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Reliability and Availability –
Integrated hydrogen production schemes for refineries

by

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Abstract

Today's hydrogen plants become more and more integrated into refineries. On one side they create value to the refiner while making use of refinery off gases (ROG) for hydrogen production as feedstock and/or as reformer fuel (depending on its composition and characteristics, ROG can be fed at different locations to the hydrogen plant).

On the other hand the hydrogen plant is an efficient producer of export steam which can be obtained at various levels up to 125 bar (HHP steam). Such steam can be integrated into a refinery steam system, e.g. for power generation or other turbine drives and/or heating purposes and/or replace, amongst other things, auxiliary boilers or other less efficient steam producers.

The article describes various hydrogen plant flow sheets which Uhde has designed recently and covers specific refinery integration models. All designs have been based on individual CAPEX/OPEX optimisations jointly with the customer while paying specific attention to plant availability and reliability.

The Uhde hydrogen concept with its integrated recycle of process condensate and its optional bi-sectional steam system offers optimum integration potential for refineries with minimised impact on the refinery side.

Principals of the hydrogen concept

The Uhde hydrogen concept was established in the early sixties, is successfully proven and undergoes continuous improvement and development processes. The heart of the plant is the top-fired Uhde steam reformer. The Uhde concept features the flexibility to process various feedstocks and to use fuels from various sources.

All Uhde designed plants are tailored to meet customer specific needs and are optimised between capital expenditures (CAPEX) and operating expenditures (OPEX). Uhde can offer supplementary maintenance and service concepts to ensure sustainable investments.

Major customers are large oil companies and operators of upgraders, but steam reformers are also applied to produce syngas by, for example, ammonia and methanol producing customers.

For all customers, reliability and availabilty are key decision parameters and contribute to the user's final satisfaction with the plant. A hydrogen plant is a workhorse with, in most cases, a refinery downstream, and that is where the Uhde hydrogen plant achieves its most competitive performance.

Uhde hydrogen plants achieve on-stream times greater than 99.5 % based on a 10 year average. Some of Uhde's customers have already achieved an availability of 99.8 % during the first year of plant operation. Modern designs allow for an operation of up to five years without catalyst exchange.

In order to achieve these goals, Uhde applies certain key design principles. Such designs must be straight and simple for easy and reliable operation. This is demonstrated in Figure 1 which presents a typical block flow diagram of an Uhde hydrogen plant.

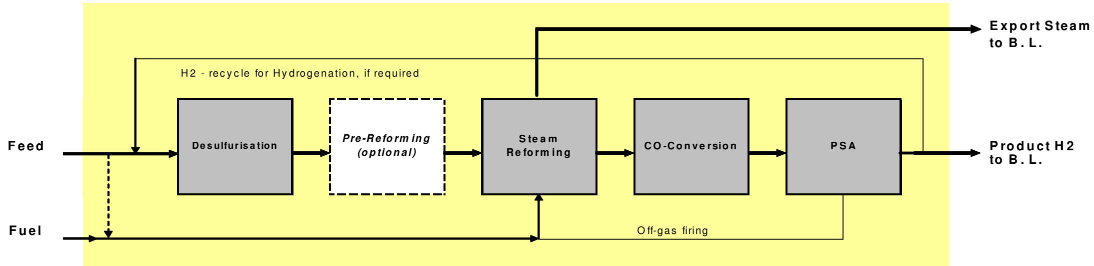

Figure 1: Typical block flow diagram of an Uhde hydrogen plant

The heart of the hydrogen plant is the reforming section with the Uhde reformer, which features various specific advantages. Uhde employs a top-fired radiant section with low NOx burners to minimise environmental emissions. The radiant section is designed using an integrated simulation approach, modelling simultaneously the firing side and the reaction side to ensure a uniform temperature distribution within the entire reformer box.

The hot reaction gases from the various reformer tubes are collected in a so-called cold outlet manifold system and routed to the Uhde designed well-proven hi-flux process gas cooler which offers the option of producing steam up to 125 barg.

The flue gases are routed via tunnels into a modularised convection section which saves significant construction time and cost.

The Uhde standard design features full process condensate recycle to minimise VOC emissions and to allow production of process contaminant free export steam.

Additional plant units such as LPG and/or naphtha evaporation, natural gas or ROG compression, as required, may complement a plant. Uhde can offer either their own design standards or customer's standards or use a 'best of'-combination.

Refinery integrated hydrogen production schemes

A high integration level of the hydrogen plant into a refinery system is demonstrated by using refinery off-gases as fuel and/or feedstock and/or while integrating the steam systems. However, both require thorough investigation and consideration of all relevant aspects which may affect plants' reliability and availabiltiy decided, however, on a CAPE/OPEX basis being customer's key parameters.

Figure 2 presents the principal options for the integration of refinery off-gases into a hydrogen plant:

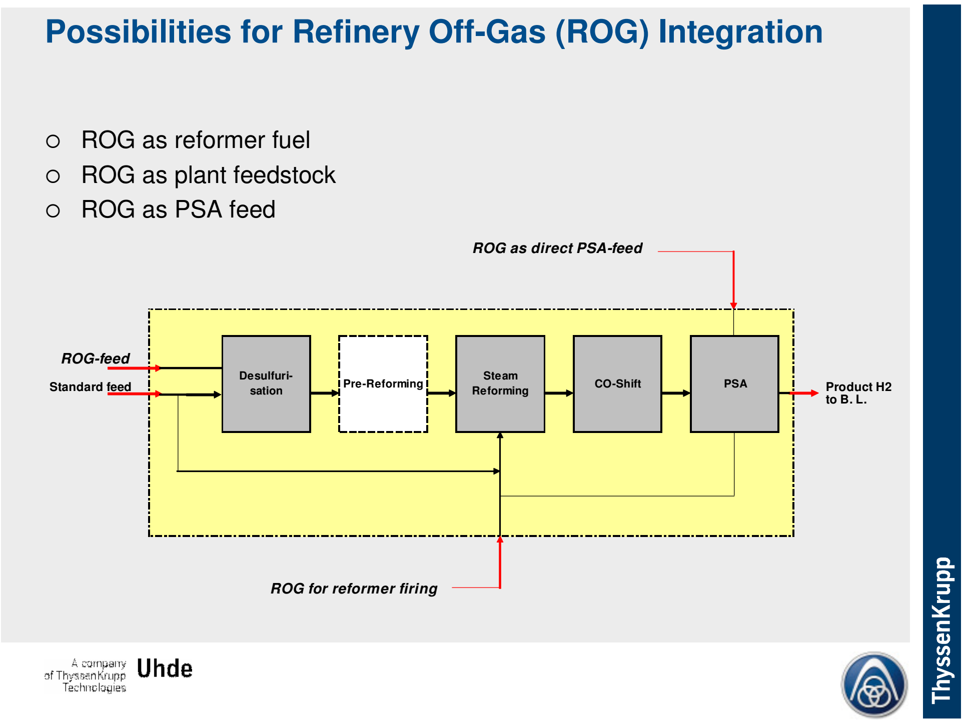

Figure 2: Possibilities for refinery off-gas (ROG) integration

The selection of the appropriate location for the integration of refinery off-gases into a hydrogen plant depends mainly on its pressure, hydrogen content and potential impurities which are not acceptable to either the catalysts or to the PSA adsorbents. Specific considerations have been published previously[1)].

As well as the integration of the refinery off-gas side, a hydrogen plant is also a highly efficient steam producer that can be linked to the steam system of a refinery.

Here, topics are steam pressure, levels and internal recycle of process condensate. Importance is to de-couple the process steam system from the export steam system, to re-use process condensate, keep by-products in the process, minimise VOC emissions and produce clean export steam to protect downstream equipment such as steam turbines.

Uhde first implemented such a system which in the meantime has been adopted by most of the key competitors.

Design examples

In the past Uhde has realised various projects which feature high integration levels in a refinery as described above. Several plant designs are presented below.

The OXENO plant in Marl, Germany, is designed for standard natural gas feed. It has been retrofitted with a pre-reformer to increase hydrogen production.

Furthermore, the OXENO plant features an alternative integration of 3 hydrogen containing off-gases upstream of the PSA. One off-gas stream maintains a minimum hydrogen supply in case of a reformer shut-down and the other two off-gases increase the hydrogen production by approx. 10% beyond the hydrogen which is generated in the reformer and the downstream CO-shift.

Of specific attention is the desulphurisation unit which uses a Süd-Chemie AG ActiSorb G1 as its hydrodesulphurisation catalyst. It combines hydrogenation of organic sulphur contained in the feedstock together with H_2S-adsorbtion. This allows operation without addition of DMDS while processing feeds with low sulphur content and a zero sulphur in feed risk. The application of ActiSorb G1 thus saves equipment (no hydrogenation reactor needed) and operating costs.

The plant is characterised by an excellent availability of greater than 99.5 % on a 10 years' average. The life-time of the actual pre-reformer catalyst loading is more than 5 years.

Figure 3 shows the principal arrangement of the plant and its key figures.

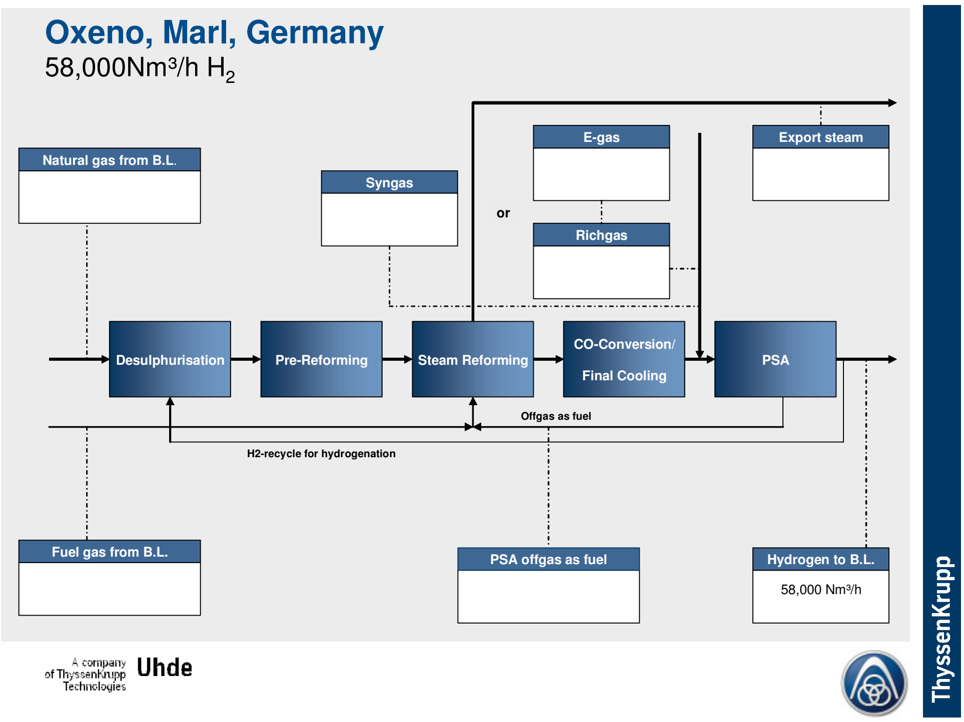

Figure 3: Block diagram of the OXENO plant

The Sincor plant, Venezuela, is one example of an Uhde built plant to ensure hydrogen supply to an upgrader complex. Located in Venezuela, it features the production of almost 200,000 Nm^3/h hydrogen in two identical trains with certain common facilities.

Uhde has built this plant under a lump-sum turn-key contract. Feedstock for hydrogen production is either natural gas or a mixture of natural gas and a hydrogen containing ROG. A second ROG is used as reformer fuel.

This plant was the first to be equipped with 14-bed PSAs which have been selected together with UOP and which became standard for following plants of this size.

Figure 4 presents the block flow diagram of the plant[2)].

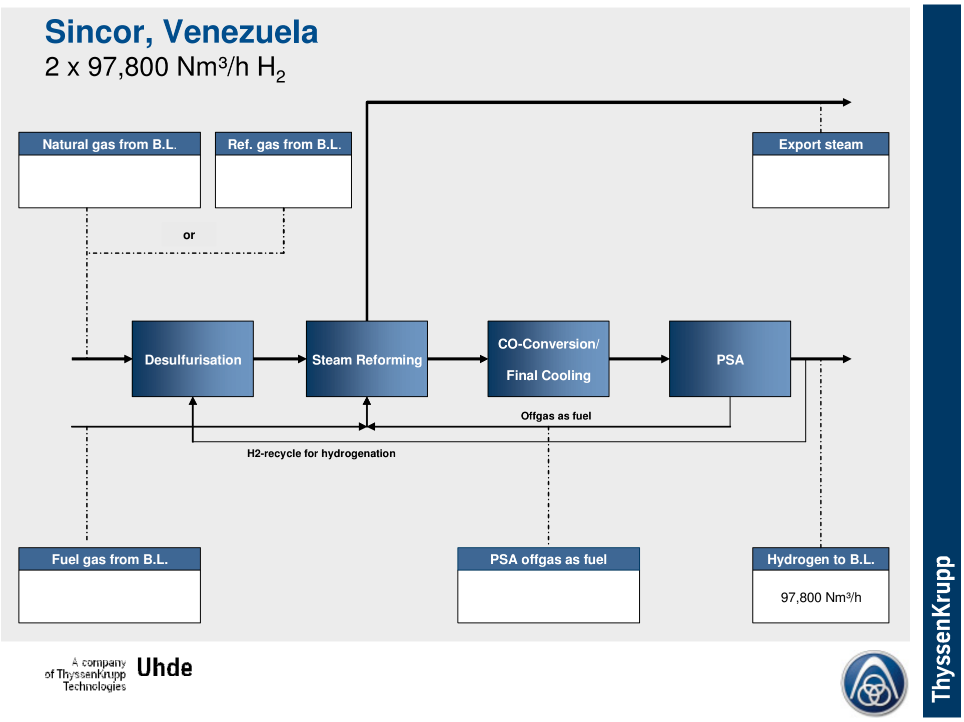

Figure 4: Block diagram of the Sincor plant

Another example of hydrogen supply to upgraders is a plant in Alberta, Canada, with two identical trains generating 260,000 Nm^3/h of hydrogen in total.

The plant processes natural gas in combination with two different off-gases as feedstock for hydrogen production. In addition, a third hydrogen containing off-gas is fed directly to the PSA.

Due to the extreme climatic conditions, the plant is winterised and features a Hudson heat pipe design for external combustion air preheating.

The set-up of the plant is shown in Figure 5.

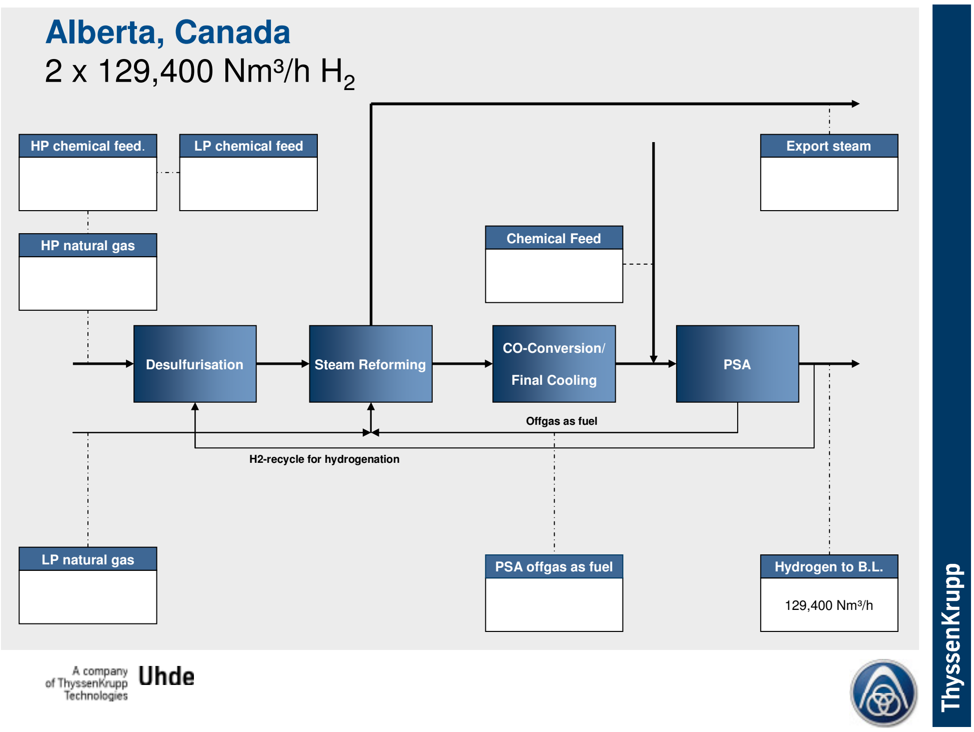

Figure 5: Block diagram of the Canadian plant

The CNOOC hydrogen plant comprises of two identical trains with a total hydrogen production of 220,000 Nm^3/h.

The plant can process either natural gas or a hydrogen containing off-gas or any combination thereof. It is equipped with a pre-reformer to condition the feed to the steam reformer and minimise its size.

The process gas cooler is designed for HHP steam production (102 barg/535 °C). The design is derived from Uhde ammonia plants, where HHP steam production is a common feature.

CNOOC has decided to equip the plant with a single PSA from a Chinese supplier. The principle arrangement of this plant is shown in Figure 6.

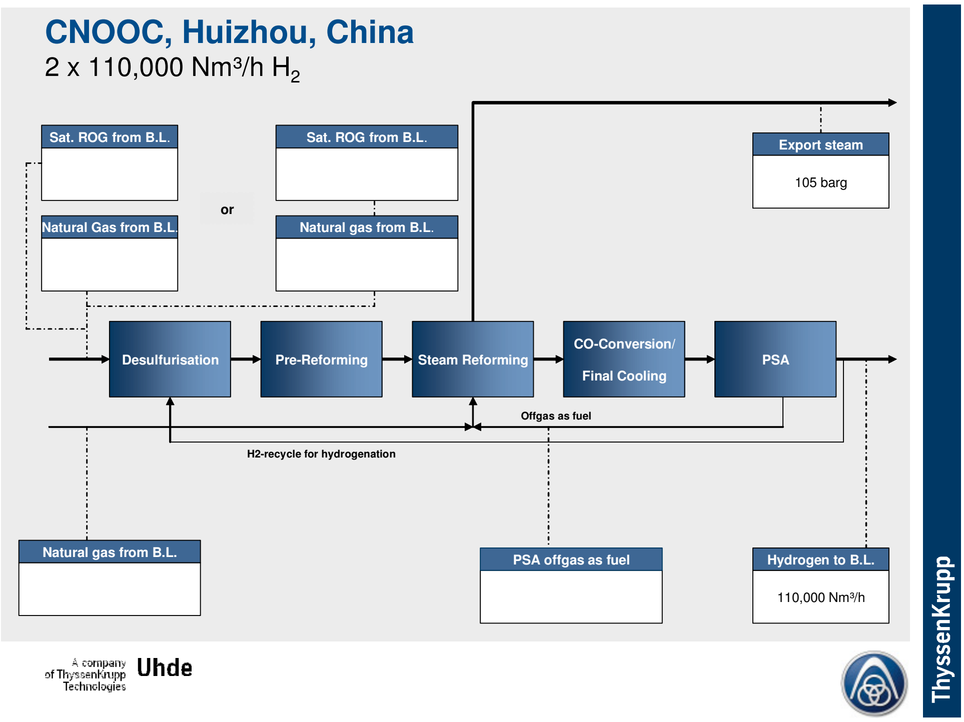

Figure 6: Block diagram of the CNOOC Huizhou plant

An example offering maximised feedstock flexibility is a plant which Uhde are currently realising for a customer in Italy. It features the use of natural gas and/or naphtha and/or LPG as feedstocks. A refinery off-gas is used as make-up reformer fuel. Furthermore, provisions are made to use a hydrogen containing off-gas as reformer feed in the future.

The naphtha evaporation and superheating is carried out with HP-steam. The plant is equipped with a prereformer to condition the feed to the steam reformer and to optimise its size. Uhde, together with the customer, has decided for a HT/LT shift concept to increase the hydrogen yield.

The plant set-up is detailed in Figure 7.

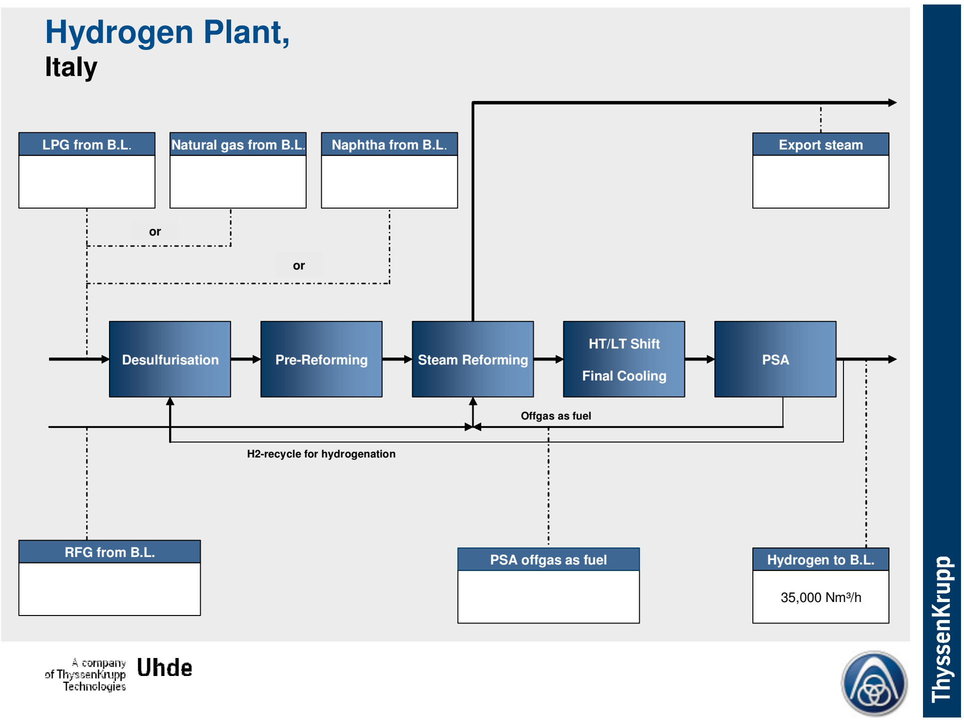

Figure 7: Block diagram of the Italian plant

The Neste Oil plant is, according to the information available to Uhde, the largest steam-reforming based hydrogen plant in Europe and one of the largest in the world. The reformer is equipped with 408 tubes.

It features processing of natural gas, LPG and ROG as feedstock for hydrogen production. Due to the cold climatic conditions, the plant design includes a glycol heating cycle. The plant was successfully started-up at the end of 2006.

In its basic layout, the plant generates 154,000 Nm^3/h hydrogen. It has built-in provisions and design features to install retrospectively a pre-reformer to increase hydrogen production to 178,000 Nm^3/h.

The plant design includes a further PSA for partial removal of CO_2 from the PSA off-gas. Such removal reduces CO_2 emissions from the hydrogen plant significantly. It is also a first step to a CO_2-free hydrogen production via steam reforming which is described later in the article[3)].

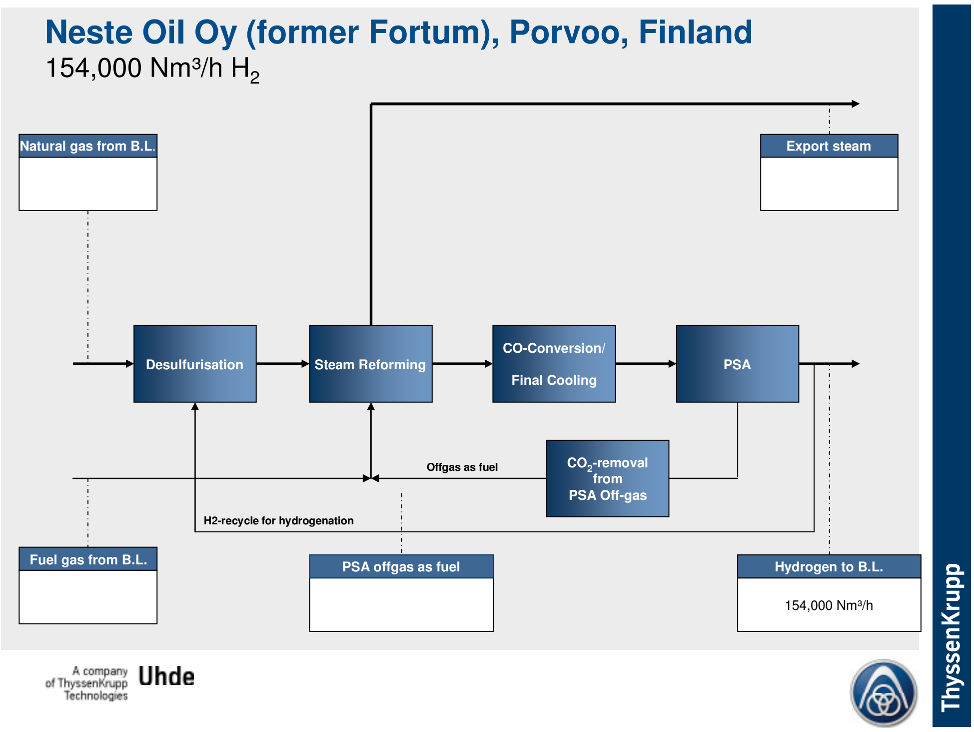

Figure 8: Block diagram of the Neste Oil plant

The Bayernoil plant is an example of a standard natural gas based hydrogen plant as part of Uhde's 100,000 Nm^3/h class. It features the production of 91,000 Nm^3/h hydrogen based on standard Russian natural gas and is a good example of a straight and reliable design.

As this feedstock has a zero to very low sulphur content, Uhde selected, jointly with the customer, a Süd-Chemie Actisorb G1 configuration on the desulphurisation side, as it has been successfully proven for the OXENO plant. In the meantime, this configuration has been selected as Uhde's standard for all European plants using this type of natural gas due to its cost advantage.

The export steam production is optimised in accordance with the refinery requirements. The principal set-up of this plant is further detailed in Figure 9.

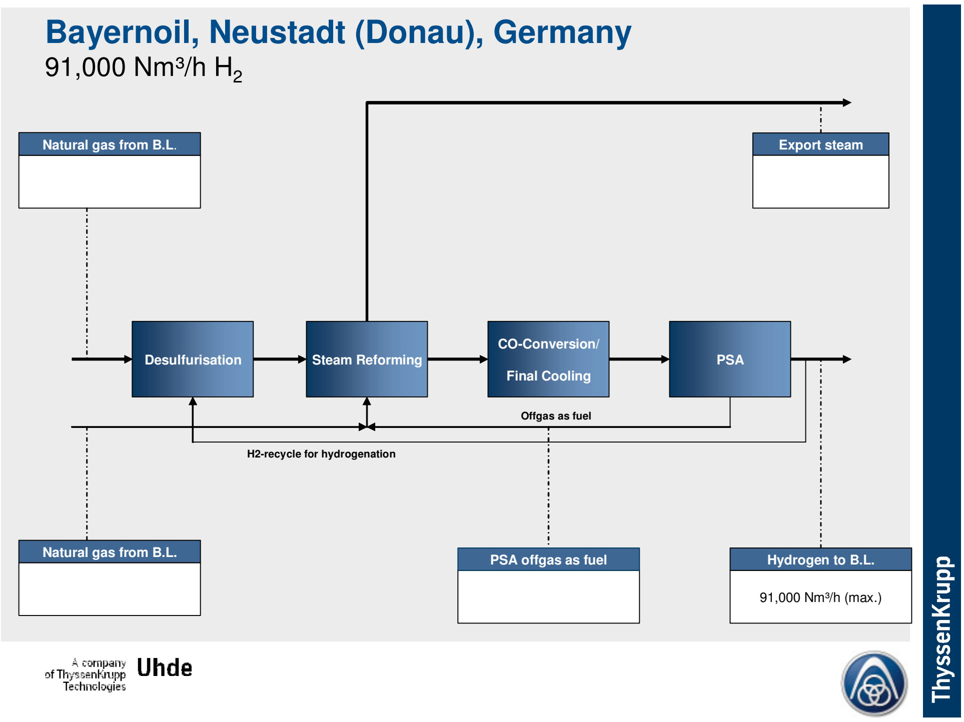

Figure 9: Block diagram of the Bayernoil plant

Potential future development

Uhde is essentially a technology driven engineering contractor. Therefore, Uhde technologies are under continuous development through internal value improvement projects, research and development programs and lessons learnt from realised projects. Although steam reforming is a well proven and mature technology, there is still improvement potential.

The reduction of heat loss to the atmosphere can be facilitated for example, by the further use of the latent heat contained in the reformed gas. Uhde has recently developed a respective system using the enthalpy of condensation in the first process condensate via direct heat exchange.

Such latent heat can be used for heating air and/or feedstock or to generate steam. It decreases heat loss via the aircooler and reduces its expensive surface by as much as 30%. Further, the process condensate preheater can be saved resulting in less pressure drop.

While using the latent heat, production costs of hydrogen can be further reduced by another 1-2 %, depending on feed and fuel costs and steam credit.

Respectively improved heat integration concept has been published and developed by Uhde's Dr. von Trotha, which further extends Uhde's positions as an innovative technology supplier.

With the Neste Oil plant, Uhde has realised the first step towards a CO_2-free hydrogen plant. In Finland, this has been achieved together with a third party having supplied the unit to remove CO_2 from the PSA off-gas, whereas Uhde has incorporated the respective impact into the core Hydrogen plant, in particular on the firing side. The drive to minimise or even completely cut out CO_2-emission from a steam reforming based hydrogen plant is now being further developed jointly with Uhde's customers.

In the context of this article, the respective patents of Messrs. Liu and Blumenfeld, Dr. Michel and Dr. Mielke should be mentioned. Initially announcing the idea in 2003, Uhde is again pioneering the development of advanced plant concepts and today's requirements regarding CO_2 emissions allow it to pursue and realise such concepts further.

Conclusion

The integration of hydrogen plants into the environment of refineries will improve their performance both economically and environmentally, provided that superior levels of plant reliability and availability are maintained. Uhde has all respective technologies and tools in place and has proven that such concepts can be realised successfully.

The experience that Uhde gained while implementing the plant concepts as described before have given Uhde a deep insight and understanding where and how to integrate ROGs into the overall plant concept and customer's related requirements while at the same time maintaining a long term trouble free plant operation.

The best results for the development of sustainable concepts have, however, been obtained whilst inviting all stakeholders to participate in a joint value improvement process through all project phases, thus optimising the plant on a CAPEX/OPEX basis to the project specific needs for which Uhde have the specific tools in place.

References

1) Larsen J., Radtke K., Ruthardt K., "Hydrogen Trends" Hydrocarbon Engineering, November 2005, pp. 41-46.

2) Michel M., Oil Gas European Magazine, February 2004

3) Peters C., "Flexibility is the key for plant design" Hydrocarbon Engineering, November 2004, pp. 27-30

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