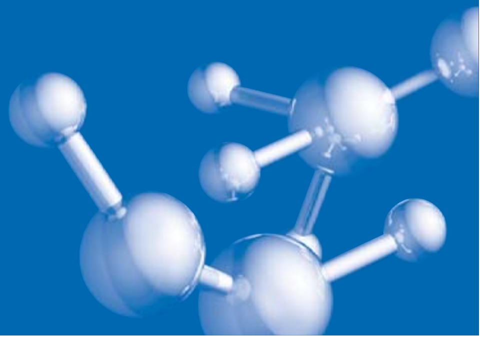
Reforming



The Market

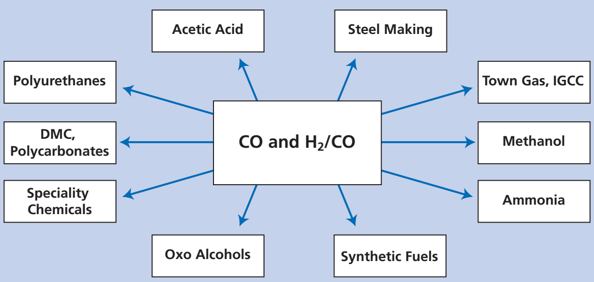
Gas Production and Purification, Reforming, MegaSyn®

Carbon monoxide (CO) and hydrogen (H_2) or a mixture of CO, nitrogen (N_2) instead of CO for few applications and H_2, called synthesis gas or syngas, are produced from a wide range of gaseous to liquid hydrocarbons by reforming.

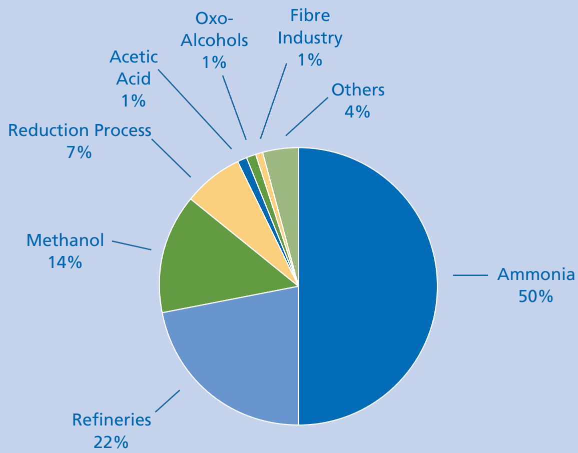
The main production processes providing CO, H_2 or syngas are:

- Steam reforming, a catalyzed reaction of gaseous or liquid hydrocarbons and steam to yield a mixture of H_2, CO and CO_2,
- Partial oxidation, a non-catalytic reaction of hydrocarbons, petroleum coke, coal, chemical waste or biomass with steam and oxygen,
- Autothermal reforming which combines steam reforming and partial oxidation in a single reactor,
- Combined reforming, a combination of steam reforming and oxygen-based secondary reforming.

The impressive variety of applications of CO and H_2/CO is demonstrated in the following diagram.



Remarkably, the right side of the diagram points to large quantities of syngas required to produce ammonia, methanol, synthetic fuels, for example.
These are the most suitable fields to make use of Lurgi MegaSyn® technology for ultra-large syngas production facilities.
Production of synthetic fuels and power generation based on an integrated gasification combined cycle (IGCC) will increase in importance.
The main fractions of the worldwide syngas market are covered by ammonia (50%), refinery hydrogen (22%) and methanol (12%) as the breakdown shows.



Demand for carbon monoxide and synthesis gas has experienced steady growth, mainly in line with considerable increase in demand for the derivatives.

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Reforming

The global market for hydrogen in the refining and petrochemical industries is expected to achieve average growth rates in the range of 10% in the future, primarily as a result of:

- Desulfurization of gasoline, diesel and upgrade of increasing supplies of heavy crude oil,
- More stringent environmental regulations governing emissions of NO_x and SO_x,
- Renewable energy production from fuel cells in future.

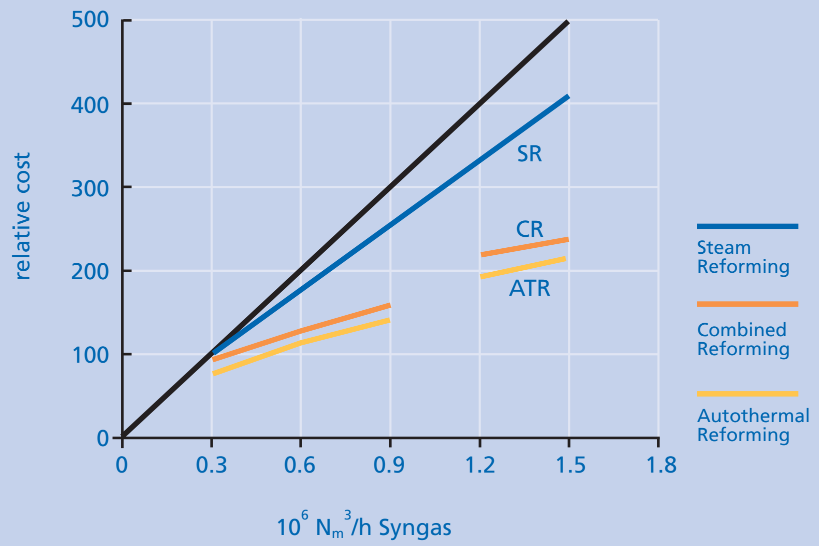
Investment and Production Cost

In addition to process features, plant capacity plays an important part in technology selection and economics. Processes producing the maximum hydrogen rates are more competitive in the lower capacity range whereas the economy of processes producing the lowest H_2/CO ratios increases in proportion with capacity.

The broad spread of investment cost is illustrated in the diagram depicting relative cost versus syngas volume for the different reforming technologies, i. e. steam, autothermal and combined reforming.

Remarkably, the spread starts at a syngas capacity of 300,000 mn^3/h getting considerably broader at 1.5 million mn3/h. For this large capacity, the comparison of investment cost for autothermal and steam reforming results in a factor of about 0.5 in favor of autothermal reforming. The investment cost figure for combined reforming is slightly higher compared to autothermal reforming.

Stressing the fact again that many selection criteria for reforming exist and differently impact on investment and production cost, detailed evaluations are required to meet the individual conditions specified for each project.



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Lurgi

Reforming

Why choose Lurgi? – Experience and References

Erfahrung und Referenzen

Lurgi offers the complete range of reforming technologies including the most suitable proprietary reaction system and catalyst available worldwide. Lurgi is incessantly committed to the optimization of its plants in terms of feedstock, products and plant cost in a single line responsibility.

The Lurgi hydrogen management strategy ensures tailored and economic solutions for the client comprising:

- Selection of the most appropriate technology for hydrogen production,
- Integration of hydrogen-containing off-streams,
- Application of the most suitable hydrogen purification technology.

The Lurgi Autothermal Reforming technology called MegaSyn® takes account of all crucial requirements of "Mega" gas production, especially regarding the design, construction and operation of the complete reactor and heat recovery system.

Lurgi's abilities are proven by unparalleled references of Mega plants in operation.

Lurgi's reforming experience and, especially, MegaSyn are based on the development, design, construction, operation and feedback derived from an outstanding plant record:

- About 100 steam reforming plants,
- More than 30 autothermal reforming plants,
- 11 combined reforming plants,
- 75 partial oxidation plants,
- Plant sizes ranging
  - from 42,000 mn³/day of carbon monoxide,
  - up to 22 million mn³/day of syngas,
- Feedstock range:
  - Light/heavy natural gas, LPG, associated gas, naphtha, fuel oil, heavy residues,
- Product range:
  - Carbon monoxide, hydrogen, town gas, syngas for products such as ammonia, methanol, oxo-alcohols, synthetic fuels, etc.

MegaSyn® is the right technology for generating large quantities of syngas for oxo-alcohols, carbon monoxide, ammonia or methanol or synfuel synthesis.

Lurgi is in a unique position to license MegaSyn® combined with other downstream processes or proprietary technologies such as MegaMethanol®, Megammonia®, if required as lump sum turnkey projects based on single line responsibility by Lurgi.

Lurgi also offers integrated schemes of own technologies such as the conversion of natural gas to propylene via generation of syngas and methanol or integrated schemes consisting of one single ultra-large syngas complex for feeding plants which produce various products like ammonia and methanol simultaneously, for example.

The main benefits are:

- Significant reduction of investment cost due to the economy of scale effect as shown in the above mentioned diagram for syngas generation,
- Minimum consumption of feed and utilities due to plant and heat integration,
- Focus on few products only, no generation of by-products such as CO_2,
- Significant reduction of production cost for "Mega" facilities.

Lurgi is the undisputed leader of references for ultra-large syngas plants and is prepared to share this experience with further clients.

Reforming

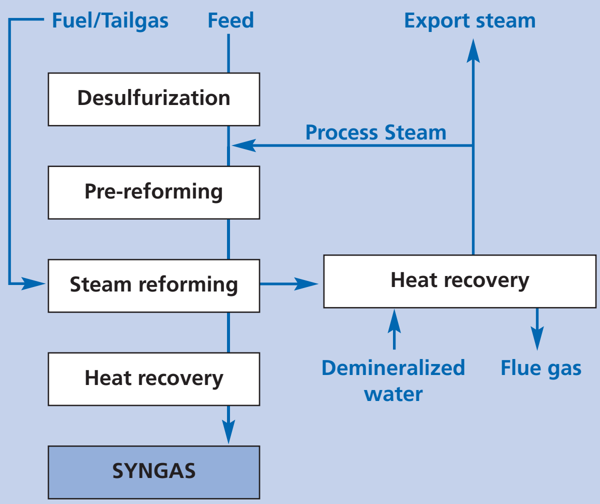
Our Technology

There are many criteria to select the most suitable reforming or partial oxidation technology and to provide the optimum solution for the client such as:

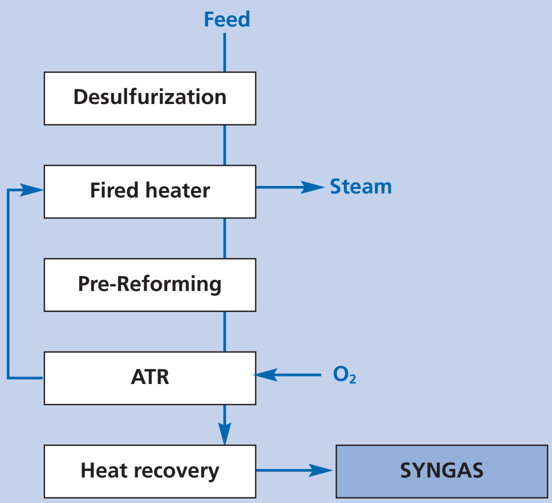
- Feedstock quality and upgrading,
- Plant capacity,
- Syngas quality, H_2/CO ratio closest to that required to minimize separation for syngas generation and to avoid by-products, for example,
- Syngas conditioning, most suitable recovery technologies e.g. regarding H_2 and CO,
- Integration with other processes at battery limit, minimizing the need for product gas compressing, for example,
- Effluent and emission constraints,
- Investment and production cost.

Common features and different series of process sections for syngas generation by steam reforming, autothermal reforming and combined reforming are illustrated in the following diagrams. A separate chapter deals with partial oxidation, i.e. Lurgi Multi Purpose Gasification (MPG)® technology.

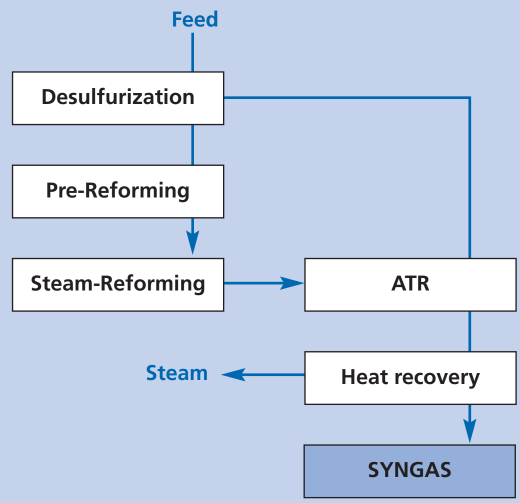
Steam Reforming



Autothermal Reforming (ATR)



Combined Reforming



Generally, the feedstock contains impurities such as sulfur compounds to be removed because they would lead to downstream catalyst deactivation.
Sophisticated heat recovery is also common to all reforming processes.

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Lurgi

Reforming

Steam Reforming

When using natural gas with elevated concentrations of heavier hydrocarbons or naphtha as feedstock, pretreatment in a pre-reformer is recommended for operational and economic reasons. The hydrocarbon feed is catalytically converted by adiabatic steam reforming to a mixture of H_2, CO, CO_2, CH_4 and H_2O in the pre-reformer. This is the first stage of the steam reforming process.
The second stage consists of the fired tubular steam reformer where methane conversion occurs by means of an endothermic catalytic reaction with steam. It provides a mixture of H_2, CO, and H_2O with minor fractions of CO_2 and non-reacted CH_4.

Typically, H_2/CO ratios between 3 and 5 are achieved, depending on feedstock, CO_2 recycle and operating conditions. An increase in temperature, decrease in pressure and reduction of the ratio defined as steam per carbon in the feed will lower the H_2/CO ratio.

The standard process route of hydrogen plants comprises feed desulfurization, steam reforming, shift conversion and hydrogen purification by pressure swing adsorption (PSA).

The distinguishing features of Lurgi steam reforming are mainly based on the special design of the so-called top-fired Lurgi reformer®. Continuous developments and improvements refer to:

- Multiple feedstock range,
- Broad range of H_2/CO ratios,
- Maximum allowable operating temperature and pressure,
- Catalyst tube fixing and suspension,
- Gas inlet and outlet systems and header layout,
- Easy and safe long-term control of operation,
- Minimizing maintenance cost.

Autothermal Reforming – MegaSyn®

This technology combines partial oxidation and steam reforming in one single reactor. The heat of reaction required for endothermic methane conversion by steam reforming is supplied by partial oxidation of the hydrocarbon feedstock using oxygen or oxygen-enriched air in the upper section of the reactor.

The lower catalytic section of the reactor ensures the desired gas composition close to the equilibrium of the steam reforming reactions.

The essential advantages are:

- No demand for external heat supply,
- Conversion of various feed materials to product gas of suitable composition at H_2/CO ratios of 1.8 to 2.6 or even lower in the case of CO_2 recycle or CO_2 from separate feed streams,
- Operating pressure and temperature much higher than for steam reforming.

These features allow for huge single train capacities with one refractory-lined reactor, which is a vertical cylindrical vessel with a cone at the top. The cone provides the combustion zone and includes the burner also called mixer for feed gas/steam and oxidant at the reactor inlet.

Lurgi successfully meets the great challenge of the Autothermal Reforming technology essentially with respect to the following critical key elements:

- Refractory-lined reactor,
- Burner,
- Waste heat boiler at the reactor outlet.

Sound know-how of scale-up, experience and feedback from running plants are important prerequisites for designing, constructing and operating facilities with ultra-large capacities.

MegaSyn® developed by Lurgi comprises the corresponding reforming technologies. Lurgi Autothermal Reforming is always the core technology for MegaSyn® which is the right choice for generating large quantities of syngas for oxo-alcohols, carbon monoxide, ammonia or methanol or synfuel synthesis.

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Reforming

Advantages of our Technology

Combined Reforming

The Lurgi Combined Reforming technology is defined as a special combination of steam reforming and autothermal reforming as depicted in the diagram.
This combination is not a simple sequence of process steps. The patented feed bypass of the steam reformer characterizes the Lurgi Combined Reforming resulting in main advantages such as:

- Adjustment of reformed gas composition by:
  - Bypassing a feed gas branch stream directly to the autothermal reactor,
  - Selection of the tubular reformer outlet temperature.
- Lower steam reformer operational temperatures allowing for higher pressure than in straight steam reforming.

The Lurgi Combined Reforming technology is suitable for a wide range of light hydrocarbon feedstock and produces reformed gas at H_2/CO ratios of 2.5 to 4 based on methane feedstock. Heavier hydrocarbon feedstock up to naphtha will result in ratios as low as about 1.3.

As less than half of the feed gas is routed through the steam reformer, the overall process steam requirements for the production of methanol or syngas for synfuels are also roughly halved compared to other process routes using steam and autothermal reforming in direct series without such a bypass.

Lurgi / BASF Pre-reforming – Benefits

- Standard shaft reactor,
- Extremely active catalyst at low operating temperature
- Low steam/carbon ratio,
- Pre-reformed gas,
- Approximation to the perfect equilibrium,
- No higher hydrocarbons,
- Heating up to high temperatures without negative impact,
- No potassium-doped catalyst in the downstream reformer required

Thanks to pre-reforming it is possible to feed higher hydrocarbons such as naphtha.
The integration with downstream steam or autothermal reforming leads to substantial improvements in economics.

Reforming

Lurgi Steam Reforming

Process Highlights	Advantages	Major Effects
▪ Top-fired reformer design	▪ Large single train capacity feasible, up to 1000 catalyst tubes	▪ Significant reduction of specific investment cost compared to other designs
▪ Unique patented metal dusting resistant design	▪ Multiple feedstock range, proven for H_2/CO ratios from 0.9 to 6.5 mol per mol	▪ Reduction of investment and operating cost
▪ Reformed gas leaving steam reformer at pressures up to 40 bar	▪ Favorable for downstream demand of high pressure gases, syngas for synthesis e.g.	▪ Reduction of operating cost and investment for downstream processes
▪ High performance reforming at temperatures of up to 950 °C	▪ Minimizing methane slip e.g.	▪ Approach to product gas specification
▪ Catalyst tube suspension system	▪ Perfect straightening of the refomer tubes ▪ Compensation of vertical and horizontal thermal expansion	▪ Completely maintenancefree, Reduction of operating cost
▪ Insulation inserts at top portion of catalyst tubes	▪ Preventing a hazardous atmosphere in the reformer penthouse	▪ Improving operational safety
▪ Outlet header sizing and application of incoloy liner	▪ Access to header for inspection	▪ Reduction of maintenance cost
▪ On-line isolation of defective catalyst tubes	▪ No need for complete shut down of the plant in case of defective tubes	▪ Improves the plant availability
▪ Feed preheating up to 650 °C	▪ Reduction of reformer size, less fuel consumption	▪ Reduction of fixed and variable cost
▪ Fully automatic control concept for smooth operation and quick load change	▪ Load control features: Plant turn down ratiofully automatic within 30 – 100%, load change at 3% of nominal capacity per minute, minimum steam to carbon ratio ensured ▪ Firing control features: Peaks in PSA tail gas flow and composition compensated by fuel gas, stable reformed gas temperature ensured, minimum oxygen content in flue gas ensured	▪ Simple and safe operation

Reforming

Lurgi Autothermal Reforming - MegaSyn®

Process Highlights	Advantages	Major Effects
▪ Autothermal reforming design, construction	▪ Huge single train capacity, ▪ No external heat supply compared to steam reforming systems, ▪ High process pressure and temperature ▪ Simplicity of the process unit and equipment	▪ Significant reduction of investment and production cost compared to steam reforming ▪ Low maintenance cost
▪ Autothermal reforming operation	High flexibility in: ▪ Feedstock selection ▪ H_2/CO ratio ▪ Operation at very high pressure / temperature, ▪ Low steam to carbon ratio, ▪ Low methane slip at high pressure ▪ Low H_2/CO ratios of product gas, ▪ Rapid start-up and load changes, ▪ Lowest possible CO_2 emission	▪ Excellent adjustment for various product gas qualities derived from different feedstock ▪ Environmentally friendly operation
▪ Sophisticated burner design, construction	▪ Long-term operation and reliability based on detailed computer models and operational feedback	▪ High on – steam factor
▪ Waste heat boiler improvements	▪ Minimum fouling caused by suitable refractory lining selected upstream, ▪ Proper design of the boiler inlet zone coping with extremely high temperatures, ▪ Excellent temperature control	▪ Long-term operation

Reforming

Lurgi Combined Reforming

Process Highlights	Advantages	Major Effects
■ Patented feed bypass of the steam reformer	■ Optimum adjustment of reformed gas composition via patented bypass independent of feedstock ■ Lower steam reformer operational temperatures allowing for higher pressure than in straight steam reforming. ■ Nearly 50% lower steam consumption compared to standard two step reforming in series, ■ Reduced energy requirements	■ Handling of various types of feedstock, ■ Significant reduction of steam reformer size, ■ Lower capital investment ■ Reduction of operating cost

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