THE LINDE GROUP

# HYDROGEN

## Our commitment, our business.

Since the inception of the chemical and fertilizer industries – and in petrochemicals - LINDE has continually been at the forefront of hydrogen generation technology. Examples include the purification of various industrial raw gas feedstocks such as coke oven and coal gasification gases, sophisticated, tailor made sourgas steps with chemical and/or physical absorption, and adsorption followed by low temperature purification and rectification processes with "cold box" units.

Among suppliers of hydrogen plants, Linde is the only company who owns all of the technologies and utilizes this in-house know-know to process a variety of feedstocks: natural gas through LPG, refinery off-gases, naphtha up to heavy fuel oil, asphalt, and coal.

The primary technologies:

- Steam reforming for light hydrocarbon feedstocks combined with LINDE's own PSA systems for hydrogen purification.
- Partial oxidation for heavy hydrocarbon feedstocks followed by a sequence of integrated process steps to shift, desulfurize and purify raw hydrogen. Pure oxygen for gasification is produced with a LINDE air separation unit.

LINDE's expertise is the essential advantage for successful integration and optimization of all process sections. The result: highly efficient, reliably operating hydrogen plants. Since the early 70's LINDE has innovatively advanced its steam reforming/pressure swing adsorption technology for the production of pure and ultrapure hydrogen, primarily from light hydrocarbon feedstocks.

With the acquisition of the Fluid Processing Division of Selas of America in 1982 (now Selas Fluid Processing in the USA and SELAS-LINDE GmbH in Germany), LINDE has a full complement of proven expertise in the design and construction of furnaces, steam reformers and heaters. With our combined capabilities, LINDE and Selas developed a proprietary top fired reformer design.

Combining the know-how of its Engineering and the Gases Divisions, LINDE is in a unique position - building, owning and operating complete hydrogen plants for continuous supply of hydrogen over the fence to large refineries and chemical companies. Our extensive bank of operating data and information on process and equipment performance in operating plants provides LINDE with substantial background for more efficient design of future plants.

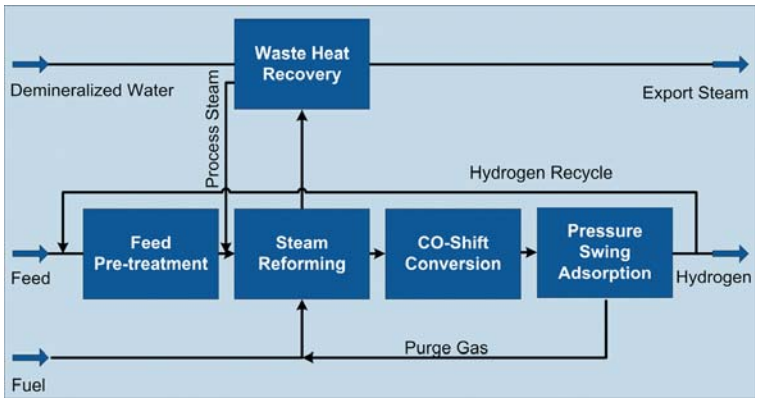
- More than 250 new hydrogen plants built worldwide for clients in the refining, chemical and fertilizer industries
- Capacities from below 0.2 MMSCFD to well above 100 MMSCFD
- All types of feedstock
- Most of these plants have been built on a lump-sum, turn-key basis.

# Production of hydrogen from light hydrocarbons

LINDE has a well-proven technology for hydrogen manufacture via catalytic steam reforming of light hydrocarbons in combination with LINDE's highly efficient pressure swing adsorption process. A typical flowsheet for a LINDE designed large capacity hydrogen plant is shown here.

The basic process steps:

- Hydrodesulfurization of feed stock
- Steam reforming
- Heat recovery from reformed gas and combustion flue gas to produce process and export steam
- Single stage adiabatic high temperature CO-shift conversion
- Final hydrogen purification by pressure swing adsorption




# Process features

Process design and optimization for each step, particularly the linking of operating parameters between the primary processes - reforming and pressure swing adsorption - are based on LINDE's process and operating experience.

## Reformer furnace

The reformer consists of a compact fire box design with vertical top-supported catalyst tubes arranged in multiple, parallel rows and a minimized number of forced draft top-firing burners integrated into the firebox arch. Compared to other designs, the advantages of LINDE reformers include:

- Combustion setup to accomodate swings in PSA purge gas composition, simplifying burner trimming and individual adjustment to achieve uniform heat flow throughout the reformer cross section.
- Concurrent firing to ensure a uniform temperature profile throughout the reformer tube. Flame and stable combustion flow pattern is supported by flue gas collecting channels arranged at ground level between the hot reformed gas headers.
- Adjustable spring hanger system inside the penthouse compensates for thermal expansion and tube and catalyst weight, removing mechanical stress from the hot manifold outlet headers at ground level.
- The radiant reformer box is insulated with multiple layers of ceramic fibre modules, mechanically stable and resistant to thermal stress.

## Convection section

Depending on the hydrogen product capacity, the convection section - a series of heat exchanger coils - is arranged either vertically with an induced draft fluegas fan and stack at reformer burner level, or horizontally at ground level for easy access and reduced structural requirements.

Reformer and Convection Section

PSA Plants

## Pressure swing adsorption

LINDE'S PSA technology offers these advantages:

- High product recovery rates
- Low operating costs
- Simple operation
- Advanced computer controls ensure high availability and easy monitoring

Engineering expertise combined with sophisticated computer software guarantees high quality design and construction of tailor-made, economical plants. Modular PSA plant skid designs reduce erection time and site costs. Fully pre-fabricated skids are thoroughly shop tested.

## Advanced load control

Linde engineers developed a model based control system for hydrogen plant load management. The Advanced Load Control (ALC) system drives the plant to the desired hydrogen load and manages the Reformer's total fuel and feed consumption. Significant process variables are kept at desired set point despite variations in the plant operating conditions, resulting in an overall smooth operation that protects catalysts and reforming tubes.

## Safety philosophy

Safety (Hazop) studies and ESD-system design philosophy are based on over 30 years of steam reforming plant experience and the cumulative knowledge gained by LINDE safety experts on numerous lump-sum, turn-key contracts - primarily with large-scale synthesis gas plants and complex olefin production units.

## Environmental protection

For steam reforming based hydrogen plants, special care is taken to minimize NOx and CO emissions and noise propagation. Design of blow-down and flare systems consider permissible levels for heat radiation and air pollution, etc.

# Multi feed plants

Refineries and operating companies focus on operational performance optimization, with high feed stock flexibility a top priority. There are many reasons to design for multi feedstock capability: shortage of traditional feeds, shutdown or maintenance work necessitating backup feeds, future changes to more economical feedstocks, increased hydrogen production reliability, and specific requirements at individual production locations are a few.

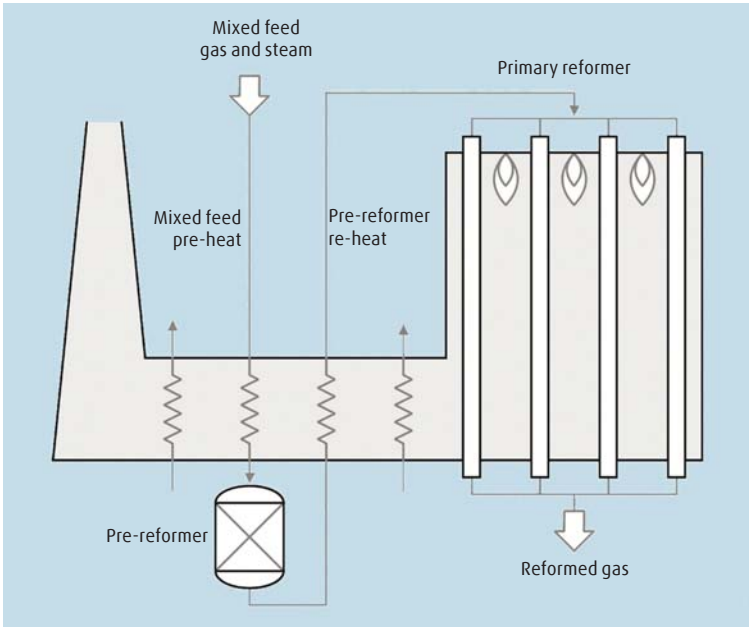
LINDE's technologies for direct reforming and pre-reforming have been proven in multiple plants with varying configurations worldwide.

## Pre-reforming

Pre-reforming is the term applied to steam reforming of hydrocarbons in a simple adiabatic reactor using highly active, nickel based catalyst, which promotes the steam reforming reaction at low temperatures.

Feedstock, ranging from natural gas to naphtha, is converted by the steam reforming reaction to produce an equilibrium mixture containing hydrogen, carbon oxides, methane and steam. Depending on the feedstock, the temperature profile can be either endothermic or exothermic.

In its most common application today the main benefits of pre-reforming are increased flexibility and optimized operating figures.



## Modular hydrogen plants

Our subsidiary Hydro-Chem, located in Holly Springs, Georgia, puts LINDE foremost in pre-fabricated and skid-mounted steam reforming hydrogen plants including methanol cracking, with typical capacities from below 0.2 to 11 MMSCFD.

### Technology

Our modular plants are based on in-house steam reforming technology employing a round up-fired can reformer design, followed by a purification step using in-house standard four- or five-bed PSA technology.

### Design

The modular plant is designed to meet exact customer needs, and the pre-assembled designs satisfy the most demanding product requirements. Layout is optimized to minimize space and simplify maintenance.

### Automation

The plant can be supplied with fully automatic remote control for unmanned operation, promoting safe start-up and shut-down, and supervised by common service centers.

Modular Hydrogen Plant

### Modular Fabrication

Modular fabrication of hydrogen facilities is performed in our own and/or pre-qualified external workshops. All components are assembled into compact, easy to install units. The pre-assembled units offer the most economical layout without sacrificing access for operation and maintenance.

## Designing Processes - Constructing Plants.

LINDE's Engineering Division continuously advances and applies its process engineering capabilities in the planning, project management and construction of turnkey industrial plants.

Selas Fluid, a wholly owned subsidiary of THE LINDE GROUP, is now the NAFTA regional supplier of LINDE Engineering HYCO technologies. Our customers will benefit from single source responsibility for the Engineering, Procurement, and Construction (EPC) of their hydrogen and synthesis gas plant needs.

Selas Fluid has been providing the engineering design, supply, and installation of combustion-based equipment for over 60 years. We have established a tradition of providing technology-based, cost effective solutions for the refining, petrochemical, and gas processing industries.

# Selas Fluid

Subsidiary of The Linde Group

Call us today to learn more about LINDE hydrogen technologies, or visit us online at
www.selasfluid.com
www.linde.com


**Head Office:**
Selas Fluid Processing Corp.
Five Sentry Parkway East, Suite 300
Blue Bell, PA 19422 USA
Phone: +1 610-834-0300
Fax: +1 610-834-0473
sales@selasfluid.com

**Houston Office:**
Selas Fluid Processing Corp.
16225 Park Ten Place, Suite 250
Houston, TX 77084
Phone: +1 281-717-9090
Fax: +1 281-717-9091

**Linde AG**
Engineering Division
Head office: Dr.-Carl-von-Linde-Str. 6-14, 82049 Pullach, Germany
Phone: +49 89-7445-0 · Fax: +49 89-7445-4908 · info@linde-le.com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