THE DIGITAL DELIVERY OF A COMPLEX HYDROGEN NETWORK

Roy Calder, AVEVA, UK, explains the importance of developing digital environments to support the success of hydrogen projects.

Hydrogen has been part of the process industry's chemical catalogue since well before industrial chemist Fritz Haber met chemical engineer Carl Bosch in the early 1900s and developed the ammonia process. Today, the focus on hydrogen extends well beyond the process industry and into almost every aspect of our lives – from transport to power to heating. All of this activity is being driven by society's need to reduce greenhouse gas (GHG) emissions emanating from fossil fuels.

However, hydrogen is not the global panacea that people might think. Hydrogen production and delivery to point of use is not a simple undertaking; producing cost-effective hydrogen safely, with minimal impact on the environment, involves an integrated approach

to planning, engineering and operations, often across multiple sites and operators.

This article looks at the digitally-integrated network approach to a multi-source/multi-end user hydrogen project, from initial planning through engineering and construction, to effective network operations

Hydrogen generation

The current view of hydrogen generation is polarised – either it should be green or blue. However, the specific aspects of each process should be considered before embarking on a project.

Green hydrogen

Generating hydrogen by electrolysis from water is a method known by every high school science student, and with renewable energy – solar and wind – the model is relatively simple in principle. However, today's electrolysis processes are far more complicated and have developed into a huge industry with the deployment of two main technologies: polymer electrolyte membrane (PEM) and alkali electrolyte membrane (AEM). Each technology has its own pros and cons, and the decision between them is normally based on a high-level modelling study (to be explored later on in this article).

Blue hydrogen

Steam methane reforming (SMR), which results in carbon dioxide (CO_2) as a byproduct/emission, has been the de-facto source of industrial hydrogen for over 100 years. While regulatory limits for low-carbon hydrogen are set at 20 g CO_2e/MJ_{LHV}, the approach to reach this limit on existing and new plants is to capture the CO_2 with a carbon capture utilisation and storage (CCUS) system.

Hydrogen project life cycle

To best illustrate how carbon-neutral hydrogen can be manufactured and distributed, this section will consider a major project that incorporates existing hydrogen generation facilities and users, as well as potential new use applications. As with any major capital project, there are vast numbers of variables that make a viable investment case, starting with an estimation of demand and growth to provide the basic project economic envelope.

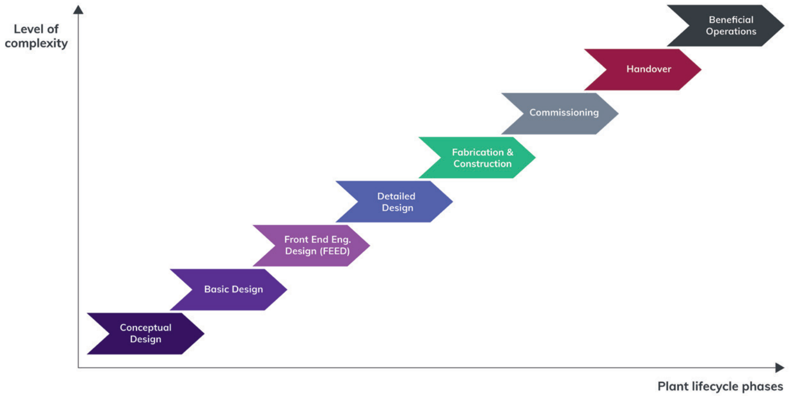

Figure 1. Level of complexity of each plant life cycle phase.

From the initial decision to go ahead with a project, the complexity often increases as we move through all the phases of a plant life cycle, as illustrated in Figure 1.

Each of these typical project phases may well involve multiple investors, locations and landowners, new/existing facilities, original equipment suppliers, process licensors, utility providers, EPCs and end users.

With this level of complexity, managing both the engineering and operations can be very challenging – at least in a traditional manner. The following project steps can potentially be managed in a connected digital environment.

Project inception

Here the adage 'fail to plan, plan to fail' is the overarching philosophy. At the heart of this stage is the master planning process, supported by simulation. Master planning is a strategic process whereby a model of the entire hydrogen supply chain is built on a process and geographic basis. This model will consist of some, if not all, of the following units:

- Renewable energy sources.
- Battery storage.
- Water sourcing.
- Water purification.
- Green hydrogen generation.
- Existing grey hydrogen plants.
- Carbon capture plants.
- CO_2 pipeline.
- CO_2 sequestration.
- New blue hydrogen plants.
- Hydrogen storage.
- Hydrogen compression.
- Hydrogen liquefaction.
- Hydrogen pipeline.
- Ammonia plant.
- Hydrogen distribution network.

This model is built on a process basis but with specific economic parameters for each of the units. The first approach takes a pre-defined hydrogen production specification, and through advanced optimisation algorithms – including artificial intelligence (AI) – produces a set of process specifications for each unit, as well as an overall cost estimation. The main outcome of this model is the best network specification that the investors can initially sign off.

Due to the nature and complexity of the process, the next phase looks to narrow the specifics of the model by optimising the sub models themselves from the process and economic basis. This would involve covering several detailed designs including, but not limited to:

- Renewable energy – define the number of wind turbines, solar panels, and batteries to supply the necessary power to the project, incorporating a detailed climate prediction model.
- Purified water supply – define the location of the water supply, the required piping network, and the purification plant needed

to produce the water supply for the electrolyser and steam generation plants.

- Green hydrogen production – define the number and type of electrolysers needed to produce the necessary green hydrogen based on the availability of renewable energy and the overall process/economic model of PEM vs AEM electrolysers.
- Blue hydrogen production – define the size of new blue hydrogen production units as part of the demand side model.
- CCUS – define the capacity and number of CCUS plants to convert existing grey hydrogen plants to blue.
- Hydrogen pipeline, storage and liquefaction – based on the demand side model, the basic sizing of these items is more closely defined and costed.

The final phase is to reintegrate these models into the overall master model and reoptimise it in terms of both the process units and the location. The models must validate whether wind and solar farms are in the correct location, and whether the sites and electrical distribution network are economically-viable. Similarly, with the blue hydrogen units (new units and grey units converted), the model must optimise the number of CCUS plants needed, and where they should be located in relation to the utilisation and/or sequestration sites.

Once these steps are complete and investors have signed off, the engineering phases can begin.

Design, construction, commissioning and handover

Such a project involves multiple parties, working in a tightly coordinated manner. Services range from engineering, fabrication and construction, including disciplines such as civil, process, instrumentation, mechanical, electrical and automation all working towards a common goal. However, there are added complexities:

- Wind and solar farm construction.
- Power delivery to the process plants and battery storage.
- Pipeline provision for hydrogen to its point of use.
- Pipelines for CO_2 to where it can be used and/or sequestrated.

Moreover, original equipment manufacturers (OEMs) for the wind turbines, solar panels, electrolysers and process compressors also need to be involved without resulting in added project risk, cost overruns, and schedule slippage.

While this complexity is not unknown in the process industry, the way in which this can be best mitigated in practice is to ensure that everyone works together in a single project digital environment.

A common set of engineering software tools, covering simulation, process flow diagram (PFD)/piping and instrumentation diagram (P&ID), data sheets, line lists, electrical and instrumentation feeding into a common 3D model, can be hosted on the cloud and utilised by all parties. By combining this with an integrated information management structure, operators can ensure that as engineering data is generated and published, it is available to all users, therefore eliminating the 'physical' passing of data with the inherent errors. This digital approach improves efficiency for everyone involved, reducing the schedule and overall engineering cost. The construction phase can also be carried out using a similar single cloud environment with corresponding improvements.

With designs predominantly built on simulation, these models provide the foundation for training for both panel and field operators, where integrated exercises can be carried out well in advance of the actual plant start-up. This approach provides significant improvements to safety and efficiency.

Integrated network operations

Multiple sites feeding multiple clients, each with differing requirements as well as a somewhat unpredictable energy source, can be a challenge to manage.

While the control of all facilities (wind and solar farms, water treatment plants, electrolysers, steam reformers, carbon capture plants, electrical supply, and pipelines) can be managed locally, the real issue is the management of the entire network.

Much has been written about enterprise visualisation and centralised control rooms, but the focus has primarily been on control rather than managing the enterprise. For a hydrogen network, visualisation is only part of the story. It must go beyond the single pane of glass view and be closely aligned with all the necessary tools to cover the elements listed in Figure 2.

The management of multiple process plants can be achieved by a well-structured Production Management System (PMS). The key to ensuring that everything works

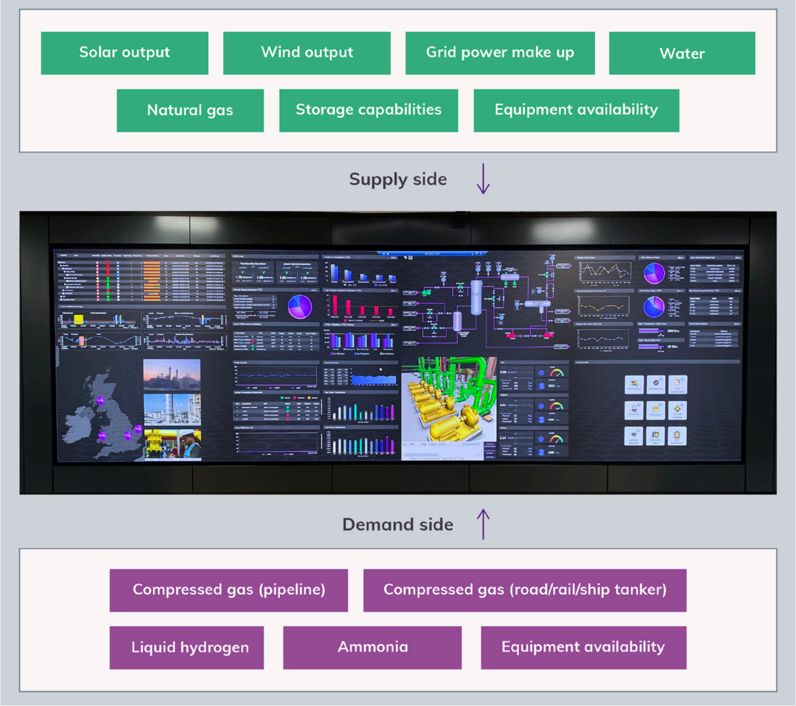

Figure 2. Visualisation and management of a complex integrated network.

Figure 3. Data required to power a fuel cell vehicle with hydrogen.

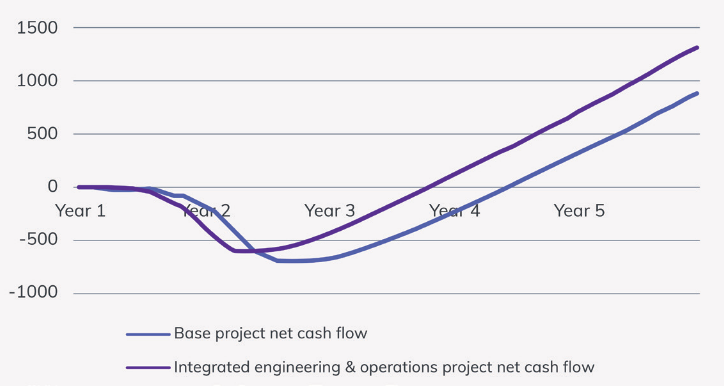

Figure 4. Improving project cash flow.

together optimally is to make certain that the data from all aspects of the network is always available in a format that is suitable for seamless operations. A key approach is to use the power of the cloud to bring together data from the process units with the necessary production planning data from the end user community. While there are many process/business routes to consider here, one is how wind and solar energy becomes hydrogen that is used to power a fuel cell vehicle, and the data that is needed to manage it, as illustrated in Figure 3.

While the demand side is similar to a regular petrol station, the supply side is not as simple or predictable. To ensure the required supply, the demand side data must be seamlessly available to the central operations control. This is achieved by using local data collection equipment, edge equipped, linked to the cloud, and made available to the master PMS model.

On the supply side, the master PMS maintains a continuous hydrogen generation model using an end-to-end simulation model running with real-time data. The simulation runs against a climate prediction model that can accurately predict the available green hydrogen output. If a shortfall in green hydrogen output is identified, blue hydrogen sources are used instead, with capacity also monitored through the PMS model.

Two common concerns are equipment availability and overall safety. Availability is critical, as these systems are integral and strategic to industrial and commercial operations, including possibly adding hydrogen to natural gas networks. E-machine learning tools can ensure that potential equipment failures are identified early, and addressed quickly. The predictive analytics generated to minimise downtime are also crucial.

The benefits of the life cycle approach

While complex projects are customary in the process industry, this approach not only relies upon strong project management, but also on having an integrated engineering environment that remains 'live' once the network is handed over to operations. Easy access to the engineering data means that operations can work more effectively, providing an economic optimum for both investors and clients.

However, the life cycle approach also provides direct financial benefits beyond the engineering, fabrication, construction, commissioning and handover phase of a project. These can be highlighted as follows, and seen in Figure 4:

- Engineering phase:
  - 15% on costs.
  - 10 – 15% on schedule.
- Construction phase:
  - 15% on costs.
  - 5 – 10% on schedule.
- Start-up and commissioning phase:
  - 15% improvement on schedule.
- Operations:
  - 20% on operational efficiency.
- Project break-even point:
  - 7% improvement.

Having benefits at all phases of the project that together deliver improvement in the break-even point and hence on the net present value (NPV) calculation for investors is significant, especially when there is no overhead cost as the tools involved are already in use within the project community.

Conclusion

As companies and governments continue to invest in order to meet their net zero commitments, the number of hydrogen projects, in all its varieties, will continue to grow. Joint venture (JV) and collaborative projects will become increasingly prevalent but will have to be managed carefully in order to ensure that all parties are capable of working together effectively, in a digital environment rather than in siloes. The benefits of this approach for investors, in terms of time and cost, are evident.

By developing an integrated life cycle approach from the outset, owner operators can ensure that the engineering and construction phases are delivered as swiftly as possible while minimising risk and cost overruns. In tandem, the project will also deliver an overall operational data infrastructure that supports OPEX optimisation, and in turn improves the overall time to break-even.