEN & SYNGAS

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

Hydrogen Liquefier (small to mid scale)

Description

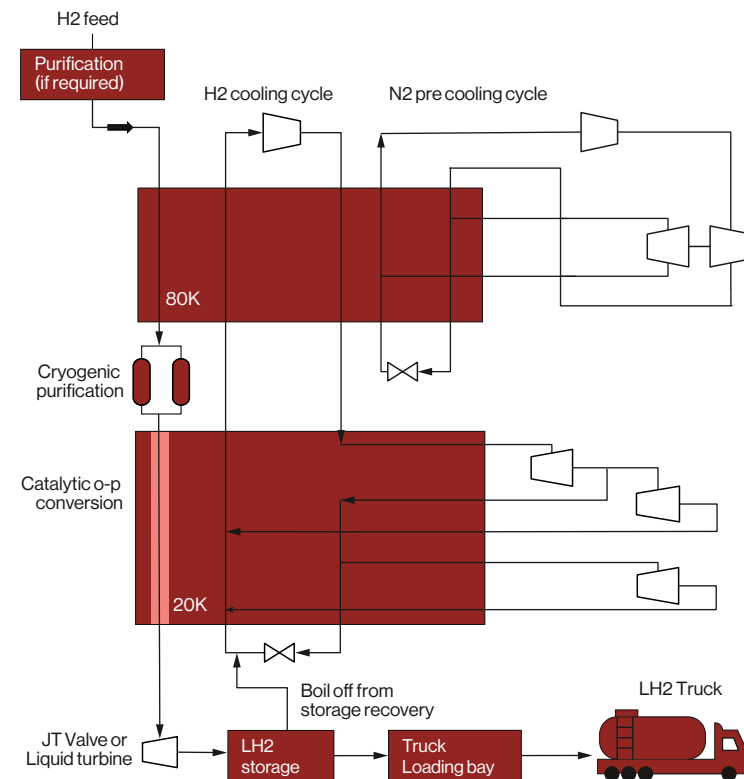
Hydrogen to be liquified may come from different sources. A warm purification upstream of the liquefier may be requested in addition to the cold purification in the liquefier itself, which is dedicated to the removal of the last traces of impurities. H₂ is first precooled from ambient temperature to 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 liquified 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 & SYNGAS

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

Hydrogen Liquefier (large scale)

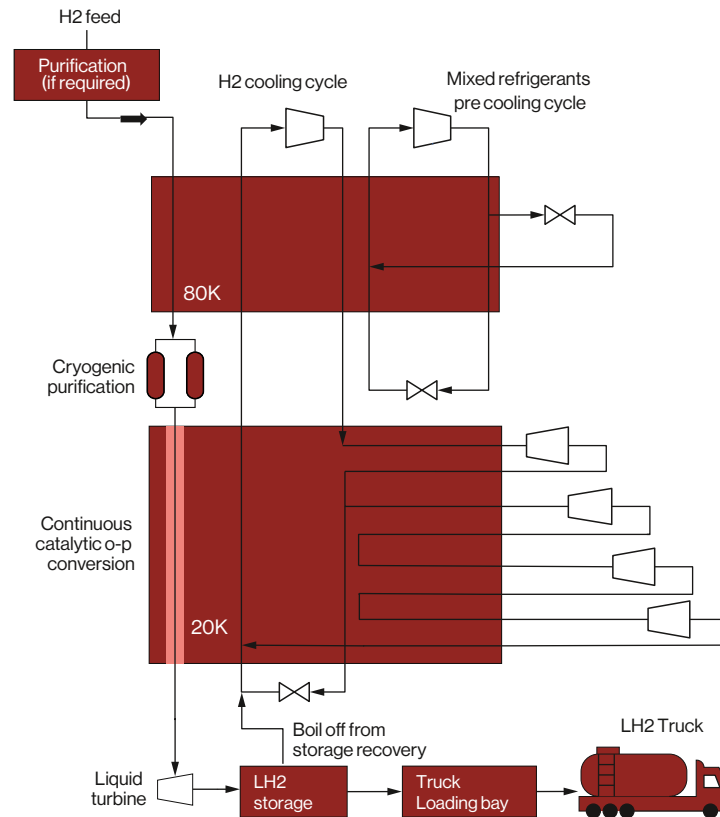
Description

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 pre-cooled 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 (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 & SYNGAS

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

Small-Scale Standard Hydrogen Plant

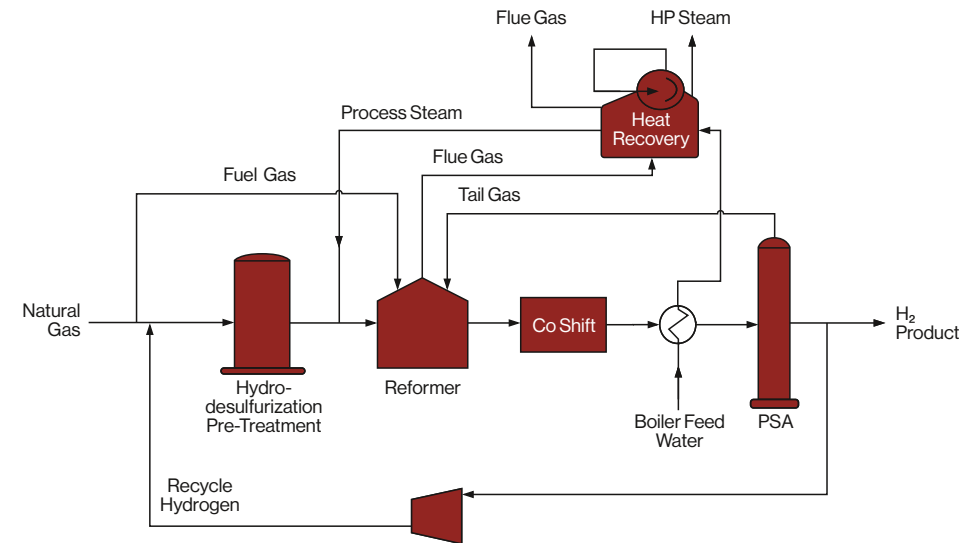
Description

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



HYDROGEN & SYNGAS

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

SMR-X™ – Zero Steam Hydrogen Production

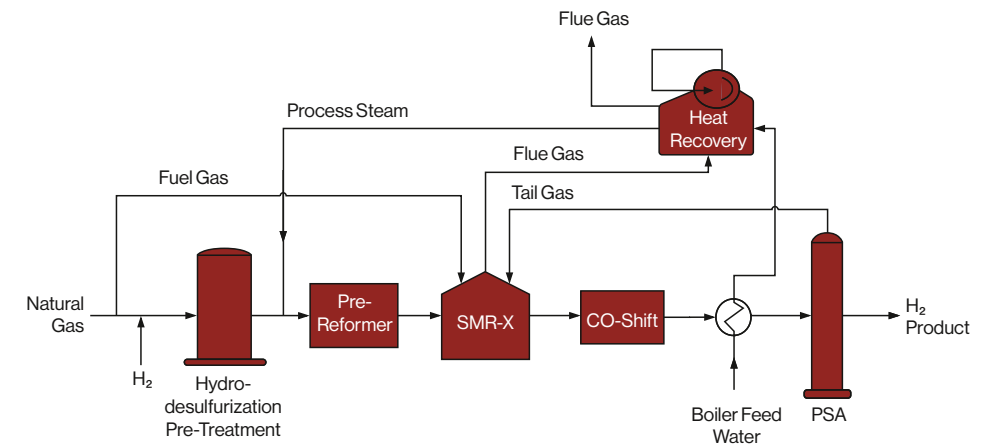
Description

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

Contact

hydrogen-syngas@airliquide.com



HYDROGEN & SYNGAS

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

Steam Methane Reforming (SMR)

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.

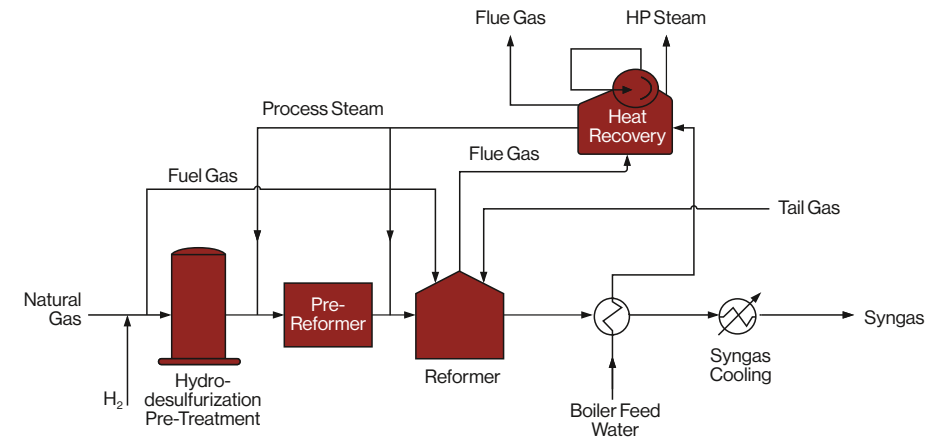
The main reforming reaction takes place in the proprietary top-fired steam reformer in which the feed/steam mixture is converted while passing catalyst filled and heated tubes at temperatures of 800 to 940 °C and pressures of 15 to 45 barg. Reformed gas leaving the reformer contains H₂, CO, CO₂ and unreacted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



HYDROGEN & SYNGAS

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

Low Carbon H₂ Solutions

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.

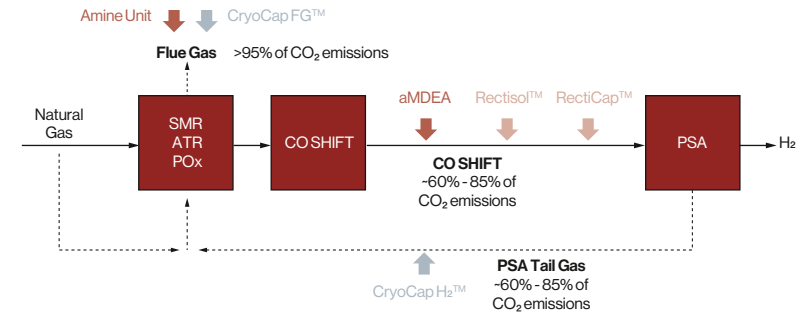
Hydrogen is purified by using a Pressure Swing Adsorption (PSA) technology.

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





HYDROGEN & SYNGAS

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)

Autothermal Reforming for low carbon hydrogen

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:

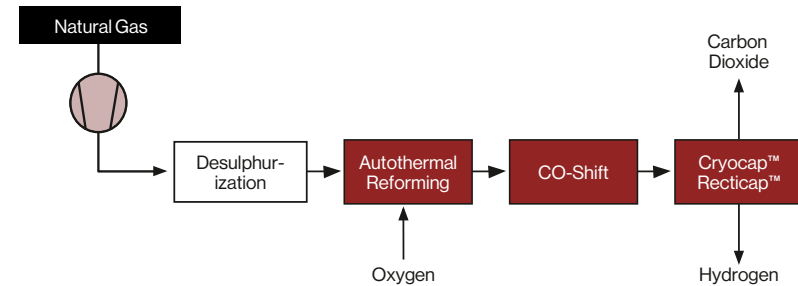
- Entire technology portfolio (ATR, ASU, Shift, Cryocap™, Recticap™, PSA; CO₂ liquefaction) available from Air Liquide
- ATR is a large-scale solution for the production of low carbon hydrogen
- The CO₂ side product is easily separated and purified and ready for capturing/use.

References

Air Liquide has licensed >40 ATR units

Contact

chemicals@airliquide.com





HYDROGEN & SYNGAS

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 ($H_2/CO < 1$), 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

Gas POX – Natural Gas Partial Oxidation

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 H_2 , CO and CO_2 are produced via partial oxidation.

Reformed gas is cooled down producing high pressure steam. CO_2 is removed from the syngas in an amine wash unit.

In case a high CO yield is targeted CO_2 may be separated from syngas and recycled to the POx. Additional import CO_2 may be added if available.

Suitable product purification technologies include: PSA and membrane for H_2 , oxogas, amine wash (aMDEA) for CO_2 removal and partial condensation Cold Box for CO.

Main Features:

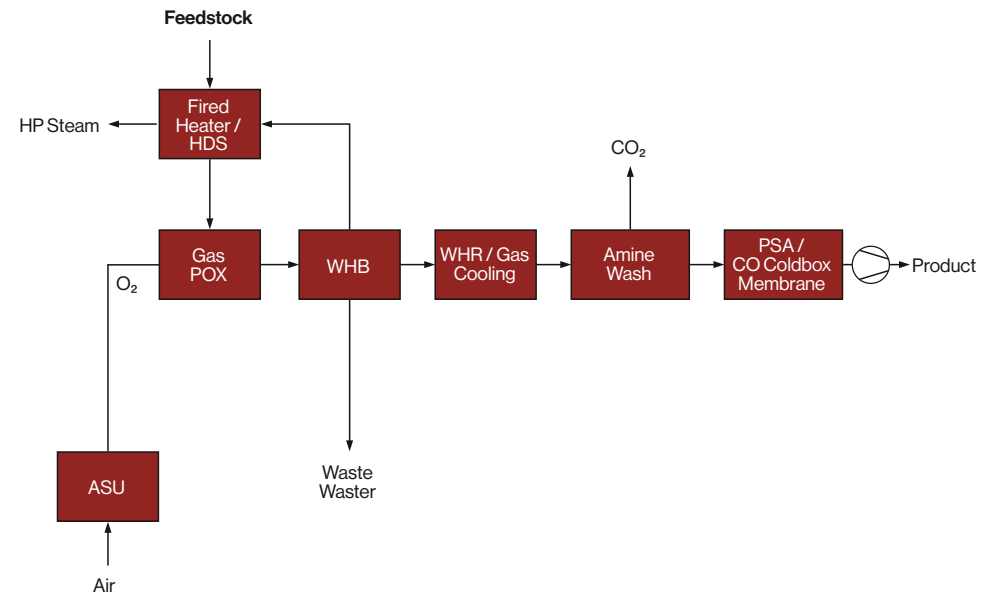
- Efficient technology for products with low H_2/CO ratio or for pure CO production
- Revamp of residue POx reactors allows for switching to more economic nat. gas feed
- Low CO_2 footprint

References

6

Contact

hydrogen-syngas@airliquide.com





HYDROGEN & SYNGAS

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

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 1500 °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.

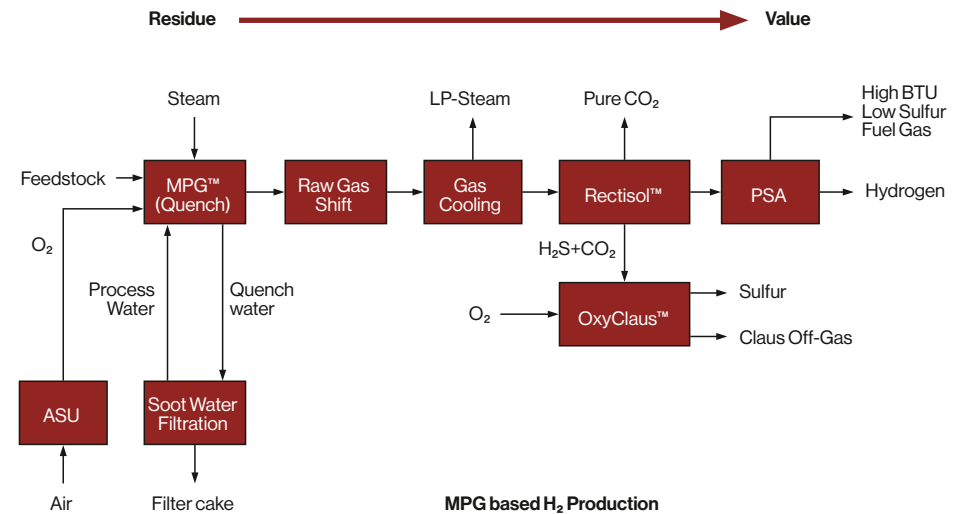
The proprietary MPG-burner design allows a wide variety of feedstock properties to be handled safely and reliably, covering high viscosity and even occasional particles up to millimeter size. The pressurized water cooling of the burner insures safe operation under all conditions. The technology may also 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

Contact

hydrogen-syngas@airliquide.com





HYDROGEN & SYNGAS

Application

Recovery and purification of pure hydrogen from different H₂-rich streams

Feedstock

Raw hydrogen from SMR, POX, cryogenic purification, methanol plant purge gases, ethylene off-gas, styrene offgas, gasification, ammonia plant, CCR, and other offgases or any combination of the above

Product

Hydrogen up to 99.9999% purity

Co-product

None

Capacity

5,000 to 200,000 Nm³/h

Economics

H₂ recovery rate: 60 to 90%

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

Capex: 1 to 5 mm USD

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%.

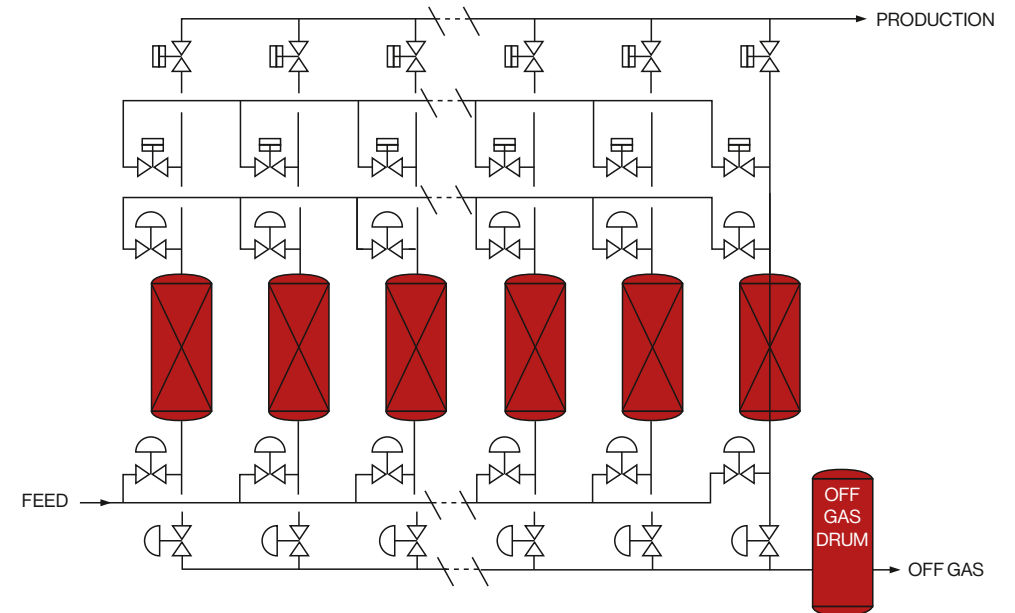
PSA units are compact, fully skid-mounted and pre-tested units designed for outdoor and unmanned operation.

References

>70 (in operation or under construction)

Contact

hydrogen-syngas@airliquide.com





HYDROGEN & SYNGAS

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:

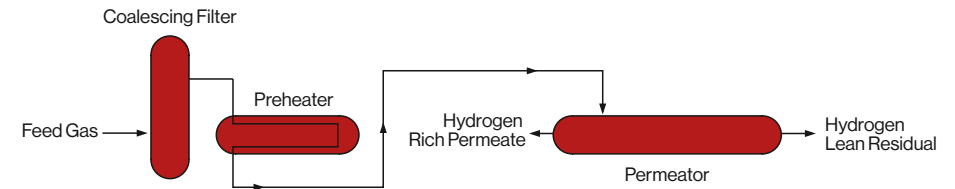
1 mm to 10 + mm USD

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



HYDROGEN & SYNGAS

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

Hydrogen Extraction from Natural Gas Pipelines

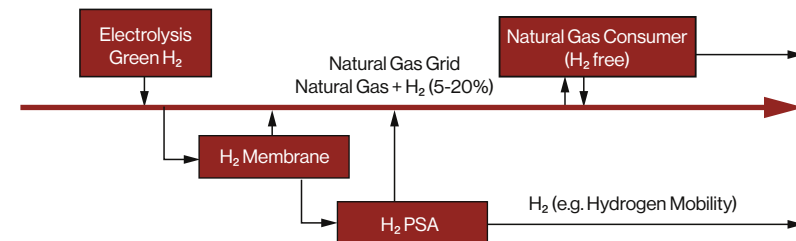
Description

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



HYDROGEN & SYNGAS

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

Blue and Green Ammonia

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.

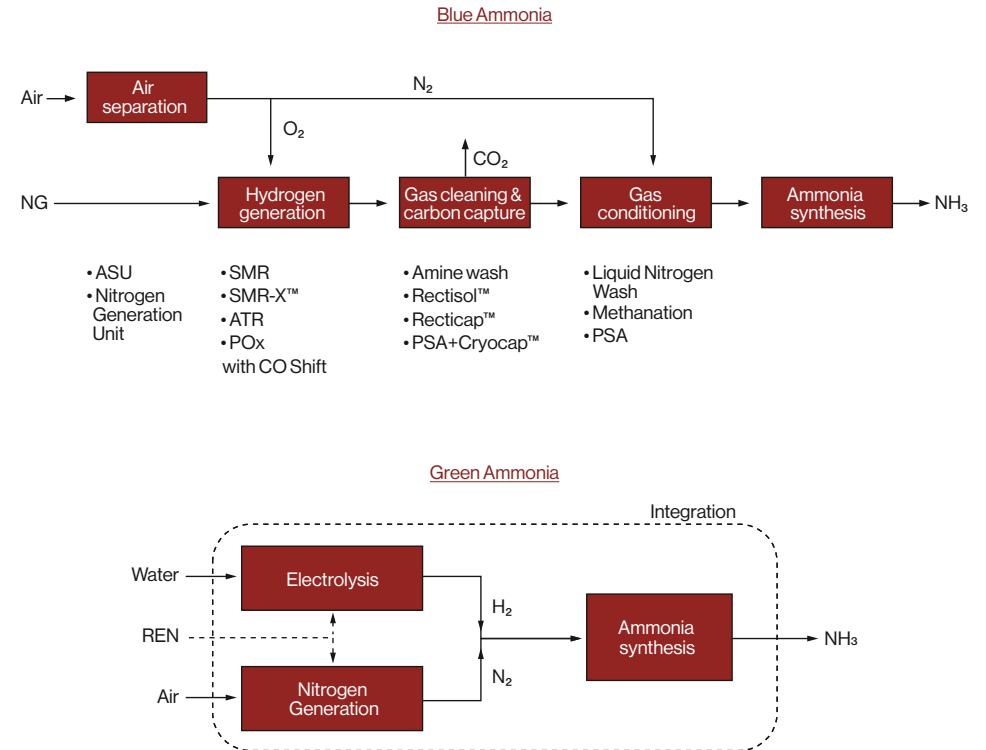
CO₂ is removed from the raw hydrogen and captured for sequestration or utilization by one of Air Liquide's proprietary carbon capture technologies Rectisol™, Recticap™, PSA + Cryocap™ or in an Amine wash.

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



CO₂ & SULFUR

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

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

Acid Gas Removal – Amine Wash

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.

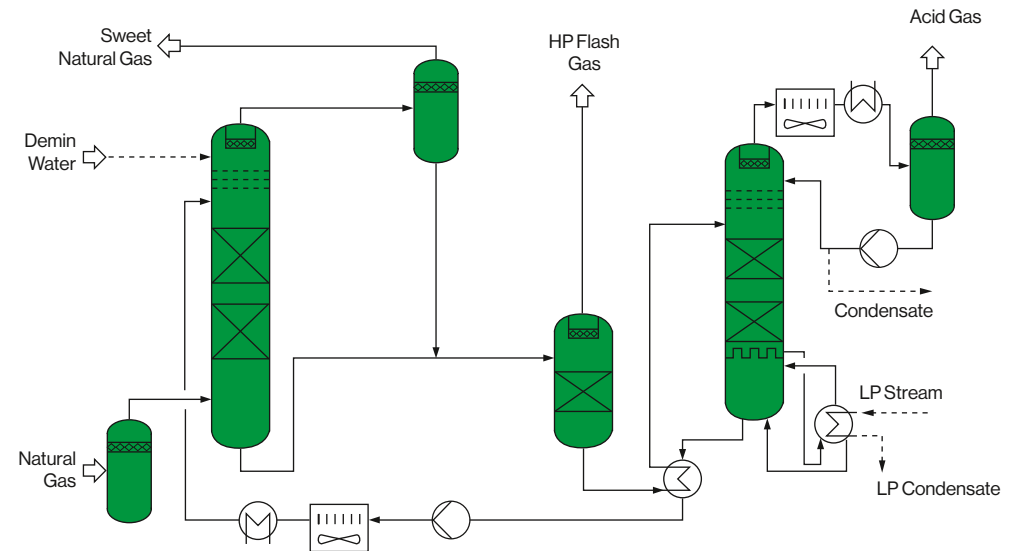
Air Liquide Engineering & Construction can offer very energy-efficient processes such as the BASF OASE® purple or OASE® yellow as well as other proprietary or generic amines for pipeline or liquefied natural gas specifications. This process presents the advantage of very low hydrocarbon co-absorption. 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



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

CO₂ Removal from Flue Gas Amine Wash

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 SO_x are handled in the upstream pretreatment.

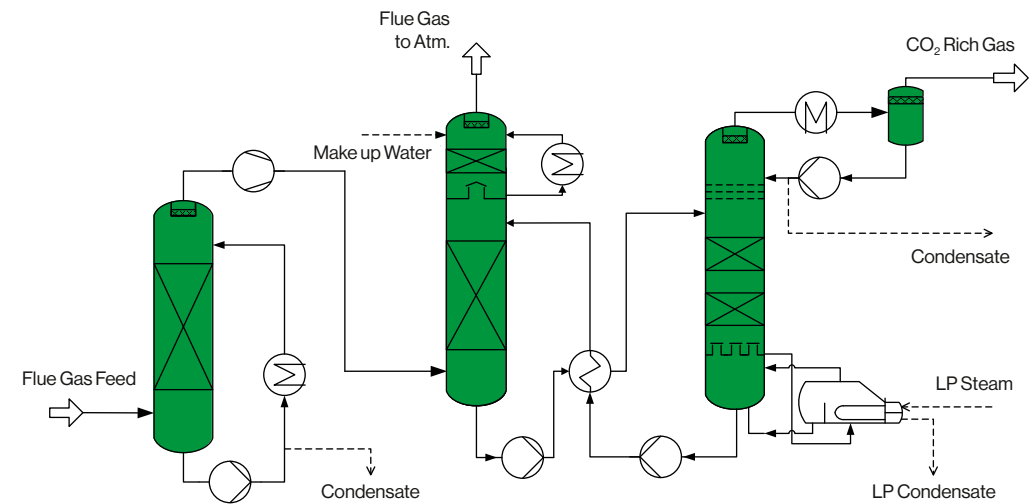
Air Liquide offers energy efficient solutions with highly stable, low maintenance solvents based on proprietary second generation amines. The process configuration will be tailored according to specific process requirements and optimized CAPEX and OPEX.

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



Application

CO₂ capture from cement, lime, H₂, refineries... plants

Feedstock

Flue gas with concentration higher than 15%v (dry basis)

Product

CO₂ (gaseous under pressure or directly liquid)

Co-product

None

Capacity

From 300 to 5000+tpd

Economics

40 to 80 €/tCO₂ captured

CO₂ Removal from Flue Gas Cryocap™ FG

Description

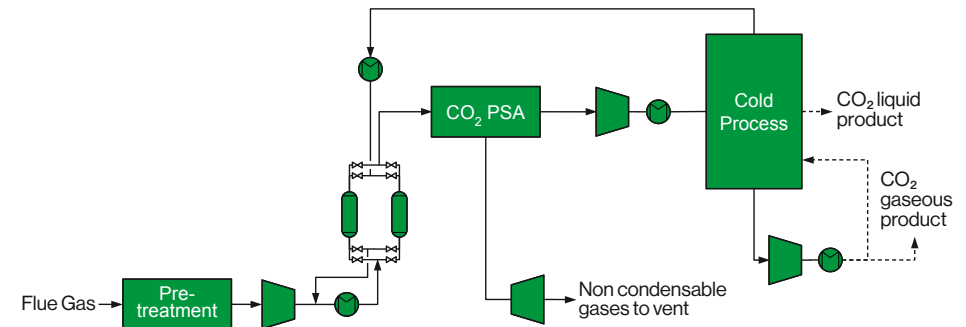
The flue gas is first compressed, dried and sent to a PSA (Pressure Swing Adsorption). The PSA pre-concentrates the CO₂ in the offgas.

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 NO_x 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 (SO_x, particulate matter, NO_x, 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

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

CO₂ Removal from Syngas Amine Wash

Description

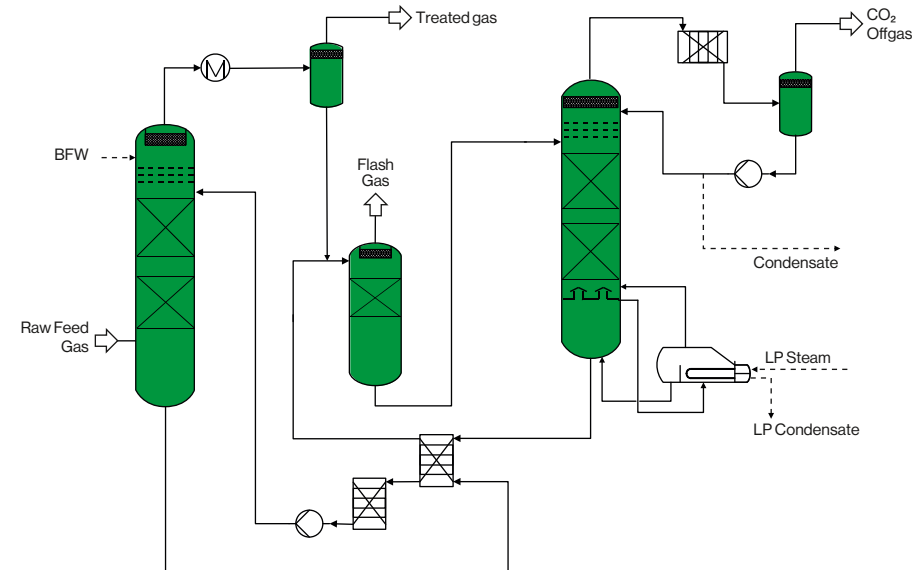
CO₂ contained in the raw gas is removed by absorption with an amine-based solvent. The rich solvent leaving the contactor is regenerated by flashing and stripping.

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

Application

CO₂ capture from
H₂ production plants

Feedstock

Offgas from H₂ plant

Product

CO₂ (gaseous under pressure
or directly liquid)

Co-product

H₂

Capacity

From 500 to 5,000 tpd+

Economics

Opex + Capex:

- 30-50 €/tCO₂ captured

- Increase H₂ production
by 13% to 20%

- Cryocap™ H₂ offers the lowest costs
for CO₂ production from H₂ plant
(20% less capex than amines)

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.

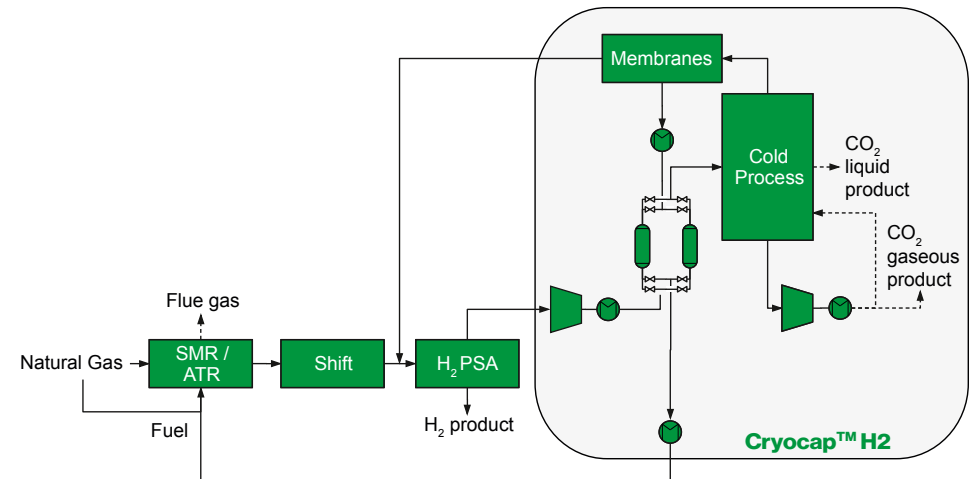
The CO₂ product is compressed up to supercritical pressure or liquefied and stored in liquid storage.

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 feature:

- 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.



Reference

1 (100 000 t/y)

Contact

cryocap@airliquide.com

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

Rectisol™ – Syngas Purification

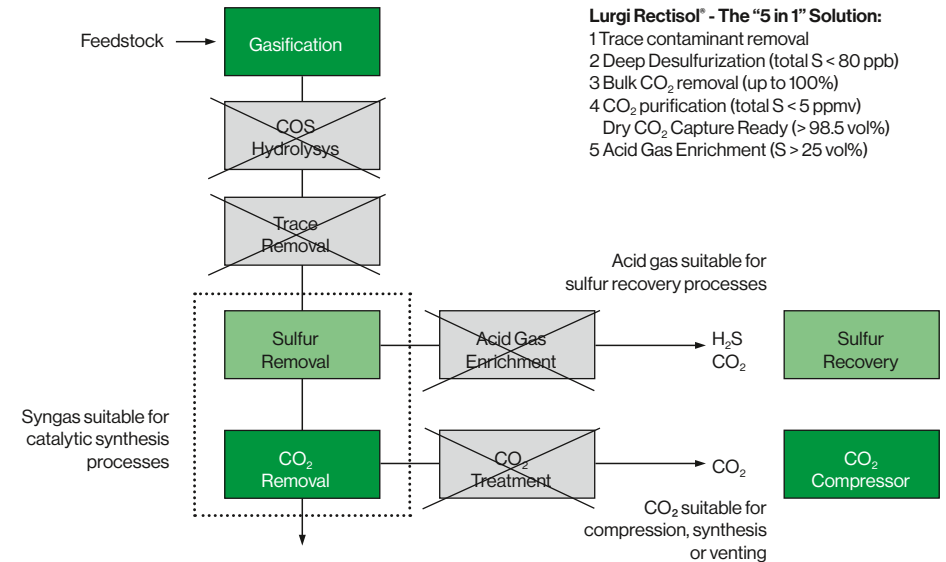
Description

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



References

> 110 (> 35 since 2005)

Contact

hydrogen-syngas@airliquide.com



CO₂ CAPTURE

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

Recticap™

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:

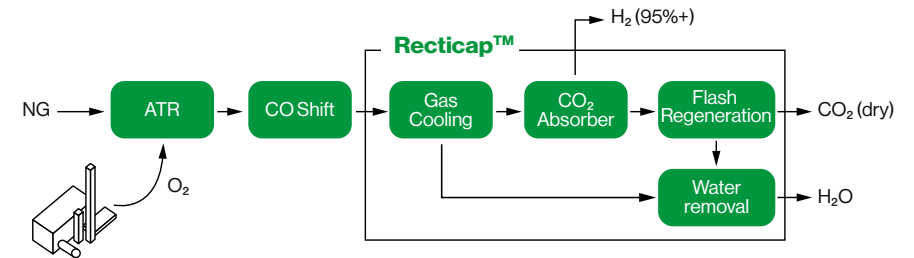
- Large capacities can be built in a single train
- High partial pressure of CO₂ reduces specific capture cost
- Low steam consumption
- Production of dry CO₂
- Methanol solvent is cheap and very robust (no degradation)
- Significantly decreased Capex and Opex compared to a Rectisol™

References

>110 (Rectisol™)

Contact

hydrogen-syngas@airliquide.com



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.

CO₂ Removal – Membranes

Description

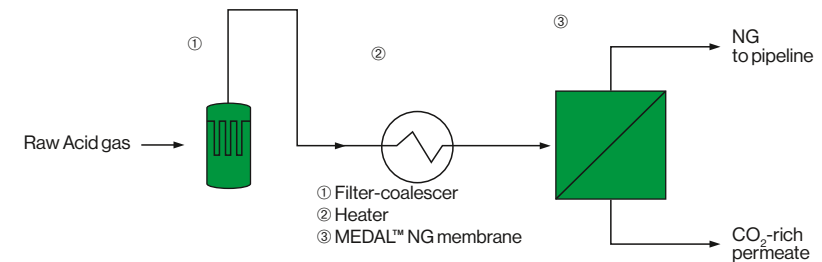
Air Liquide Engineering & Construction offers a vast portfolio of gas separation membranes for natural gas treatment: the natural gas product is recovered as a high-pressure retentate while the impurities are concentrated in the low pressure permeate. This includes bulk CO₂ removal with the highly selective 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.

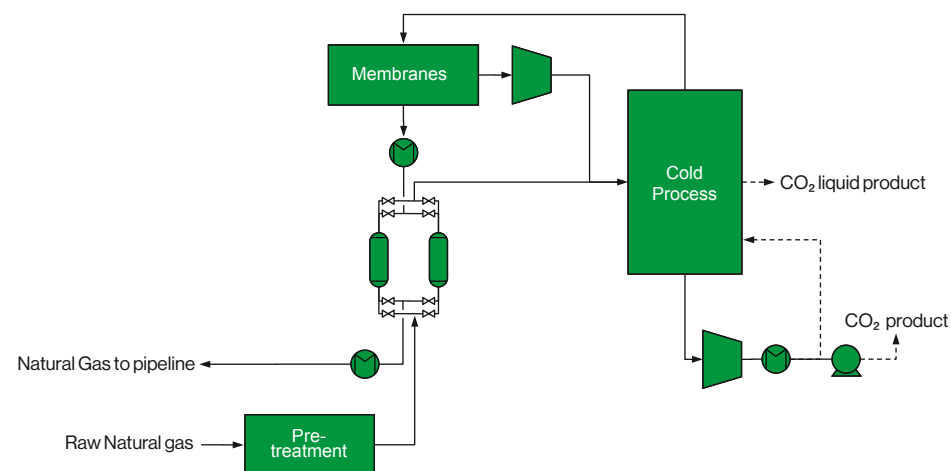
The non-condensable gas is enriched in methane and sent to a membrane for final purification.

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



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

Cryogenic CO₂ Separation for Oxycombustion Cryocap™ Oxy

Description

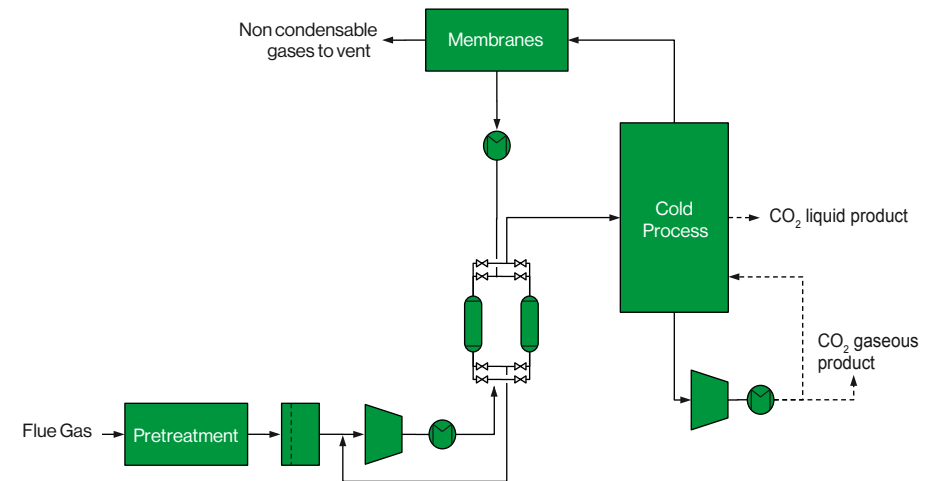
The flue gas issued from the cement or lime or power plant is first treated in a pre-treatment unit, which aims to cool the gas and remove the SO_x, HF, HCl, most of the NO_x, and the dust. Then the gas is compressed and dried before entering the cryogenic purification unit.

In the cold process, CO₂ is recovered by combination of partial condensation and distillation, which allow the removal of the heavy compounds such as NO_x 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 (SO_x, particulate matter, NO_x, 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.



References

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

Contact

cryocap@airliquide.com

Application

CO₂ capture from steel making plants

Feedstock

Gas from blast furnace

Product

CO₂ (gaseous under pressure or directly liquid)

Co-product

CO & H₂ enriched gas

Capacity

From 300 to 5000+tpd

Economics

25-50 €/t CO₂ captured

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:

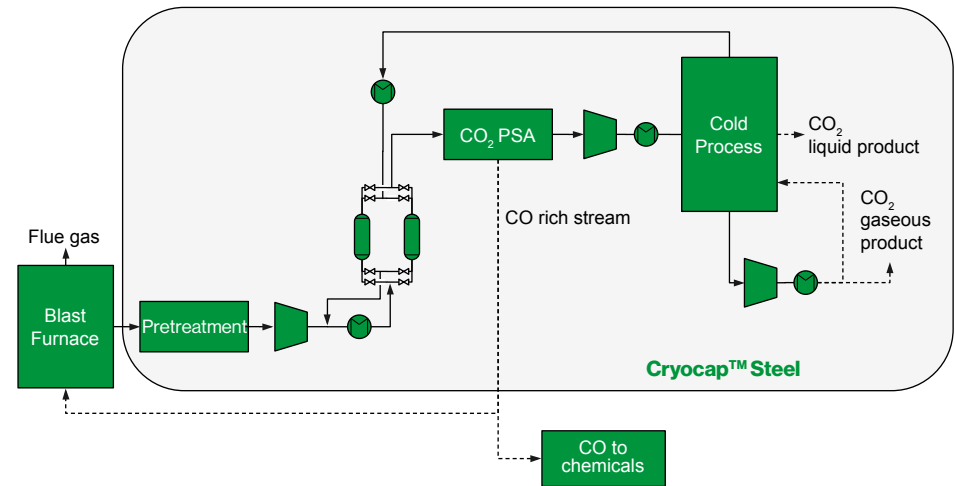
- Cryocap™ Steel is a solvent free solution that runs on electricity rather than thermal energy. It can run on renewable energy to further reduce the environmental footprint of the sites equipped on.

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

Liquefied CO₂

Co-product

None

Capacity

From 800 to 10 000tpd+

Economics

5-25€/tCO₂ liquefied

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.

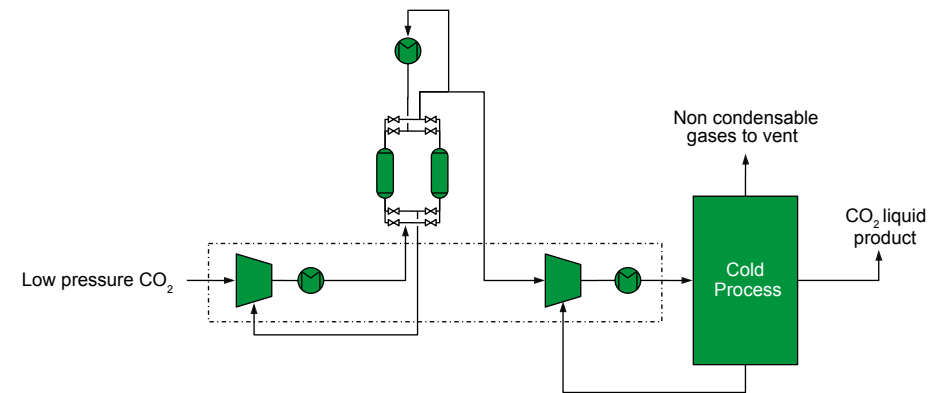
The CO₂ feed gas is compressed in the feed/ recycle compressor, dried at an intermediate pressure and then compressed again.

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

Application

- Oxygen enriched SRU operation for
- Capex / plot space savings for new SRU
 - SRU debottlenecking and revamps

Feedstock

Acid gases, Oxygen

Product

Bright yellow sulfur, up to 99.9% purity

Co-product

None

Capacity

Up to 600 tpd sulfur

Economics

Opex :

Pure oxygen requirement:

Approx. 0.15 - 0.4 ton O₂ / ton sulfur
(depending on enrichment level and feed gas composition)

Capex :

Oxynator™: less than 0.5 mm USD

OxyClaus™ : up to 35% less than conventional SRU with same capacity

Oxynator™ / OxyClaus™ for Sulfur Recovery Units (SRU)

Description

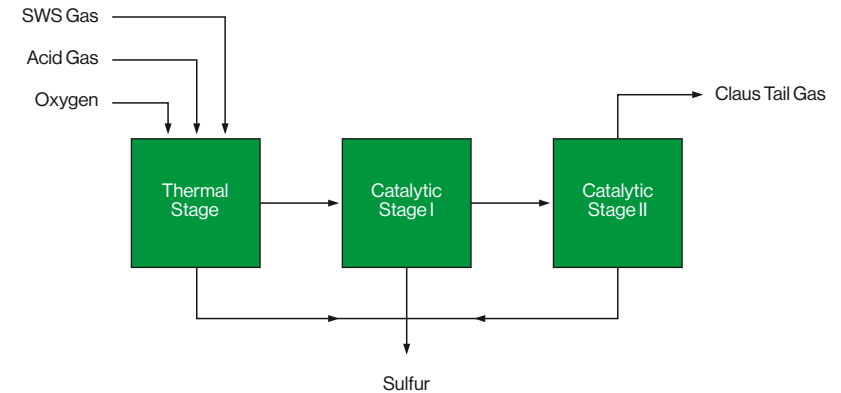
In a conventional Sulfur Recovery Unit ambient air is used to oxidize part of the hydrogen sulfide (H₂S) in the acid gases to sulfur dioxide (SO₂). By enriching the combustion air to the Claus unit with pure oxygen more feed gas can be processed in the SRU without violation of pressure drop or residence 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



CO₂ CAPTURE

Application

Recovery of sulfur from acid gas streams containing hydrogen sulfide (H₂S) with 100% sulfur recovery

Feedstock

Acid gases from acid gas removal unit and sour-water strippers

Product

Bright yellow sulfur with up to 99.9% purity

Co-product

None

Capacity

Up to 1,000 tpd

Economics

Capex: 25% less than conventional amine-wash tail gas treatment

Sulfur recovery: 100%

Contact us for more information.

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.

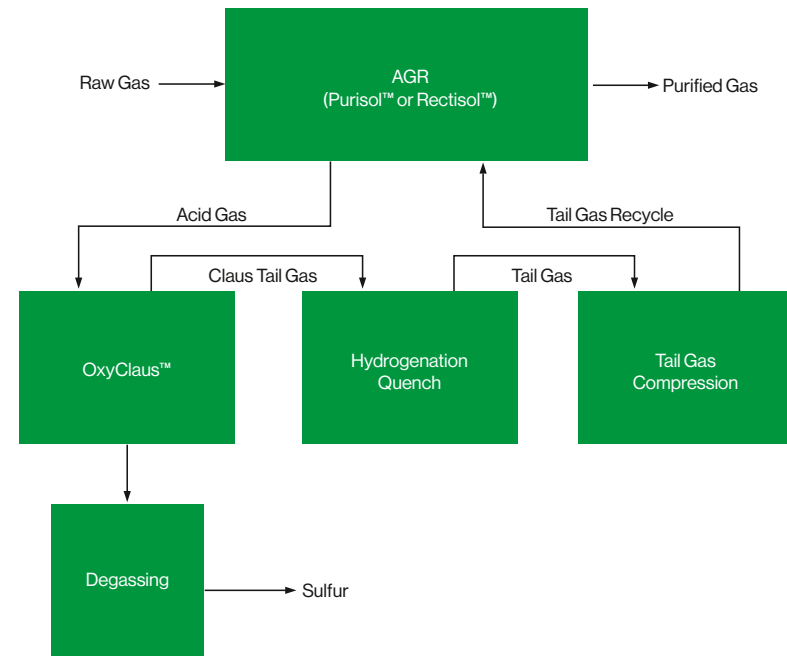
OxyClaus™ is used in this concept because this reduces the process gas volume and therefore lowers not only investment cost plus operating cost but also the amount of inert gas sent to AGR.

References

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

Contact

sulfur@airliquide.com





CO₂ CAPTURE

Application

Recovery of sulfur from acid gas streams containing hydrogen sulfide (H₂S)

Feedstock

Acid gases from sweetening units and sour-water strippers

Product

Bright yellow sulfur with up to 99.9% purity

Co-product

None

Capacity

Up to 1,000 tpd

Economics

Sulfur recovery: >95%

Operating costs can be considered negligible if credit is given for steam produced in SRU.

Capex: 10 to 100 mm USD

Sulfur Recovery Unit

Description

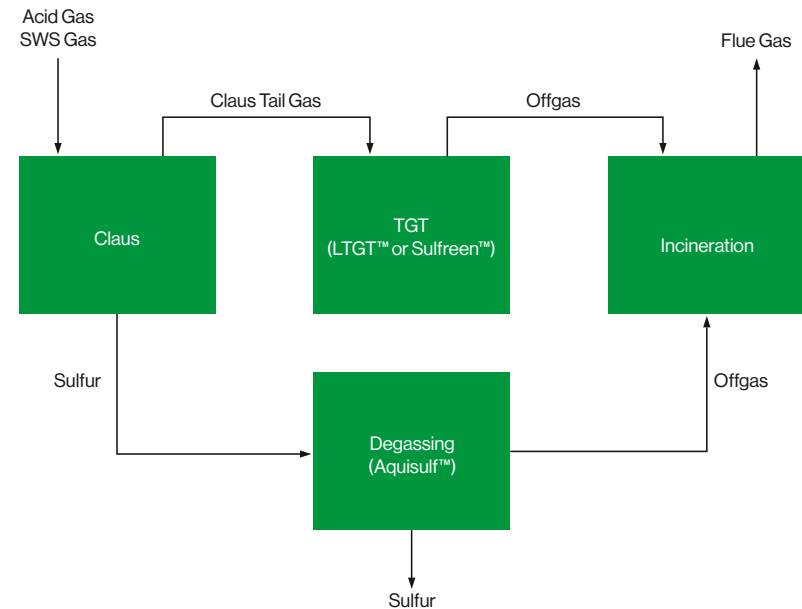
The acid gases are burnt sub-stoichiometrically with air in a refractory lined furnace. Resulting mixture of H₂S and SO₂ reacts to form elemental sulfur which is removed from the process through condensation. In subsequent catalytic stages, typically two or three, the conversion to sulfur is promoted 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 1,000 tpd)
- >60 tail gas treatment processes
- >50 Aquisulf™ in operation

Contact

sulfur@airliquide.com



AIR GASES

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.



AIR GASES

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

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.

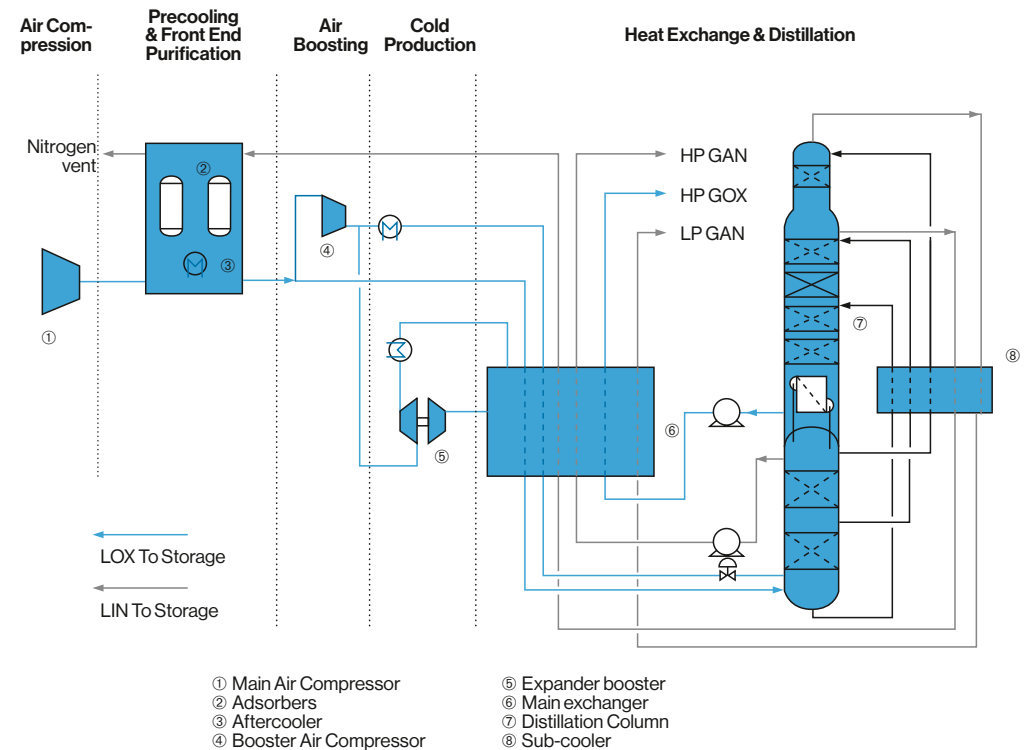
Some liquid co-production could be available to refill backup liquid storages.

References

>40

Contact

airgases@airliquide.com





AIR GASES

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

Yango™ – Standard Air Separation Unit

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.

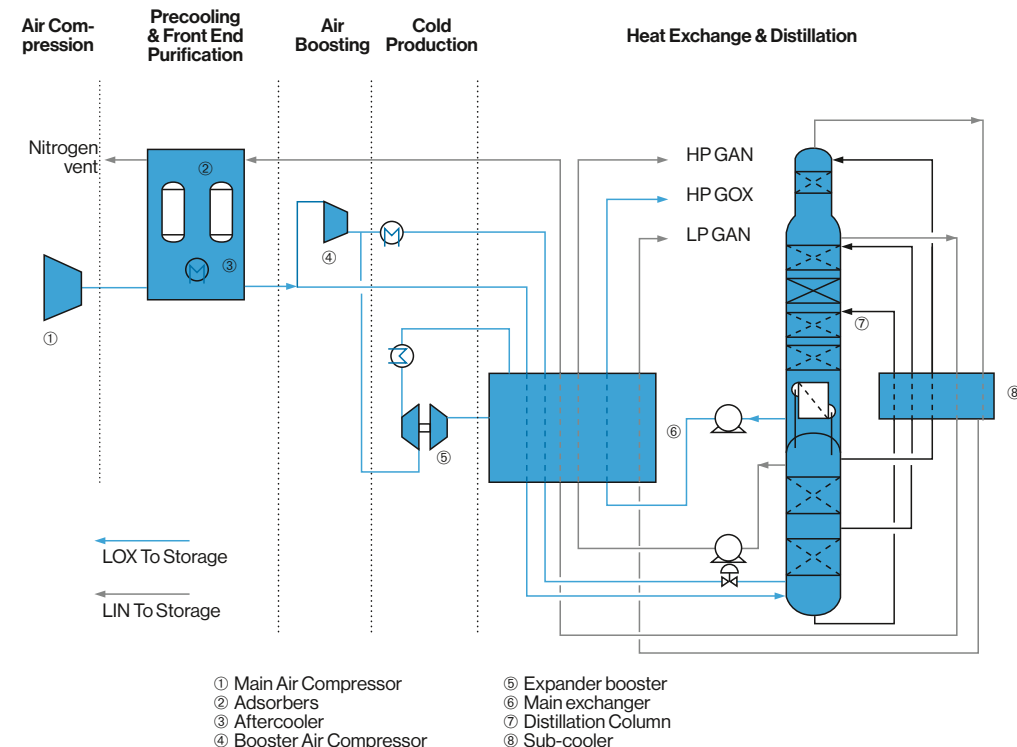
Air Liquide Engineering & Construction offers optimized solutions in terms of construction strategy, operating philosophy and reliability.

References

>20

Contact

airgases@airliquide.com



Vacuum Swing Adsorption (VSA) On-Demand Oxygen Generation

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

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

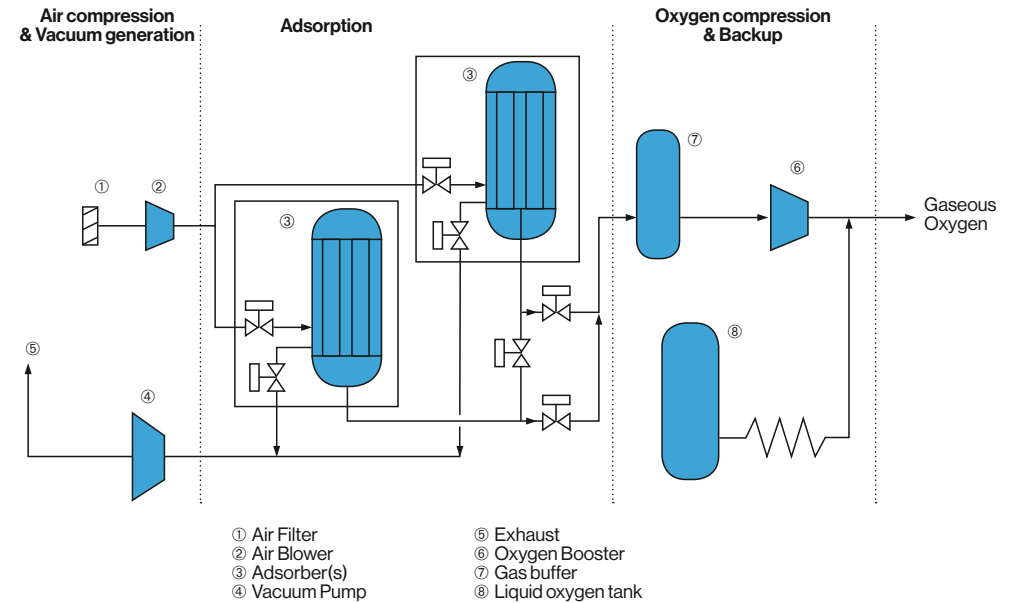
Capitalization of more than 30 years of operating and maintenance experience.

References

>100

Contact

airgases@airliquide.com





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

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 storage designed as per customer's requirements (availability and reliability).

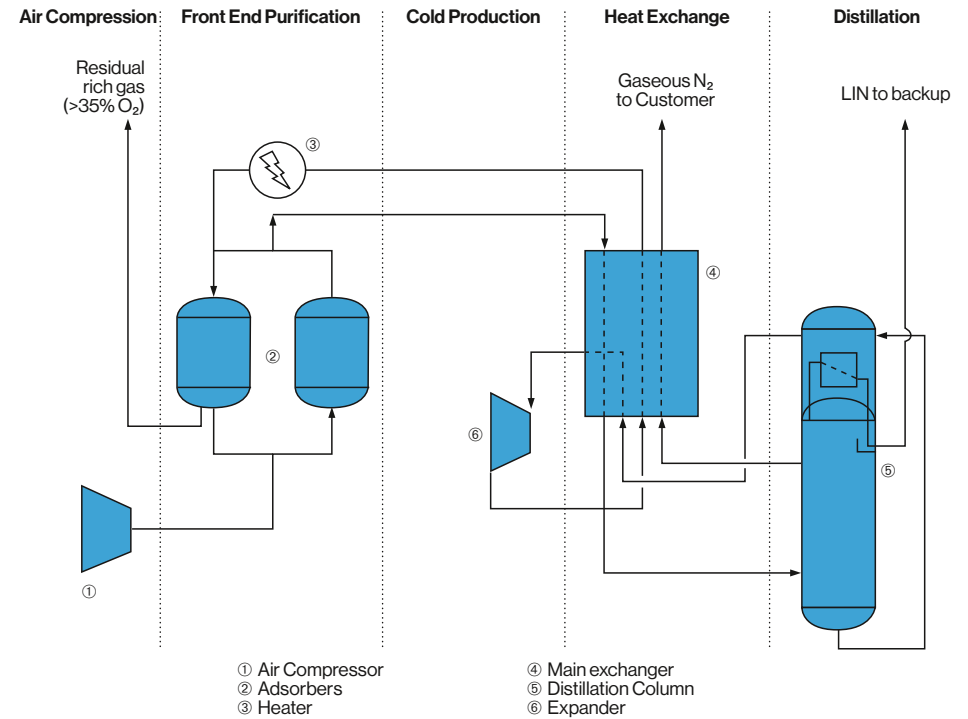
These systems are safe, reliable and easy-to-operate and maintain.

References

> 100

Contact

airgases@airliquide.com



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 barG

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:

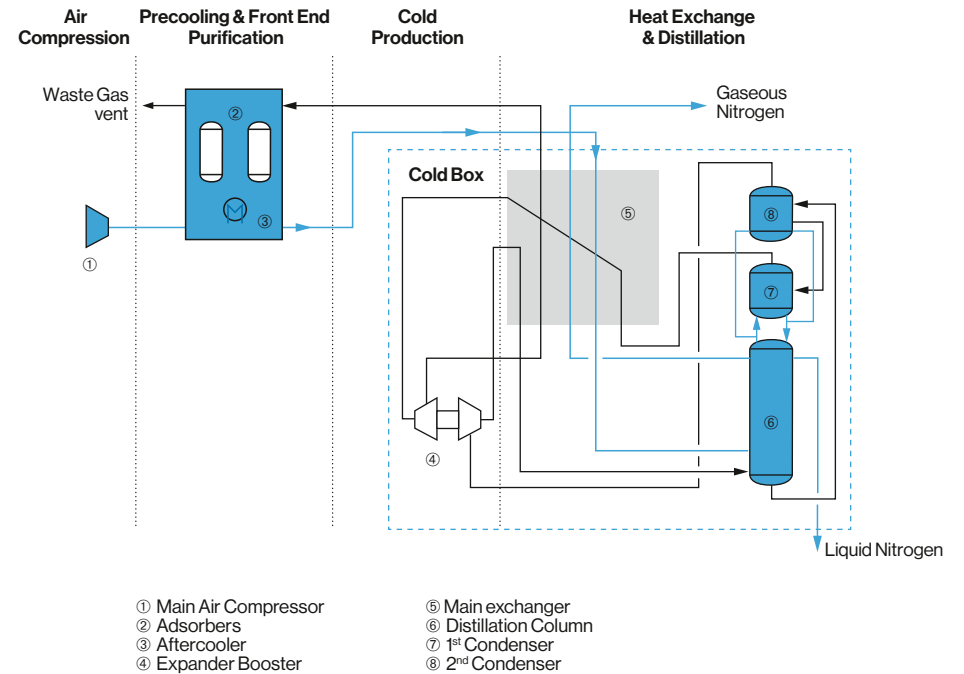
- Low Nitrogen Specific Energy Consumption
- Single column, Single Machine process.

References

> 50

Contact

airgases@airliquide.com





AIR GASES

Application

Steel making (basic oxygen furnaces, blast furnaces, electric arc furnaces), gas monetization (gas-to-methanol, -propylene, -liquids), coal gasification, chemicals (ethylene and propylene oxide, etc.), clean power (IGCC, oxycombustion)

Feedstock

Air + Energy (electrical or steam)

Product

Oxygen up to 99.8% purity and 100 bara

Co-product

Nitrogen, rare gases (Kr, Xe, He, Ne), liquid oxygen, nitrogen and argon, compressed dry air

Capacity

Up to 6,000 tpd

Economics

Specific energy: 160 to 500 kWh/t

Capex: 40 to 300 mm USD

Several processes are available to optimize economics depending on product requirements, energy cost and process integration.

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.

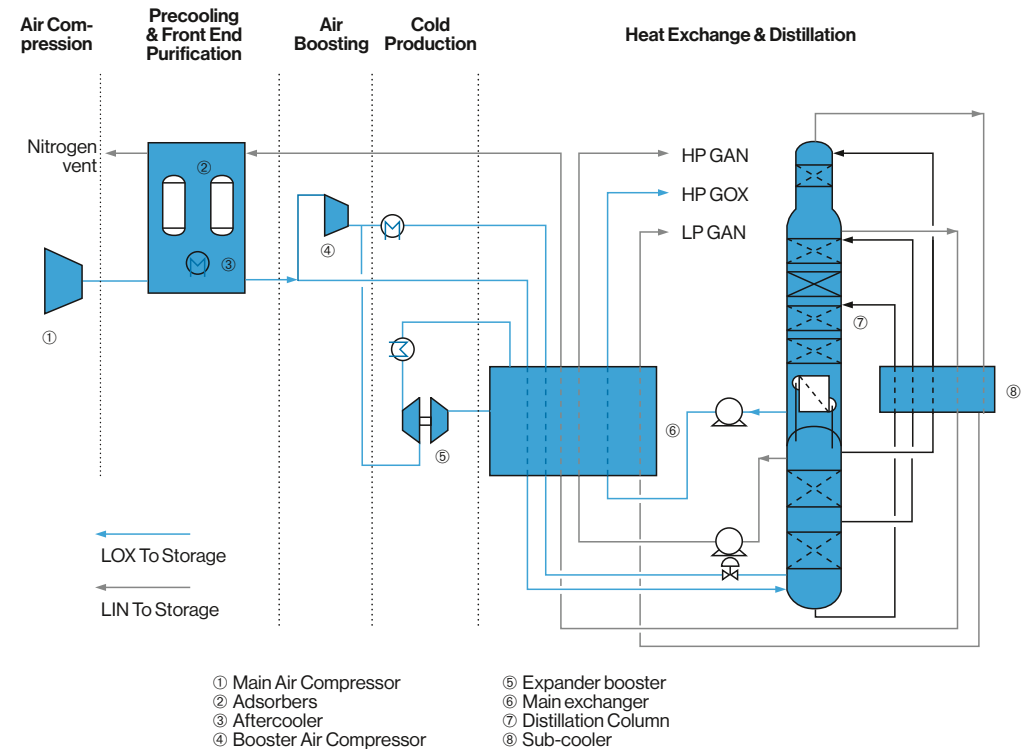
From the small standard of a few hundred tonnes per day to Mega ASU complexes (multi-train) of more than 15,000 tonnes per day, Air Liquide Engineering & Construction offers optimized solutions in terms of construction strategy, operating philosophy and reliability.

References

>4000

Contact

airgases@airliquide.com





AIR GASES

Application

Production of Krypton & Xenon mixture concentrated at > 98%

Feedstock

Liquid oxygen stream from a large Air Separation Unit (>3,000 tpd)

Product

Krypton + Xenon Mixture at > 98%

Co-product

None

Capacity

From 4,000 Nm³/annum up to 20,000 Nm³/annum

Economics

Opex : small size

- Power: depending on the ASU integration : 500 kWh/h - 1000 kWh/h
- Cooling water + gaseous nitrogen (negligible quantity compared to ASU utilities)

Capex: small size

5 - 15 mm USD (EP)

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).

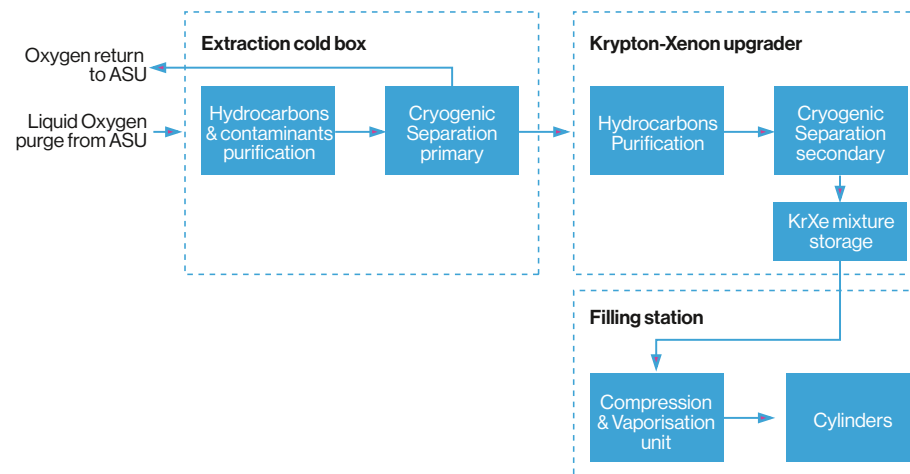
This concentrated cryogenic mixture (typically Kr 91%, Xe 7%, O₂ 2%) is then compressed and vaporized to fill gas cylinders at 150 barg.

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



SYNGAS SEPARATION

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.



SYNGAS SEPARATION

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.

Product

CO up to 99.99% purity

Co-product

Hydrogen, oxogas, methane, LNG

Capacity

Up to 34 000 Nm³/h (1020 tpd) CO

Economics

Opex: Specific energy:
300 to 600 kWh/tonne

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

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:

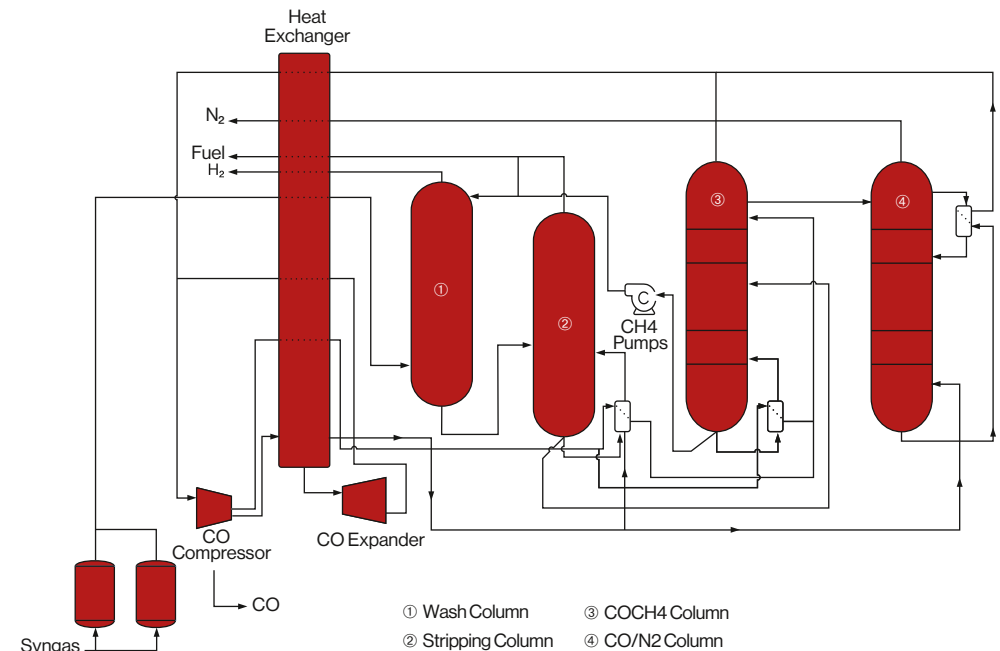
- Greatest number of references in CO/N₂ separation
- Highest safety standards for all Cold Boxes
- In-house technology for highly safe, highly reliable & highly efficient CO expander
- High CO recovery

References

34 (latest 2021)

Contact

hydrogen-syngas@airliquide.com





SYNGAS SEPARATION

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

CO Cold Box – Partial Condensation

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:

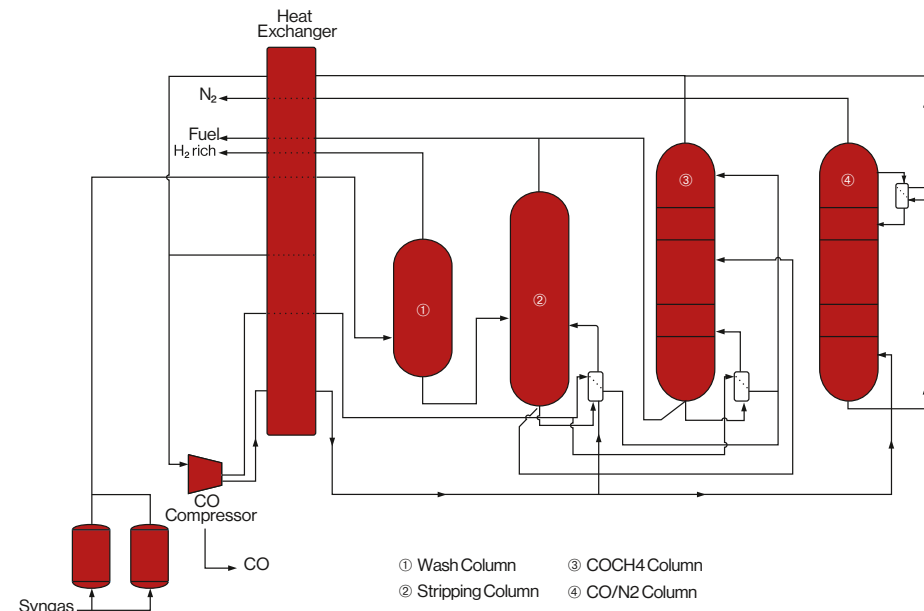
- Greatest number of references in CO/N₂ separation
- Highest safety standards for all cold boxes
- Low specific energy consumption for wide range of feedstock

References

23 (latest 2021)

Contact

hydrogen-syngas@airliquide.com





SYNGAS SEPARATION

Application

Production of pure synthesis gas for ammonia plants

Feedstock

Raw hydrogen
(from Amine Wash / Rectisol™)

Product

Pure ammonia synthesis gas with a stoichiometric N_2/H_2 ratio of 1:3

Co-product

Methane, LNG

Capacity

Up to 230 000 Nm³/h (2 100 tpd)

Economics

Opex:

- LIN: 0 to 0.02 tonne/tonne of syngas

- Power: 0 to 900 kWh/tonne of LNG
(if LNG co-production)

Capex:

Economics are highly dependent on the co-product requirements and required scope of supply

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 H_2/N_2 ratio, high pressure nitrogen is added to the process stream.

Main Features:

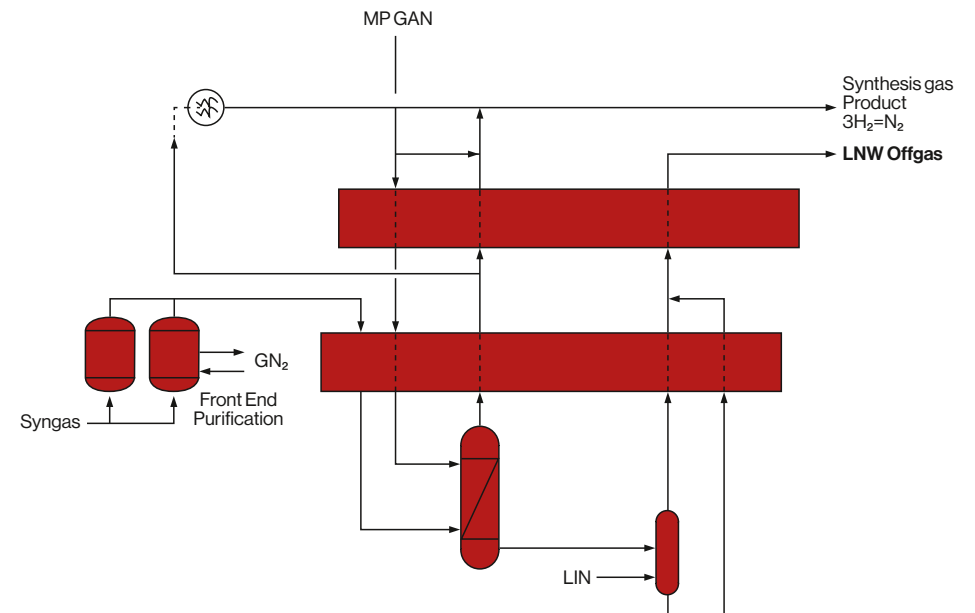
- Highest safety standards for all Cold Boxes
- Low specific energy consumption for Methane / LNG co-production

References

49 (latest 2015)

Contact

hydrogen-syngas@airliquide.com





NATURAL GAS TREATMENT

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.



NATURAL GAS TREATMENT

Application

Sweetening and processing of natural gas by removing CO_2 , H_2S , COS, mercaptans, water and mercury to pipeline or LNG specifications as well as production of liquid elemental sulfur while minimizing SO_2 emissions to the atmosphere to meet most stringent environmental regulations

Feedstock

Raw natural gas, associated gas

Product

Dry sweet gas, sulphur (99.9+% purity)

Co-product

None

Capacity

Up to 1,500,000 Nm^3/h

Economics

Economics are highly dependent on feedstock and requirements (high efficiency or low Capex).

Contact us for more information

Acid Gas Removal – OmniSulf™

Description

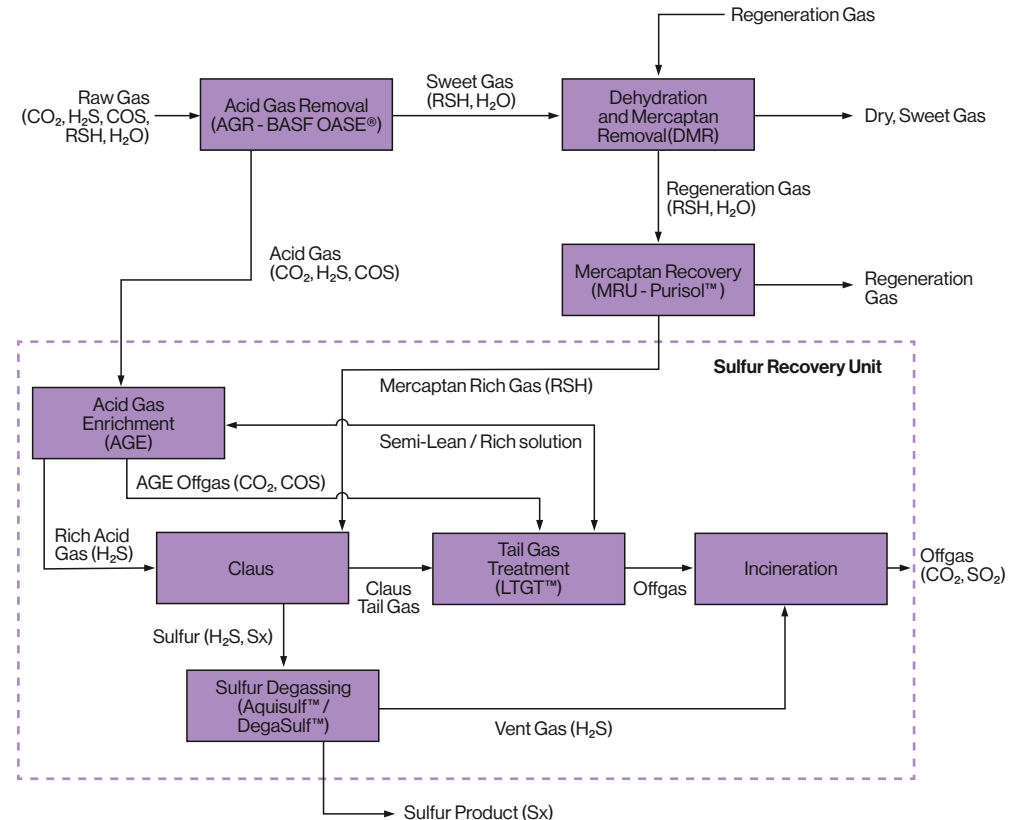
The OmniSulf™ technology encompasses the following proprietary key processes:

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 zeolite/molecular 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 SO_2 emissions. The liquid sulfur product is degassed to H_2S 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





NATURAL GAS TREATMENT

Application

Highly selective removal of acid gases (H₂S, mercaptans, etc.) from natural gas and process gases

Feedstock

Natural gas, regeneration gas, process gas

Product

Clean sulfur free gas

Co-product

Sulfur rich gas for SRU

Capacity

50 000 - 500 000 Nm³/h

Economics

Individual costs vary significantly depending on capacity and purity request

Opex: This process has typically very low Opex due to the high selectivity and easy regeneration as well as a stable solvent with low losses due to high boiling point

Capex: 3 to 40 mm USD

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.

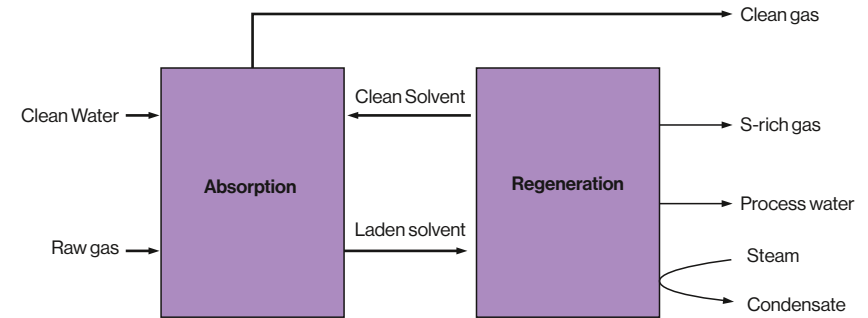
The process can be modularized and also easily be integrated into existing plants.

Main Features :

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

Contact

gas-treatment@airliquide.com





NATURAL GAS TREATMENT

Application

Removal of nitrogen from natural gas, associated gases and unconventional gas sources

Feedstock

Natural gas with high nitrogen content

Product

Natural gas, nitrogen

Co-product

LNG, liquid nitrogen, crude helium

Capacity

Up to 1,000,000 Nm³/h

Economics

Economics are highly dependent on feedstock and requirements (high efficiency or low Capex).

Contact us for more information.

Nitrogen Rejection Unit

Description

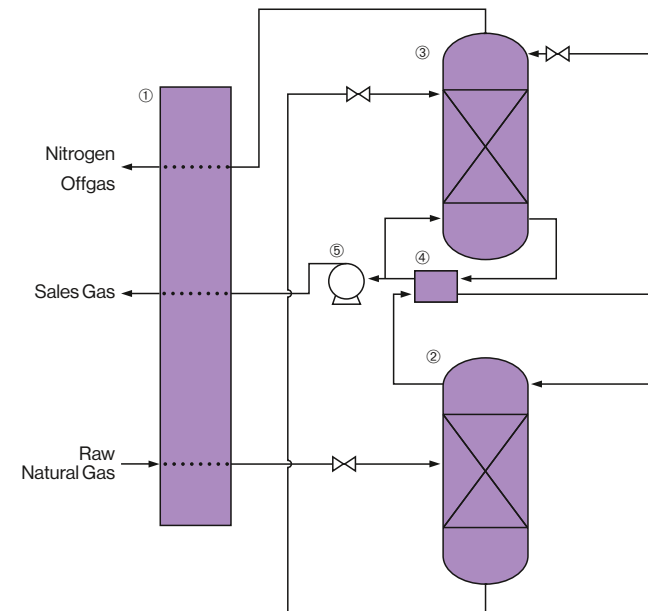
Natural gas feed is partially condensed, then methane and nitrogen are separated into a system of distillation column(s). Depending on the feed composition and pressure, the system can include one to three distillation columns. The process scheme selection is done according to project-specific parameters 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



- ① Main Heat Exchanger
- ② High Pressure Column
- ③ Low Pressure Column
- ④ Condenser/Reboiler
- ⑤ Sales Gas Product pump



NATURAL GAS TREATMENT

Application

Liquefaction of natural gas for small scale plants serving power applications (peak shaving, remote power) or fuel (marine, truck, rail, etc.)

Feedstock

Natural gas

Product

LNG

Co-product

NGLs, depending on feedstock composition

Capacity

Up to 0.25 Mtpa

Economics

Opex: Typically 450 kWh/ton of LNG

Turbofin™ (Nitrogen Refrigerant Cycle)

Description

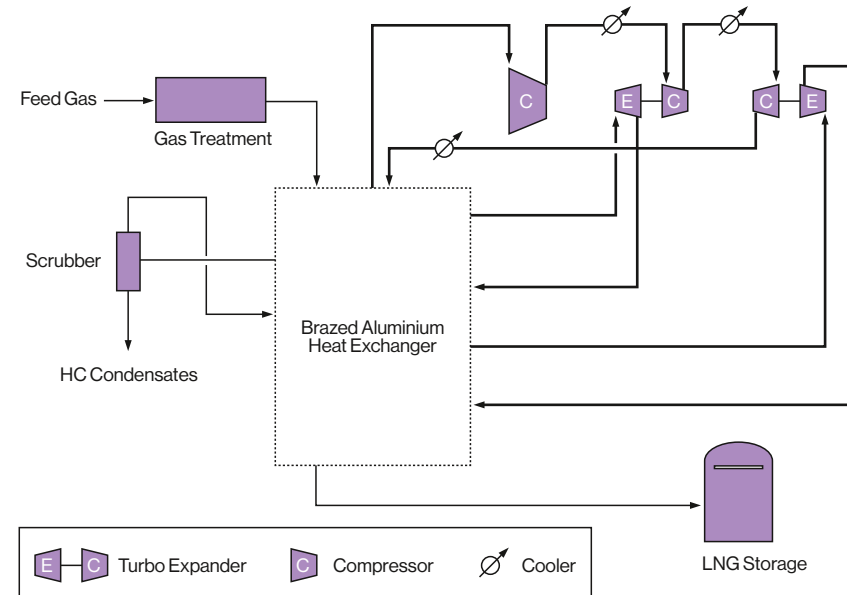
The process consists of three main modules: pre-treatment of natural gas (NG), liquefaction and LNG storage and loading (truck, trailer, bunkering barge, etc.).

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 Braze Aluminium 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

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Contact

lng@airliquide.com



NATURAL GAS TREATMENT

Application

Liquefaction of natural gas for mid scale plants serving LNG for mid-size export terminals and peak shavers

Feedstock

Natural gas

Product

LNG

Co-product

NGLs, depending on feedstock composition

Capacity

Up to 1.5 Mtpa

Economics

Opex: Typically 350 kWh/ton of LNG

Smartfin™ (Single Mixed Refrigerant Cycle)

Description

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

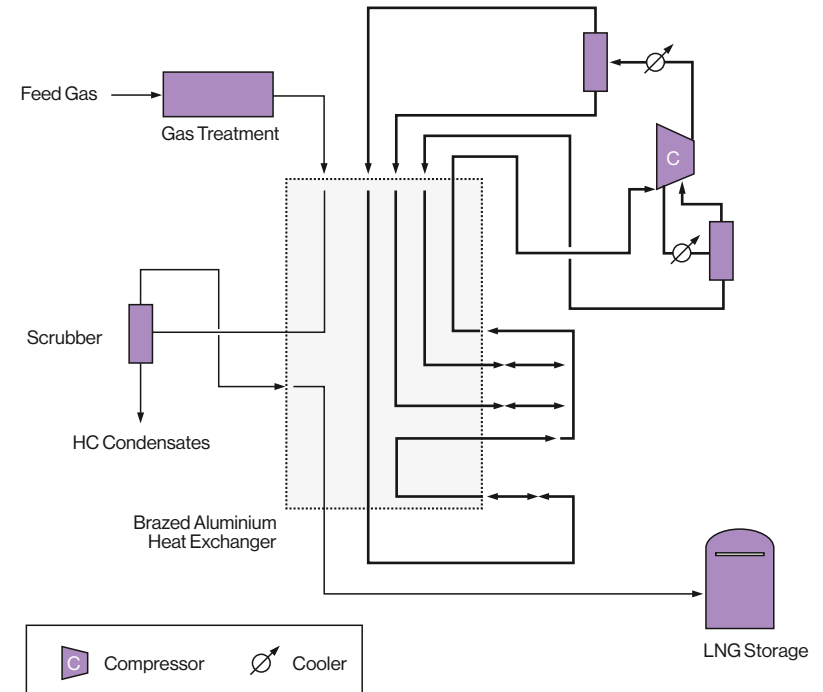
The refrigeration cycle is filled with a mixture of hydrocarbons and nitrogen.

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



NATURAL GAS TREATMENT

Application

Pure liquid helium production and loading into ISO containers

Feedstock

Natural gas or impure helium gas extracted as non-condensable side-product from LNG units or impure helium gas extracted from nitrogen rejection units

Product

Liquid helium

Co-product

None

Capacity

Up to 20 tpd (one train)

Economics

The highly efficient process combined with the vapor recovery system allows for a very high helium recovery (> 99%).

Capex: 40 to 300 mm USD

Helium Extraction and Liquefaction

Description

The impure helium feed gas is purified in a first section, where N_2 , CH_4 , H_2 , CO , Ar , O_2 , water and CO_2 are separated from helium.

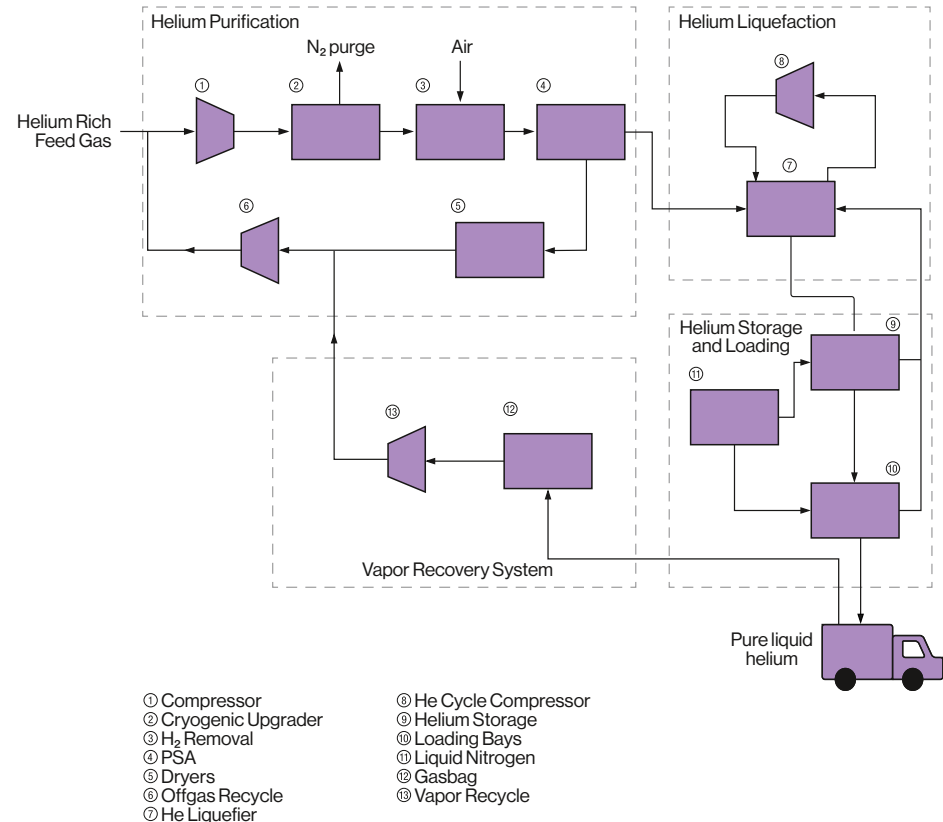
It is composed of a cryogenic partial condensation unit, a hydrogen removal system and a Pressure Swing Adsorber (PSA) unit.

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





CHEMICALS & FUELS

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.



CHEMICALS & FUELS

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 (H_2 , CO, CO_2)

Feedstock

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

Product

Syngas (H_2+CO)

Co-product

None

Capacity

Up to 1,000,000 Nm^3/h
(dry) per reactor

Economics

Yield: 2.5- 4.0 Nm^3 syngas / Nm^3 natural gas (including fuel for fired heater)

Oxygen consumption:
0.15 - 0.25 kg O_2 / Nm^3 syngas

Capex: 160 to 280 mm USD

ATR – Autothermal Reforming for syngas production

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:

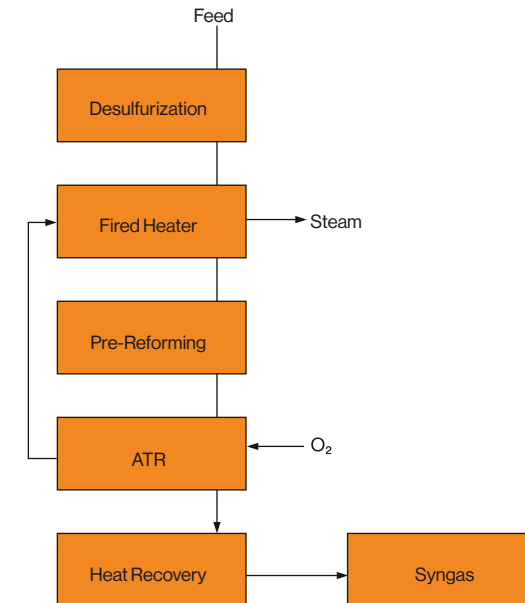
- Provide large quantities of H_2 -rich gas at lowest cost
- Compact reactor
- High pressure (up to 100 bar)

References

Air Liquide has licensed >40 ATR units

Contact

hydrogen-syngas@airliquide.com





CHEMICALS & FUELS

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 MMBTU (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™ 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 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:

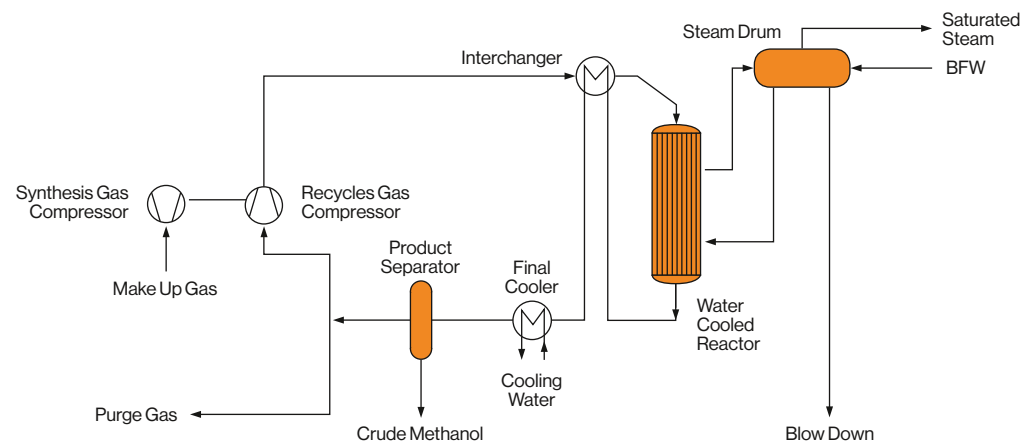
- Simple to operate over full catalyst life time
- Optimized heat transfer preventing temperature peaks in the methanol reactor
- Flexible integration with any syngas generation

References

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Contact

chemicals@airliquide.com



Note: scheme represents only the methanol synthesis unit



CHEMICALS & FUELS

Application

Large scale production of Methanol (> 1 mil metric tons per year) from synthesis gas derived from many kinds of carbonaceous material

Feedstock

Natural gas, synthesis gas, carbon dioxide, coal, oil residues (near parity between natural gas-based methanol and coal based methanol capacities)

Product

Methanol in common international specifications (AA, IMPCA etc.)

Co-product

none

Capacity

From 2,500 metric tpd to 10,000 metric tpd

Economics

Capex:

Between \$ 400 mil and \$ 1.2 bil.

Natural gas consumption:

Combined reforming: 26.8 MMBTU per metric t of MeOH- LHV (if O₂ demand is included overall 28.5 MMBTU);

Pure ATR high pressure: 26.1 MMBTU per metric t of MeOH- LHV (if O₂ demand is included overall 28.5 MMBTU)

Lurgi MegaMethanol™

Description

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

Syngas Production

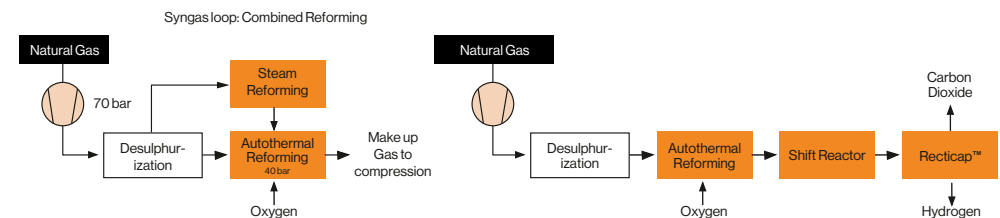
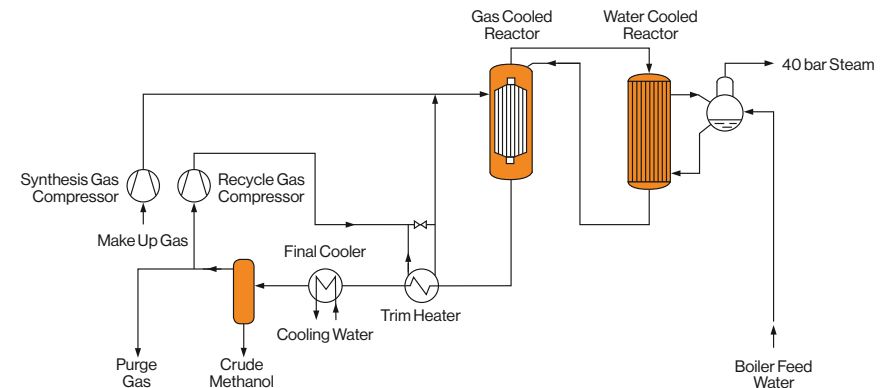
Natural gas is converted in a combination of SMR (Steam Methane Reformer) and ATR (Auto-Thermal Reformer) to Synthesis gas (carbon monoxide and hydrogen). The Synthesis gas is compressed and fed into the methanol reactor system. Alternatively, natural gas can be converted in an ATR at higher pressure, 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

Note: scheme represents only the methanol synthesis unit



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



CHEMICALS & FUELS

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

Lurgi MTP™ – Methanol-to-Propylene

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:

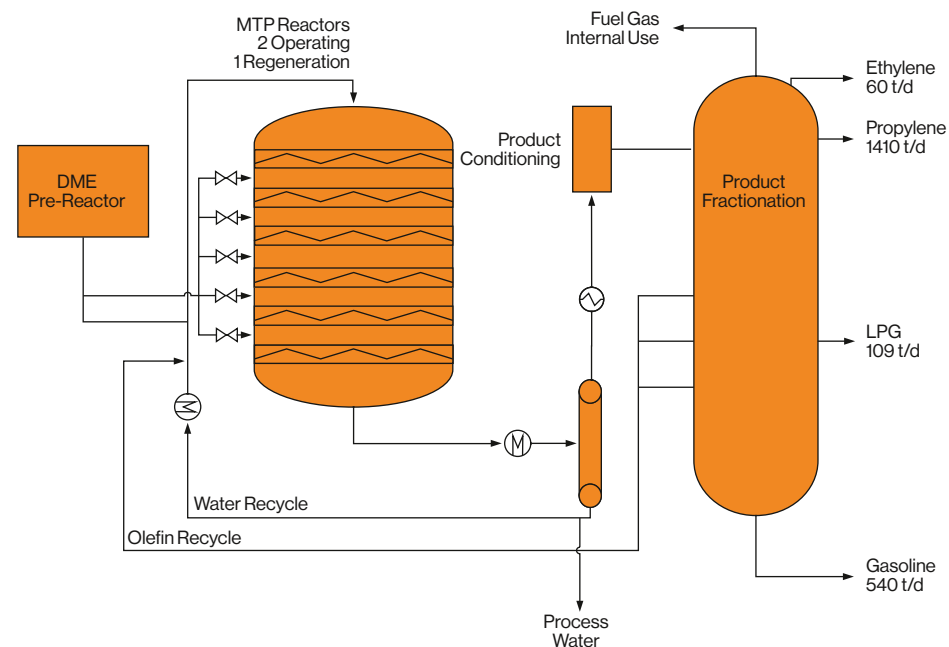
- Focus on propylene product
- Lowest cash cost
- High integration potential with methanol and other technologies

References

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

Contact

chemicals@airliquide.com





Application

Recovery of 1,3 butadiene from a crude C4 stream from olefins plants by extractive distillation

Feedstock

Crude C4

Product

1,3 butadiene

Co-product

None

Capacity

6 to 35 t/h

Economics

Utility consumption:
(per tonne butadiene)

- Steam: 1.7 t/t
- Electricity: 150 kWh/t
- Water, cooling: 150 m³/t

Capex: 80 to 110 mm USD

Butadiene Extraction (BASF NMP Licensed)

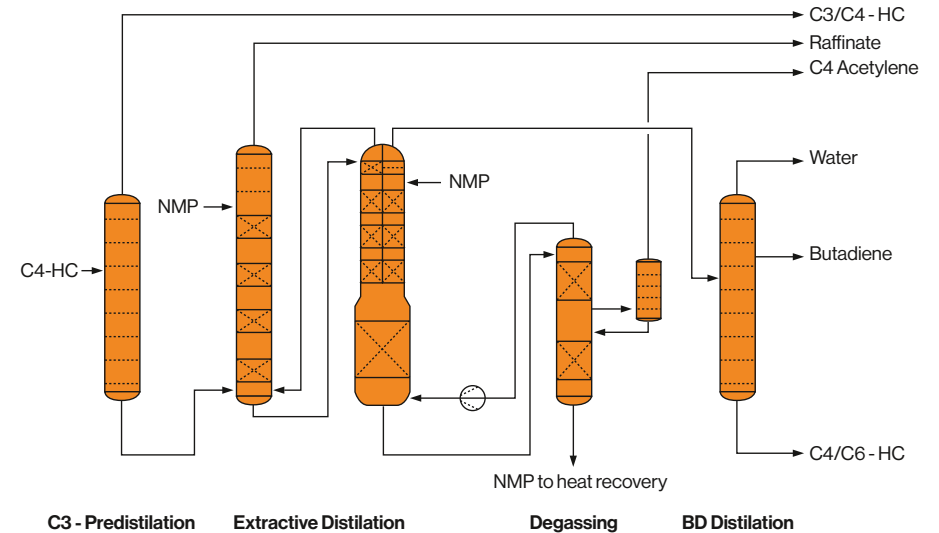
Description

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

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Contact

chemicals@airliquide.com



CHEMICALS & FUELS

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:

CO₂ to Methanol

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.

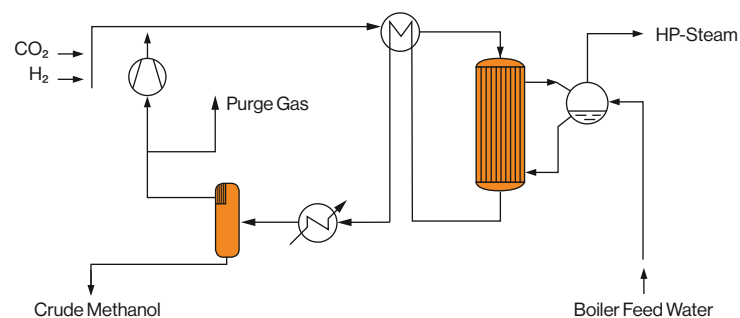
Methanol is distilled to grade AA or IMPCA quality.

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





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

Bio Propylene Glycol (BASF Licensed)

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.

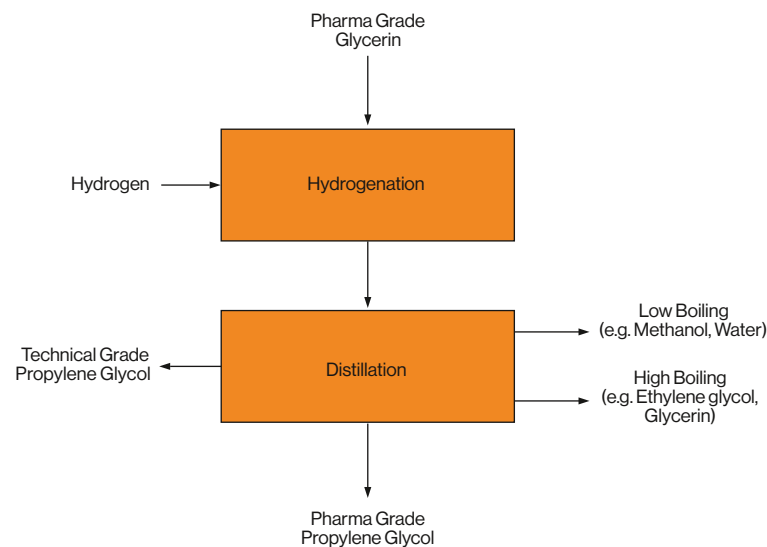
The crude product is purified in a two-column distillation unit to yield pharma grade propylene glycol.

References

- 1 commercial plant
- 1 plant under construction
- 1 plant in engineering phase

Contact

green-chemicals-fuels@airliquide.com





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

HVO-Solutions: (Crushing & Extraction, Pretreatment, Oil Refining & Splitting)

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.

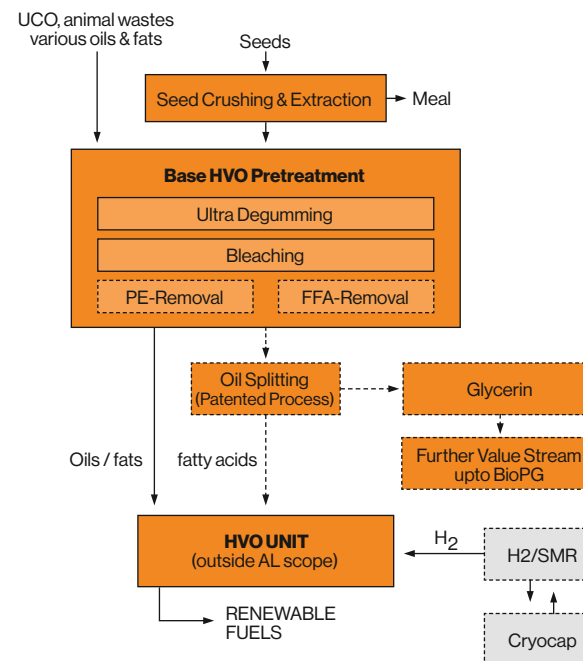
Patented Oil Splitting

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



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

Supercritical Biodiesel (Inventure Licensed)

Description

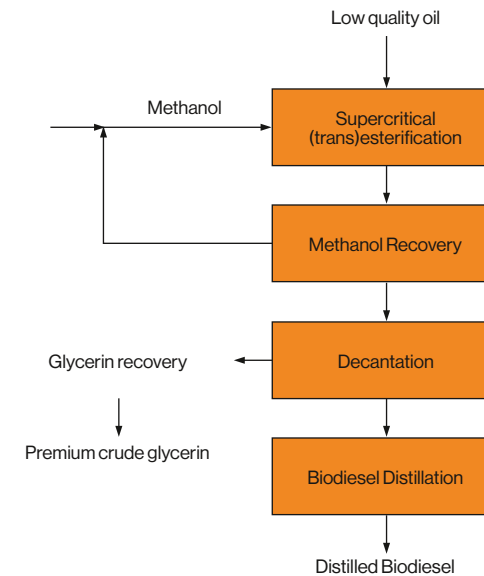
Unpretreated low quality oils and fatty acids are directly converted with Methanol to Biodiesel (FAME) without usage of any catalyst. The esterification and transesterification is conducted under supercritical conditions. Glycerin is separated and dried to give premium crude Glycerin, which is free of 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





CHEMICALS & FUELS

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

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.

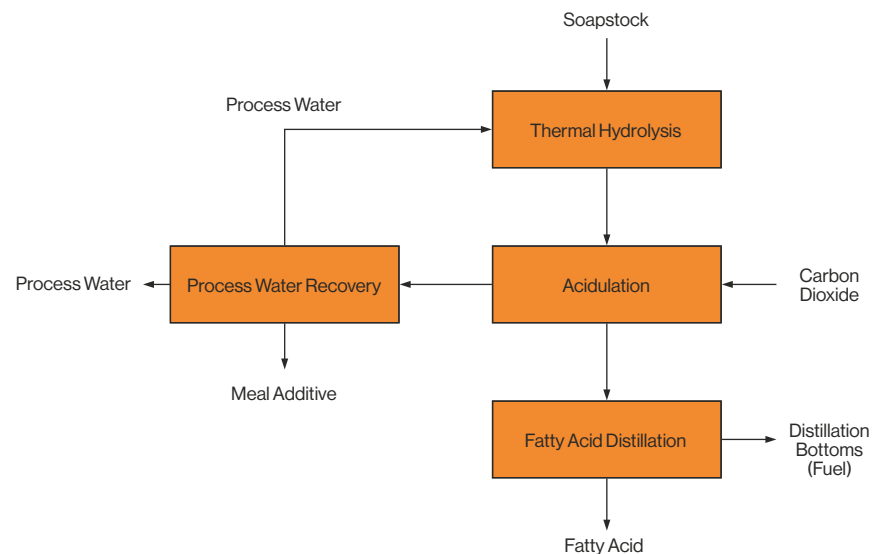
This technology is licensed from Inventure Renewables, Inc.

References

1 commercial plant under construction

Contact

green-chemicals-fuels@airliquide.com





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

Glycerin Distillation and Bleaching

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.

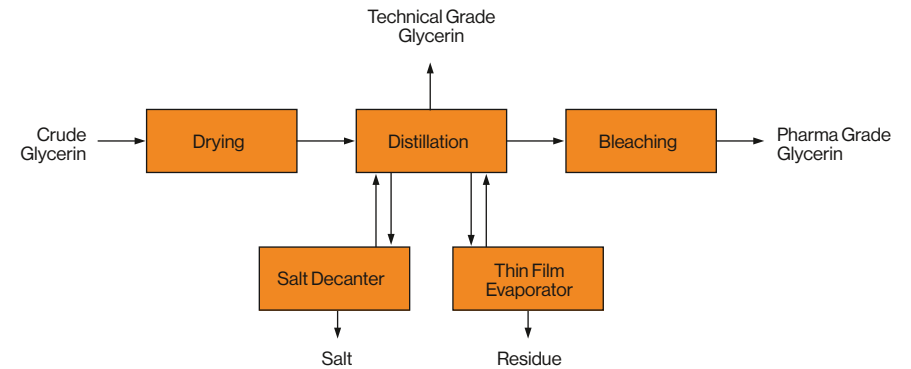
Pharma grade glycerin as main product is polished by bleaching, i.e. adsorption at fixed beds of activated carbon. Light impurities end up in the by-product, technical grade glycerin.

References

> 45

Contact

green-chemicals-fuels@airliquide.com





CHEMICALS & FUELS

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

Sorbitol

Description

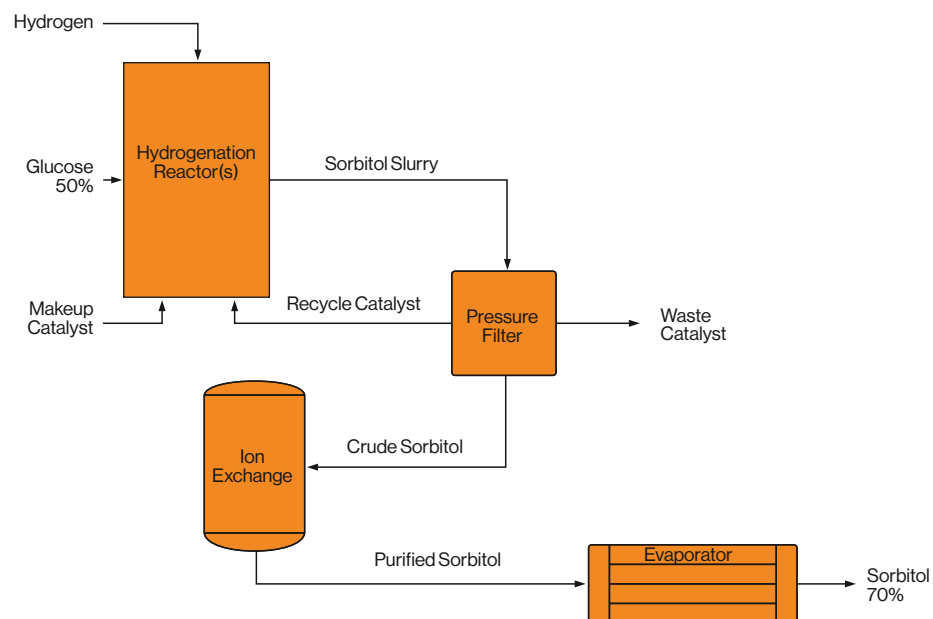
The glucose solution is hydrogenated in a batch reactor using nickel or ruthenium catalysts. Reaction takes place at 110°C and 40 bar pressure. After reaction, the product slurry is filtered to recover the catalyst. Makeup catalyst compensates catalyst loss and deactivation. The crude sorbitol solution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

References

>10

Contact

green-chemicals-fuels@airliquide.com





CUSTOMER SERVICES

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.



CUSTOMER SERVICES



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

customer-services@airliquide.com



CUSTOMER SERVICES



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 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.



CUSTOMER SERVICES



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

Contact

customer-services@airliquide.com

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



CUSTOMER SERVICES



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.



CUSTOMER SERVICES



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 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

Contact

customer-services@airliquide.com

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



CUSTOMER SERVICES

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.



TURBO EXPANDERS



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.



TURBO EXPANDERS

Application

Industrial Gas Production -
Air Separation & Liquefaction

Feedstock - Fluids Handled

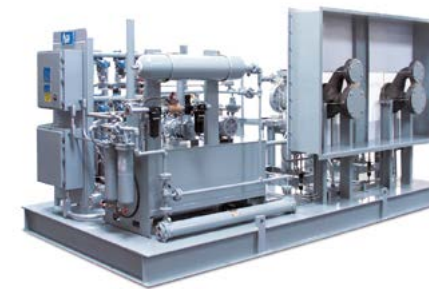
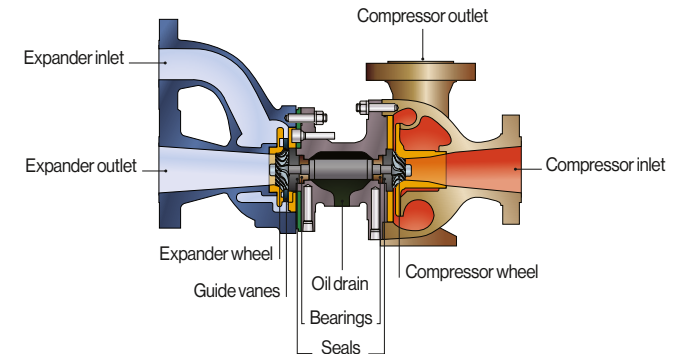
Air, Nitrogen, Waste Gas (high oxygen content), Carbon dioxide and carbon monoxide

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

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 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:

- 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



TURBO EXPANDERS

Application

Industrial Gas Production -
Air Separation & Liquefaction

Feedstock - Fluids Handled

Air, Nitrogen, Waste Gas (high oxygen content), Carbon dioxide and carbon monoxide

Hydrobrake Cryogenic Compressor (THC) Series THC-3000, THC-4000, THC-6000

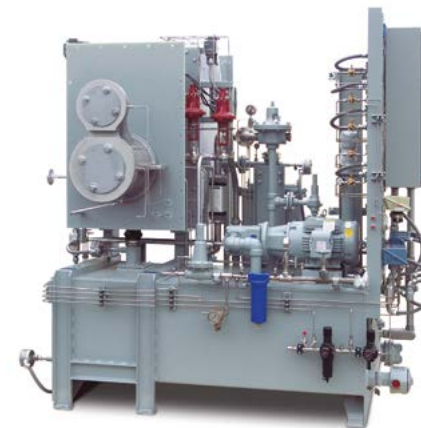
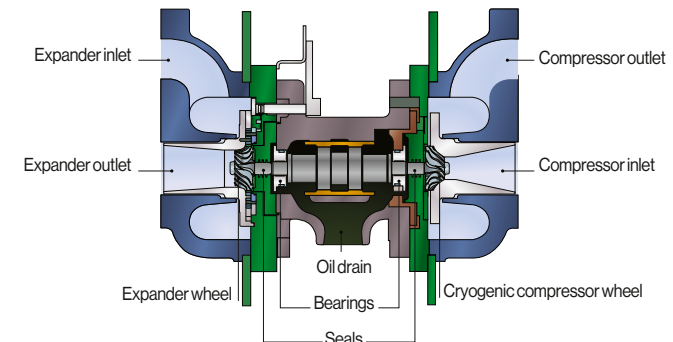
Available options

- 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)

Cross Section: Thc-3000



Hydrobrake Cryogenic
Compressor
Loaded Expanders



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 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



TURBO EXPANDERS

Application

Industrial Gas Production - Air Separation & Liquefaction

Feedstock - Fluids Handled

Air, Nitrogen, Waste Gas (high oxygen content), Carbon dioxide and carbon monoxide

Turboexpander - Hydrobrake (TH) Series TH-3000, TH-4000, TH-6000

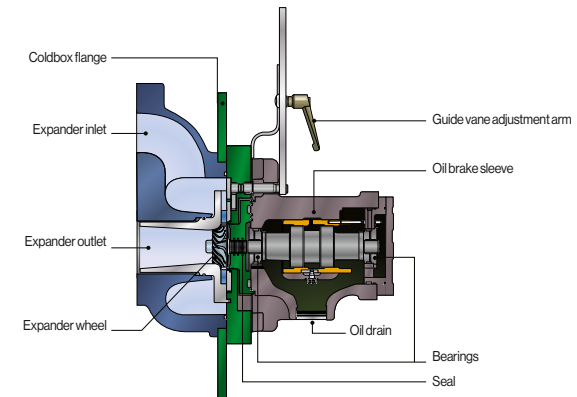
Available options

- 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)

cross section: TH-3000



Oil Brake Loaded Expanders



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
- 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 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

turboexpanders@airliquide.com



TURBO EXPANDER

Application

Industrial Gas Production -
Air Separation & Liquefaction

Feedstock - Fluids Handled

Air, Nitrogen, Waste Gas (high oxygen content), Carbon dioxide and carbon monoxide

Compressor TC - Series TC2000, TC3000, TC4000, TC6000, TC9000, TC12000

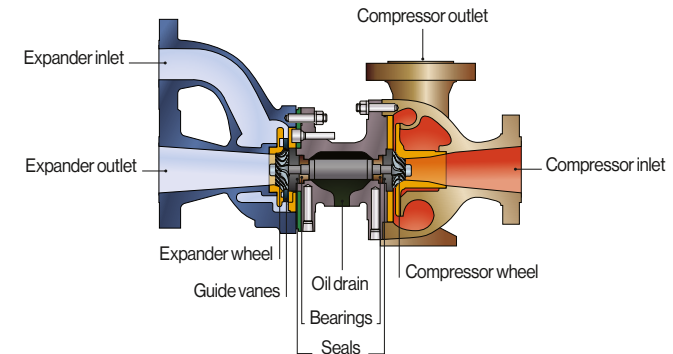
Available options

- 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

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)

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 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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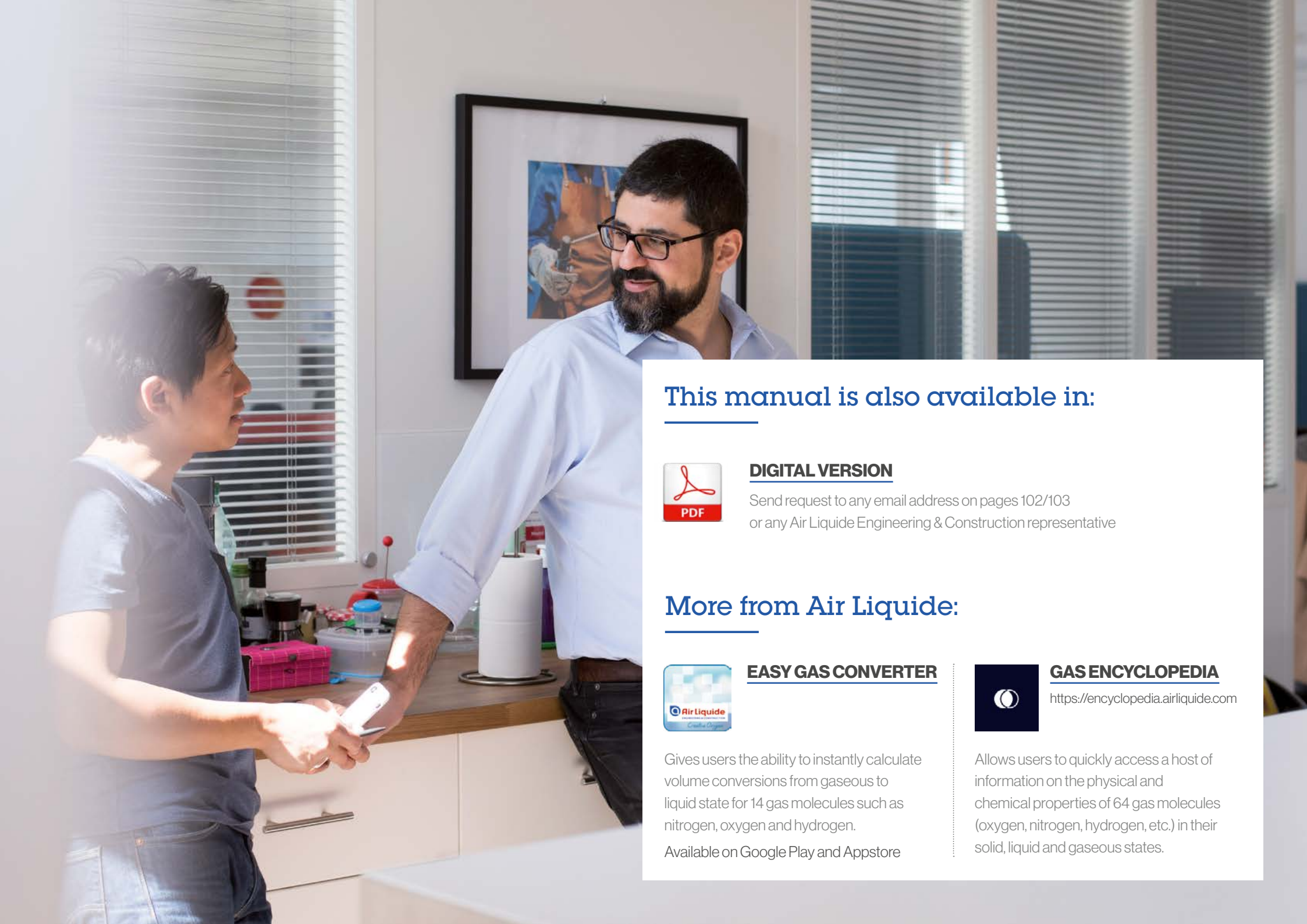
List of abbreviations and acronyms

2EHOH	2-ethylhexanol
AA	Methanol specification per US federal regulation O-M-232e
AcAc	Acetic acid
AGR	Acid gas removal
APH	Air pre-heater
Ar	Argon
ASU	Air Separation Unit
ATR	Autothermal reformer/reforming
BFD	Block flow diagram
BFW	Boiler feedwater
BOG	Boil-off gas
BTU	British thermal unit
BuOH	Butanol
C2+	Hydrocarbons with 2 or more carbons
C4	Mixture of 4-carbon hydrocarbons (butane, butylenes and butadienes)
Capex	Capital expenditures
CCR	Continuous catalytic reforming
CDU	Crude distillation unit
CH4	Methane
CLS	Claus
CO	Carbon monoxide
CO₂	Carbon dioxide
COS	Carbonyl sulfide
CSFT	Cold soak filtration test
Cu	Copper
CW	Cooling water
DEA	Diethanolamine
DME	Dimethyl ether
DMR	Dehydration and mercaptan removal unit

DRI	Direct reduction of iron ore
DTDC	Desolventizer, toaster, dryer and cooler
E&C	Engineering and construction
EOR	Enhanced oil recovery
EtOH	Ethanol
FAD	Fatty acid distillate
FAME	Fatty acid methyl ester
FEED	Front-end engineering design
FFA	Free fatty acid
FOB	Free on board
F-T	Fischer-Tropsch
G2G	Gas-to-Gasoline
GAN	Gaseous nitrogen
GAR	Gaseous argon
GNG	Gaseous natural gas
GOX	Gaseous oxygen
H₂	Hydrogen
H₂S	Hydrogen sulfide
HC	Hydrocarbon
HCl	Hydrochloric acid
HCN	Hydrogen cyanide
HDS	Hydrodesulfurization
He	Helium
HF	Hydrofluoric acid
Hg	Mercury
HHC	Heavy hydrocarbon
HP	High pressure
HT	High temperature
IGCC	Integrated gasification combined cycle
IMPCA	International methanol producers and consumers association

ISO	International Organization for Standardization
JT	Joule-Thomson
Kr	Krypton
LAR	Liquid argon
LIN	Liquid nitrogen
LNG	Liquefied natural gas
LOX	Liquid oxygen
LP	Low pressure
LP3	Low pressure fatty alcohols production
LPG	Liquefied petroleum gas
LTGT	Lurgi tailgas treatment
MDEA	Methyl diethanolamine
MDI	Methylene diphenyl diisocyanate
MEA	Monoethanolamine
MEG	Monoethylene glycol
MeOH	Methanol
MP	Medium pressure
MPG	Multi-purpose gasifier Mono propylene glycol
MTG	Methanol-to-Gasoline
MTP	Methanol-to-Propylene
NaOH	Soda
Ne	Neon
NG	Natural gas
NGL	Natural gas liquids
NH₃	Ammonia
Ni	Nickel
NMP	N-methylpyrrolidone
NO	Nitrous oxide
NOx	Nitrous oxides
NRU	Nitrogen removal unit

Opex	Operating expenditures
PAH	Polycyclic aromatic hydrocarbon
PC	Polycarbonate
PDH	Propane dehydrogenation
PDP	Preliminary design package
PIMS	Proprietary simulation software
PIP	Performance improvement program
POX	Partial oxidation
PSA	Pressure swing adsorption
PSD	Prevention of significant deterioration
PTSA	Para-toluene sulfuric acid
RBD	Refined, bleached and deodorized
RSH	Carbon-bonded sulfhydryl or thiol
SMR	Steam methane reforming or reformer
SNG	Synthetic natural gas
SO₂	Sulfur dioxide
SOx	Sulfur oxides
SRU	Sulfur removal unit
TDI	Toluene diisocyanate
USD	United States dollar
VDU	Vacuum distillation unit
VSA	Vacuum Swing Adsorption
WHRS	Waste heat recovery system
Xe	Xenon



This manual is also available in:



DIGITAL VERSION

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or any Air Liquide Engineering & Construction representative

More from Air Liquide:



EASY GAS CONVERTER

Gives users the ability to instantly calculate volume conversions from gaseous to liquid state for 14 gas molecules such as nitrogen, oxygen and hydrogen.

Available on Google Play and Appstore



GAS ENCYCLOPEDIA

<https://encyclopedia.airliquide.com>

Allows users to quickly access a host of information on the physical and chemical properties of 64 gas molecules (oxygen, nitrogen, hydrogen, etc.) in their solid, liquid and gaseous states.



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.

Editor: Air Liquide Engineering & Construction

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Artwork: **comnext***



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.



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