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GREEN HYDROGEN POTENTIAL

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Case study of a 100mw green hydrogen production facility integrated in the bardawil & sinai initiativ

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Case study of a 100MW green hydrogen production facility integrated in the Bardawil & Sinai Initiative

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Abstract- *A high-level investment business case is prepared for a 100 MW green hydrogen production facility as part of the Bardawil & Sinai Initiative. During the day a large solar PV plant produces the electricity which is directly used for green hydrogen production in the plant close to Al Arish. Simultaneously electricity is used to pump water into a large upper reservoir of hydro storage dam in Maghara mountain range. At night the water flows from the upper reservoir to a lower reservoir and generates power. This enables an autonomous and full continuous green hydrogen production in the Sinai.*

This project requires an estimated 1.6 B$ of investments and shall produce 14-16 kilotonnes of green hydrogen per year of approximately 15 $ / kg, given a 10% project IRR.

Index Terms- Green Hydrogen, Electrolysis, Pumped Hydro Storage, Sustainable Energy Infrastructure, Bardawil & Sinai Initiative (BSI), Hydrogen Export, Hydrogen Production Costs

I. INTRODUCTION

Green hydrogen is hydrogen produced primarily through electrolysis powered using renewable energy sources. This process splits water molecules into hydrogen and oxygen, with the hydrogen considered "green" because it's produced with minimal or zero greenhouse gas emissions, unlike hydrogen produced from fossil fuels.

The Bardawil & Sinai Initiative (BSI) is an evolving initiative comprising ecological restoration and fisheries enhancement at Lake Bardawil. Integrated development of the desert Sinai, supported through PPP with international collaborators and a long-term environmental regeneration—a visionary push to re-green the desert. These efforts aim to reinvigorate local ecosystems, boost the economy, enhance food security, and align with higher sustainability goals.

In addition to the many benefits of Bardawil & Sinai Initiative an extra opportunity arises in this geography: the development of a green hydrogen production site. The unique combination of abundant solar power, a mountain range nearby and the proximity of a port makes this a suitable location for green hydrogen by solar power only. Producing green hydrogen is relatively expensive compared to traditional grey hydrogen made from natural gas. However, if three geographical conditions are just in the sweet spot, green hydrogen can be produced at competitive ranges for the world hydrogen market.

Firstly, the geographical conditions must be able to supply a constant, reliable source of renewable energy. During the whole year the sun of the Sinai is very fierce and abundantly present.

Secondly, the hydrogen plant should be operational 24/7 for optimal plant performance and price optimisation and therefore at night another renewable energy source is needed. Hydro dams are a very efficient way to store and release the abundant energy of the day during the night. The Maghara mountain range provides the natural height and topography to construct a lower and upper water storage reservoir.

At last, the hydrogen plant requires sufficient water for electrolysis and the proximity of a port to export the produced hydrogen to the rest of the world.

The next chapters describe the used technologies in more detail as well as the high-level investment business case analysis.

II. TECHNOLOGY OVERVIEW - GREEN HYDROGEN PRODUCTION BY SOLAR POWER ONLY

The concept combines three existing technologies into one powerful concept:

A. Solar power:

The Sinai is a very suitable spot for solar power production. At least 2300 kWh per square meter (GSA) of solar energy reaches the ground every year (compared to less than 1000 kWh per square meter in the Netherlands and Belgium). The solar panels also provide shade for the underlying crops and plants. Furthermore, the presence of the sun is very constant during the year.

B. Pumped-hydro-storage

For many decades large hydro dams are used as a very efficient way to store energy. This system operates with pumped hydro storage: a water reservoir at a high altitude is connected to a lower water reservoir via piping. To fill the reservoirs water is provided via pumps and piping from sea. (This contradicts with single reservoirs which are filled by water supplied by upstream sources). With the abundant electricity from the solar power farm, the water is pumped into to the upper reservoir. At night, when no solar power is available, the waterflow is reversed and flows downwards to the lower reservoirs, through the pumps which now operate as generators to make electricity. This electricity is used to keep the hydrogen plant operational during the night. In other words, the pumps, pipes and two reservoirs operate like a battery.

C. Green hydrogen production and export

At the hydrogen plant green hydrogen can be produced 24/7 by solar power during the day and by hydro power during the night. The plant has a 100 MW capacity, which is expected to become a standard unit size in the evolving hydrogen market. The plant is assumed to be located near the city of Al Arish, where sufficient labour is present and large elements for construction can be supplied by the port. In addition, transport of electricity is less costly than hydrogen (0.5 M EUR / km vs 2 M EUR / km)).
Figure 1. Schematic chart of the concept of pumped-storage hydrogen production

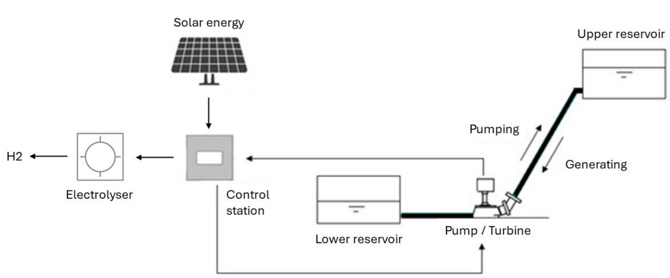

Figure 1. Schematic chart of the concept of pumped-storage hydrogen production

III. SYSTEM WORKINGS

A. Operation solar farm

- In Sinai the irradiation of the sun is fierce. A Megawatt of installed PV panels (peak MW or MWp) produces per year approximately 1.9 GWh of electricity.
- This solar farm needs approximately 633 MWp installed on 5.8 km2.
- Due to the suitable location the production is quite evenly distributed over the months. In the summer months a bit more sun is present, enabling more power to load the hydro dams. On average 45% of the solar power is directly send to the hydrogen plant, the other 55% is first stored in the hydro dams to be used at night at a later moment.

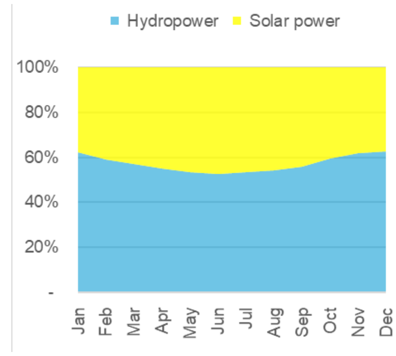

Figure 2: Hydrogen plant yearly power source

- The power of the PV panels is also used to power the pumps transporting water between the reservoirs
- To optimise the size of the converters and substations, peak shaving can be applied to reduce CAPEX. During the hottest hours of the day no more PV power is required than at most 400 MWe

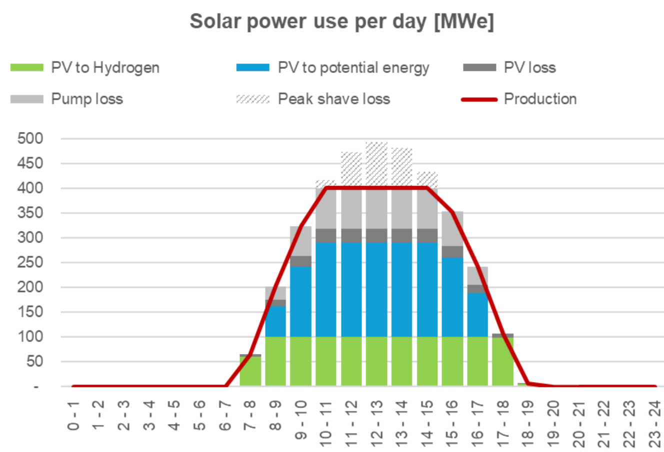

Figure 3: Usage of electricity production on average day

B. Operation pumped storage reservoirs

The pumped storage reservoirs are located in the Maghara mountain range. The upper and lower reservoirs are connected via piping. The pumps used for transporting the water into the upper reservoir are also used in reversed operation to generate power when water flows from the upper reservoir back in to the lower reservoir. Some conceptual design characteristics:

- Upper reservoir:
    - situated at 379m above sea level
    - containing 36 million m3 of water
    - Maximum depth of 40m
- Lower reservoir
    - 123m below the upper reservoir (256m MSL)
    - Storage capacity of 56 million m3 of water
    - Maximum depth of 30m

Water to fill the reservoir before operation and to balance evaporation losses is provided with piping from Lake Bardawil.

In this concept earthen dams are foreseen. These have lower investment requirements than the half-moon shaped concrete dams mostly used in Europe. Large scale earthen dams are used in many locations around the world and are a proven concept for storing water. They can be hundreds of meters long and up to 50m in height. Given the shallow slopes of the dams (1:4), a large footprint of the dam is required. The mountain range provides ample space for this.

C. Operation hydrogen plant

Globally limited data is available on large commercial hydrogen plants. 100MW capacity is assumed to a reasonable standard size for efficient operation. The plant needs to be supplied with a very constant supply of electricity to minimise stack degradation. Therefore, the combination with solar power and pumped hydro storage is very powerful.

The hydrogen is stored on site and to be exported by sea-going-vessels to the rest of the world.

IV. FINANCIAL INVESTMENT MODEL: THE BUSINESS CASE OF GREEN HYDROGEN FROM SINAI

A financial investment model was made to show the first feasibility of the green hydrogen concept powered by solar panels only, in the Sinai. The potential cost savings generated by combinations between the green hydrogen business case and the Bardawil & Sinai Initiative are discussed last paragraph.

To prove the autonomous value of the green hydrogen project this business case is a scoped as a stand-alone operating system

<u>In scope:</u>

- Large scale solar plant (5.75 km2 with 633 MWp)
- Two water reservoirs with earth dams and relevant piping and turbines / generators
- A hydrogen plant with electricity demand of 100 MW
    - Producing 14,000-15,000 tonnes of green hydrogen per year
- All additional investments
    - Overhead powerlines between solar park and pumps and plant
    - Electrical substations
    - Piping to supply reservoirs with water (to mitigate evaporation and for first fill)
    - Hydrogen loading facilities in Port Said
    - Financing cost

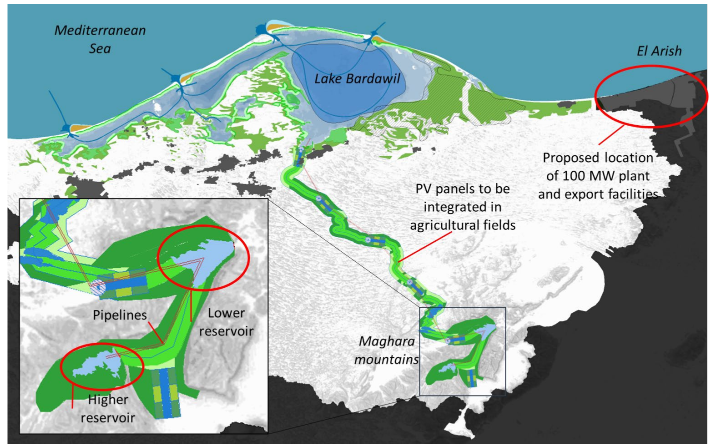

Figure 4: Map showing the conceptual regeneration masterplan of the Bardawil & Sinai Initiative (first 10 years), indicating the green hydrogen infrastructure

A high-level CAPEX estimate is created based on general design rules and available market data. In total 1,664 M$ is required, including all auxiliary works, financing costs and contingencies. The solar power plant (702 M$) and the hydrogen plant (589 M$) require most of the CAPEX investments.

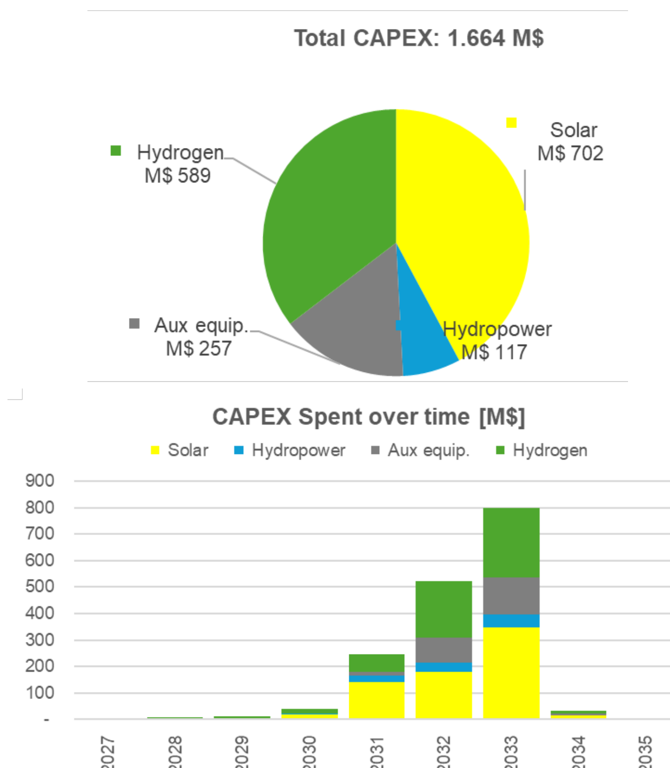

Figure 5: CAPEX overview (top) and CAPEX expense in first years of project (bottom)

<u>Timing</u>

Erecting the complete project in the Sinai is a complex task. It shall take many years to prepare, design, and construct. A rough timeline is composed: preparing, planning, permitting and design until 2030. Major construction works from 2031-2033, a year of commissioning and finally start operation in 2035. For the business case an operational lifetime of 25 years is assumed, when the end-of-life of the solar panels and hydrogen plant is reached.

Financial layout

The complete project is project financed with a leverage of 80% debt. Total debt is 1331 M$. With 20% equity a significant tickets size remains for the shareholders (333 M$).

A project IRR of 10% is demanded, given the large size of the project and the complexity of combining all technologies at this scale. Based on this project IRR the required wholesale price of the green hydrogen is calculated.

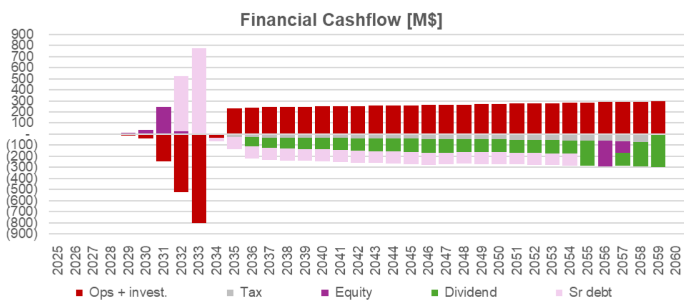

Figure 6: Cashflow overview full project

Equity

Based on an equity-first injection strategy, the shareholders should provide the required capital during the first years of design, research, permitting and first CAPEX expense (refer to purple bars in Figure 3 and Figure 4). Shareholders receive dividends if the minimum cash balance requirement of 5M$ is met.

From 2035 onwards, dividend distributions of on average 119 M$ per annum are expected. Shareholders equity is repaid at the end of the project. The current set-up of the project forecasts an equity IRR of 16%.

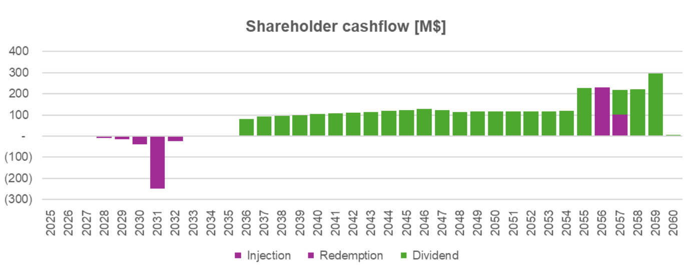

Figure 7: Equity injection, distributed dividends and equity redemption for shareholders

Debt

In this conceptual first stage a single tier of debt is assumed with a grace period of 3 years and a tenure period of 20 years afterwards. In a later stage of the project development a syndicate of suitable banks has to be selected. An assumed fixed all-in interest rate during the complete debt period (grace + repayment) is 5% per annum.

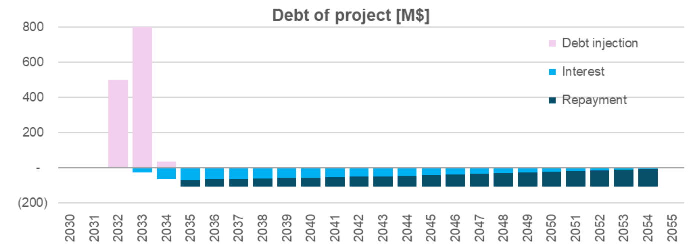

Figure 8: Debt injection, with an annuity repayment profile and fixed interest

OPEX

For all equipment Operating & Maintenance Cost (O&M) are included in the business case. Either as cost per installed MW or as fixed percentage of CAPEX. In total 18 M$ per annum (increasing to 28 M$ / annum due to inflation) is spent on O&M.

Revenue

All revenues in the project are generated at the hydrogen plant. To achieve the demand project IRR of 10% the hydrogen price should be around $ 15 / kg. (price level 2025, 2% inflation expected). Currently, there is no global trade in green hydrogen, but a global market shall slowly develop over time. It is hard to foresee whether $15 / kg is a globally competitive rate. However, there are estimates this could be within reasonable boundaries

The hydrogen plant produces between 14-16 kilotonnes of H_2 per annum in the first year, while this declines over time, due to degradation of the plant stack.

V. VALUABLE COMBINATIONS BY INTEGRATING GREEN HYDROGEN PRODUCTION IN LANDSCAPE REGENERATION

Potential valuable combinations with other activities in the BSI have not been included in the current financial assessment and could lead to improvement of the business case. The following activities or components could provide synergies between the green hydrogen production and the landscape regeneration works as stipulated in the BSI:

- A combined use of the water distribution infrastructure such as the water reservoirs, pipes and pumps. This infrastructure is also required for the resource-based dredging activities such as the transport of sediments, bioremediation of the soils and for the strategic evaporation efforts.
- A combined investment in the port facilities. Other activities in the BSI will require import and handling of large equipment as well as new export facilities for newly produced commodities
- Combined land use for solar panels can be used to provide shade for nurseries and agriculture, also known as agrivoltaics

VI. CONCLUSION

This high level study shows the feasibility of the project. While many things are still uncertain and need more research, the first indications show a feasible hydrogen production price in combination with a healthy project and equity return. Besides all financial benefits this projects generates more value to the BSI, also in terms of synergies by combining infrastructure and land-use.

VII. DISCUSSION AND RECOMMENDATIONS

This project is large, complex and ambitious, but also potentially very beneficial for shareholders, lenders and other stakeholders of BSI. More research is needed in the coming period for more detailed analysis.

- Further technical research and design is needed, to create a more detailed scope and budget of the required investments, in order to reduce the uncertainties and lower the contingencies.

- Market research is needed to gather more sense of interest of financing this type of complex, long term projects. A suitable syndicate of commercial banks and financial development institutes needs to be researched.

- A long-term offtake agreement with a large energy company could derisk the business case and improve the success-rate of the project. Many energy companies around the globe are looking for reliable, long term green hydrogen sourcing.

- Validation of the tenure duration, the grace periods and the interest rates are valuable for a better investment model.

- Hydro dams are notorious for their lengthy lead times. A realistic permitting and construction duration needs further research.

- Realistic modelling of stack degradation (included) and stack replacement (excluded) in large scale hydrogen plant needs further research.
- The global market for green hydrogen is developing slowly but has shall remain volatile for the coming years. Being an early player in this global market could prove to be beneficial.

VIII. ACKNOWLEDGMENT

"The Weather Makers Foundation" has been established to set the plan for a regenerated Sinai in motion. This document has been created in a series with several other articles that detail the plan on Regenerating the Sinai. These documents are distributed freely.

IX. REFERENCES

GSA Data obtained from the "Global Solar Atlas 2.0", a free, web-based application is developed and operated by the company Solargis s.r.o. on behalf of the World Bank Group, utilizing Solargis data, with funding provided by the Energy Sector Management Assistance Program (ESMAP).

International Hydropower Association (2024), World Hydropower Outlook

International Forum on Pumped Storage Hydropower (IFPSH), sept 2021, Pumped Storage Hydropower Capabilities and Costs,

International Renewable Energy Agency, Abu Dhabi.

IRENA (2021), Making the breakthrough: Green hydrogen policies and technology costs,

IRENA (2023) Renewable Power Generation Costs in 2023

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