REFHYNE

CLEAN REFINERY HYDROGEN FOR EUROPE

Lessons Learnt

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Dissemination Level: [PU]

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Delays to the project have been caused by several factors including, but not limited to, COVID-19

Design Phase

Delays were caused by the need to overcome barriers and knowledge gaps by industrial partners.

The first of a kind nature of the project resulted in ITM needing to learn fundamental refinery design rules, while Shell needed to adapt to electrolyser design rules.

Overcoming these hurdles and identifying where to devaite from traditional industry rules added time to the project.

Manufacturing Phase

The COVID-19 Pandemic began during the manufacturing phase of the project and led to signficiant delays.

Multiple national lock downs in the UK impacted the building and Factory Assurance Testing of electrolyser system parts at the ITM site.

Equipment suppliers were also heavily delayed and face-to-face meetings were halted due to travel restrictions.

Execution Phase

The execution phase was further delayed by COVID-19 as travel restrictions limited ITM's access to the site in Germany.

As a multi-national project, travel restrictions that prevented the entry of UK citizens into Germany had significant impacts on productivity

Building delays were also experienced as pipe suction lines were required to be rebuilt to accomodate unforseen changes.

The REFHYNE project has experience delays of around 6-9 months in system start up, excluding the impact of COVID-19. Delays during the design stage were largely caused by different approaches to the project from different parties, as there are often disparities between the usual methods of work between different experts, while the manufacturing and execution phases have been heavily impacted by COVID-19.

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Many obstacles have been faced due to the “first of a kind” nature of REFHYNE

The oil and gas industry is very mature and has established patterns to follow in projects. These have not applied to REFHYNE.

- An oil and gas industry project can ordinarily rely on proven technologies and well-established experience of large industrial sites. This gives a clear understanding of how to undertake the work.
- REFHYNE encompasses a maturing technology, so isn’t as developed as the rest of the industry. REFHYNE and other such projects are working to mature this technology from research stage to practical applications. This step is happening very fast and REFHYNE has been caught up in this.
- The Final Investment Decision was taken significantly earlier than normal project timelines, which required substantial additional design, engineering and project management work.

The use of pre-approved subcontractors has been a key learning.

- The project has benefited from using subcontractors that were pre-approved by both ITM and Shell.

ITM approached REFHYNE as an SME.

- ITM began the REFHYNE project with fewer than 80 staff and a business culture that reflected the needs or early technology innovation, contrasting with the mature culture of partners such as Shell.
- It was necessary to combine the approaches of mature organisations and SME culture to build a cross functional team.

It is important to acknowledge that future projects will also be first of their kind.

- REFHYNE has paved way for many future projects, but these will still be first of a kind in their own right and will continue to have steep learning curves
- E.g., the scale up to REFHYNE 2 requires work on an entirely different scale. Although this can build upon REFHYNE, there will continue to be “FOAK” challenges and obstacles due to the increasing scale of one order of magnitude.

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Traditional Oil and Gas project rules and Shell protocol did not apply, and new methods needed to be established

The REFHYNE project developed a packaged system guided by but not following Shell Design and Engineering Practices (DEPs).

Shell Design and Engineering Practices are Shell's internal technical standards for all aspects of design, specification and construction of equipment and are normally required to be used and followed by any organisation executing any work for, or on behalf of, Shell.

It was agreed in 2019 that REFHYNE constituted a self-contained 'packaged unit' and DEPs would not apply to the design and construction of the system.

The decision not to follow Shell DEPs was reached approximately 12 months into the REFHYNE project. Had this been agreed earlier in the design stage, considerable time would have been saved.

The Oil and Gas industry is having to rapidly accelerate processes, which REFHYNE has helped to provide learnings on.

In traditional Oil and Gas projects, all testing and checks of equipment would be carried upfront. This was reversed in the REFHYNE project to align with Clean Hydrogen Partnership processes, which increases the risk levels.

Shell have had to adapt to this new approach, and work on a faster timescale than in other typical projects. REFHYNE, and the energy transition, is resulting in a change in typical Oil and Gas industry mindsets.

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REFHYNE has brought together SME culture from ITM and mature industry culture from Shell and has managed to build a functional, cross company team

Despite differences between partners, the REFHYNE consortium has successfully brought together SME and mature industry cultures to achieve the project goals. This has been achieved through the following steps:

Structure	Extensive face-to-face discussions and joint learning helped to bring the team together. Partners adopted a "**one project one team**" approach to bring together expertise from industrial partners.
Planning	A Joint Plan and clear critical paths were established and monitored to create clear tasks. Parallel construction and manufacturing activities between Shell, ITM and suppliers was carried out successfully.
Processes	Weekly project management calls took place between partners. An early and prompt start of the preparation stage involving key contractors helped to progress the project.

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There have been several integration challenges due to the "first of a kind" nature of REFHYNE

The REFHYNE project required the integration of a first-of-a-kind 10MW electrolyser, contained in a dedicated building, into a working refinery system.

- REFHYNE required a move towards a 'packaged unit', making it important to recognise the limits of industry rules
- Prior to the project, the effort and changes that would be required to carry this out were not really understood and estimated
- The project timeline was determined by the primary source of funding (FCH JU) which was mirrored in the ITM-SDO bilateral contract. Although not known at the time, this timeline was unrealistic for a project of this magnitude.

The up-scaling of all system elements was necessary which had not been done before and required significant work

- All balance of plant systems, H2 & O2 / water separation, cooling system, H2 dehydration was required.
- All internal and external interconnecting pipework, cables and supporting steel structures required detailed structural analysis. This included wind and seismic loading analysis.
- This led to additional time and costs, particularly as it took time to agree on legal contracts between parties.

Bespoke engineering work was needed outside of core electrolyser scope.

- There is a lack of awareness that specific engineering is required for different tasks– even equipment. Bespoke work has been required for different stages and processes.
- The project needed to bring together a number of components in an optimised way, which represented a challenge.
    - Case study: decision on whether to use containers or buildings. Engineering required is impacted when these decisions are made. Normally parts are manufactured in Sheffield, UK and then shipped to customer site. Therefore, constrains are imposed by the containers size, which wasn't suitable for a project of this size. Lots of iterations were needed to find a solution.

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There are key differences between REFHYNE and other ‘traditional’ projects in the industry

The mindset of oil and gas industries has had to change, and the REFHYNE project has differed significantly from ‘traditional’ oil and gas projects.

Key differences:

- The electrolyser system requires ultra pure water, which can only be guaranteed using plastic pipework. This differs from the steel that Shell would ordinarily use on site.
  - There are no Shell piping classes for non-metallic pipes and there was no knowledge or experience in the use of plastic pipe materials on site.
  - It was necessary to provide multiple justifications for the use of plastic materials to multiple stakeholders and provide documents to justify the design decisions.
  - It was also necessary to provide detailed stress analysis of all pipe sections and vessels, and finite element analysis of supporting steel structures incorporating wind and seismic loading during the design stage to confirm the designs were fit for purpose.
  - The hydrogen pipework is <50mm and as such is classed as ‘tubing’ not pipework. There is no requirement to have a pipe class for tubing.

- Lots of electrical thinking was needed
  - Use of the AC / DC power supply rectifiers of the type used for electrolyser systems was unfamiliar to many stakeholders in the refinery

There is a need to disaggregate and then standardise. This will take time to learn and achieve completely.

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There have been several technical learnings from the project

Software

Large scale Distributed Control System (DCS) was integrated into the existing refinery system(s)

This had not been initially planned or agreed upon based on the project bid document and Technical Description of Supply, and therefore added considerable time to the design phase of the project.

Following an uncertain start, this became an excellent collaboration between Shell and ITM technical experts and has been a valuable learning experience

Water

The electrolyser system requires ultra pure water, which can only be guaranteed using plastic pipework.

There are no Shell piping classes for non-metallic pipes.

It was necessary to provide multiple justifications for the use of plastic materials to multiple stakeholders and provide documents to justify the design decisions as this differed from ‘traditional’ industry projects.

Permitting

A permit was issued for the construction and operation of the plant. Plant parts covered by the permit: Electrolysers, tanks, pumps, cooling systems, transformers, switching station, pipe bridges

The permit was limited to a maximum of three years operation following commissioning as it is defined as a test facility.

Approval for the test facility expires in June 2024. The deadline can be extended by a further year.

Plans envisage continuing to operate the plant after which public proceedings are required.

A dedicated approval procedures for 'energy transition' projects such as REFHYNE would lead to simpler and faster approvals.

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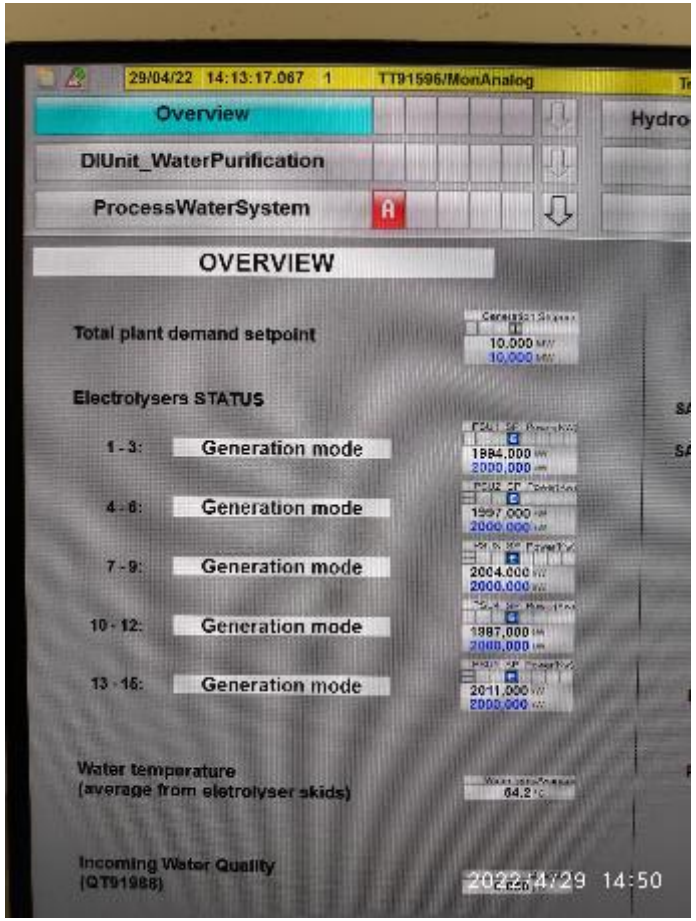
Implementing ITM Siemens DCS in the plantwide Shell Honeywell system proved challenging

Distributed control system (DCS) and communication between ITM system (Siemens DCS) and refinery system (Honeywell DCS) has been successful

- Large scale DCS was successfully integrated into the existing refinery systems
  - This was not planned or agreed upon in the Technical Description of Supply but led to excellent collaboration between Shell and ITM technical experts and was a valuable learning experience
- This added considerable time and delays to the design phase of the project and could have been more efficient had this been agreed upon at earlier stages.

Extensive collaborative work has been undertaken on alarm suppression

- It has been a valuable learning experience to identify important alarms to prevent alerts from activating excessively.
- Ordinarily ITM would handle alarms live, but due to large scale nature of REFHYNE there could be >100 alarms at any given time.
- Workshops were held between ITM and Shell to sort through these alarms and prevent uneccessary notifications.



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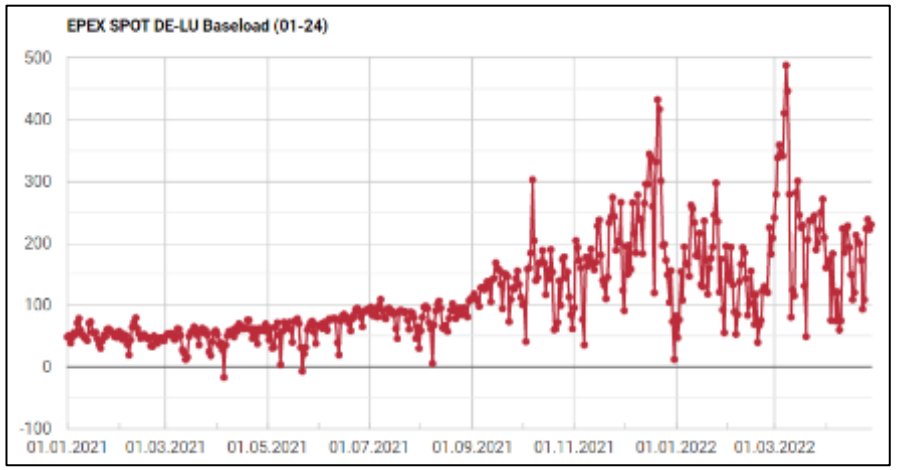
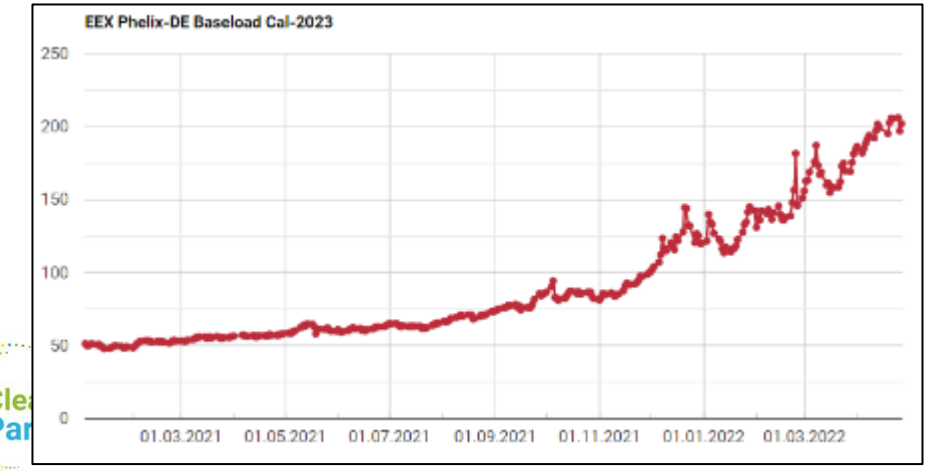
Energy price developments since Jan 2021

Currently, energy prices for power and natural gas, as well as forwards, are at **high levels**. This has and will continue impacting the marginal cost of electrolyser H_2.

Power

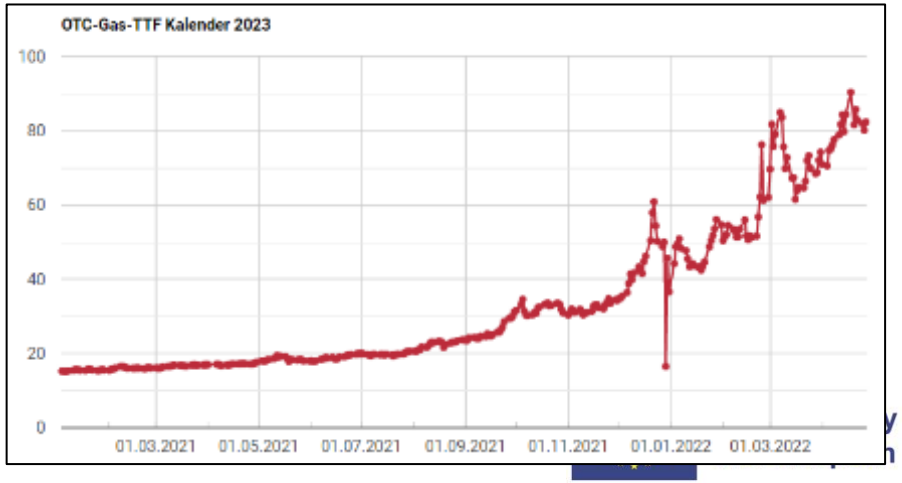


Day Ahead prices



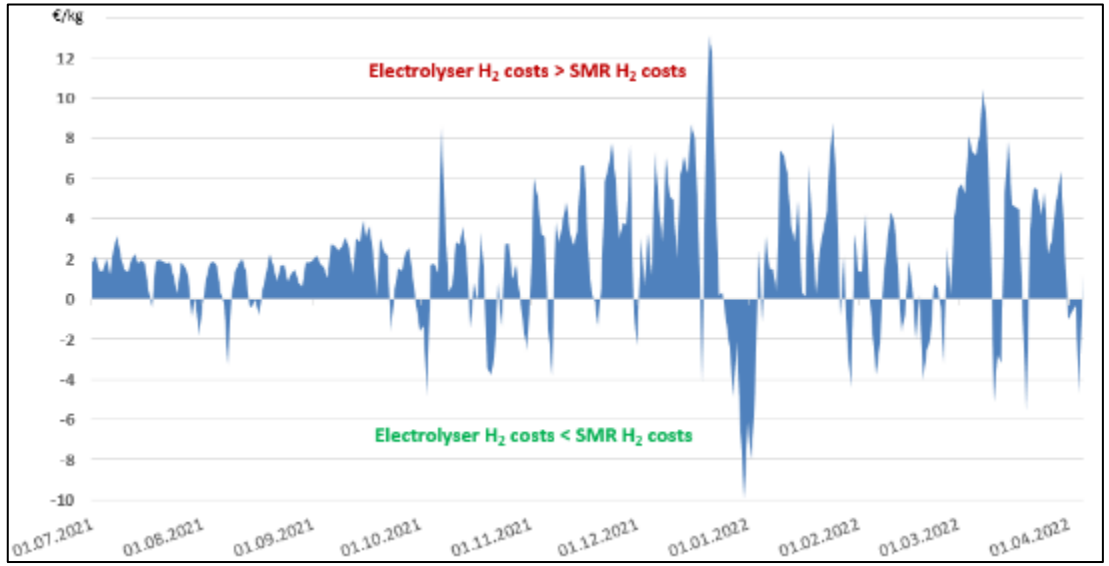
Forwards
Calendar year 2023

Natural gas

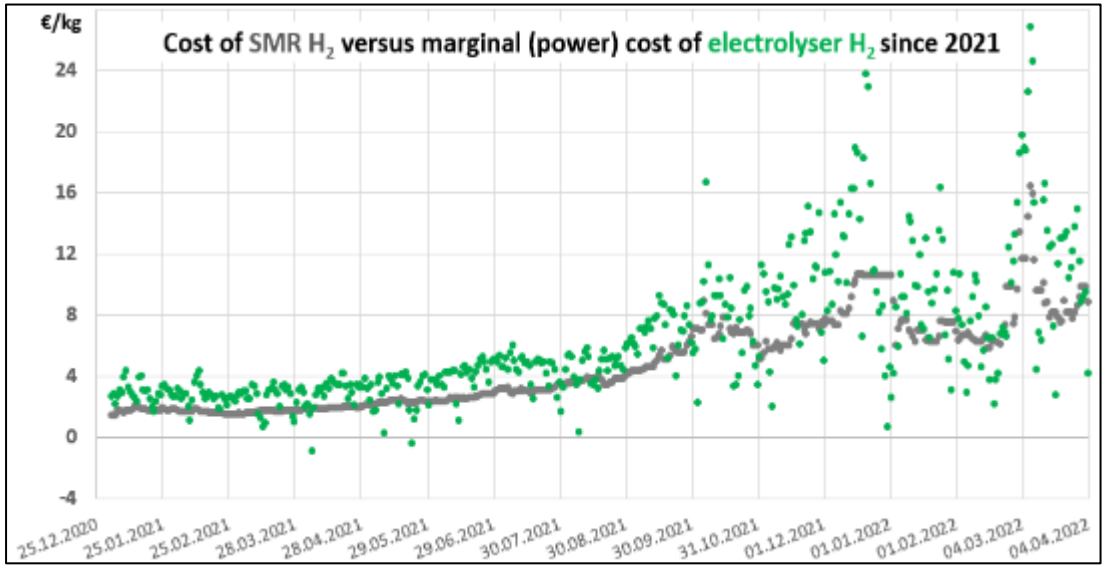


Marginal cost of electrolyser H_2 versus SMR H_2

- The number of hours where power is cheaper than natural gas + CO_2 would have limited utilisation factor of electrolyser operation to only 10% in 2021



- In addition, since mid-2021 and increase in price delta between electrolyser H_2 and SMR H_2 has been observed



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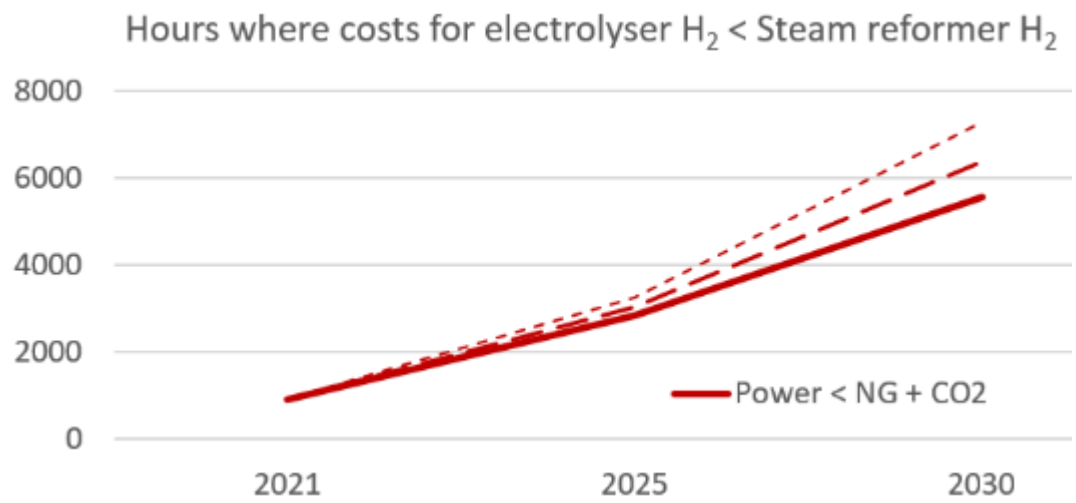
Outlook for electrolyser operation

- Replacement of SMR H_2 is only economically viable in hours of **high renewable power generation and cheap power prices**
- The ambitious renewable target of **80% by 2030** in Germany will lead to more hours of low electricity prices
- Additional uncertainty linked to the Delegated act (Article 27 (3) Renewable Energy Directive II), not expected before October 2022.
  - Requirements for fully renewable electricity not defined yet
  - Additional value of renewable fuel of non biological origin not known yet

Generation > Demand → Price cannibalisation

Renewable goals	2021	2025	→ **2030**	→ 2035
Solar:	59	104	**200**	300 GW
Onshore Wind:	56	78	**127**	177 GW
Offshore Wind:	8	11	**30**	50 GW



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Electricity procurement is being negatively impacted by the delay in the publications of regulations such as RED II.

The REFHYNE electricity procurement strategy depends on requirements of RED II.

This has been heavily delayed and is not yet finalised.

If supply has to come from renewable PPAs from **new** assets **not being subsidized** with **hourly matching** being located in the **same bidding** zone only

- No availability of new German Offshore Wind before end of 2026
- No access to German Onshore Wind, still under renewable subsidy scheme
- Only access to German new PV
- Limitation of about 1100 full load hours if only access to new PV

Renewable PPAs only offered at fixed- or floor prices → no optionality of optimized electricity sourcing, tenor 10 years or longer for new renewable assets.

April 2022 market feedback:

- German offshore wind from 2026/27 onwards: > 70 €/MWh
- German PV from 2023 onwards: > 80 €/MWh

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Options for power sourcing in REFHYNE

Option 1 (high Full Load hours (FLH), high power price, no opportunity for price optimization)

- Renewable PPA (only fixed prices)
  - Offshore Wind + PV: 5000 FLH (but very limited availability of German Offshore Wind) + 2300 FLH from spot market if mix & match is not limited by RES-E share, otherwise only 5000 PPA FLH
  - Onshore Wind + PV: 4000 FLH + 1850 FLH from the spot market if mix & match is not limited by RES-E share, current RES-E is about equivalent to 4000 FLH

Option 2 (low FLH, low power prices, price optimized sourcing)

- Sourcing from spot market if power is < 20 €/MWh or power is < 0,36 * CO2 allowances price (0,36 t/MWh * 83,33 €/t = 30 €/MWh)
- FLH hours depends very much on growing RES-E share

Mixing of Option 1 and Option 2 is possible, e.g. 50% PPA sourcing, 50% price optimized spot sourcing

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Conclusions

- **It is important to be ambitious but agree realistic timescales for a first-of-a-kind project.**
  - Some delays could have been prevented if expectations of timescales were more realistic.
- **Building a collaborative cross-functional team including all necessary disciplines from all participating companies has been essential for REFHYNE's success.**
  - For example, design reviews frequently took too long, due to multiple conflicting opinions and incompatibility between IT systems e.g., 3D model reviews
- **It is important to establish open communications between all disciplines**
  - Be prepared to make pragmatic decisions to maintain cost forecast / benefit / schedule
- **Face-to-face meetings are always the most productive**
  - Face-to-face meetings helps to solve language barrier problems and helps when working with unfamiliar technology
- **Work together and collaborate to solve problems; "one project = one team"**
  - REFHYNE has brought together a united and experienced team
- **It is important to acknowledge that future projects will also be first of their kind.**
  - REFHYNE has paved way for many future projects, but these will still be first of a kind in their own right and will continue to have steep learning curves

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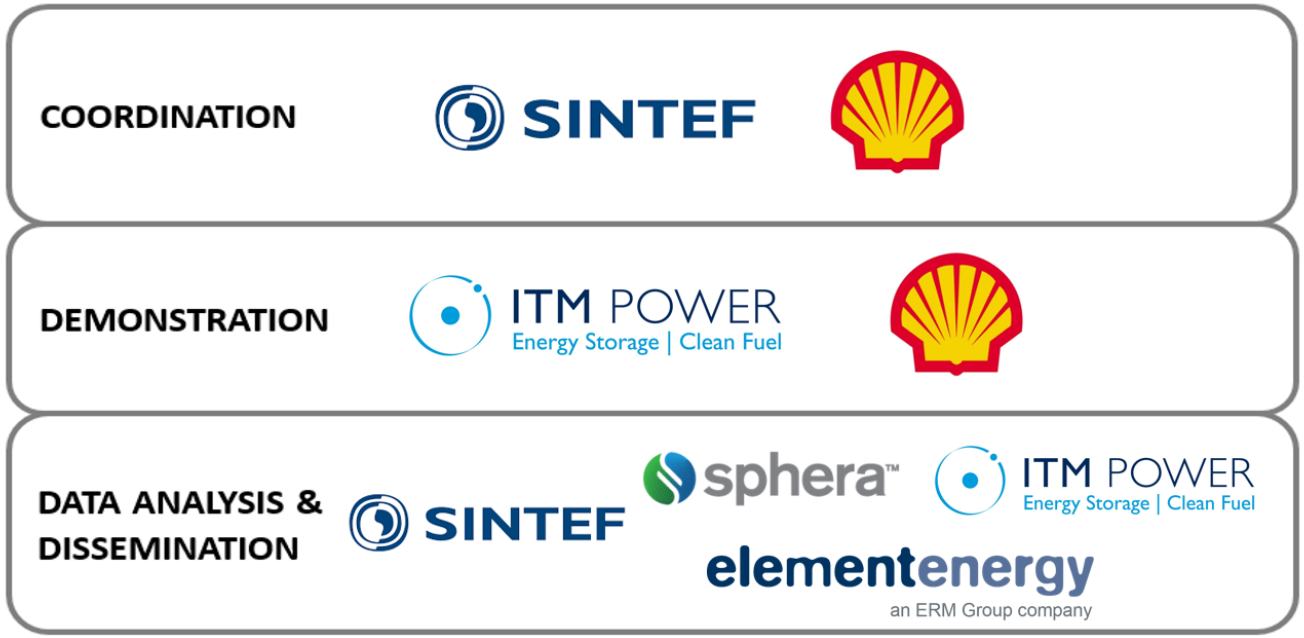

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