Techno-economic feasibility study of the Iron Fuel ecosystem

JUNE 2020

Based on the results of a techno-economic feasibility study performed by Berenschot

Berenschot

The Lighthouse Metal Power consortium, a project consortium funded by the Province of Noord-Brabant, aims to scale up the Iron Fuel technology. This multidisciplinary 2-year project that started in January 2019 focusses on technological, economical and societal development of the Iron Fuel technology. The results based on a techno-economic feasibility study performed by Berenschot and funded by Enpuls, and the future steps by the Lighthouse Metal Power consortium are presented in this contribution.

Iron Fuel development

The world is producing more renewable energy than ever before. The renewable generation capacity is growing day by day and this trend is strengthening as the business case of investing in renewable energy generation is improving. This, however, comes with challenges as for the spatial and temporal discrepancy between energy demand and supply large amounts of energy will need to be stored and transported around the globe. Therefore, the need is arising for energy carriers that are easy to store and transport. Metal Fuels[1] can be such an energy carrier, and the consortium focusses primarily on Iron, as it can overcome these challenges in a safe and cost-effective way.

Metal Fuels has gained more attention at TU/e since 2015, when metals as sustainable energy carriers were discussed in an international research project. Not much later, Bergthorson et al. published a study regarding metal powders as a viable long-term replacement for fossil fuels[2]. Up to the start of this Lighthouse Metal Power project in January 2019, which is co-funded by the province Noord-Brabant, the focus was primarily on what was then identified as the biggest hurdle: a stable combustion and particle collection system on a near industrial scale. An important objective of this project is the prototype Iron fueled boiler system with a capacity of 100 kWth that is realized by the project partners and is demonstrated at the Swinkels Brewery in October 2020. The system allows further technological development of the Iron Fuel technology at the Metalot Future Energy Lab in Crannock (NB).

With this project, the consortium set another important objective, i.e. to develop the Iron Fuel business. Enpuls, part of Enexis Group, acted as the work package leader for this part of the project and engaged Berenschot to perform a techno-economic feasibility study together with TU/e and student team SOLID. The goal of this study was to identify the most promising or commercial interesting application areas for Iron Fuels and its role in the energy market, and to advise on the route forward. Berenschot addressed this by organizing two steps. In the first qualitative step, the visions and assumptions regarding the development of Iron Fuels by the consortium were made explicit by defining distinct cases. In the second quantitative step, the cost effectiveness and competitiveness of the Iron Fuel cases were analyzed by calculating the total value chain costs. Efficiencies are reflected in these costs. Through a sensitivity analysis, insight was provided on opportunities to improve the business case.

Business opportunities

Berenschot expects that promising and commercially interesting applications of Iron Fuel in the Dutch energy storage market are to appear in the post-2030 era. The total energy storage market in the Netherlands is assumed to be around 10 – 35 TWh. The need for storage in the future emerges from different economic sectors with different demands and characteristics. Based on the characteristics of iron powder, three distinct cases of foreseeable applications and scales of applications of the Iron Fuel technology can be foreseen, i.e.:

1 https://www.youtube.com/watch?v=8rm6kc202PE

2 https://doi.org/10.1016/j.apenergy.2015.09.037

1) Non intermittent heat production (mid-scale for the process industry or district heating)
2) Non intermittent electricity production (large scale central production)
3) Power to propulsion (small scale for sea vessels for international shipping)

Calculating the total value chain costs of the Iron Fuel technology for these applications and comparing them with costs of its most likely competitor allows a quantitative comparison. At the same time, prognosing future costs is highly subjectable to technological development, governmental policies and other factors. For example, in this comparison it is assumed that post 2030 a nationwide hydrogen backbone is available with sufficient hydrogen storage in salt caverns and projections on Iron Fuel technology component costs on a commercial scale. Bearing that in mind and subject to a certain margin, the quantitative model of Berenschot allowed the consortium to compare the total value chain cost of different cases.

Non intermittent heat production

A comparison of the first case, a 10 MW non intermittent boiler for heat production in process industry or district heating, is presented in Figure 1. The calculation are based on the work of Berenschot and performed by the consortium. Iron Fuel (Metal Fuel) production, storage and combustion is compared to hydrogen production, storage and combustion for an off-grid case in the Netherlands (H2 tank (NL)), an on-grid case (H2 Salt cavern (NL)), and when energy is imported from countries with lower renewable energy prices like Spain and the Middle East (Qatar) in the form of Ammonia. Ammonia is considered to be the most likely competitor when overseas transportation of energy is required but depending on the type of boiler requires reconversion back to hydrogen before it can be combusted.

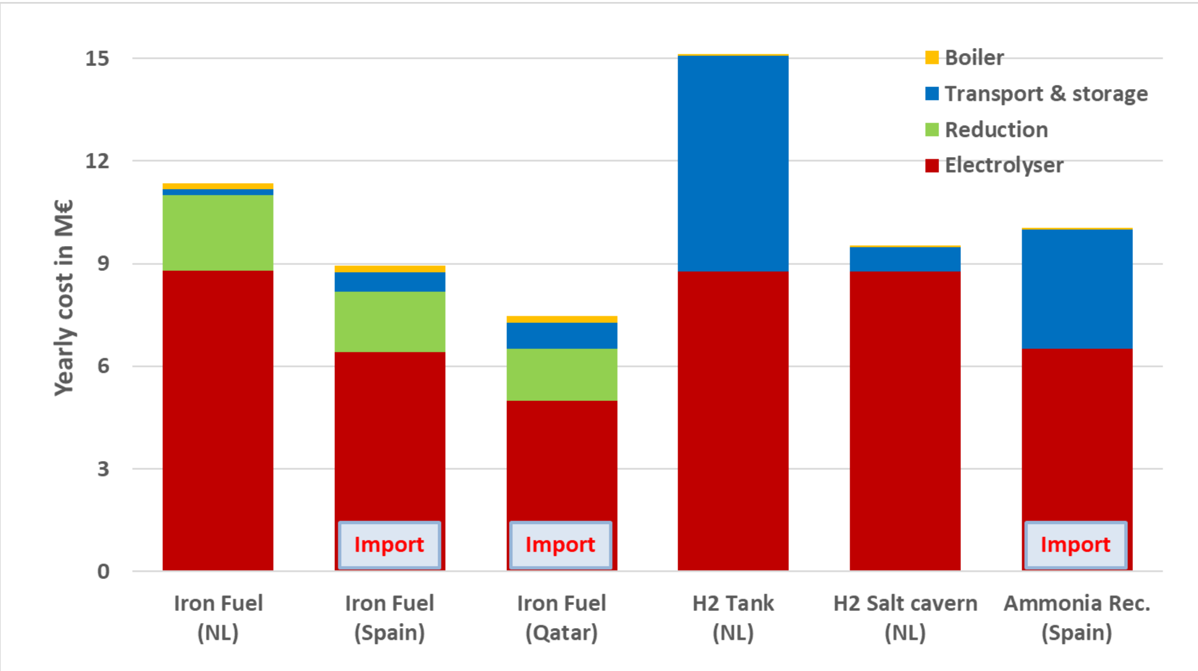

Figure 1: Yearly cost comparison of the total value chain for a 10 MW boiler running on iron powder, hydrogen or ammonia where the energy carriers are produced either in the Netherlands, Spain or Middle East (Qatar).

The value chain costs are divided into four parts. The first part is that of the electrolysis costs and highly dependent on the renewable energy price. In line with the IEA prognosis[3], hydrogen prices of 3 €/kg in NL, 2.2 €/kg in Spain and 1.7 €/kg in the Middle East (Qatar) are used. The second part, reduction, is unique for Iron Fuel and corresponds to the conversion step to store the renewable energy in green hydrogen in iron powder. Thirdly is transportation and storage. For the local Dutch cases, no transportation is included. For Iron Fuel, the transportation of iron powder to the Netherlands, but also the transportation of iron oxides back to the regeneration plant are included. For Ammonia, this is a one-way trip. Reconversion of Ammonia back to hydrogen is also included in this part. Lastly, the boiler, although being an important technological aspect, has little impact on the total value chain costs.

From Figure 1 it can be concluded that when looking at a sheer Dutch case, and when a user is connected to the hydrogen grid, Iron Fuel is less attractive in utter economical perspective. However, an extensive hydrogen grid is expensive and not all end users will be connected to such a grid. Then, when comparing it to off-grid storage of energy, Iron Fuel can be an interesting option. However, if the iron powder can be produced at locations with cheaper hydrogen prices, the price difference weighs up to the transportation and conversion cost and import of energy becomes interesting even undercutting hydrogen grid solutions. Especially towards 2050, when the entire energy system including industry must be carbon neutral, energy import will play a major role. Therefore, energy system design and integration of various systems will have a big influence on the attractiveness of Iron Fuel.

Non intermittent electricity production

Non-intermittent electricity production, the second case, is especially interesting when coal fired power plants can be retrofitted to Iron Fuel plants. These solid fuel power plants have slightly lower efficiency than hydrogen fired combined cycled power plants and thus require more primary energy input. Undercutting the production costs of a hydrogen power plant in the Netherlands would be possible if the Iron Fuel can be produced at sufficiently low costs, e.g. in the Middle East. Moreover, an Iron Fueled power plant requires a significant amount of Iron powder, as also stated before by Dirven et al.[4], which would in its turn require a significant increase in the Iron powder market. Therefore, to pursue fast introduction of Iron Fuel technology, retrofitting solid fuel power plants should follow the introduction of the technology in heat intensive applications.

Power to propulsion

The third case, using Iron Fuel to propel ships, was assisted by a parallel MIIP project[5]. Due to the relatively high weight of Iron Fuel for ships, the technology initially appears to be the most suitable for ships with a high payload / displacement ratio such as inland vessels and bulk carriers. To develop the technology to a level required for such applications, on-land development of an Iron Fuel ecosystem and fundamental technology such as boiler design and dense efficient power cycle design is recommended.

The way onwards

The exact point in time when Iron Fuel becomes economically feasible is highly dependent on governmental policies affecting fossil fuels and sustainable energy technologies, as well as other factors such as progress in technological development. Post 2030, natural gas prices will likely rise to levels that are decreasingly acceptable for, and threatening, the business case of natural gas-fired CHPs and peak boilers, while TRL and CapEx for Iron Fuel CHP plants and boilers can be expected to be improved. Therefore, application of Iron Fuel for baseload and peak heat supply in the mid-scale process industry and district heating are considered as potentially interesting first applications. Following the results of the feasibility

3 https://www.iea.org/reports/the-future-of-hydrogen
4 https://doi.org/10.1016/j.seta.2018.09.003
5 https://www.mkc-net.nl/library/documents/1157/

study, the consortium formulated high potential business opportunities for Iron Fuel in order of application:

1) Off grid – or grid supporting – high & medium heat intensive applications,
2) Transporting (and using) renewable energy from energy dense locations to energy scarce locations with medium to long distance for heat and power generation, and
3) Expand technology to large scale power plants and maritime applications.

For Iron Fuel technology, the Iron Fuel production price seems to be leading and minimizing the production costs is crucial. The latter resulted in the start of a new project in January 2020, the Lighthouse Metal Energy Carrier project. In this project, Iron Fuel production, i.e. iron oxide reduction, technologies are compared, and a new technology is being developed with the aim to improve cycle efficiency and to reduce cycle costs. Furthermore, this project continues on developing the roadmap for Iron Fuel technology which will result in a program. Within this program, new projects, collaborations and research are defined to boost the acceptance of Iron Fuel technology and to accelerate the energy transition.

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