Decarbonising the energy ecosystem

Juan Ruiz, Carlos Ruiz and Michelle Wicmandy, KBC (A Yokogawa Company), explain the real-world impact of energy management systems for green hydrogen on cost, emissions, and efficiency.

In the face of escalating global concerns surrounding greenhouse gas (GHG) emissions, the energy sector is facing a critical juncture, driven by a pressing need for change. According to the World Economic Forum, fossil fuel emissions now exceed 34 billion tpy, up from 22 billion tpy in 1990.[1] A shift is underway as companies acknowledge the profound implications of energy on emissions and costs alike. As the world struggles with this environmental issue, S&P Global Commodity Insights predicts a bold future for clean energy technology (CET) investments. Its forecast anticipates CET investments will approach US$800 billion in 2024 and US$1 trillion by 2030.[2]

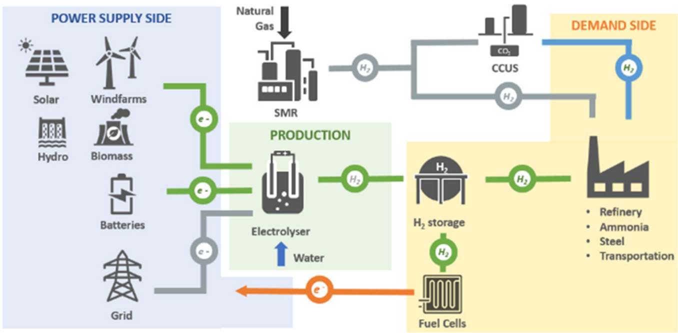

Figure 1. Hydrogen generation network.

Challenges and opportunities

Although renewable energy sources such as solar and wind power hold great promise to reduce carbon emissions when satisfying electric power needs, they cannot be considered as the sole solution to decarbonise the economy for several reasons. First, the variability and uncertainty of electric power generation arising from these sources pose challenges that affect reliability. This issue directly impacts decision making, which may produce suboptimal solutions or impractical recommendations and lead to economic losses. Second, energy in the form of electric power accounts for only a small fraction of all energy needs. The majority of CO_2 emissions arise from industrial processes that generate steam in boilers, which consume fossil fuels.[2]

Finding ways to electrify these systems is still under research.[3] Several challenges must be overcome before electric power can fully replace steam generation processes or steam used as an energy transporter.

Several energy storage technologies have been proposed to tackle the variability of renewable energy sources, such as the use of battery energy storage systems (BESS). However, their cost and required finite resources like lithium may still present obstacles. To address improved energy storage needs and alternatives to heating methods, green hydrogen has emerged as a key enabling component.

Hydrogen as a change enabler

Hydrogen can play an important role towards decarbonisation in a wide variety of sectors, including the process and power sector, along with the transportation and agriculture sector. It provides an alternative way to store energy, an alternative clean fuel source, as well as feedstock for several industries, as shown in Figure 1.

Moreover, incorporating renewable resources and green hydrogen into the pool of energy vectors in the industrial environment has significant potential to reduce costs – particularly if it is well integrated with the existing, traditional, hydrocarbon-based systems. However, achieving a high level of integration requires higher investment and leads to a greater complexity in managing and operating these mixed energy systems.

At a real-time, operational level, decisions on how much and when to use cogenerations or fossil fuel sources, which usually depends on power prices and fuel prices, will now be directly affected by the predictions of weather conditions such as wind speed or solar intensity. Moreover, when to store hydrogen, use it as feedstock or to produce electricity via fuel cells will be driven by expected market conditions. All these factors lead to a great challenge to the person or group in charge of managing these energy systems.

Green hydrogen is one example of a low-carbon emission energy vector that can help decarbonise the economy with the aid of advanced technologies.

These tools need to meet the following requirements to make this complex set of decisions feasible:

- Integrated model: considers not only individual pieces of equipment or subsystems often encountered in traditional energy systems (fuel, steam, electricity), but also incorporates elements related to renewable energy, to be managed all-in-one.
- Forecasting capabilities: handles the site's future conditions and its environmental conditions such as weather, market conditions, and energy demand.
- Performance analysis: analyses both current and past energy efficiency and performance of the site through effective monitoring.
- Energy inventory management support tools: facilitate management of energy inventory to ensure efficient tracking and use of resources.
- Automating generation of recommendations: generates optimal recommendations to relieve operators from complex and time-consuming activities to foster efficiency.
- Autonomous operation: streamlines processes and overall system efficiency in both the short- and long-term scenarios.
- Flexible interfaces: accommodates different information providers and stakeholders, including plant information system, aggregators, forecasters, and more.

Energy management system for green hydrogen systems

An energy management system (EMS) is an integrated suite for monitoring, optimal scheduling, real-time optimisation and GHG accounting of various energy system components such as electrolysers, gas turbines, boilers, and renewable energy subsystems such as solar panels, wind turbines, and BESS. The EMS addresses the full spectrum of energy system activities related to past, present, and future information. This enables real-time monitoring, optimisation, and optimal multi-period scheduling for ongoing operations at the lowest economic cost and within emission constraints.

An effective EMS is crucial to reduce costs and emissions during the current energy transition while adapting to evolving circumstances. This involves continuous process improvement programmes, as well as seamlessly incorporating renewable energy vectors, energy storage devices, decentralised assets, and GHG emissions reporting needs. The system delivers faster and more informed operational decisions to provide actionable insights for energy planning, scheduling, and trading. Real-time actions can be taken in either open-loop (advisory mode) or closed-loop (acting directly on the control system set-points or advanced process control targets) scenarios that align with the optimal schedule.

Within the system, the digital twin can model, monitor, schedule, optimise, and track and report energy systems and their GHG emissions across various complexities – from single units to entire sites and regions.

This digital twin decision support tool relies on integrated, holistic models to manage and optimise both conventional energy systems and renewable energy sources. With integrated models, interactions between the subsystems are understood and costs and emissions of any optimisation actions can be assessed.[4,5,6]

Key capabilities of these tools include:

- Integration with multiple data sources.
- Data validation.
- Support forecasting.
- Analysis of current and past energy efficiency and performance.
- Optimal energy schedule calculation.
- Automated optimal schedule generation.
- Track GHG emissions.
- Multi-objective optimisation.
- Support autonomous operation in the short- and medium-term.

By leveraging these capabilities, companies can move from manual or semi-automatic and reactive energy and emissions management to a fully automated and proactive approach. This shift allows engineers to save time, prioritise higher-value tasks, and be more proactive in energy and GHG emissions management.

Additionally, the EMS suite provides remote accessibility for effective information sharing among various stakeholders.

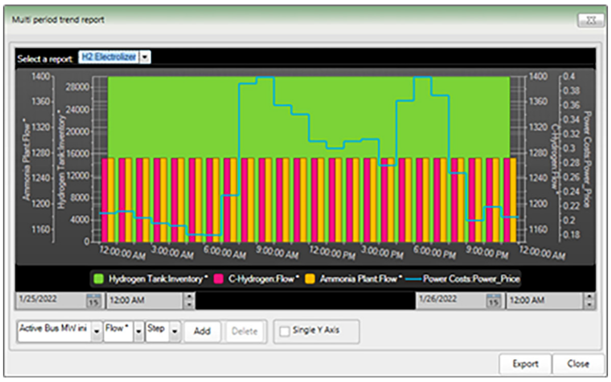

Figure 2. Unmanaged hydrogen production.

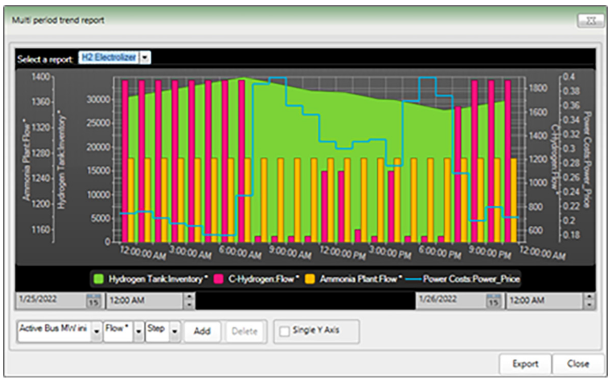

Figure 3. Managed hydrogen production.

Transformative impact of energy management systems

The two use cases that follow show how the entire EMS reduces costs and emissions, and simplifies the lives of engineers, planners, and operators.

Case study 1: management of hydrogen production for ammonia process plant

This case study highlights the use of an EMS to efficiently manage a 100 MW electrolyser system under the Dutch electric market grid. The key challenge for the electrolyser operator is to determine the optimal allocation of hydrogen generation and storage, considering expected power prices and hydrogen demands from an ammonia plant.

In Figure 2 and Figure 3, an optimally managed vs an unmanaged operation case are compared and contrasted.

Under an unmanaged operation, as depicted in Figure 2, the production of hydrogen is solely based on meeting the ammonia plant's demand without considering electricity prices. While this operation will satisfy demand and system requirements, it may not be the most effective or cost-effective method and lead to higher hydrogen production costs.

When the operation is managed by an EMS (shown in Figure 3), the system will optimally account for the power price variability, storage capacity, constraints, and electrolyser operating point efficiencies, to determine the best times to produce hydrogen while satisfying demand. The crucial aspect in this system lies in the proper management of the hydrogen inventory as shown in the green area in Figure 2 and Figure 3. As expected, the EMS identifies the economic benefits of hydrogen production (red bars) during periods of low electric prices, as indicated by the light blue curve, and recommends proper usage of the storage tank. However, determining the optimal production quantity is complex considering factors such as storage capacity, electrolyser efficiencies, demand forecasts, renewables, and more. The EMS can autonomously navigate this complexity by using a first principles model of the system tied to the real-time data. This model is frequently updated to reflect current plant conditions (e.g., current hydrogen storage level, electrolyser efficiency, ambient temperature, and more) and considers the latest forecasts, over a rolling horizon, such as power grid price and hydrogen demand to ensure an informed decision-making process.

Comparing the operational scenarios with and without an EMS, the EMS reduced energy costs by 10% based on the author's experience. This reduction in energy costs directly translates to a substantial decrease in the total cost of the system. In the unmanaged case, the total cost of the system is €488 620/d. However, the total cost decreased to €439 860/d in the optimally managed case. Therefore, by implementing an EMS, daily savings of approximately €50 000 +, or €18 million/yr can be achieved. Ultimately, using an EMS ensures effective and efficient use of energy, which is crucial for sustainability and environmental impact.

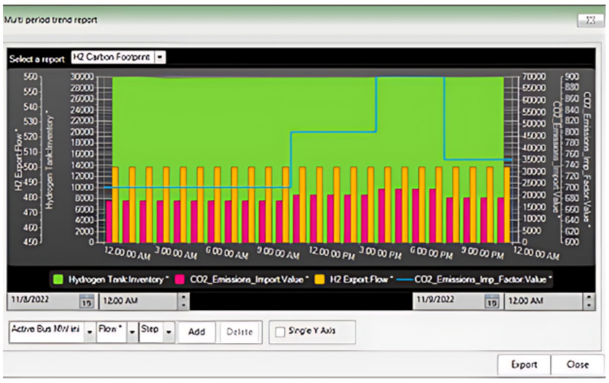

Figure 4. Hourly carbon footprint in the production of H_2 without management.

Figure 5. Hourly carbon footprint in the production of H_2 with management.

Case study 2: carbon reduction via energy management

The EMS facilitates real-time monitoring and tracking of the carbon footprint associated with hydrogen systems.

This footprint is affected by a variety of assets in different ways. The emissions incurred by building and transporting wind turbines and solar panels, for instance, carry a carbon footprint when used to generate electric power for an electrolyser to produce hydrogen.

Alternatively, demineralised water used in the electrolysers can be produced via reverse osmosis or multi-flash evaporators. Like the former, which relies mainly on electricity to operate, the latter uses steam, too. Therefore, the steam generation's carbon footprint must also be considered. Moreover, electricity imported from the grid also has a carbon footprint that needs to be considered.

By using an effective EMS, the hydrogen/power generation process can track and report individual carbon footprints for each asset or subsystem.

The EMS offers more than monitoring capabilities. It reduces the carbon footprint by offering real-time recommendations for optimising the use of energy sources, ensuring optimal hydrogen production while minimising environmental impact and still meeting the demand. To minimise the carbon footprint across each time horizon, forecasts of imported electric power costs updated automatically, in real-time over a given time horizon, can be used to manage hydrogen production and storage.

Figure 4 and Figure 5 show how the site's carbon footprint will be affected with and without management. CO_2 emissions are represented by pink bars, hydrogen export is represented by yellow bars, the carbon intensity of imported electricity is indicated by blue lines, and H_2 storage tank inventories are represented by green areas.

The production plant that exports 500 kg/h of hydrogen without proper management has a carbon footprint of 458 490 lb/d (207.9 tpd) CO_2. However, with optimal management, the carbon footprint drops to 411 770 lb/d (186.8 tpd). Leading to a significant 10% reduction in GHG emissions. Assuming a constant electricity price, this reduction does not compromise hydrogen export rates or operating costs.

The optimiser/system uses the storage tank capacity to determine over-production of hydrogen during periods of low-carbon intensity of electrical power (i.e., accumulating excess hydrogen in the storage tank) and under-production during periods of high-carbon intensity of electrical power (exporting hydrogen from the storage tank). Therefore, the net carbon footprint is reduced.

Conclusion: charting a sustainable energy future

The energy sector is at a crucial turning point, driven by the urgent need to address escalating GHG emissions. With fossil fuel emissions surpassing 34 billion tpy, companies are recognising the imperative to transition towards cleaner energy sources.

While renewable energy shows promise, it cannot be the sole solution due to its variability and limited contribution to overall energy needs. To effectively decarbonise the economy, incorporating renewable resources and green hydrogen into the industrial energy mix is crucial. However, this integration requires higher investment and complex management systems.

Advanced technologies like EMS and digital twins play a vital role in enabling proactive energy management and optimising both conventional and renewable energy systems.

The case studies presented in this article have demonstrated the transformative impact of EMS, including significant cost reductions and carbon footprint reductions without compromising production rates or operating costs. By adopting these advanced technologies, companies can navigate the complexity of the energy landscape and contribute to decarbonise the energy ecosystem.

References

1. https://www.weforum.org/agenda/2022/11/visualizing-changes-carbon-dioxide-emissions-since-1900/#:~:text=However%2C%20with%20the%20increased%20use,tonnes%20of%20CO%E2%82%82%20each%20year.
2. https://press.spglobal.com/2024-01-22-TOP-10-Trends-in-Clean-Energy-Technology-in-2024-S-P-Global-Commodity-Insights
3. RUIZ, J., and RUIZ, C., 'Optimal energy and emissions management during energy transition', https://decarbonisationtechnology.com/article/29/optimal-energy-and-emissions-management-during-energy-transition, (2022).
4. https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/Renewable%20Energy%20Guidance%20Document%20-%20September%202021.pdf
5. RUIZ, J. P., 'Decision-Making Tool for the Optimal Planning and Scheduling of Utility Assets', AICHE Spring Meeting, San Antonio, Texas, US, (2017).
6. AEGERTER, R., LAM, J., ADARME, R., MAMPRIN, J., RUIZ, C., and MONTAGNA, P., (KBC), 'Online Monitoring and Optimization of the Energy System at Motiva Port Arthur Refinery', Industrial Energy Technology Conference (IETC), New Orleans, US, (2018).