Insert flexibility into your hydrogen network—Part 2

Fine-tuning utilities operation can conserve energy management and reduce operating costs

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The integration of energy markets has fiercely increased competition among refiners. Yes, final products sold from refineries include transportation fuels and petrochemical feedstocks and consumer products. However, other energy products such as electricity and steam have economic value for the refinery. In the current competitive economic environment, refiners are challenged to meet first tier economic goals as well as second tier goals gained from secondary products (hydrogen, steam and electricity) produced and consumed within the refinery.

Existing hydrogen and utilities units are a complex problem. Refiners must scrutinize how to retrofit or replace utilities operations to meet energy and hydrogen needs for individual facilities. New technologies are available that can optimize hydrogen and energy (steam and electricity) supplies and demand will be discussed.

Existing SMR plants—expansion options. Revamping and debottlenecking an existing hydrogen plant can be a cost-effective way of fulfilling incremental hydrogen needs. Increasing hydrogen production from 5% to 30% may be possible depending on the age, extent of previous debottlenecking work, utility availability, constraints of emission permits, and the flexibility of the refinery with respect to product hydrogen pressure, steam production and design margins. Some debottlenecking options available are:

Integration with refiner's steam system. Every refiner has unique steam requirements and should be aware of the impact that steam balance has on its total plant efficiency as well as capital investment. Beginning with a base SMR process cycle that results in "natural" steam make, Fig. 7 illustrates how the 50 Nm^3/h (45 MMscfd) SMR design can be changed to increase or decrease the export steam make. The base process cycle is the lowest in terms of capital expense. As the cycle is modified to either increase or decrease steam make, additional capital is required and results in

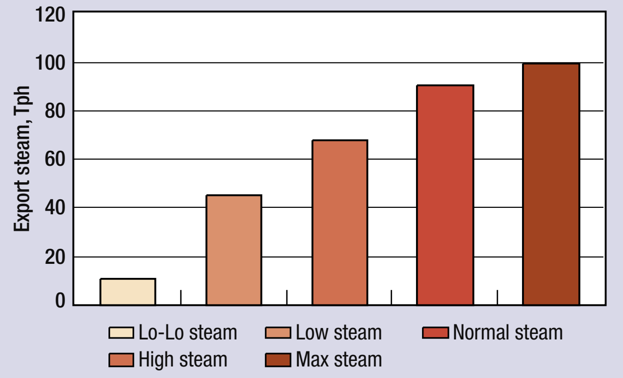

FIG. 7 Steam export flexibility.

TABLE 5. Steam reformer expansion options

Debottleneck option	Incremental hydrogen, %	Steam rate	Feedrate	Fuel rate	Capital cost	Issues
Increase reformer firing	7–10	Proportional, assuming adequate convection surface	Proportional to increased production	Proportional to increased production	Low	Tube life
Reduce steam to carbon ratio	0–4	Increase	Increase	Decrease	Low	Lower H_2 purity and steam
Low temp shift	2–5	1–3% increase	No change	Increase	Medium	Steam purity
Pre-reformer	8–10	10–15% decrease	Proportional	Same	Medium	Pre-reformer catalyst cost
Post-reformer	20–30	15–30% decrease	Increase slightly higher proportion than increased H_2	Same	High	Metal dusting (EHTR); O_2 cost (secondary)
Improved PSA recovery	1–2	Same	Same	Increase	Low	Low purge gas pressure
Addition of CO_2 recovery	3–5	6–10% decrease	Same	Decrease	Low/High	Specific market
Replace PSA with CO_2 recovery	15–20%	4–10% decrease	Same	Increase	Low/High	Purity benefits in refinery units

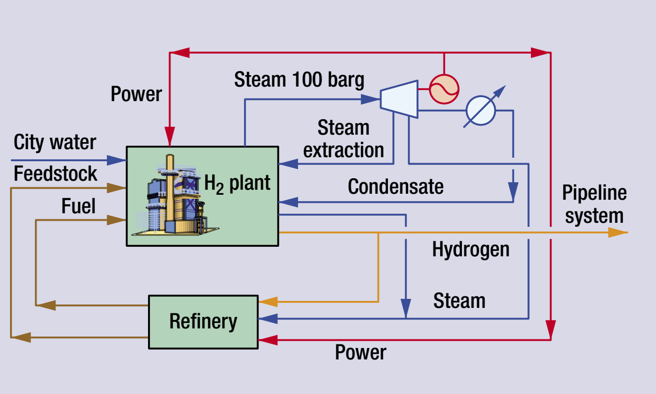

FIG. 8 Topping/condensing turbine with SMR case.

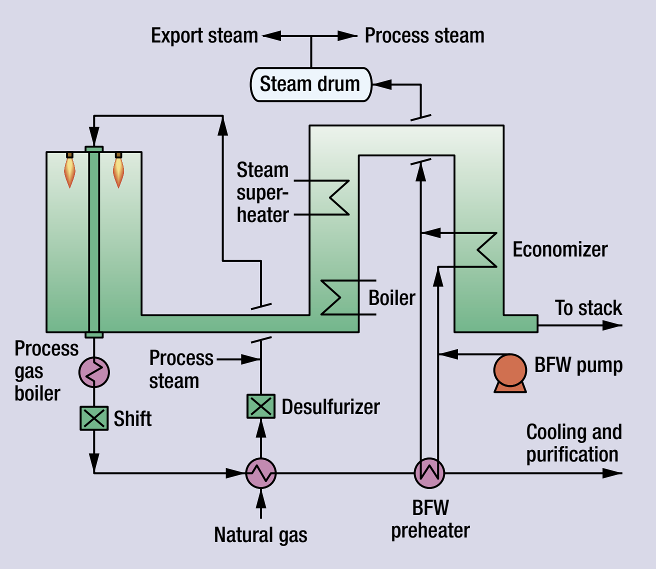

FIG. 10 High steam make flow diagram.

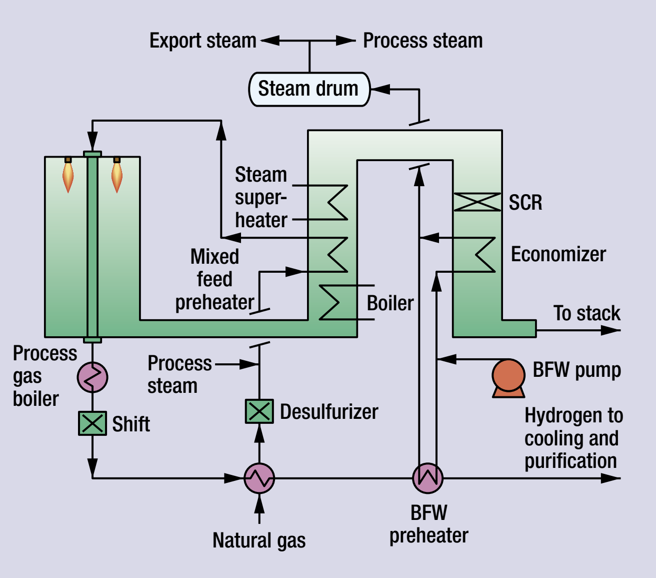

FIG. 9 Natural steam unit flow diagram.

TABLE 6. Typical totally integrated cogen/SMR economics

Dimensions		Economics	MM $/yr
H_2, kNm^3/h	88	Capital charges	6.12
Export steam, tph	160	Nat. gas ($76/1,000 m^3)	4.47
Export power, MW	41	Total	10.59
Heat rate, kWh/kWh	1.55	Unit cost, $/kWh	0.031
Capital, $/kW	700		

Note: These energy prices are used for comparative purposes only.

a higher capital component in the total unit cost of hydrogen (Fig. 8). The need for and value of steam within a refinery will dictate the type of SMR to be built.

Natural steam production. Desulfurized feed is mixed with process steam and is preheated in a mixed feed preheat coil in the convection section. Preheating the feed reduces the amount of convection section heat to be recovered by the steam system and also reduces the radiant section fuel firing. The process gas heat recovery train consists of a waste heat boiler, feed preheater, boiler feedwater preheater and makeup water heater. The convection section heat recovery train consists of boiler coils, mixed feed preheat coil, steam superheat coil and boiler feedwater preheat coil (economizer). The natural steam production for the base case would be approximately 70 tph (see Fig. 9).

High-steam production. If the refinery requirements favor high-steam export, the process configuration as described above is modified to delete the mixed feed preheat coil (Fig. 10). Feed and steam now enter the steam reformer at a substantially reduced temperature (around 370°C or 700°F). Therefore, additional firing is required in the radiant section to achieve the required reaction temperatures. Further, because of the deletion of the mixed feed preheater coil, that duty also goes toward steam generation.

Maximized steam production. To further increase the export steam capability of the plant, a low-temperature shift (LTS) reactor can be added (Fig. 11). This provides additional heat recovery from the syngas train; it is recovered in the boiler feedwater preheater. Typical temperature at the inlet to the LTS reactor is 200°C (400°F).

Additional enhancement of steam export is possible through the addition of auxiliary firing in the convection section of the steam reformer (Fig. 11). Natural draft burners are mounted in the convection section and auxiliary firing is established to the extent of increased export steam demand. Additional boiler coils are provided to recover the auxiliary firing duty in the convection section. This option enables the operator to tailor the steam production to the refinery site demand without largely upsetting hydrogen production. For example, auxiliary firing can be provided in the event of a power outage resulting in a sudden increase in steam demand.

Low-steam production. If the refinery requirement favors limiting the export steam amount to a lower than normal level, the “natural” process configuration is modified to include a combustion air preheater in the convection section (see Fig. 12). Ambient air is compressed in a centrifugal forced draft fan and is sent to the convection section for heat recovery against hot flue gas. Preheating combustion air reduces the amount of convection section duty

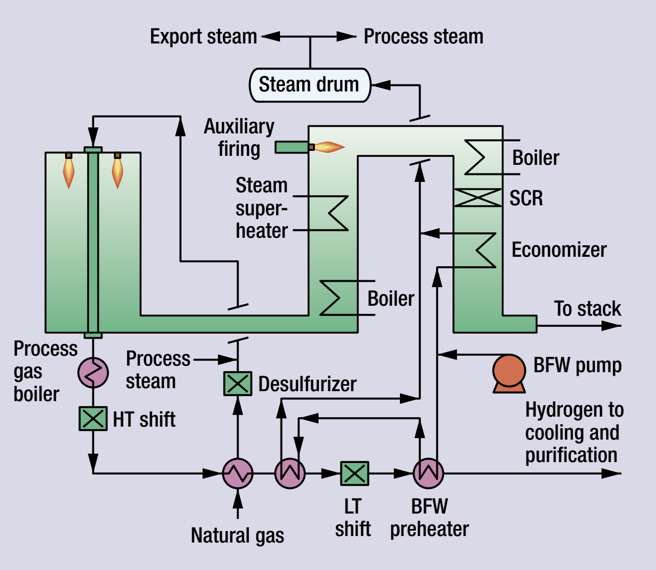

FIG. 11 Max steam production LTS and auxiliary firing flow diagram.

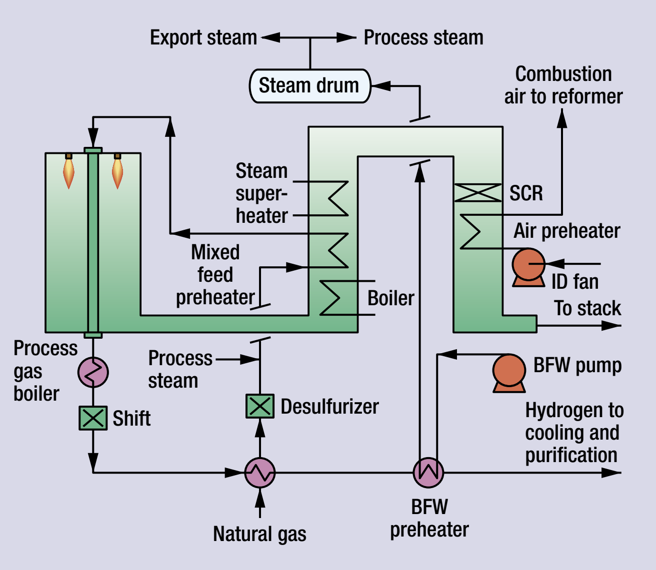

FIG. 12 Low-steam production flow diagram.

to be recovered by the steam system. The air preheater also reduces the total firing in the radiant section.

Minimize steam production. If refinery requirements dictate even further reduction of export steam quantity, this can be achieved by installing a pre-reformer to the process configuration (Fig. 13). Feed and steam are preheated and sent to the pre-reformer reactor. Process gas from the pre-reformer is further preheated in the convection section before entering the steam reformer.

First, adding a pre-reformer impacts the total plant efficiency by initiating the steam reforming reactions outside of the radiant section. Next, installing a pre-reformer allows further preheat of the process gas without fear of cracking, thus reducing the amount of convection section duty to be recovered by the steam system. Finally, since part of the steam reforming process takes place outside the radiant box, the total radiant duty is also reduced, thus lowering firing. Fig. 14 summarizes the impact each of the above cycles has on the capital cost of the hydrogen plant.

Utility integration. In terms of volume and value for a typical refinery, H_2 is generally the largest product that is outsourced. Consequently, the entire project will usually be structured around H_2 in terms of timing, location and economic viability. However, other utility needs should also be carefully evaluated during the planning stages of a refinery clean fuels project. An industrial gas company can evaluate these options, select the optimum processing technology, and analyze utility synergies with the host refinery. This effort can take several months to complete. If all needs are evaluated in parallel and the appropriate design features are included at an early stage, it is possible to reduce the net cost of hydrogen, steam and electric power.

Hydrogen, steam and power integration. The SMR, which is principally designed for the production of hydrogen, can also produce both steam and electric power economically. Technically, SMR is an endothermic reaction. However, for acceptable kinetics, the temperature has to be above 785°C (1,450°F) in the radiant section of the reformer furnace. Hence, waste heat is usually available. Normally, waste heat is used to make export steam for process uses. An SMR also consumes power for fans, compressors and pumps.

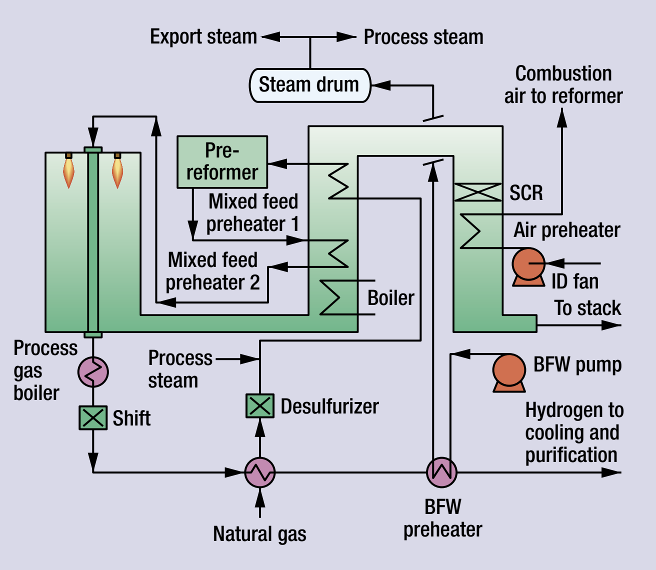

FIG. 13 Minimize steam make flow diagram.

In many cases, sufficient power can be produced to meet not only the hydrogen plant's own internal needs but also export some to the host refinery and/or the local electrical grid. This technology is proven and cost-effective. Often, electrical power generation can represent a higher value end-use of steam. Once hydrogen and steam requirements have been established, the amount of power produced can be set by incorporating the appropriate power generation technology, which will be integrated into the total plant design.

Waste heat is available from two sources in a typical steam reformer:

1. Heat in the reformer furnace flue gases and
2. Heat in the process gases coming out of the reformer.

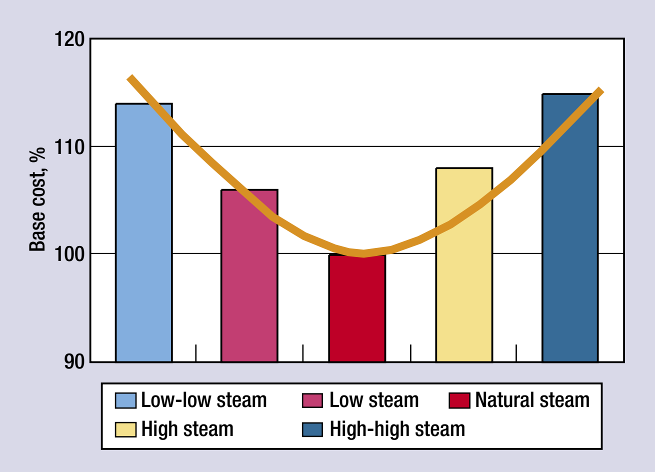

FIG. 14 Natural steam, results in the lowest capital costs.

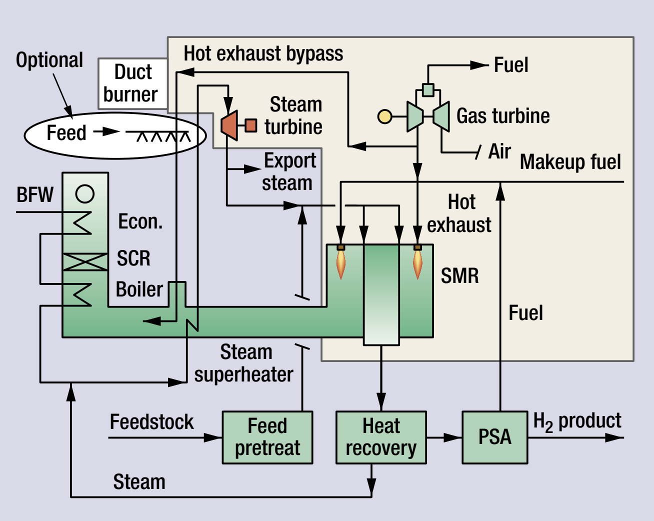

FIG. 15 Totally integrated cogeneration/H_2 case with steam topping/gas turbine design.

The heat from the reformer furnace can be used to generate steam, superheat steam, preheat air, and preheat the feed/steam mixture. Heat from the process gas is used in preheating the feed to the desulfurizer, generating steam in a process gas boiler, heating boiler feedwater, heating condensate, providing de-aeration steam, and providing heat to the makeup water. As more heat is recovered, the fuel efficiency is improved and cooling water requirements are reduced. However, additional heat integration does increase capital costs.

Power integration. The SMR will normally be base-loaded and run in a near steady state condition for H_2 production. Demands for H_2 will dictate the operational "dispatch" of the plant. Hence, the ability to independently vary steam or power output is limited. The preferred mode of SMR operation for steam and power would be "baseload," and other process boilers would handle swings in demand for either of these products.

A limited amount of steam demand variation can be incorporated if a condensing turbine is incorporated in the plant design (Fig. 8). However, the incremental power produced from swings in steam demand would probably have a reduced value if its availability cannot be guaranteed.

The technical viability of cogenerating power in hydrogen plants has been unequivocally established in several commercially operating plants. Ultimately, in a competitive and cost-driven marketplace, a technical concept will be adopted only if it is economically attractive.

Case 1: Steam topping/condensing turbine. In a steam topping/condensing turbine scheme, the steam produced in the SMR is produced at higher than normal pressures, from 45 to 100 bar g. The higher-pressure steam is then throttled back to generate power and steam is exported as 45 bar g medium-pressure steam or to a lower pressure to generate additional power, depending on the refiners' steam system requirements. If maximum power output is desired and the export steam is not required for the refinery operations, the export steam can be condensed. Fig. 8 is a diagram of a topping turbine integrated with an SMR.

Case 2: Steam topping/gas turbine integrated SMR. This configuration is a combination of a steam topping turbine and a gas turbine. Basically, power production and economics are obtained as a combination of both the steam and gas turbines. A simplified flowsheet (Fig. 15) shows how the two turbines are integrated with an SMR. One of the key benefits of a gas turbine is the ability to use the hot exhaust from a gas turbine in the radiant section of the steam reformer. This hot gas at 540°C (1,000°F) still contains 13% oxygen and serves as combustion air to the reformer. Since this stream is hot, fuel consumption in the reformer is decreased.

The convection section takes the place of a heat recovery steam generator (HRSG) in a cogeneration design. Once the heat is recovered, the cooled gas enters an induced draft fan and leaves via the stack. Steam raised in the convection section can be put through either a topping or condensing turbine for power generation. In this design, the steam system in the hydrogen plant is upgraded above 45–100 bar g and sent to the topping turbine for further power recovery before export to the refiner. Appropriate bypasses can be incorporated into the plant design to decouple hydrogen and steam production from power production.

The system can be designed so that production of hydrogen and steam can continue in the event of loss of the power generation units through the incorporation of fresh air inlets into the SMR. This permits outages of the gas turbine for maintenance and repair. Separately, a gas turbine exhaust bypass system allows the gas turbine to be decoupled from the reformer. In the event of a reformer trip, the gas turbine can operate and continue to produce electricity and some steam. Economics for this combination can result in a favorable power cost of approximately $0.03/kWh using a basis of $76/1,000m^3 ($2.52/MMBtu) for NG. Table 6 provides details of the economics. For comparative purposes, utilizing an NG price of $166/1,000m^3 ($5.50/MMBtu), power is still generated for less than $0.055/kWh.

Table 6 illustrates that electricity can be generated in a hydrogen plant in a number of process schemes. In general, power generation from an H_2 plant is most cost-effective when a large steam requirement exists. If steam production must be minimized, the reformer becomes more expensive and the turbine system suffers from the lack of economy of scale. From a practical standpoint, the price of power generated in an integrated H_2 plant is competitive. As a result, the total need for power should really determine the decision of whether and how much power should be produced. It is essential to carry out a detailed analysis and optimize hydrogen, steam and power requirements to minimize total cost.

Refinery utilities. In addition to the already discussed power and steam byproduct potentials from a hydrogen plant, there are often opportunities for synergy between a new SMR project and a refinery upgrade or expansion project. Sharing other utilities such as cooling water, boiler feedwater, refinery fuel gas or instrument air provides economies of scale for integrated savings. Frequently, one party has excess capacity that is underutilized and can be used to significantly reduce capital investment. As every refinery is unique, this must be evaluated on a case-by-case basis. However, the opportunities for integration should not be overlooked.

Outlook. The refining industry is facing critical issues world-wide under the constraints of producing clean fuels and reconfiguring refinery processes with restricted capital resources, all under the umbrella of changing crude and product slates. With large capital investment expected to be a requirement in the near to midterm, outsourcing offers an effective method to reduce costs. Third-party-supplied hydrogen can assist refiners with flexibility in their operations and improvements in the important financial measure of return on capital employed (ROCE).

Perhaps more significantly in today's climate, it releases capital (by outsourcing the hydrogen plant investment) for other investment opportunities aimed at improving the refinery margin. Outsourcing hydrogen should not be considered in isolation. Significant benefits can be derived from considering co-products and other utility requirements, such as power and steam, and the entire project should be optimized in parallel to the refiner's hydrogen needs.

A hydrogen steam reformer plant can be designed to produce high-pressure steam and power in addition to hydrogen, thereby allowing the refiner to optimize its total energy balance and efficiency by critically evaluating the replacement of aging utility systems. This enables a refiner to outsource all three products and focus its capital and human resources on its core business and release capital for other investments aimed at improving the refinery margin. The main advantages of such an approach to a refiner are: integrated project execution, economies of scale, improved energy efficiency, improved reliability, improved environmental performance, and operations excellence through benchmarking a large pool of SMRs.

The integration of an SMR with various power generation technologies such as a topping turbine or a steam topping/gas turbine has been commercially demonstrated. Integrated power production in a hydrogen plant becomes more economical as the cost of energy increases due to the superior heat rate of a topping and gas turbine compared to a stand-alone cogeneration plant. Integrated utility supply schemes are expected to gain greater acceptance as the refining industry continues to streamline operations and reduce costs. **HP**

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