

Making our world more productive



State-of-the-art nitrogen rejection technology

Increasing the energy density of natural gas

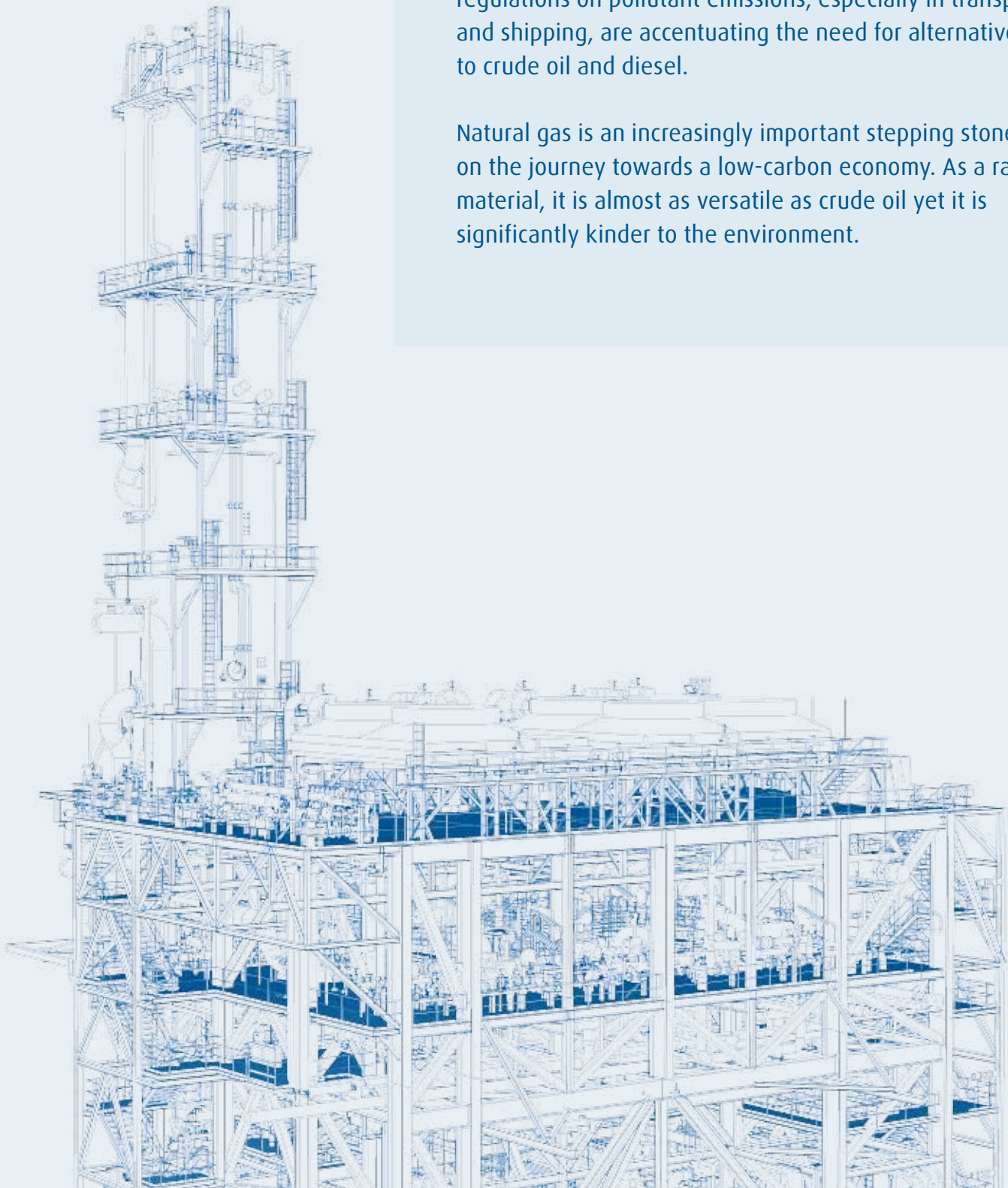




Need for cleaner sources of energy.

One of the biggest challenges facing society today is the need to find more environmentally sound, futureproof sources of energy. This is being driven by rising demand for energy, dwindling fossil fuel reserves and growing climate change pressures. Stricter environmental regulations on pollutant emissions, especially in transport and shipping, are accentuating the need for alternatives to crude oil and diesel.

Natural gas is an increasingly important stepping stone on the journey towards a low-carbon economy. As a raw material, it is almost as versatile as crude oil yet it is significantly kinder to the environment.





LNG plant at Hammerfest, Norway.

Natural gas in focus.

When natural gas is combusted, it produces around 30% less carbon dioxide (CO₂) than mineral oil products, and almost 45% less CO₂ than coal. It also releases around 90% less sulfur oxide and 80% less nitrogen (N₂) oxide than fossil fuels. In addition, advanced extraction technologies are unlocking new fossil hydrocarbon deposits all the time, especially in shale reserves.

Natural gas is a mixture of gases, with hydrocarbons being the main component. However, raw natural gas also frequently contains the inert gas nitrogen. Nitrogen lowers the heating value of natural gas and increases transport volumes.

Pipeline specifications for nitrogen vary. Typically, however, no more than 3–4% nitrogen is allowed in most specifications. Liquid natural gas (LNG) should not contain more than 1% nitrogen to avoid storage problems. Some state-of-the-art, world-scale LNG plants thus feature a nitrogen rejection unit (NRU) for the safe and economical

rejection of nitrogen. This is required, for instance, if surplus nitrogen cannot be sent to gas turbines. Not only does the rejection of nitrogen reduce transportation volumes, it also increases the heating value of LNG. Alternatively, a NRU can be used to recover methane from tank return or end-flash gas.

It is also considered economical to remove nitrogen from low-BTU (British Thermal Unit) gas to either allow for liquefaction or to avoid unnecessary flaring and resulting air pollution. Gas with a low heating value needs to be treated before it can be fed into the grid with the required Wobbe index.

Increasing thermal efficiency by removing nitrogen

For high flow-rate applications, nitrogen is typically removed from natural gas through cryogenic separation. This is a low-temperature rectification (distillation) process, which utilises the different volatilities

of methane (atmospheric boiling point of –161.6°C) and nitrogen (atmospheric boiling point of –195.7°C) to achieve separation.

In this process, a system of distillation columns and heat exchangers in combination with J-T expansion drastically reduces the temperature of the gas mixture to a point where methane liquefies, whereas nitrogen still remains gaseous.

Cryogenic expert

With over 135 years of experience in cryogenic process technologies, Linde has in-depth expertise in manufacturing cryogenic process equipment and managing engineering, procurement and construction (EPC) contracts. Building on the know-how we have gained from several NRU plants built over the years, we deliver a broad portfolio of proprietary technologies for optimum recovery results. We also work closely with our clients to develop customised NRUs.



Contributing to customer success.

Linde's nitrogen rejection units reduce the nitrogen content in natural gas to below one percent. This reduces both transport volume and increases the calorific value of the gas, thus meeting the high requirements of industry and trade.

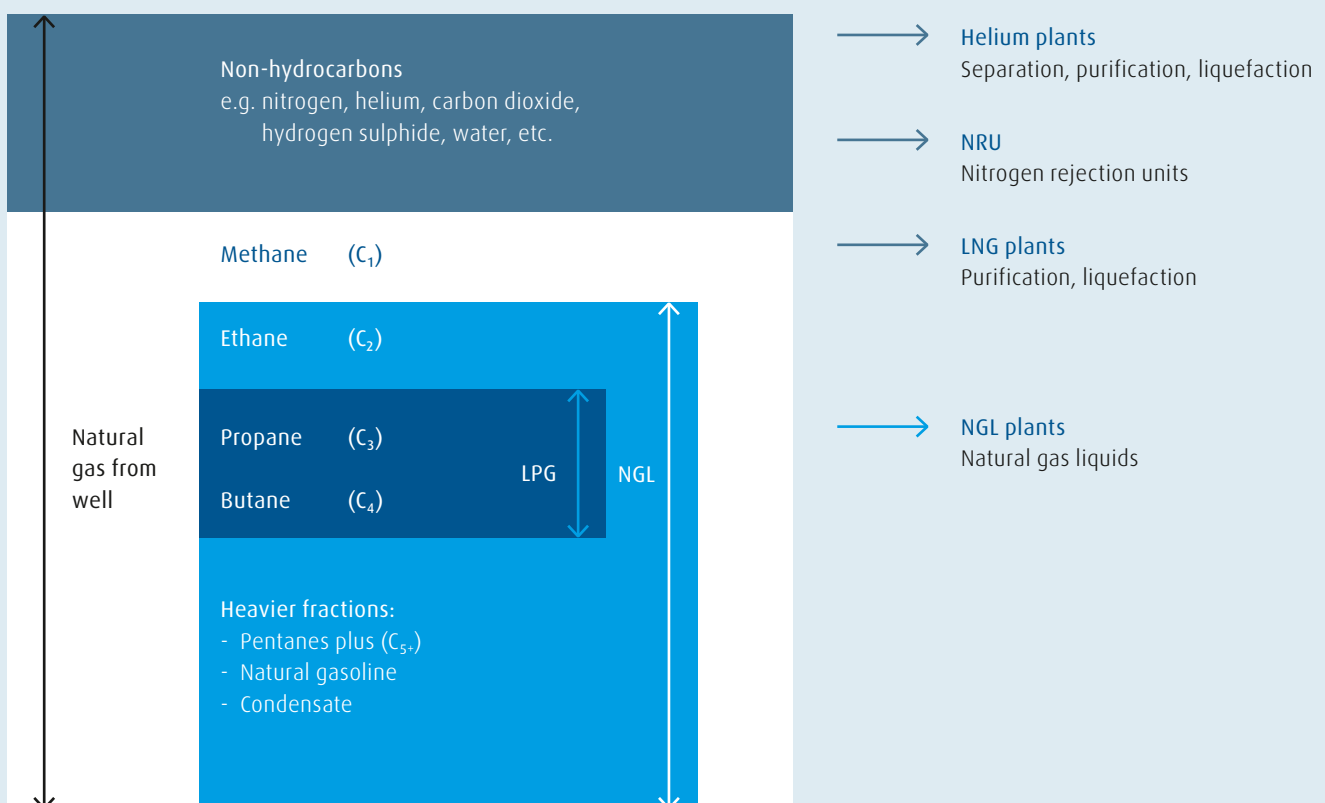
Perfect fit for individual needs

Our portfolio for nitrogen rejection from natural gas includes single-column, single partitioned column and double-column processes as well as double-column processes with an enrichment step. We offer customised configurations tailored to the individual composition of the gas in relation to both the

nitrogen content and other impurities, which could solidify in the cryogenic process.

If helium is also present in the gas stream in relevant quantities, we combine nitrogen rejection with helium recovery. High-purity helium is obtained by combining cryogenic and pressure swing adsorption process steps.

Typical components of NG and related processing plants



Fields of application.

Nitrogen rejection for enhanced oil and gas recovery (EOR/EGR)

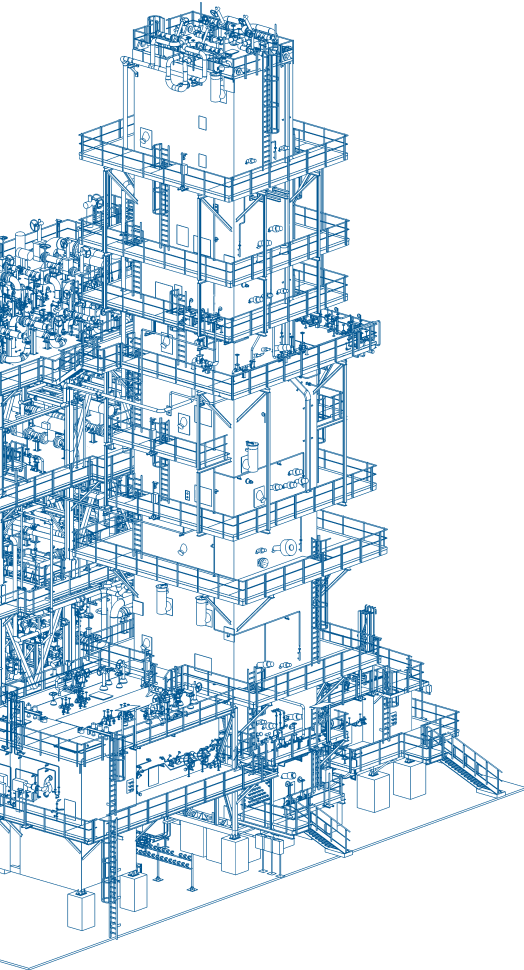
Gas with a low heating value needs to be treated before it can be fed into the grid with the required Wobbe index. This is also important for enhanced oil recovery, where nitrogen is used as a displacement gas and gets dissolved in the oil.

When hydrocarbons are recovered from a new reservoir, the typically high reservoir pressure ensures that these substances naturally flow to the production wells and then gush to the surface. Over time, however, the pressure in the reservoir drops. Procedures for remedying this involve artificially increasing the pressure in natural gas reservoirs. This can be done, for example, by injecting nitrogen into a gas pocket. Other inert gases can also be used for this. In the USA, carbon dioxide from underground sources is a cost-effective variant.

Depending on the geological conditions, some of the injected nitrogen can mix over time with the natural gas during recovery. If the concentration of nitrogen exceeds a specific level, the natural gas is no longer suitable for industrial use. It may then be necessary to remove the nitrogen during treatment of the recovered gas. This has a dual benefit: the transport volume is decreased and the calorific or fuel value is enhanced.

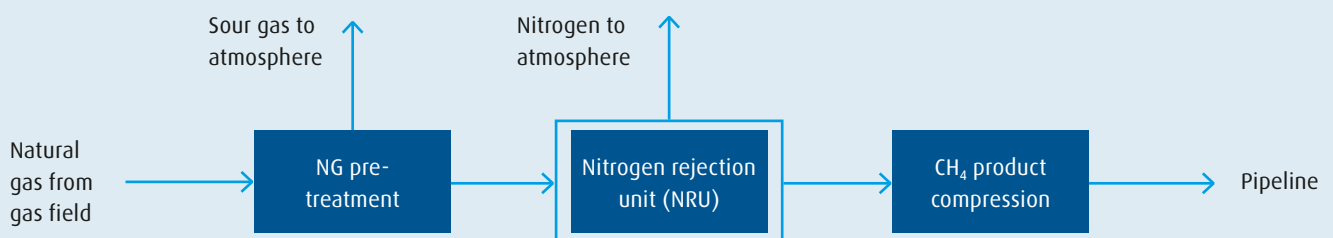
NRU for upgrading nitrogen-rich gas streams to pipeline quality

Pipeline specifications for nitrogen are variable. Typically no more than 3–4% of nitrogen is allowed in most specifications. Natural gas contains a certain volume of nitrogen. If the concentration of nitrogen exceeds the pipeline specification, the natural gas cannot be sold. In order to monetise nitrogen-rich gas fields, the recovered gas can be either blended with another low-nitrogen natural gas stream or an NRU can be installed.



NRU integrated in LNG plant at Hammerfest, Norway.

NRU for upgrading a nitrogen-rich natural gas stream to pipeline quality





NRU integrated in a helium plant in Skikda, Algeria.

< 1%

concentration of nitrogen
to transport or store natural
gas in liquid form

NRU integrated in LNG complex

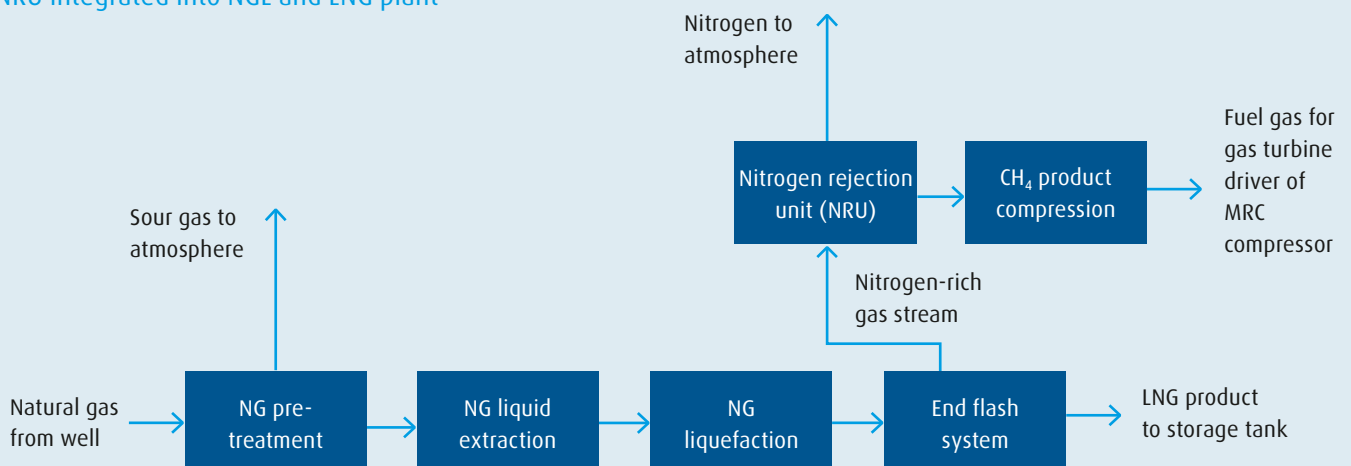
In order to store or transport natural gas in liquid form, the nitrogen content should be below one percent. To meet this specification, a flash gas stream which is rich in nitrogen is separated – typically downstream of the natural gas liquefaction plant. This flash gas stream can be used, for example, as fuel for the turbines which power the liquefaction process. In order to meet fuel gas requirements, excess nitrogen needs to be separated from this flash gas stream.

Woodside, the largest Australian oil and gas company, uses nitrogen rejection units at both its Pluto and Xena natural gas fields near Karratha, off the country's west coast. There the nitrogen content in the well stream is over six percent, so Woodside decided to integrate a Linde NRU when it was planning its natural gas liquefaction plants. At the end of 2011, the plant successfully went into operation.

Read more:

linde-engineering.com/nru

NRU integrated into NGL and LNG plant



-273.15°C

= absolute zero

Helium recovery and liquefaction plants.

Helium is a rare gas and highly valued in the market, making its recovery and liquefaction from natural gas an attractive option – even in small amounts. It is used, for example, in the space industry, MRI and NMR equipment (superconducting magnets), welding and shielding processes, lasers and optical fibre manufacturing.

So, if helium is also present in the natural gas stream, nitrogen rejection is typically combined with the recovery of helium. High-purity helium is obtained by combining cryogenic and pressure swing adsorption process steps.

We offer field-proven processes and plants for the cryogenic recovery of raw helium from natural gas, the purification of the raw helium in pressure swing adsorption (PSA) units, the liquefaction and production of high-purity helium (>99,999%) and its storage at temperatures of about -270°C.

Our technologies cover each step in the helium value chain, enabling us to offer complete plants on a turnkey, lump-sum basis. Our wide range of process technologies is tailored to the capacity and helium concentration in the feed gas for optimum recovery results.



Erection of NRU coldbox at Karratha, Australia.



Nitrogen rejection unit (NRU) in Karratha, Australia.



Nitrogen rejection unit (NRU) in Karratha, Australia.



Helium recovery and liquefaction plant in Skikda, Algeria, customer Helison S.p.A.



NRU module fabrication at Tarragona, Spain.

Nitrogen rejection – how does it work? Multiple process options.

Excess nitrogen is removed in Nitrogen Rejection Units (NRUs). The removed nitrogen typically has a concentration of 1,000 vppm (volume parts per million) of methane (CH_4). This stream is vented to the atmosphere. The maximum CH_4 concentration is generally regulated by local authorities and can lie anywhere between 100 vppm and 10,000 vppm. Bulk rejection of nitrogen with high methane recovery rates corresponding to the stringent emission limits tends to be complex and expensive. Thus, different techniques have evolved for various plant sizes.

- PSA systems (e.g. Molecular Gate® by BASF)
- Membranes (e.g. MTR)
- Lean oil absorption (e.g. AET)
- Cryogenic processes

Non-cryogenic processes, such as the first three entries, are typically limited to applications with less than 50,000 Nm^3/h of feed gas. Non-cryogenic treatment of higher feed gas volumes requires higher investment and operating costs (due to recycle compression). Cryogenic treatment of higher feed gas volumes typically offers lower CAPEX and OPEX.

The following takes a closer look at the different cryogenic process technologies available for the separation of nitrogen (single column, single partitioned column, double column, and double column with enrichment). With cryogenic nitrogen rejection, sour gases and water must be removed upstream of the low-temperature section to avoid corrosion and freezing problems. Amine systems for carbon dioxide removal and molecular sieve bed driers are readily available for this application. They come in all required sizes and are a cost-effective option.

CH_4 concentration capped at
100–10,000
vppm by local authorities

Process selection criteria.

Defining the key parameters

The nitrogen rejection process best suited to individual needs will depend on the operating flexibility required, the degree of complexity of the plant, sensitivity to feed gas composition and lifecycle costs. The key parameters are nitrogen and carbon dioxide content in the feed gas, feed pressure, flow rate, methane recovery and impurity levels.

An important constraint to bear in mind when designing an NRU is the fact that it has a limited ability to tolerate the most common impurity in natural gas, carbon dioxide. Generally, carbon dioxide tolerance is determined by the coldest spot where carbon dioxide tends to freeze. Since the maximum solubility of carbon dioxide depends in essence on the temperature of the solvent, for example liquid hydrocarbons, processes at elevated pressure (typically above 20 bar) are more carbon dioxide-tolerant than those operated at low pressure and thus lower fluid temperatures.

Basic single-column NRU process

Cryogenic N_2 rejection from pipeline gas requires at least one rectification column, which separates light components including N_2 (as the overhead stream) from the hydrocarbon-rich bottom streams.

The single-column process is often favourable if the nitrogen content in the feed gas is below 30%, whereas the double-column process is the preferred choice for concentrations above 30%. In addition, the single-column NRU process can be applied at higher pressure levels and thus with higher levels of tolerance to carbon dioxide.

A simple process sketch for this concept is shown in figure 1, where part of the column bottoms are used under low pressure as coolant for the reflux condenser. This arrangement is simple and efficient, as the heat duty of the condenser can be satisfied easily with this once-through operation. However, the bottom streams need to be very lean in CO_2 , as the condenser is operated in a temperature range between -150 and $-160^\circ C$. In addition, the C_2 plus content must not exceed a few percent to avoid vacuum suction conditions in the refrigerant compressor.

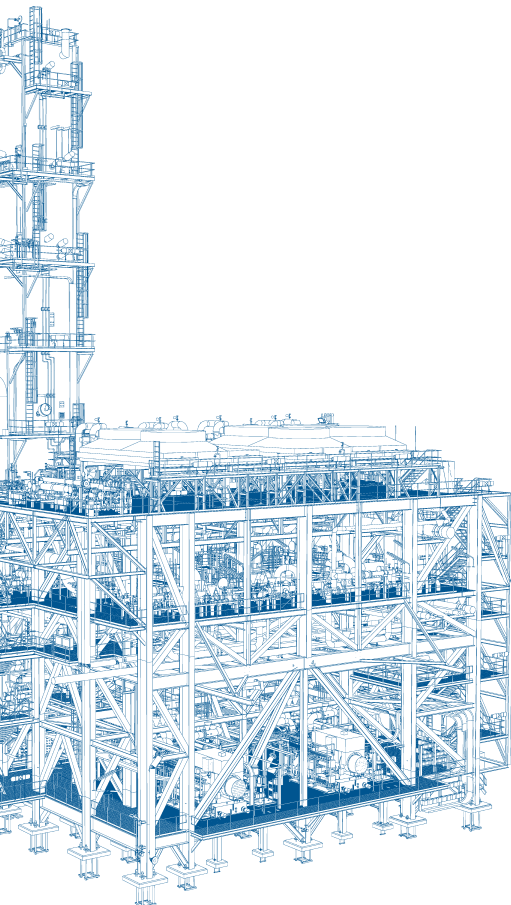
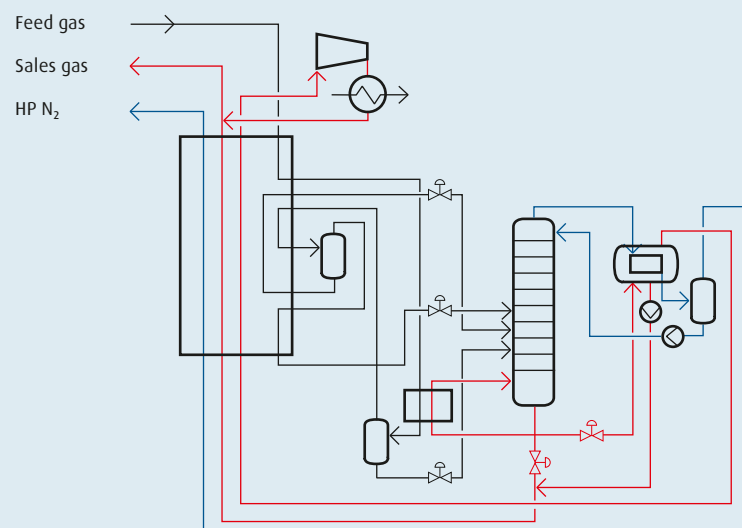


Figure 1: NRU with open refrigeration loop



These limitations for the refrigerant composition can be avoided if a closed refrigeration loop is used for the reflux condenser (see figure 2).

Figure 2: NRU with closed refrigeration loop

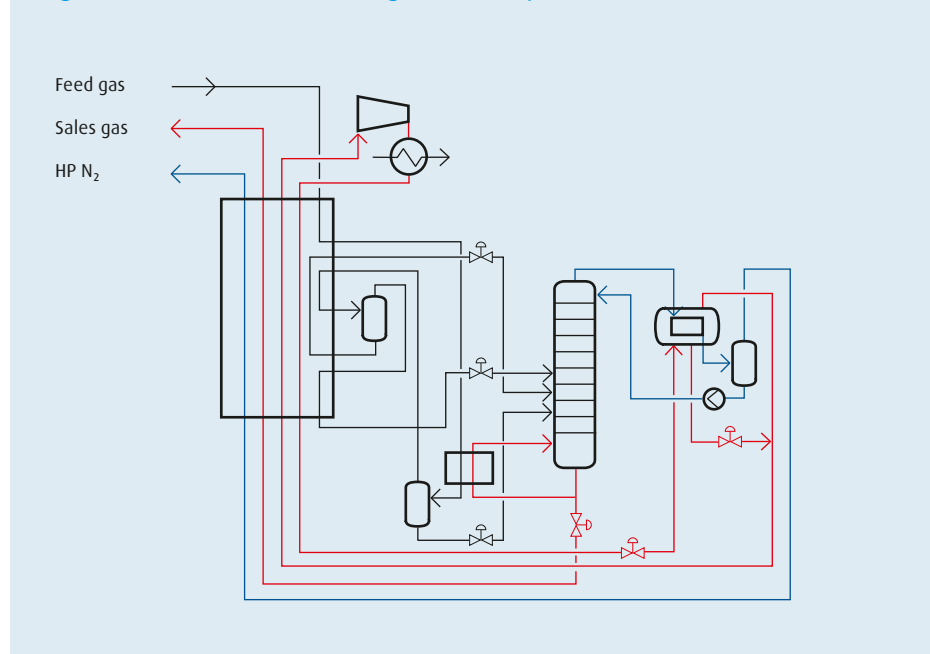
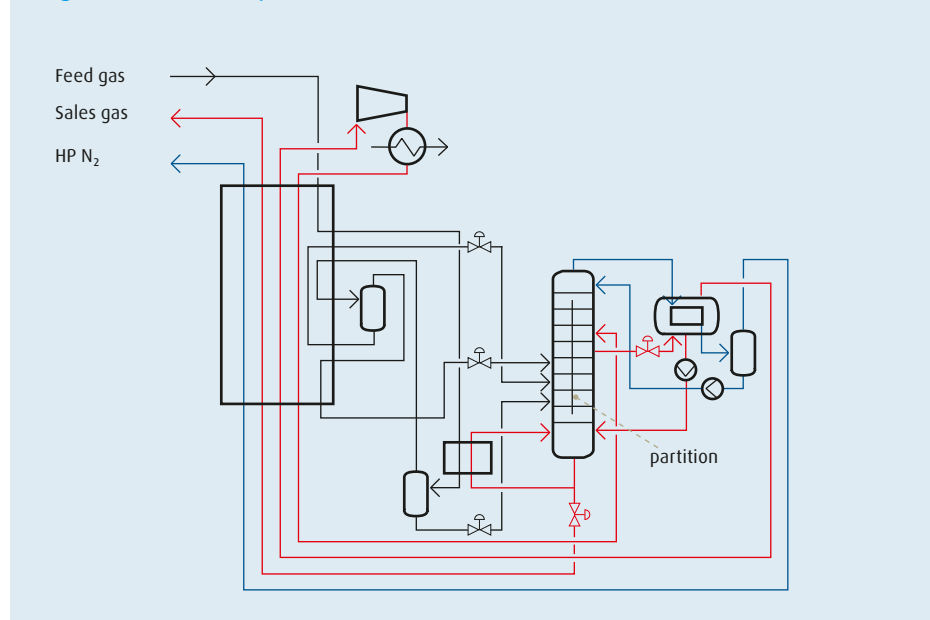


Figure 3 illustrates a novel process configuration, where the coolant for the reflux condenser is taken from a side stream of the column and not from the bottom stream – as is typically the case. To avoid contamination of the side (product) stream by feed streams, a partition is installed inside the column, which splits the column in the middle section into two largely independent segments. While both segments are coupled hydraulically, the composition on the divided trays may vary. In particular, heavier components including CO_2 and C_2 plus from the feed lines are pushed to the bottom section without contaminating the product side of the partition. This rectification concept was commercialised by BASF in 1985 and has proven to be reliable and efficient in the field ever since.

Figure 3: NRU with partitioned column



NRU single-column process

- Simple and CO_2 -tolerant concept with a single column
- Flexible and robust in response to changes in feed gas composition and flow rate
- High load variability from 20 to 100% possible
- Suited to feed gases with an N_2 concentration from 3 up to 60 mol%
- One-stop service for customers
- High availability and reliability

Basic double-column NRU process.

Cryogenic nitrogen rejection with a double-column process is similar to the well-known air separation process. While air separation units separate nitrogen from oxygen, NRUs remove nitrogen from methane.

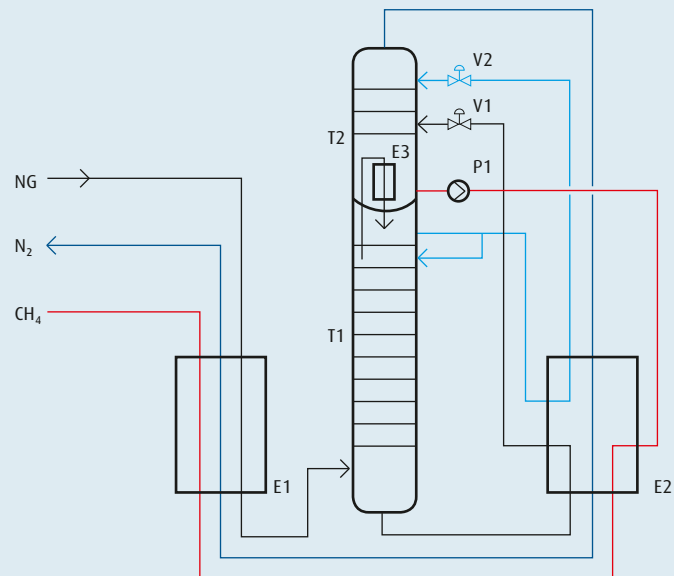
In a typical double-column NRU process, the low-temperature profile in the low-pressure column means that carbon dioxide must be removed from the feed gas down to a few ppm. In order to achieve this, a complex pre-purification step, for example by means of

amine scrubbing, must be installed.

As shown in figure 4 exchanger E1 using the cooling power of N_2 and CH_4 , and fed to the bottom part of the pressurised

column T1. Reflux for T1 is condensed in E3, which reboils the bottom of the low-pressure column. The sophisticated heat integration between T1 and T2 in E3 governs the operating pressures of both columns.

Figure 4: NRU double-column process



NRU double-column process

- Energy-efficient concept due to extensive heat integration and use of an open N_2 refrigeration cycle
- Suited to feed gases with an N_2 concentration from approx. 25 to 80 mol%
- Flexible and robust in response to changes in feed gas composition and flow rate
- Mechanically robust - high availability and reliability

Double-column NRU process with pre-separation and nitrogen enrichment

Gas with a nitrogen concentration below 25 to 30 vol% cannot usually be processed successfully in a basic double column. It typically requires further processing steps, including a nitrogen enrichment column. These columns can also remove heavy hydrocarbons contained in the feed gas.

NRUs based on double-column processes can be easily integrated into end-flash systems of LNG plants if the nitrogen concentration is

at least 25 vol%, which can be achieved with a nitrogen stripper instead of a simple flash drum. Linde Engineering has designed and/or built many of these plants worldwide.

Recycling pure nitrogen as auxiliary reflux to the double-column system gives operators the flexibility they need to maintain hydrocarbon emission levels low – even during drastic changes in feed gas compositions. The high flexibility of this concept has been demonstrated in a helium liquefaction plant in Algeria (see picture above).

Reference list for plants including nitrogen rejection

Start-up year	Client	Location	Feed gas capacity	Plant type	Product	Process	Scope of work
2018	Gazprom	Svobodny, Russia	6 x 815,000 Nm ³ /h	NGL/NRU	6 x 732,000 Nm ³ /h C ₁ 6 x 55,000 Nm ³ /h C ₂ + 6 x 28,000 Nm ³ /h He/N ₂	Heat pumped & CO ₂ -tolerant single column NRU	Engineering, procurement of main equipment, construction supervision, start-up supervision
2016	Confidential	Australia	255,000 Nm ³ /h	NRU	246,000 Nm ³ /h sales gas	N ₂ removal and dew point control in a domestic gas plant	Basic engineering, detail engineering, procurement, module construction, start-up assistance
2016	China Petroleum Engineering Huabei Company (PetroChina), Huanggang Company Ltd.	Xinghe, China	77,600 Nm ³ /h	LNG/NRU	1,357 tpd	LIMUM® with coil wound heat exchanger	Engineering, procurement of main equipment, construction supervision, start-up supervision
2015	MLNG (Petronas)	Bintulu, Malaysia	130,000 Nm ³ /h	LNG/NRU	2,100 tpd	Boil-off gas re-liquefaction with closed mixed refrigerant cycle featuring coil wound heat exchanger	Engineering, procurement, construction, start-up supervision
2012	Woodside Burrup Pty. Ltd.	Karratha, Australia	78,000 Nm ³ /h	NRU	36,000 Nm ³ /h fuel gas	N ₂ removal in LNG plant	Basic engineering, detail engineering, procurement, module construction, start-up assistance
2011	Xinjiang Ji Munai Guanghui	Jimunai, China	62,500 Nm ³ /h	LNG/NRU	1,200 tpd	LIMUM® with coil wound heat exchanger	Engineering, procurement of main equipment, construction supervision, start-up supervision
2007	Snøhvit Group	Hammerfest, Norway	71,400 Nm ³ /h	NRU	53,000 Nm ³ /h	N ₂ removal in LNG plant	Basic engineering, detail engineering, procurement, construction, construction supervision, start-up supervision
2005	Helison Production S.p.A.	Skikda, Algeria	47,000 Nm ³ /h	NRU	4,700 Nm ³ /h N ₂ 2,200 Nm ³ /h He 40,000 Nm ³ /h sales gas	N ₂ removal in He recovery plant	Basic engineering, detail engineering, procurement, construction, construction supervision, start-up supervision
1998	Warren Petroleum Co.	USA	11,200–47,400 Nm ³ /h	NRU	Pipeline-quality NGL	N ₂ removal in low-temperature unit	
1998	NGC/Warren Petroleum	USA	55,800 Nm ³ /h	NGL/NRU	NGL/NRU	Cryogenic gas plant revamp/NRU	Engineering, procurement, fabrication, construction
1994	BHP Petroleum	Onslow, Australia	47,000 Nm ³ /h	NRU	40,000 Nm ³ /h pipeline-quality gas, 22,000 t/a propane	Membrane unit for CO ₂ removal, mercury adsorber, adsorber for H ₂ O removal, H ₂ S conversion to COS, N ₂ removal in low-temperature unit	Basic engineering, detail engineering, procurement services, start-up supervision
1988	Sun Exploration and Production Company	USA	20,100 Nm ³ /h	NRU	Pipeline-quality sales gas, Y-grade NGL	Amine treatment unit for CO ₂ removal, cryogenic natural gas plant for ethane removal, N ₂ removal in low-temperature unit	

Global reach 100+

We are represented in over
100 countries worldwide

Since 1981 Linde has
supplied more than 11,000
vacuum brazed aluminium
heat exchanger blocks.



Aluminium plate-fin heat exchanger.

Deep, proven fabrication expertise – where and when you need it.

Over the last 135 years, we have gained invaluable experience in the fabrication of cryogenic modules and packaged equipment. We operate numerous facilities around the world to ensure we are always close to our customers. Our main fabrication facilities for plant components is located in Schalchen, approx. 100 km east of Munich, Germany. It covers a total area of 200,000 m² with more than 750 employees specialised in the engineering and fabrication of cryogenic equipment. For very large units, satellite workshops are available at the North Sea coast (e.g. Bremen/Germany and Antwerp/Belgium) as well as in Tarragona/Spain. Further fabrication facilities are located in Oklahoma/USA at the Tulsa Port of Catoosa Industrial Complex and in Dalian/China.

Over the years, we have designed, built and delivered several NRU plants around the

world. Combining the experience we have gained from those projects with our broad portfolio of proprietary technologies, our engineers work closely with our clients to develop customised NRUs that match individual needs.

At every stage of the project – from your very first query to turnkey handover – our servicefocused engineers are there to support you. You can rely on our team to deliver the project development services you need to make the best investment in nitrogen rejection technology and maximise your return on that investment.

Talk to our experts today.



Fabrication facility Schalchen, Germany.

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Your partner for the production and processing of gases

Delivering reliable process plants for maximum capital efficiency

Linde has been optimizing gas processing technologies for 140 years, successfully delivering more than 4,000 plant engineering projects around the globe. Favoring trusted, lasting business relationships, the company collaborates closely with customers to enhance plant lifecycle productivity and innovate process flows. The company's proven gas processing expertise plays an indispensable role in the success of customers across multiple industries – from natural gas and oil refining through petrochemicals and fertilizers to electronics and metal processing.

Operational excellence along the entire plant lifecycle

We work closely with our customers to gain an in-depth understanding of individual needs. Building on the unique synergies of Linde as an integrated plant operator and engineering company, Linde offers innovative process technologies and services to exceed our customers' reliability and profitability expectations. This commitment to innovation extends along the entire plant lifecycle. The LINDE PLANTSERV® service team supports customers every step of the way – from maintenance and repairs to full revamps. Leveraging the latest digital technologies to offer on-site and remote operational and support services, we consistently take asset performance to the next level.

Making the impossible possible

From the desert to the Arctic, from small- to world-scale, from standardized to customized designs, Linde's engineering specialists develop solutions that operate under all conditions. The company covers every step in the design, project management and construction of gas processing plants and components. Customers can always rely on Linde to deliver the plants, components and services that fit their needs best – anywhere in the world.

Discover how we can contribute to your success at www.linde-engineering.com

Get in touch with our natural gas plant team:

Phone +49 89 7445-3434, inquiry: www.linde-engineering.com/contact

Core competencies at a glance

Plant engineering

- Air separation plants
- LNG and natural gas processing plants
- Petrochemical plants
- Hydrogen and synthesis gas plants
- Adsorption plants
- Cryogenic plants
- Carbon capture and utilization plants
- Furnaces, fired heaters, incinerators

Component manufacturing

- Coldboxes and modules
- Coil-wound heat exchangers
- Plate-fin heat exchangers
- Cryogenic columns
- Cryogenic storage tanks
- Liquefied helium tanks and containers
- Air-heated vaporizers
- Water bath vaporizers
- Spiral-welded aluminum pipes

Services

- Revamps and plant modifications
- Plant relocations
- Spare parts
- Operational support, troubleshooting and immediate repairs
- Long-term service contracts
- Expert reviews for plants, operations and spare part inventory
- Operator training

