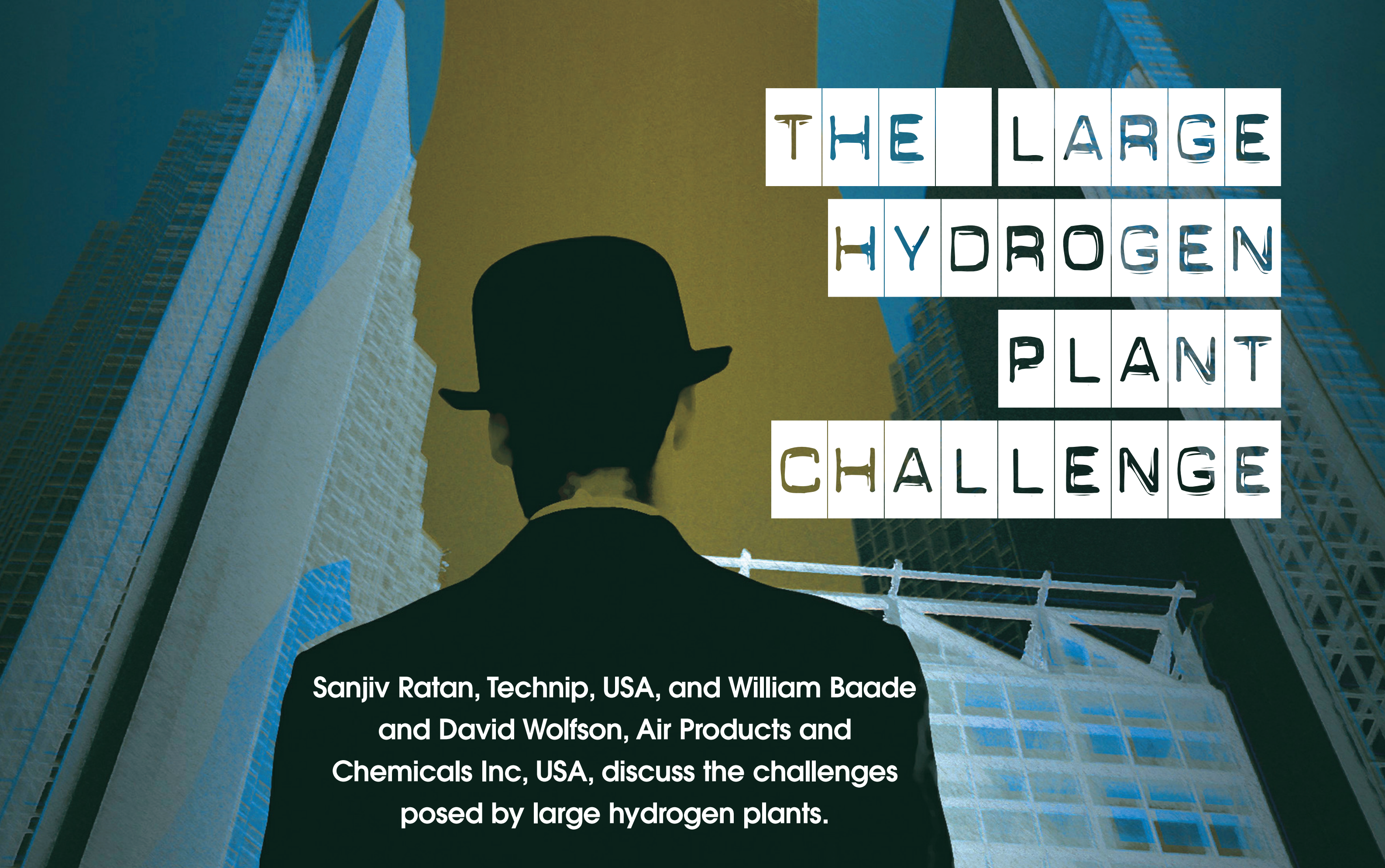

THE LARGE HYDROGEN PLANT CHALLENGE

Sanjiv Ratan, Technip, USA, and William Baade and David Wolfson, Air Products and Chemicals Inc, USA, discuss the challenges posed by large hydrogen plants.

Large, single train hydrogen plants, with a capacity in the range of 60 - 200 mmscfd are becoming increasingly prevalent. The economies of scale from supplying multiple customers, synergies with energy integration and proven reliability have all boosted their popularity.

However, the characteristics of large capacity hydrogen plants present greater challenges than medium sized (< 60 mmscfd) plants and demand a different approach in their design and operation. Such challenges require stronger emphasis on design boundaries, reliability valuation, utilities integration and effective execution strategies, as well as a stronger commitment to efficiency, environmental compliance and overall economics. Moreover, these large facilities generally demand tighter execution schedules and rapid commissioning, while facing the familiar project budget pressures and site specific (such as cold climate) constraints.

For Technip and Air Products there are four major challenges that must be addressed in providing large hydrogen plants to the refining and oil sands upgrading industries:

- Leveraging lessons learned from previous large scale projects into streamlined project schedules and optimised startup/commissioning schedules.
- Optimising the hydrogen/steam/power balances within the context of a refinery's future utility infrastructure, including refinery fuel gas utilisation.
- Implementing design reliability at the lowest justified cost, while enlarging scale up envelop.
- Implementing product development and modularisation techniques learned from small/medium capacity hydrogen projects.

Drivers for large hydrogen

The growing demand for transportation fuels, increasing pressure for cleaner fuels and higher crude oil prices are supporting a significant number of refining investments for: processing more sour and heavier crudes; deeper conversion capacity such as hydrocracking and residue upgrading; and oil sands upgrader projects to produce synthetic crude. Furthermore, in emerging refining markets such as China and India, as well as the export oriented economies of the Middle East, several large scale expansions and grassroots refining complexes are planned. All of these trends require large quantities of 'on purpose' hydrogen generation, with inherent prospects for 'site wide' energy integration.

One of the major challenges for refiners today is to assess their current and near term hydrogen demand and satisfy such demand in a reliable and economical manner. Major refiners worldwide have increasingly outsourced their refinery hydrogen needs to third party suppliers through pipelines or over the fence plants. This enables large hydrogen facilities to serve multiple customers in the same vicinity.

To satisfy refiners' hydrogen needs reliably and cost effectively, Air Products and Technip formed an alliance in 1992 for over the fence hydrogen supply. Under this alliance, more than 1.3 billion scfd of hydrogen production have been installed or placed under contract. Air Products is scheduled to start up four new large hydrogen plants in 2005 and 2006 supplied by Technip (70 - 110 mmscfd), while Technip plans to commission three large hydrogen plants in the next two years, including the largest single train plant (200 mmscfd) for Canadian oil sands upgrading. The underlying objective of these projects is to lower the unit cost of hydrogen while meeting the specific needs of each facility in terms of synergistic steam power integration and/or feedstock flexibility.

Economies of scale

On purpose hydrogen generation plants are capital intensive due to high temperature catalytic processing and customary gas phase purification. The total investment can also vary considerably depending upon site specific factors such as location, feedstock, export steam conditions,

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Table 1. Hydrogen plant economics			
	Large (> 60 mmscfd)	Medium (20 - 60 mmscfd)	Small (<20 mmscfd)
Variable costs (%)	60 - 80	50 - 70	30 - 50
Fixed costs (%)	20 - 40	30 - 50	50 - 70

degree of utility integration and reliability needs.

For larger hydrogen plants (above 60 mmscfd), the variable costs linked to specific energy consumption costs (feed plus fuel minus export steam per 1000 scf H_2) are the major components of the unit cost of hydrogen. With current high natural gas or naphtha prices, the energy cost portion becomes even more significant. The challenge lies in proper assessment of the specific refinery's future hydrogen demand and utility infrastructure to achieve both integrated optimisation of hydrogen, steam and power on a site wide basis and high utilisation from the first year of operation.

Table 1 provides an overview of the sensitivity of variable and fixed costs to plant capacity. Accordingly, emphasis should be placed on energy efficiency for large plants to improve the unit cost of hydrogen. A 1% reduction in the energy costs of a hydrogen plant of 100 mmscfd can result in approximately US$ 600 000 savings per year based on US$ 4/million Btu. Thus, for larger hydrogen plants, there is a bigger incentive for incremental investment in extended heat recovery in addition to that of optimising the flowsheet and operating conditions, which typically has a payback period of two - four years.

Although the capital investment costs are not of primary importance for larger plants, their reduction is vital in lowering the unit cost of hydrogen. Based on economies of scale, the cost of hydrogen produced by a single train large capacity hydrogen plant can be appreciably lowered by the capital exponent contribution. Figure 1 illustrates the economy of scale reduction in the unit cost of hydrogen from a 50 mmscfd to a 110 mmscfd hydrogen plant based on US gulf coast economics and natural gas pricing of US$ 4/million Btu.

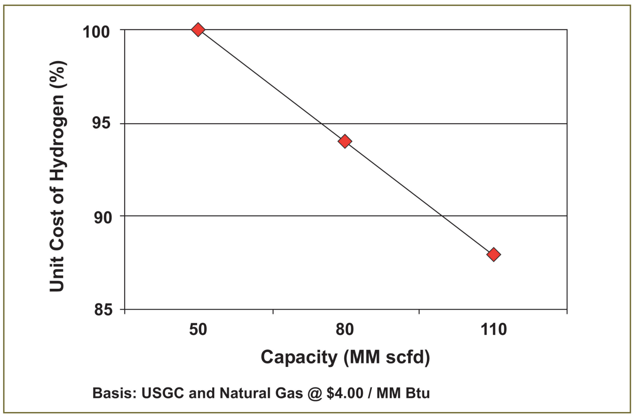

Figure 1. Economies of scale on hydrogen costs.

Although economies of scale favour larger plants, there is a size limit above which a single train plant starts becoming cumbersome and requires detailed evaluation to establish the break point for two or more trains. Physical size, weight and transportable limits on the equipment, valves and piping as well construction facilities must be taken into consideration. Such limits have progressively increased from 100 mmscfd up to a recent project size of 200 mmscfd, due to advances in compacting equipment, equipment design, piping modeLling and modular construction concepts.

Facility replacement

As noted, focusing on energy efficiency can yield significant saving to hydrogen unit costs. The reduction in energy consumption of hydrogen plants from the 1960s and 70s can be more than 10 - 15% (or up to 70 Btu/scf) when compared to modern PSA purification based plants. Accordingly, for an 80 mmscf hydrogen plant, it can provide US$ 6 million/y of energy cost savings based on US$ 4/million Btu.

For a refinery expansion, there is usually a simultaneous need for additional hydrogen, steam and electrical power and this provides an opportunity to reassess their balances within the refinery to improve its overall cost structure. In addition, refiners are required to significantly improve the environmental emissions performance of such older plants and/or create emissions allowances for the new hydroprocessing project in an overlapping timeframe to comply with clean fuels legislation. As a result of these evaluations, many refiners have opted for over the fence hydrogen supply instead of refurbishing and/or expanding them based on the overall shutdown economics.

Design considerations

For large hydrogen plants, especially above 80 mmscfd, the design basis and margins must be carefully applied to ensure both reliable long term performance and cost effectiveness. Some investments are easier to justify for large plants but the equipment scale up for a single train configuration must be properly devised not only in terms of material cost, but also taking into account fabrication, proven supply, transportation and site erection. There is an inherent need for compacting equipment and piping items and, in doing so, design considerations will include:

- Average and critical heat flux in the reformer firebox as well as the process gas boiler.
- Catalyst space velocities and L/D ratios for reactor sizing.
- Continuous run cycle and the need for ant online catalyst replacement.
- Flow distribution in reactors for lowest turndown.

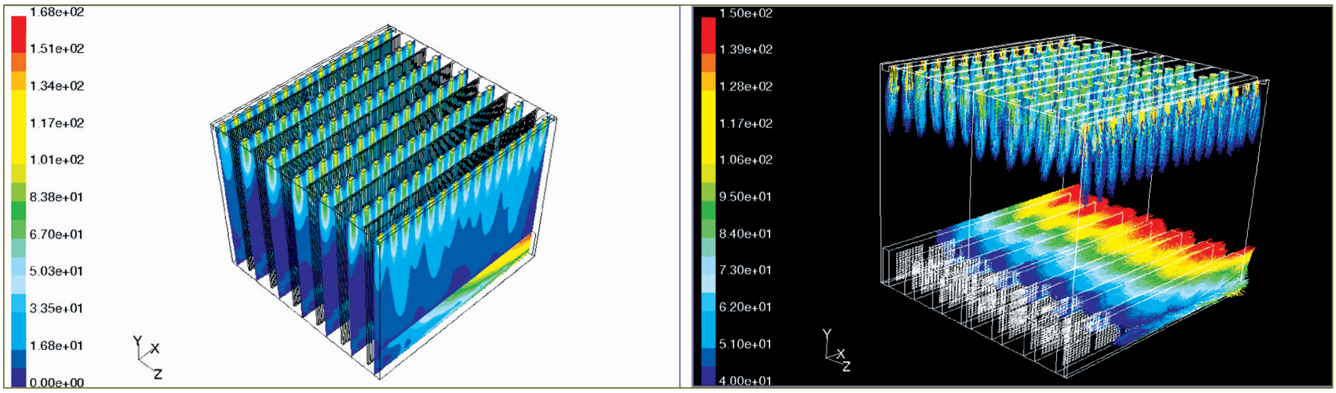

Figure 2. CFD modelling of large reformer radiant section.

- Momentum flux limits and hydraulic pressure drop optimisation for pipe sizing.
- Optimisation of heat exchanger surface against pressure drop.
- Optimisation of PSA H_2 recovery (and the related number of PSA adsorbers).
- Establishing PSA purge back pressure based upon the criticality of H_2 recovery versus size and the cost of the purge gas fuel circuit.
- ID/FD fan rating and value engineering of variable speed coupling or variable frequency drive versus turbine drive.

It is very important when designing very large reformers to avoid excessive maldistribution of flow and resulting temperatures in the radiant box. This becomes the limiting factor when scaling up the reformer. Although single box large reformers are best served by multi lane top fired configuration, adding excessive design margins to cover for the temperature maldistribution both adds to the investment cost and restricts the metallurgical and mechanical limits, which otherwise can be favourably exploited.

Using CFD modelling and the experience of building very large reformers, improvements on the burner layout and design of air and fuel manifolds as well as flue gas tunnel design are applied for achieving uniform heat release and its distribution in the large reformer radiant fire box (Figure 2). Such modelling becomes even more important for very large radiant boxes since they tend to be deeper and often have higher combustion air preheat levels. This not only increases their volume but also requires extra attention to thermal expansion. The model is also utilised to study the flow patterns and heat distribution at low turn down operation, which in some instances can prove to be critical.

For larger scale up of a steam reformer inherently operating at near creep conditions, proper compensation for thermal expansion and related stresses becomes increasingly critical due to increased material growth for maintaining system elasticity. An increasing number of tube rows calls for greater flexibility, especially in relation to the outlet conditions. This is usually accomplished by employing a long pigtail outlet system design. Technip executes the total 'hot system' of the reformer comprising the feed header, inlet system, catalyst tubes and the outlet system as 'one free floating system' designed to accommodate sustained worst case thermal stresses. It ensures proper mechanical integrity and reliable operating life of the critical parts under normal operating conditions as well as expected thermal cycling during several shutdowns and restarts.

Meanwhile, when designing a large top fired reformer, special attention to the temperature contours in the penthouse is important. Maintaining acceptable working temperatures for operation or maintenance personnel as well as instrumentation components is of key importance. Special systems have been developed and implemented for achieving penthouse climate control in large reformers, especially in tropical locations.

Cogeneration integration

Steam and power can be integrated with a refiner's hydrogen needs and integrated with a pipeline system if they are located near other refineries or chemical facilities. Further optimisation of a refinery hydrogen system can be achieved through purge streams containing significant concentrations of hydrogen currently sent to the refinery fuel system. Integrating these streams into the design of a new, large energy efficient steam reformer integrated with a gas turbine can provide opportunities to unlock the value of refinery fuel gas into a new hydrogen and utility supply system. The value is illustrated in Table 2 in the form of an efficient heat rate (Btu/kWh) and competitive capital factor (US$/KW).

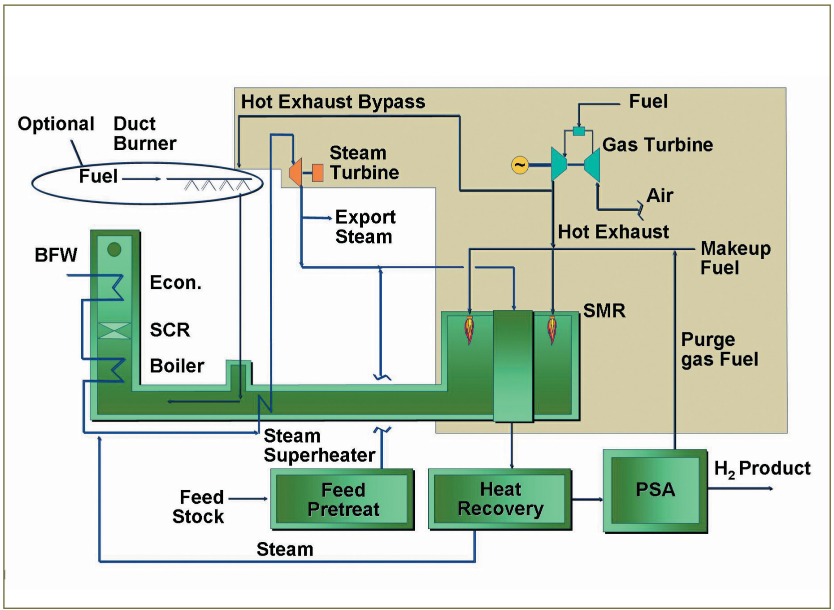

Figure 3. Block flow diagram for SMR / Integrated cogen unit.

Table 2. SMR/cogen Integration economics	
Cost component	
Heat rate	5300 Btu/kWh
Capital	700 US$/kW
Unit power cost	
at US$ 2.50/million Btu	0.03 US$/kWh
at US$ 4.25/million Btu	0.04 US$/kWh

Figure 3, meanwhile, illustrates the block flow diagram for the SMR/Integrated Cogen unit design for high availability of steam and hydrogen. The challenge for Air Products and Technip was to design the SMR and cogen equipment to be operated independently. The concept was successfully implemented into the ongoing operations for the past four years at the Port Arthur facility.

To date, Air Products and Technip have installed large SMRs integrated with cogen units at six refineries in the USA and Europe. In April, Air Products announced its latest large SMR project (100 mmscfd) for supplying hydrogen, steam and power to Premcor's refinery in Port Arthur, Texas, and Technip will be commissioning a 200 mmscfd SMR integrated with a 75 MW cogen unit for Syncrude upgrader complex in Canada.

Reliability challenges

As designs have advanced and needs changed over the past years, refiners have come to expect a 99+% onstream performance. Refiners are under significant pressure to maintain high utilisation rates to meet the increasing demand for product. A lapse in hydrogen supply can have a significant impact on both the refinery's operations and its consumers, such as hydrocrackers, gas oil hydrotreaters and diesel hydrotreaters, and thus on overall profitability.

For instance, a hydrogen plant outage of two hours can result in a 48+ hour hydrocracker outage, leading to a margin loss in the range of US$ 400 000 - 1 million (based on refining margins of US$ 10 - 20/bbl). The challenge with

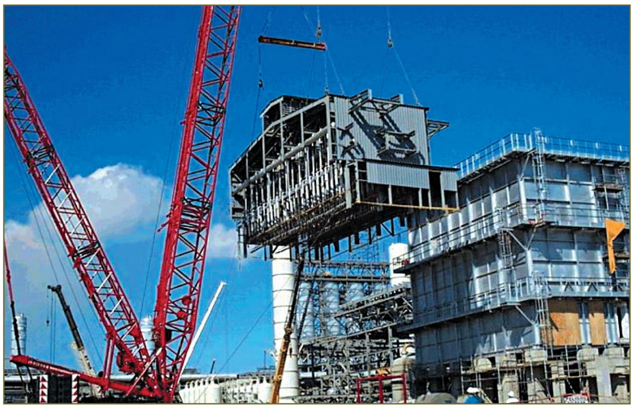

Figure 4. Large reformer modularised penthouse.

large plants is to constantly evaluate core designs and plant operations to maintain the highest level of reliability at the lowest justified cost. The focal areas for maximising onstream availability (time between unplanned outages) and continuous operation cycle for large hydrogen plants include:

- Reformer design based on computational fluid dynamics (CFD) modelling to maintain proper heat distribution and hydraulics for process performance, long term life and reliability.
- Reliable large process gas boiler design selection.
- Catalyst stage of run profiling and online catalyst change over provisions as needed.
- Design criteria and specifications as well as design margins, prudent material selection and cost effective sparing philosophy.
- Advanced process control, monitoring and shutdown logic with fall back modes to minimise avoidable shutdowns (e.g. two out of three voting on critical control systems and diagnostic sequences).
- Startup and transient diagnostic sequences to minimise process excursions and trip conditions during process upsets, as well as to enable smooth and rapid restarts.
- Extensive cumulative operational experience and shared expertise from multiple hydrogen facilities.

Construction challenges

The construction of a hydrogen plant requires considerable level of skilled labour. However, often its availability may be limited. Thus modularisation concepts, which were traditionally applied to small and medium sized plants, are now used for larger hydrogen plants, not only to shorten execution schedules but also to enhance construction quality and curtail execution costs.

Efficient construction planning involves multidisciplinary reviews to establish the detailed prefabrication and modularisation strategy while taking into account the equipment layout, expansion loops and accessibility. The underlying objective is not to maximise the shop fabrication, but to find the optimum between shop and field work, considering site location; local labour availability; overall project scheduling; engineering and shop man hours; shipping and transport limits; the costs of the entire routing; rigging facilities; and local costs. The challenge is to manage the overall complexity of the project using a risk assessment approach to deliver net cost savings upon completion of the project.

Design techniques have been developed to aid in the progressive evaluation and selection of modularisation and pre-assembly concepts to enable optimisation of shop and field erection activities, taking into account the site specifics and overall project activity in the area.

Modularisation of a large hydrogen plant mainly concentrates on two areas, the reformer and the heat recovery sections, and can result in several different modules, dependent on the project specific factors. The radiant box panels with ceramic fibre modules pre-installed can be applied to minimise lifting and bolting requirements at site. The platforms and ladders can also be sectional prefabricated. The penthouse prefabrication can be optimised with the trusses and walls as pre-assemblies and can include inlet system components as well as burner piping and manifolds in varying proportions (Figure 4). Such modularisation can account for a fairly large portion of the structural steel and related field construction.

The convection coils can be pre-assembled into compact, dense modules complete with refractory lining and shop hydrotesting, whereas the crossover piping can be spooled in the shop to reduce total field welds. The inlet manifold and outlet system can be harped into shippable assemblies. The refractory lined transfer line can also be shop fabricated with its refractory lining, and supplied after testing and painting.

Degree of modularisation of process and heat recovery sections can be established depending upon the size and layout requirements of the heat exchangers and related vessels and the maximum transportable envelop for the modules from ex works to the site. Exchangers, pumps, piping and instruments can be installed on steel support structures after fully hydrotested, cleaned and being made ready for commissioning at site. Supervision and logistical support during shop fabrication as well as the precommissioning phase is very important to accomplish efficient and quality construction.

For construction in the cold climate zones, the modularisation strategy must be specifically established, taking into account special logistics, civil works, transportation time window and overall construction management. Several Canadian locations allow transportation and related handling of megamodules, which can prove to be quite effective and proficient for such cold site construction. In recent years, several large plants have been designed and supplied using the modular approach demonstrating improvements in logistical safety performance, plant quality, cost effectiveness and project schedule.

Conclusion

Technip and Air Products have sufficiently overcome the challenges of implementing advanced concepts for the successful design, scale up, streamlined execution and reliable operation of large hydrogen plants. Specifically, they have met the large plant challenges through: leveraging lessons learned from previous large scale projects into streamlined project schedules and optimised startup/commissioning schedules; optimising the hydrogen/steam/power balances within the context of a refinery's future utility infrastructure, including refinery fuel gas utilisation; implementing design reliability at the lowest justified cost; and implementing product development and modularisation techniques learned from small/medium capacity hydrogen projects.

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