

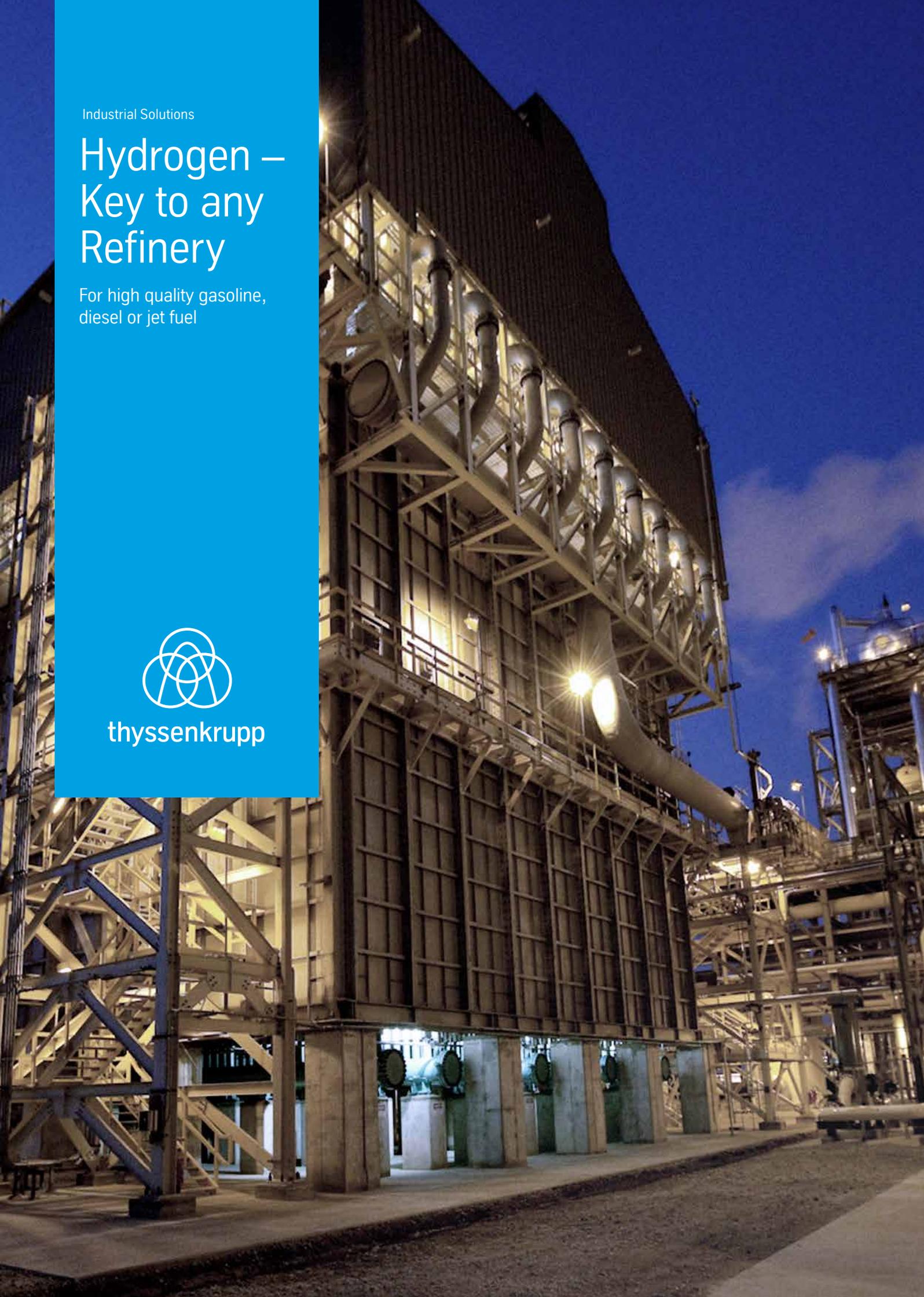
Industrial Solutions

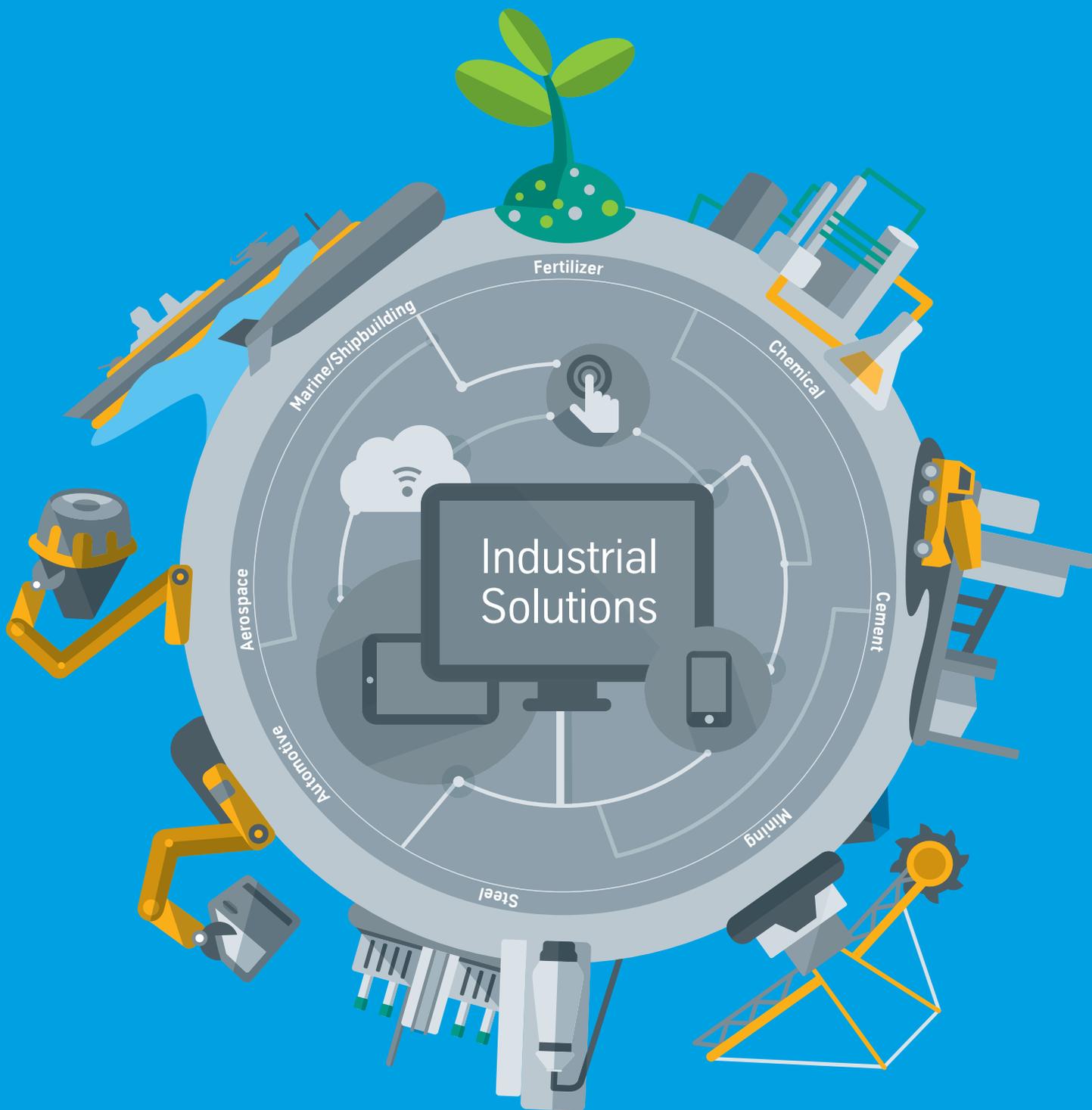
Hydrogen – Key to any Refinery

For high quality gasoline,
diesel or jet fuel



thyssenkrupp





The power of true efficiency

The Business Area Industrial Solutions of thyssenkrupp is a world leader for planning, construction and service in the field of industrial plants and systems. Together with our customers we develop solutions at the highest level and deliver efficiency, reliability and sustainability throughout the entire life cycle. Our global network, with around 19,000 employees at 70 locations, enables us to provide turnkey solutions worldwide which set new benchmarks with their high productivity and particularly resource conserving technologies.

We are at home in many different industries. Along with chemical, fertilizer, coking, refinery, cement and other industrial plants, our portfolio also includes equipment for open-cast mining, ore processing and transshipment, as well as associated services. In the naval sector, we are a leading global system supplier for submarines and surface vessels. As an important system partner to our customers in the automotive, aerospace and battery industries, we optimize the value chain and improve performance.

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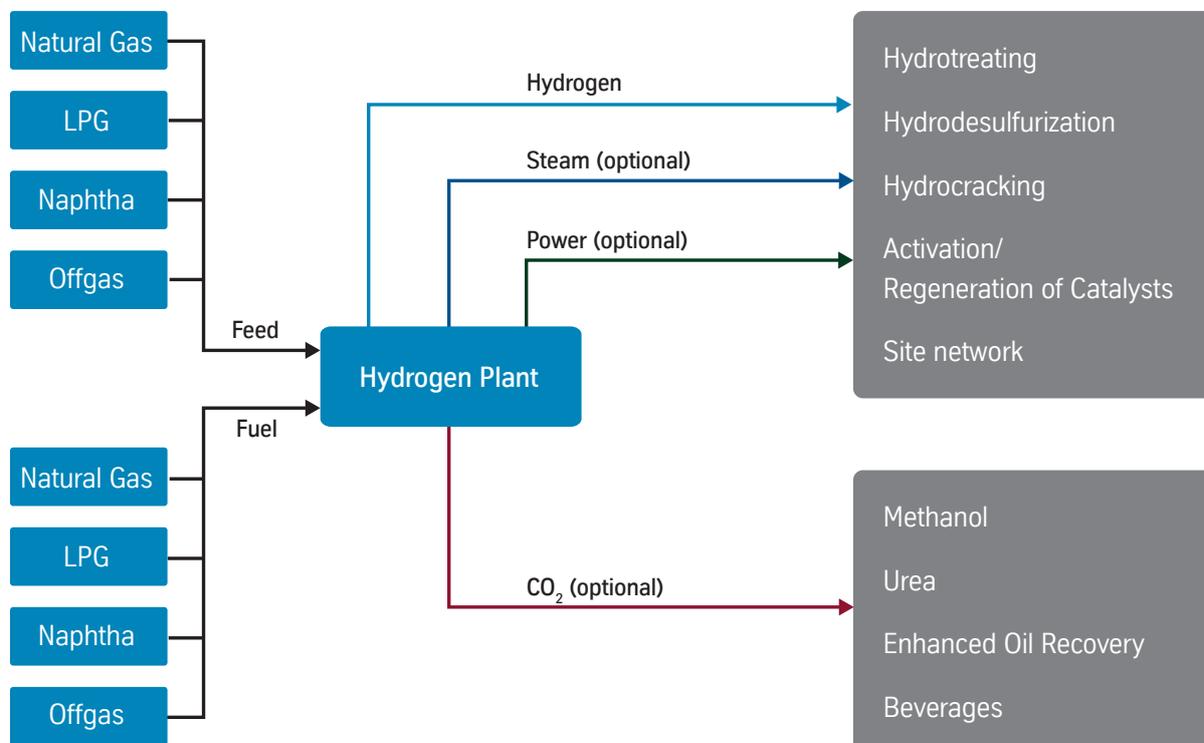
Introduction

There is a growing demand for cleaner, lighter fuel products at a time when oil resources (feedstocks) are becoming heavier. This has created a huge demand for hydrogen worldwide and thus the need to increase hydrogen capacities.

There are various feedstocks which can be used for hydrogen production, including products which are not particularly attractive, such as heavy residue or coke. However, the most efficient option for hydrogen production is steam reforming of hydrocarbons at a low energy consumption.



At a glance the advantages of Uhde's Hydrogen Technology



thyssenkrupp Industrial Solutions (formerly known as thyssenkrupp Uhde) has been building reformers since 1962. Over this period of more than 50 years, thyssenkrupp Industrial Solutions has continuously improved the design of the steam reformer to achieve high efficiency and reliability, optimised Capex and Opex-values, low emissions and excellent manufacturing quality.

- top-fired design with a minimum number of state-of-the-art burners (low NO_x guaranteed) and maximum tube wall cooling where heat flux is high
- modularised concept for easy transportation and more economical construction
- reformer box design that assures easy access and requires minimum plot space
- proven long lifetimes for the reformer tubes
- unique proprietary cold outlet manifold system with shop testing of all critical welds for maximum reliability
- advanced modularised shop-tested convective zone

A variety of benefits, including lower capital investment and operating costs, reduced energy consumption, maintenance costs and emissions, increased efficiency and on-stream time, and improved safety and reliability have been created by successfully combining the following features:

- proven process gas cooler design with steam-cooled internal by-pass flap
- in-situ recovery of process condensate, thus avoiding it being exported to battery limits and preventing emissions of VOCs to the atmosphere
- no contamination of boiler feedwater or export steam from process side through separation of process/export steam via environmentally clean bi-sectional steam system
- high reliability and maximum availability due to validated simulation tools
- maximum automation to minimise labour requirements and facilitate operation.

The Uhde Hydrogen Concept

Availability and reliability

On-stream time higher than 99.5% (10-year average)

Continuous operation of up to six years in accordance with turnaround cycles



Neste Oil Oyj, Porvoo, Finland
Capacity: 153,500 Nm³/h of hydrogen

The Uhde process

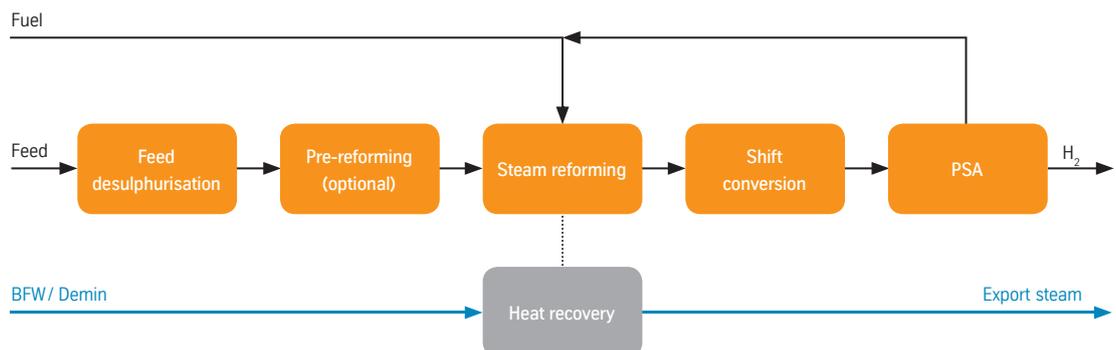
Our process for producing hydrogen from light hydrocarbons involves the following process steps:

- feed desulphurisation
- pre-reforming (optional)
- steam reforming
- shift conversion
- synthesis gas purification (PSA)
- heat recovery and steam production.

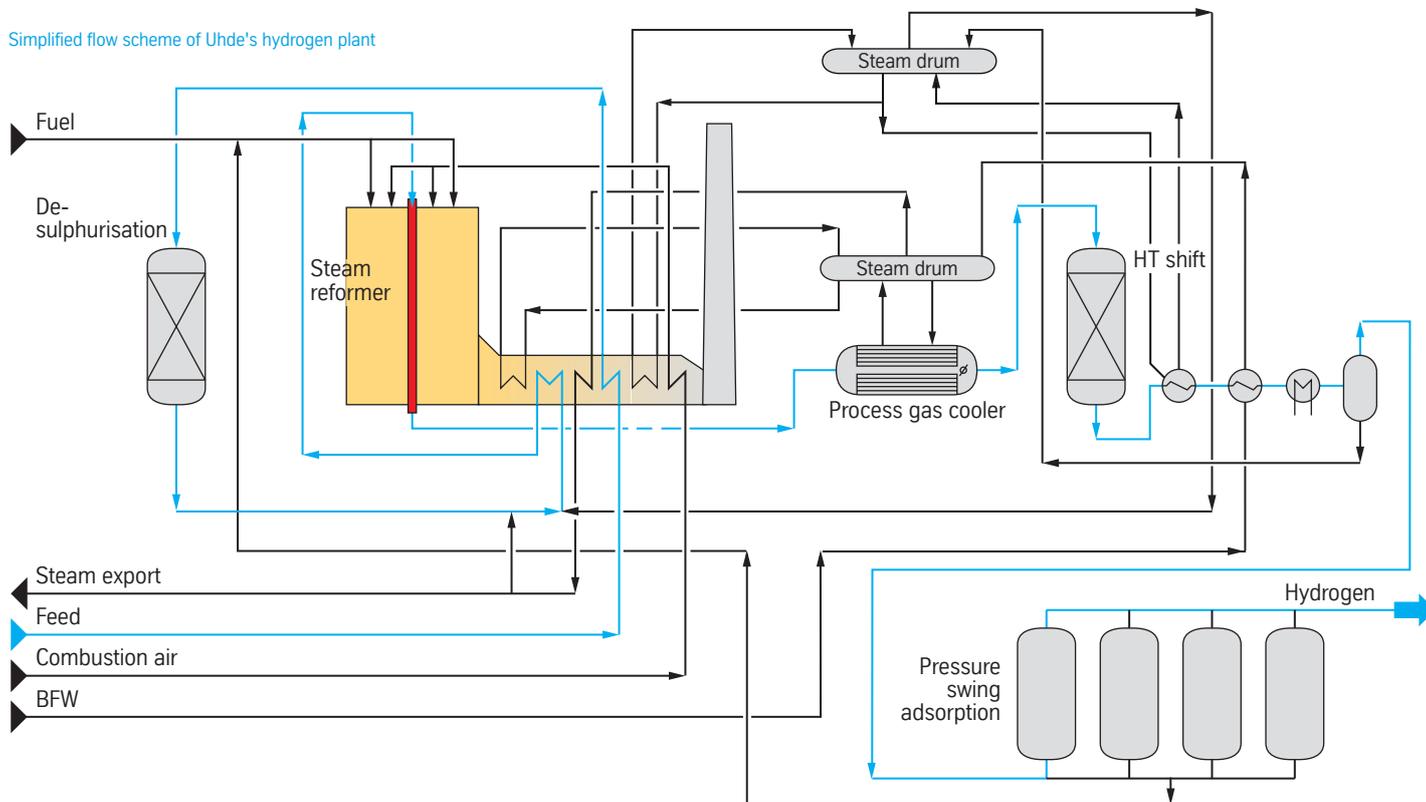
Each plant concept is tailored to the specific needs of our clients.

Additional process steps, such as CO₂ removal can also be included.

Simplified flowscheme:



Simplified flow scheme of Uhde's hydrogen plant



Feed preparation

thyssenkrupp Industrial Solutions offers flexibility in the feedstocks and fuels which can be used. These include natural gas, naphtha, LPG and/or offgases.

Feed gas desulphurisation

Feed gas desulphurisation is normally carried out in two steps:

- hydrogenation of organic sulphur compounds into H_2S
- absorption of H_2S on zinc oxide

Due to the lead and lag configuration of the two desulphurisation reactors, the absorbent in one reactor can be replaced while the plant is running at full capacity.

Pre-reforming (optional)

The principle of the pre-reformer involves the partial conversion of hydrocarbons in

an adiabatic reactor located upstream of the steam reformer. The reactor is filled with Ni-based catalyst and operates at temperatures between 450-540 °C.

All heavy hydrocarbons are converted to methane and carbon oxides in the pre-reformer. This allows optimum process parameters to be selected in the steam reformer, especially in naphtha and LPG-based plants, which would otherwise not be possible.

Integration of the pre-reformer in the overall process achieves the following:

- lower overall feed and fuel consumption
- alternate feed operation (from natural gas to naphtha/LPG) possible
- reduced reformer size
- lower emissions (flue gas)
- lower steam export
- higher reformer inlet temperature possible.

The Uhde Hydrogen Concept

The Uhde reformer

Uniform temperature profile over the entire reformer

Uniform tube wall temperatures

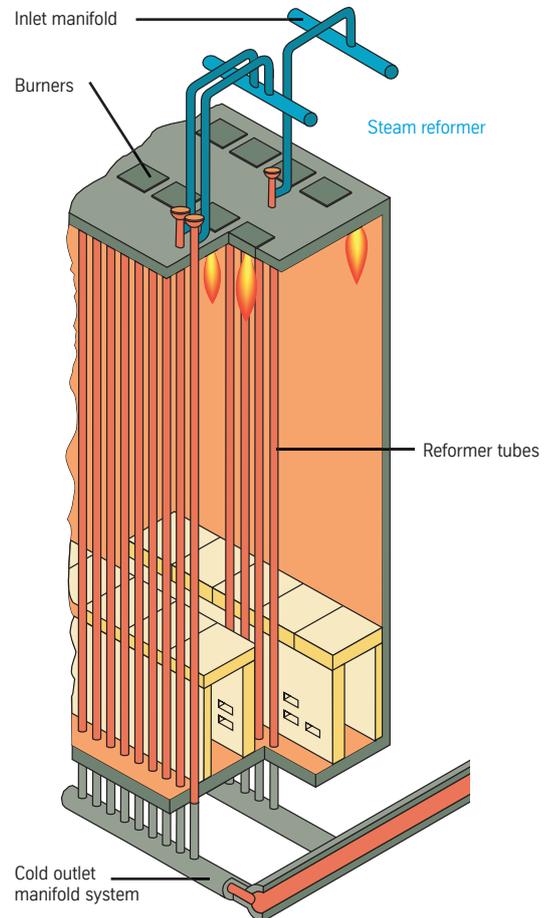
Lowest number of burners amongst all types of reformer designs

Micro-alloy tube material

Steam reforming

During steam reforming hydrocarbons react with steam to produce mixtures of hydrogen and carbon oxides. The reaction takes place in reformer tubes of the box-type steam reformer. These tubes are centrifugally cast from micro-alloy material and are filled with a Ni-based catalyst. Since the overall reaction is strongly endothermic, external heat is required. The heat for the overall endothermic reaction is supplied by burners which are positioned at the top of the steam reformer, thus ensuring optimum uniformity of the skin temperature profile along the reformer tubes.

The basic principle of steam reforming is represented by the hydrocarbon conversion reaction (eq. 1) and the water-gas shift reaction (eq. 2).



Bayernoil
Neustadt/Donau, Germany





Cold outlet manifold system

The reformed gas from the steam reformer is collected in a refractory-lined manifold. The cold manifold system conveys the steam reformer effluent to the process gas cooler.

In Uhde's cold outlet manifold system the number of critical elements has been reduced to the minimum as hot pigtails and hot manifolds have been eliminated. The skin temperature of the manifold system drops rapidly to below 250°C.

Cold outlet manifold system

Unique patented design

Many decades of experience with trouble-free and highly reliable operation

No outlet pigtails necessary

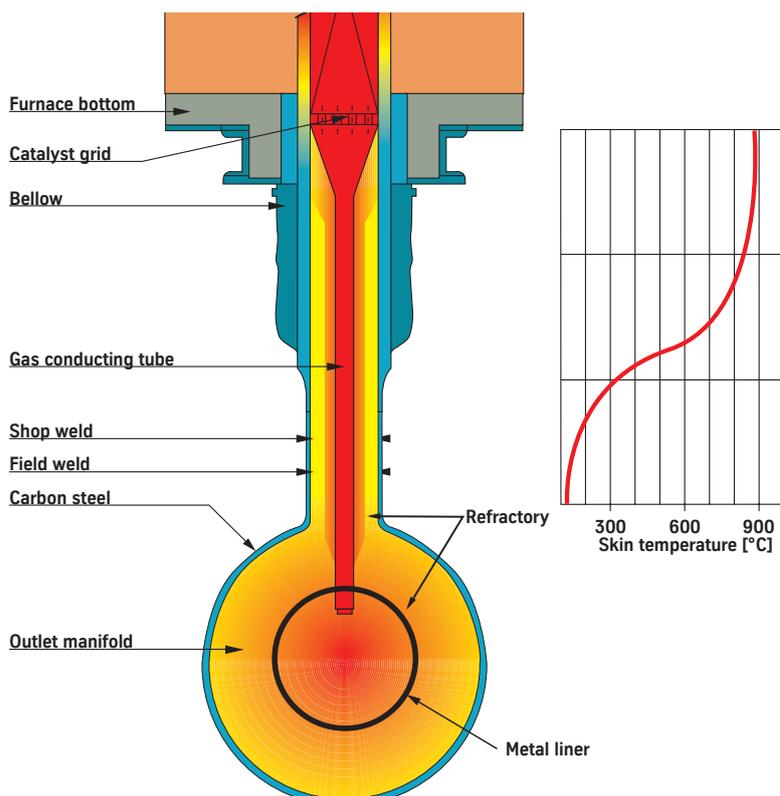
Separates high pressure from hot temperatures

All critical welds shop-made and fully tested

Only carbon steel welding required at site

Long lifetime

Cold outlet manifold system



The Uhde Hydrogen Concept

Convection bank design

Optimised accessibility

Modularised and
pre-fabricated

Minimised construction costs

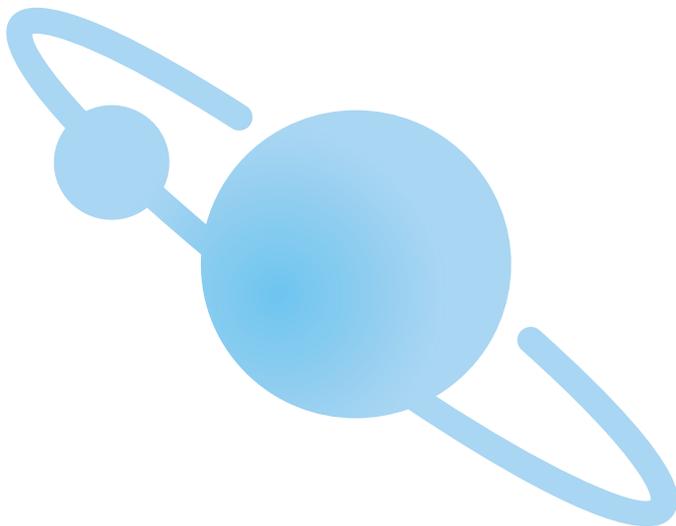


Convection bank design

The flue gases flow from the bottom of the reformer radiant box through flue gas tunnels located between the rows of tubes to the reformer convection section. These gases have a temperature of approximately 1000-1050°C.

The heat is utilised for evaporating process condensate, superheating steam and preheating combustion air and feed/steam mixtures.

The flue gas exits the system via the flue gas fan at temperatures selected to prevent potential condensate formation of the flue gas and subsequent corrosion of the flue gas duct and/or equipment.





Process gas cooler

Internal bypass with steam-cooled damper blades for temperature control

Metallic or ceramic tube inlet ferrules to limit heat flux

Double-layer refractory lining of inlet chamber and, if necessary, of outlet chamber with high-duty bricks on hot surface

Completely prefabricated

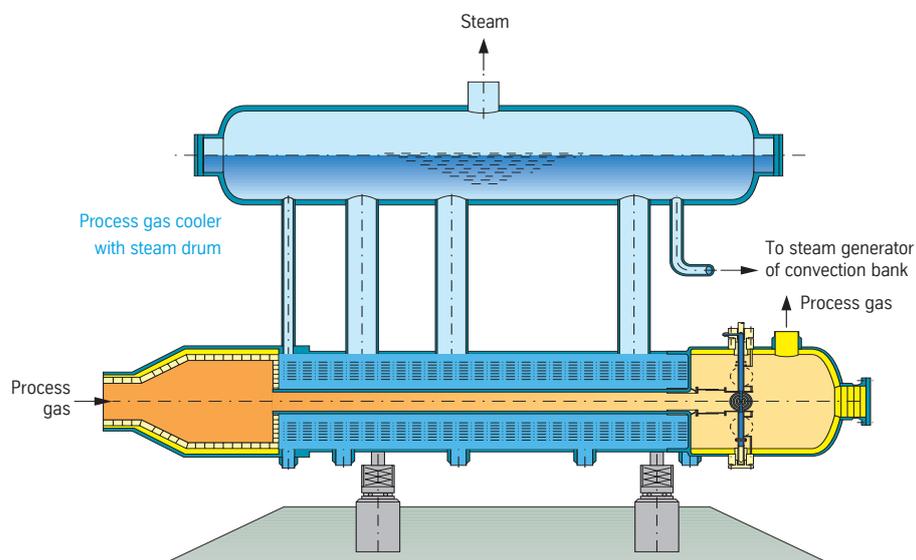
Process gas cooler

The process gas cooler is a horizontal fire-tube boiler generating steam. It is designed for natural circulation and is connected to the steam drum by risers and down comers.

selection of materials and in-house thermal design are the basis for the high reliability and extremely long lifetime of our process gas coolers. Features of this design are:

Intensive research and development, strict design requirements for critical parts (such as ferrules and the bypass system), a proper

- flexible tube sheets
- full penetration tube-to-tube sheet welds
- safe natural water circulation



The Uhde Hydrogen Concept

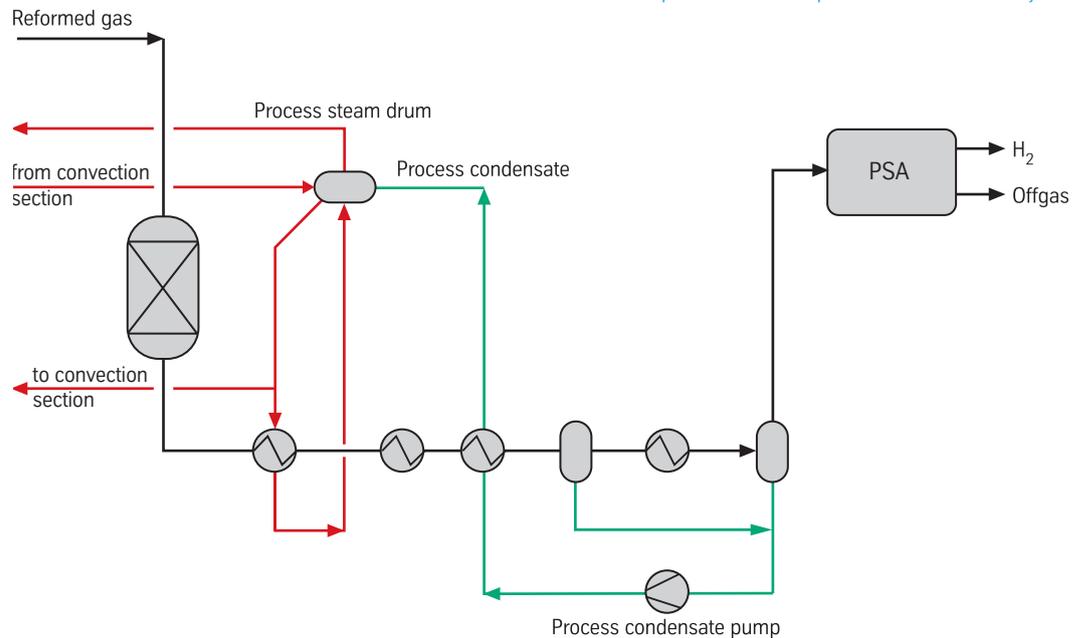
Process condensate recycle

Direct reuse of process condensate to generate process steam

No stripper required and therefore no emissions of VOC's

Clean export steam from demineralised water

Successful operation for more than two decades



Shift conversion

A higher conversion of CO (water-gas shift) to H_2 and CO_2 obviously reduces the feed demand and simultaneously reduces the calorific value of the fuel available from the pressure swing adsorption (PSA). This, in turn, means an increase in import fuel. The different options for the CO conversion are high-temperature (HT) shift, medium-temperature (MT) shift or a combination of high-temperature and low-temperature (LT) shift. All shift conversions are exothermic.

Adding an LT shift reactor achieves the following results:

- a reduction in feed and an increase in fuel, resulting in a marginal increase of combined 'feed & fuel'
- an increase in steam export
- a reduction in absorbed heat duty

Therefore in case of an expensive feed and a cheap fuel, the additional investment involved in supplementing the HT shift with an LT shift is justified. The above results can also be achieved by replacing the HT and LT shift with a MT shift.

Heat recovery and process condensate recycle

The Uhde design incorporates efficient heat recovery in the process gas cooling train and in the flue gas duct.

Part of the steam produced in the process gas cooler and flue gas duct is used as process steam and the balance is exported.

A special feature of the Uhde technology is that the process condensate obtained from unconverted surplus steam is directly utilised to generate part of the process steam.

This is done by collecting the condensate in the cooling train downstream of the shift converter, then preheating and evaporating it.

The steam produced is used exclusively as process steam. This totally eliminates the need to return process condensate to a boiler feedwater treatment unit (e.g. stripper) and reduces the amount of volatile organic components (VOCs).

Synthesis gas purification

Pressure swing adsorption (PSA) is a well-established purification step used to obtain high-purity hydrogen (99.9% and higher). It uses an adsorption system where gaseous impurities such as CO, CO_2 and CH_4 are adsorbed at high pressure and desorbed at low pressure. The PSA unit is supplied as a package unit.



What we offer our customers



PDVSA Petrocedefo S.A., Jose Refinery, Venezuela
The two-train plant has a capacity of 196,000 Nm³/h H₂ and is integrated into a large crude oil upgrader complex.

Value improvement process (VIP) and Capex/Opex optimisation

We at thyssenkrupp Industrial Solutions place particular importance on collaborating with our customers at an early stage to combine their ambition with our experience in a special value improvement process. This results in tailor-made design solutions jointly worked out with our customers to achieve an optimum CAPEX/OPEX balance. For example, the modularisation of key components and completely prefabricated modules minimises site works and construction costs, maximises supply quality and ensures easy transportation. Moreover, the

- unit cost of feedstock
- unit cost of fuel
- steam export credit

are important factors which also need to be taken into account in process configuration and hence process optimisation considerations.

Health, safety and environment

In awareness of our environmental responsibility, Uhde hydrogen plants are designed for minimised environmental emissions.

Take, for example, the burners used in our reformers. We install only special down-firing forced-draught burners of well-proven design from the world's leading manufacturers. These ensure extremely stable and complete combustion, allow the proper mix-

ing of air and fuel even at higher excess air levels and have defined flame profiles over a wide range of fuels. The proper mixing of air and fuel, the recirculation of flue gas and air and fuel staging ensure low NO_x levels.

The complete in-situ reuse of process condensate also ensures that environmental emissions are minimised and uncontaminated HP steam can be exported. Therefore, no process condensate stripping is needed and there is no venting of dissolved gases to atmosphere.

Moreover, to ensure the safety of operating personnel, we offer special training programmes.

Research and development

In order to prepare thyssenkrupp Industrial Solutions for the future, we place great emphasis on research and development to further improve its technologies. Using in-house simulation tools to improve the existing technology and design. The accuracy of our simulations and process design are backed by the many reformers we have designed and built.

In recent years, catalysts and burner designs as well as heat and condensate recovery, amongst others, have all been improved.

thyssenkrupp Industrial Solutions' services

thyssenkrupp Industrial Solutions provides the entire spectrum of services associated with an EPC contractor, from the initial feasibility study and project management right up to the commissioning of units and grass-roots plants. Our large portfolio of services includes:

- feasibility studies/technology selection
- project management
- arranging financing schemes
- financial guidance based on an intimate knowledge of local laws, regulations and tax procedures
- environmental studies
- basic/detail engineering
- utilities/offsites/infrastructure
- procurement/inspection/transportation services
- construction work
- commissioning
- training of operating personnel
- plant operation/maintenance.

At thyssenkrupp Industrial Solutions we are dedicated to support the success of our customers in their line of business and to provide them with a wide range of services to ensure sustainable investments.

With this in mind we like to cultivate our business relationships and our after-sales service includes regular consultancy visits which

keep the owner informed about the latest developments or revamping possibilities.

Low maintenance requirements

There are no components in an Uhde steam reformer that have to be replaced or that need metallurgical checks on a frequent basis, e.g. hot pigtails or hot manifolds. The following design features based on years of experience have reduced the amount of maintenance work required to a minimum:

- less burners compared to side-fired reformers
- box-type design with flat walls that reduce the number of critical areas with regard to the refractory lining
- one reformer box only, even for large capacities
- maintenance-free tube and inlet suspension system
- pigtails designed for full flexibility
- cold outlet manifold system.

There is no other design which has successfully combined long life, simplicity, maintainability, operability, safety, reliability, and cost effectiveness.

Training programmes

As part of our services, thyssenkrupp Industrial Solutions also offers training programmes to enhance the skills of the plant operating crew.

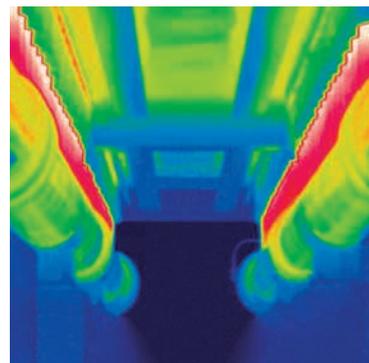
The policy of the thyssenkrupp Industrial Solutions group and its affiliates is to ensure utmost quality in the implementation of our projects. Our head office and affiliates worldwide work to the same quality standard, certified according to DIN/ISO9001/EN29001.

Uhde hydrogen technology stands for tailor-made concepts and international competence. For more information contact one of the thyssenkrupp Industrial Solutions offices near you or visit:

www.thyssenkrupp-industrial-solutions.com



Infracor Oxeno,
Marl, Germany



Reality meets design: Thermal
image of an outlet manifold system



Koch-Glitsch A.S.,
Novopolotsk, Belarus
Capacity: 39,000 Nm³/h H₂

Industrial Solutions
Fertilizer and Syngas Technologies

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