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A collaboration between
KTH, Ovako, Volvo Trucks
and Hitachi Energy

How can a steel plant offer flexibility to the power grid?

- A Case Study at Ovako Hofors

KTH Railway Group's spring seminar 2025

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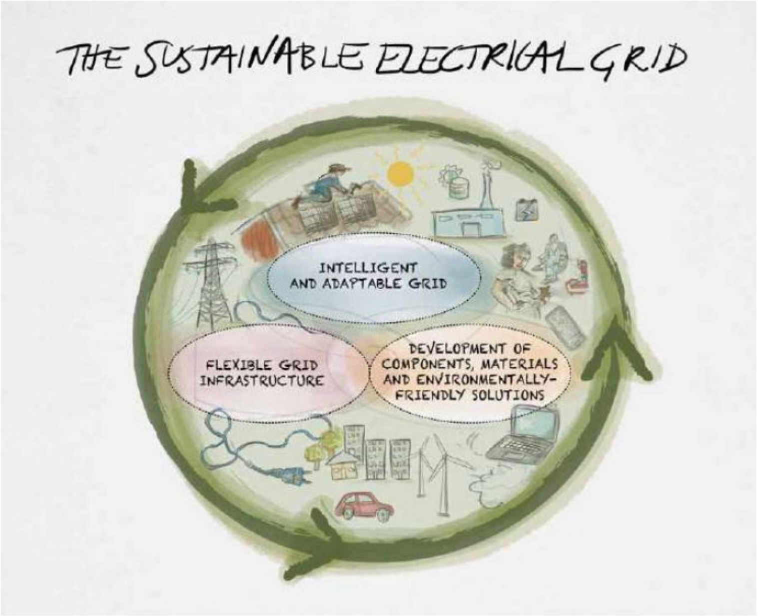
Overall objectives and sustainable electrical grid

The United Nations adopted a resolution for sustainable development with 17 goals (sustainable development goals – SDG) to be achieved by 2030.



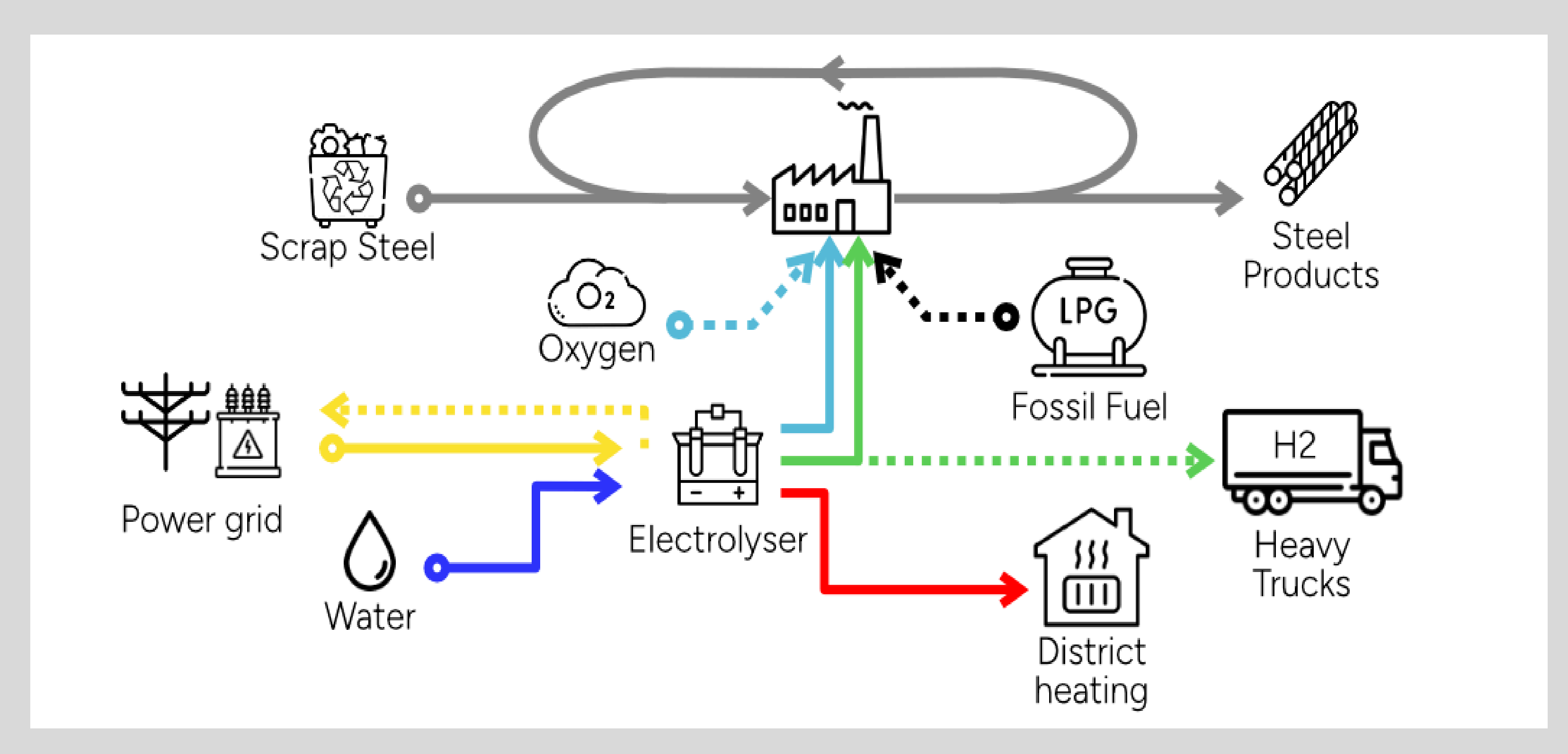
▲ *Figure 2:* GreenGrid's vision for a sustainable society with three interconnected thematic areas.

Bertling Tjernberg, L. (2022). *Sustainable electricity grids – a prerequisite for the energy system of the future*. In F. Brounéus & C. Duwig (Eds.), Towards the energy of the future – the invisible revolution behind the electrical socket.

Research in brief and main reference

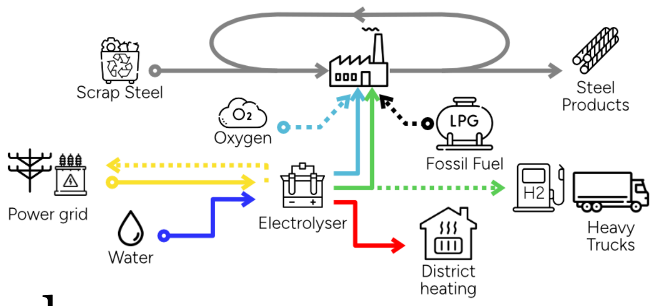
Example: Sector-coupling Green Hydrogen, Steel Production and Grid Flexibility

- **A Case Study at Ovako Hofors**
- Vinnova project with partners:
  - ✓ Ovako
  - ✓ Volvo Technology
  - ✓ Hitachi Energy
  - ✓ KTH
- More information: https://www.kth.se/profile/linab/page/hydrogen-power-grid-technologies-and-transportation



T. Elmfeldt, Y. Arafat, L. Bertling Tjernberg, A. Lugnet, and G. Nyström, Sector-coupling Green Hydrogen to Electrify Steel Production - A Case Study at Ovako Hofors, Proceedings of the International Conference on Probabilistic Methods Applied to Power Systems (PMAPS), Auckland, June 2024. from (Elmfeldt et al. 2024.)

Background (Hydrogen's Role in a Decarbonized Future)



❖ About **7 % of world CO2 emissions** come from steel production alone

❖ **Hydrogen** offers a **clean energy solution** that supports emissions reduction

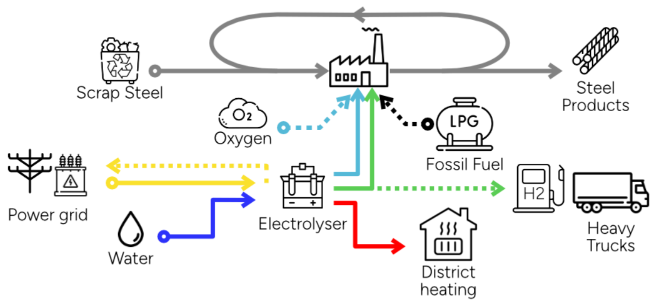
➢ **Current Key Applications of Hydrogen**

Pure H_2, can be used

- ❑ To refine oil and make products like ammonia for fertilizers
- ❑ To generate heat through combustion, or
- ❑ To generate electricity through a fuel cell

❖ **The burning of H_2 with O_2 creates only water**, and is therefore a good alternative to the burning of coal-based fuel that releases carbon dioxide (CO_2)

Background (How most Hydrogen is produced today ?)



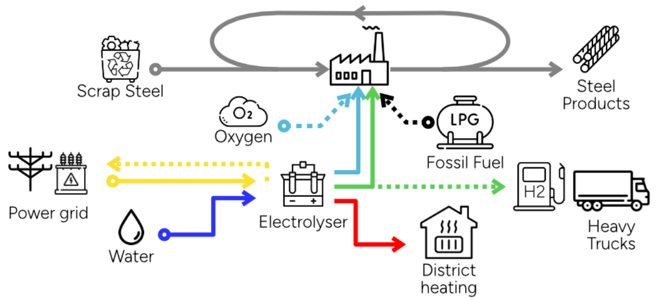
❖ **Most production of H2 today is based on natural gas and coal, that emits CO2**

➢ **Grey H_2** accounts for ¾th of current production and is made using Steam Methane Reforming (SMR) where fossil fuels such as natural gas or coal is used

➢ **Brown H_2** is produced using brown coal gasification (CG) represents most of the remaining H_2 production

❖ Only **Green H_2** (produced using renewable energy) and **Pink H2** (produced using nuclear energy) does not by design emit CO2, and therefore qualify as Renewable fuels of non-biological origin (RFNBO)

Background (Hydrogen Plant at Ovako Steel in Hofors)



- ❑ **There are 14 active steel plants in Sweden**
- ❑ **Ovako Steel** at Hofors uses the **Electric Arc Furnace** (EAF) method, based on **scrap steel**

  There are mainly three steps of steel production -

(1) Melting (This process has been Electrified)

(2) Heating up before hot-forming (This process has not been Electrified, LPG was used for Heat)

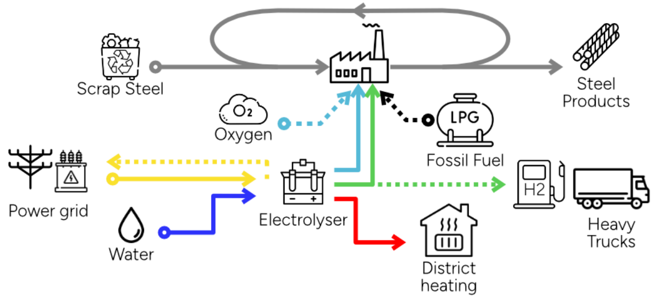
(3) Heat treatment (This process has also been Electrified)

- ❑ **In September 2023, the world's first hydrogen heating of steel was inaugurated at Ovako in Hofors**

➢ The 20 MW electrolyser generates 4000 m^3 of H_2 or 350 Kg of H_2

- Replacing LPG use in-place for the same demand
- Therefore, contributing to lower the CO_2 emissions

Background (Key International Hydrogen Initiatives)



- The **Paris Agreement (2016)** commits to limit global warming to well below 2°C, driving the transition away from fossil fuels
- **Renewable Energy Directive** of **2023** emphasizes the promotion of H2 usage and advancements in sustainable energy technologies
- The **European Green Deal (2020)** aims for climate neutrality by 2050, making hydrogen essential for decarbonizing industry and energy
- The **EU Hydrogen Strategy (2020)** sets the foundation for building a hydrogen economy, targeting 10 million tonnes of green hydrogen production by 2030
- The **European Clean Hydrogen Alliance (2022)** brings together industry, governments, and research bodies to support investment and infrastructure
- **Fit for 55 (2023),** emphasised a 55% reduction in GHG emissions by 2030 compared to 1990 levels
- **Alternative Fuels Infrastructure Regulation (AFIR) (2023)** envisions at least one H2 refueling stations available in every urban node and along the transport networks with a maximum distance of 200 km by 2030

Previous Studies and Contributions (Completed)

Vinnova Hydrogen Project Phase 1 (Pre-study)	Year	Scope
Research team (Prof. Lina, Dr. Yasir and Teo)	Oct 2023– Dec 2023	Pre-Study on wider system benefits and sector couplings for the 20 MW Electrolyser system of the Ovako, Hofors facility
Student Team's report as part of the Project course EI2525 (Sarika, Diviya, Erik and Mark)	Sept 2023– Dec 2023	Analysis on the CO_2 emission reduction due to the integration of Electrolyser and the income potential associated with the operation
Teo's further contribution	Jan 2024 – Mar 2024	Report writing, Application for Phase 2 of the Project, Master thesis supervision

Vinnova Hydrogen Project Phase 2	Year	Scope
Divya's Thesis	2024	Analysis on Electrolyzer and Battery systems powered by Renewable energy for 4 different electricity regions of Sweden
Sarika's Thesis	2024	Optimization of Green Hydrogen Production considering three different renewable power-supply scenarios: solar, wind, and a solar-wind hybrid
Ekansh Sharma's Interim Report	Oct 2024– Feb 2025	Analysis on the operational data (1 month data) of the Electrolyser system and Master thesis supervision

System overview

Hydrogen -based steel with Sector Couplings - World first facility in Hofors

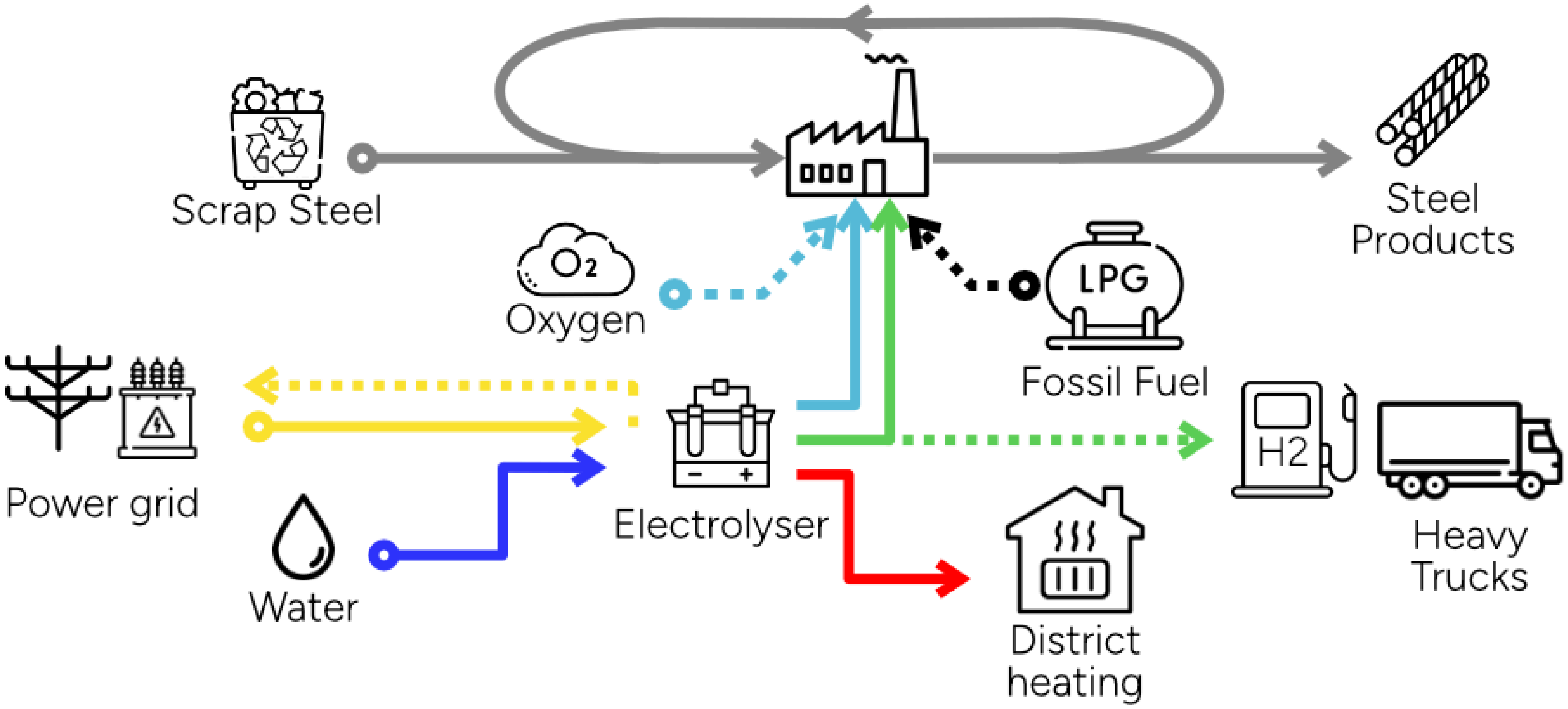


Fig: Amended from Elmfeldt et al. 2024

The Hofors facility

Electrolyser

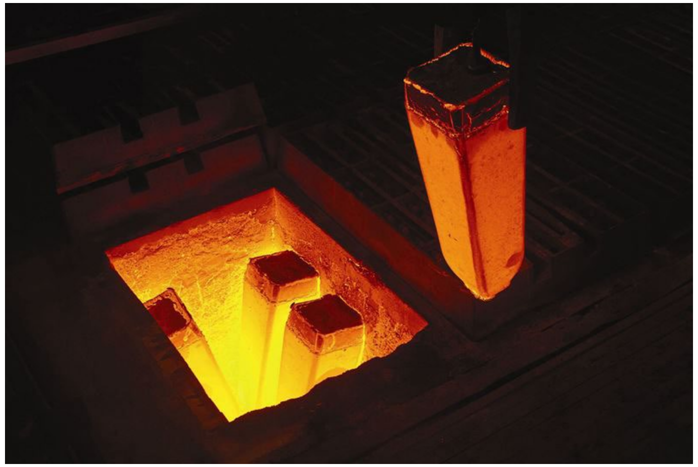
Heating Steel

Water

Electricity

H2

O2



Photos: Ovako

Furnaces at the Ovako Hofors Facility

(Without the Electrolyser)

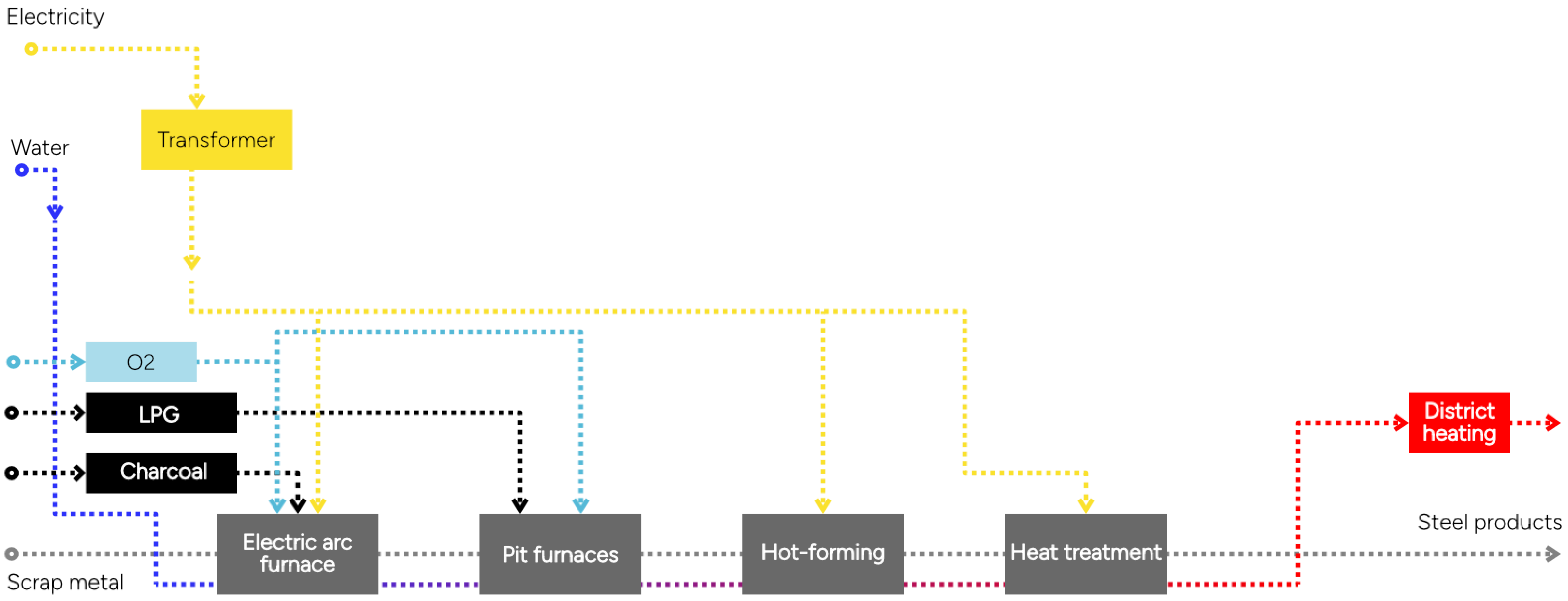


Fig: Amended from Elmfeldt et al. 2024

Hydrogen Production with Electrolyser at Ovako Hofors

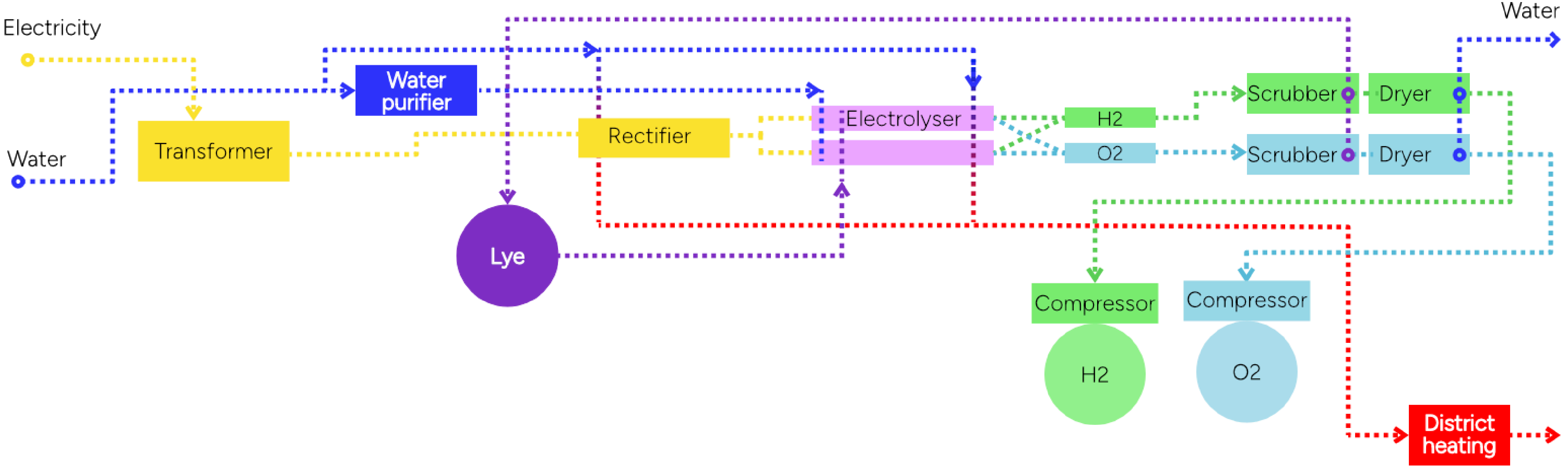


Fig: Amended from Elmfeldt et al. 2024

Furnaces at Ovako Hofors Facility

(Including the Electrolyser)

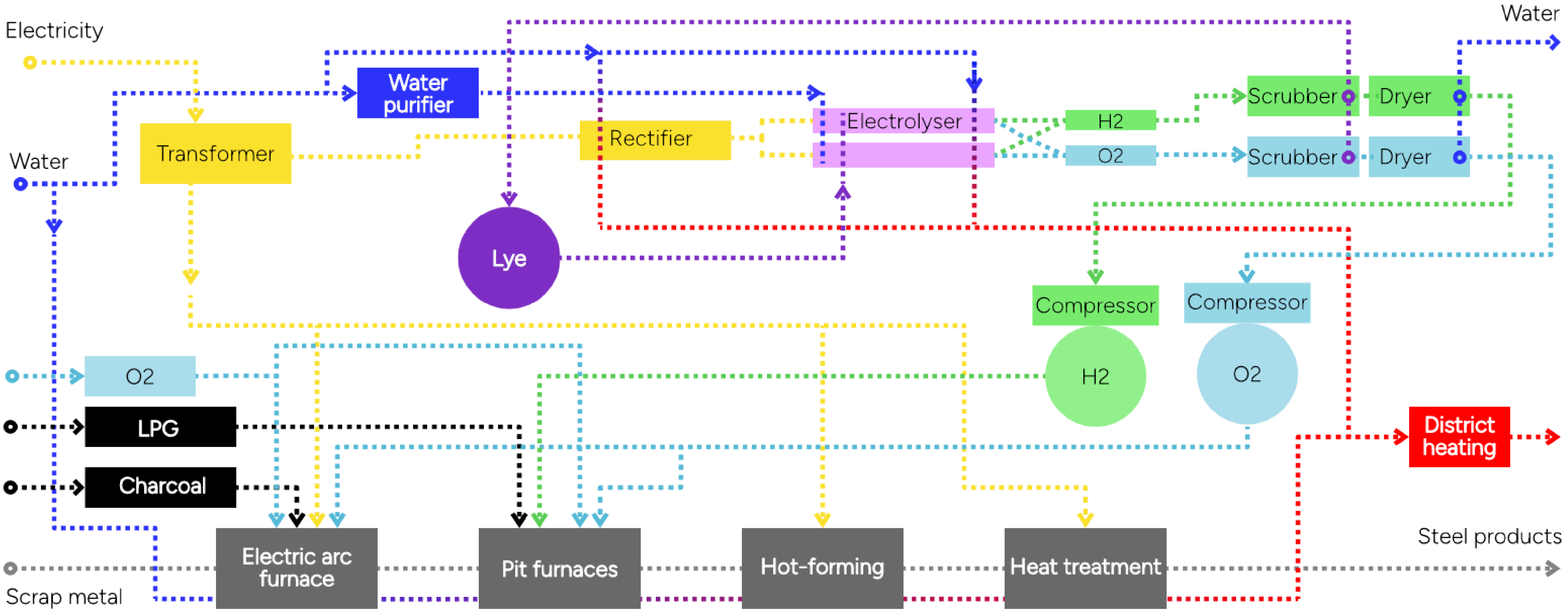


Fig: Amended from Elmfeldt et al. 2024

Power Stages of the Electrolyser System

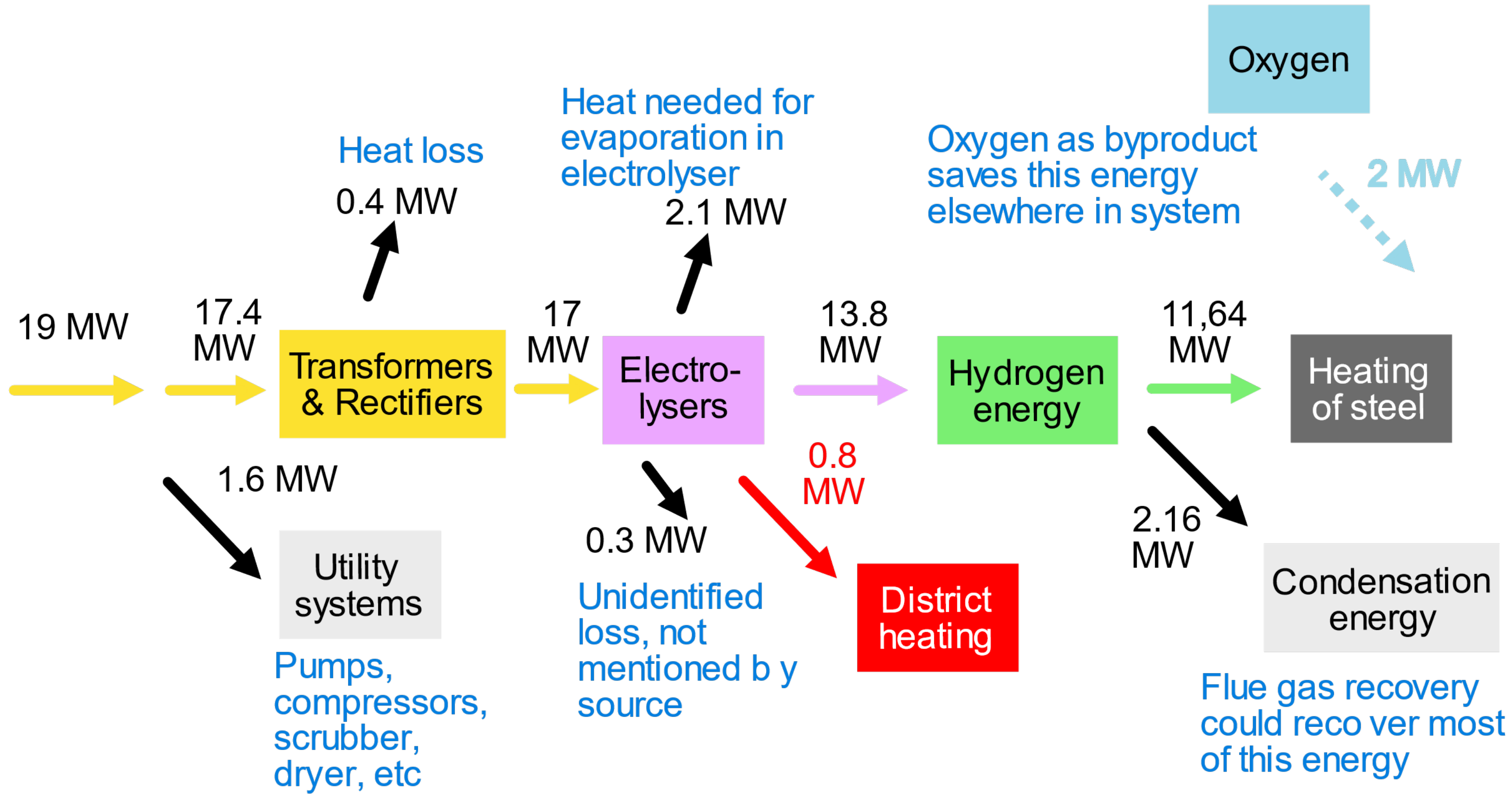


Fig: Elmfeldt et al. 2024

FCR-D Market

FCR-D (Frequency Containment Reserve – Disturbance):

- A reserve product used by transmission system operators (TSOs) to maintain **grid frequency stability** during disturbances

➢ **"Up Regulation"**: The grid needs **more power** – participants reduce consumption or increase generation

➢ **"Down Regulation"**: The grid has **excess power** – participants increase consumption or reduce generation

❑ These markets respond to **frequency deviations** outside the normal band (typically 49.8–50.2 Hz in Europe)

Eligible industries typically have:

- Flexible energy loads (e.g., compressors, pumps, HVAC, **electric furnaces**)

FCR-D Market Participation with Electrolyser

Why Electrolysers are Ideal for FCR-D Participation

- In FCR-D, it is needed to **quickly reduce or increase power consumption** (usually within seconds)
- Electrolysers can **rapidly ramp up or down** power consumption within seconds, meeting FCR-D timing needs
- **Bidirectional in capability** – makes them premium flexible assets
- **Grid stability support** – can help to prevent blackouts by instantly responding to disturbances
- **LPG backup** can provide additional flexibility to the grid

Enhancing FCR-D Participation with Electrolyser + Buffer Tank

Buffer Tank

❖It is a **hydrogen storage unit** that temporarily holds gas produced by the electrolyser

❖In Ovako, it can **store 30 minutes worth of hydrogen** needed for downstream production.

❖If the grid operator signals a **need to drop load** (e.g., frequency drop), the electrolyzer can quickly **reduce power**

❖The **buffer tank will continue to supply hydrogen**, so the downstream production is **not interrupted**.

FCR-D (Benefits from Electrolyser)

Participation in FCR -D with Electrolyser + Buffer Tank

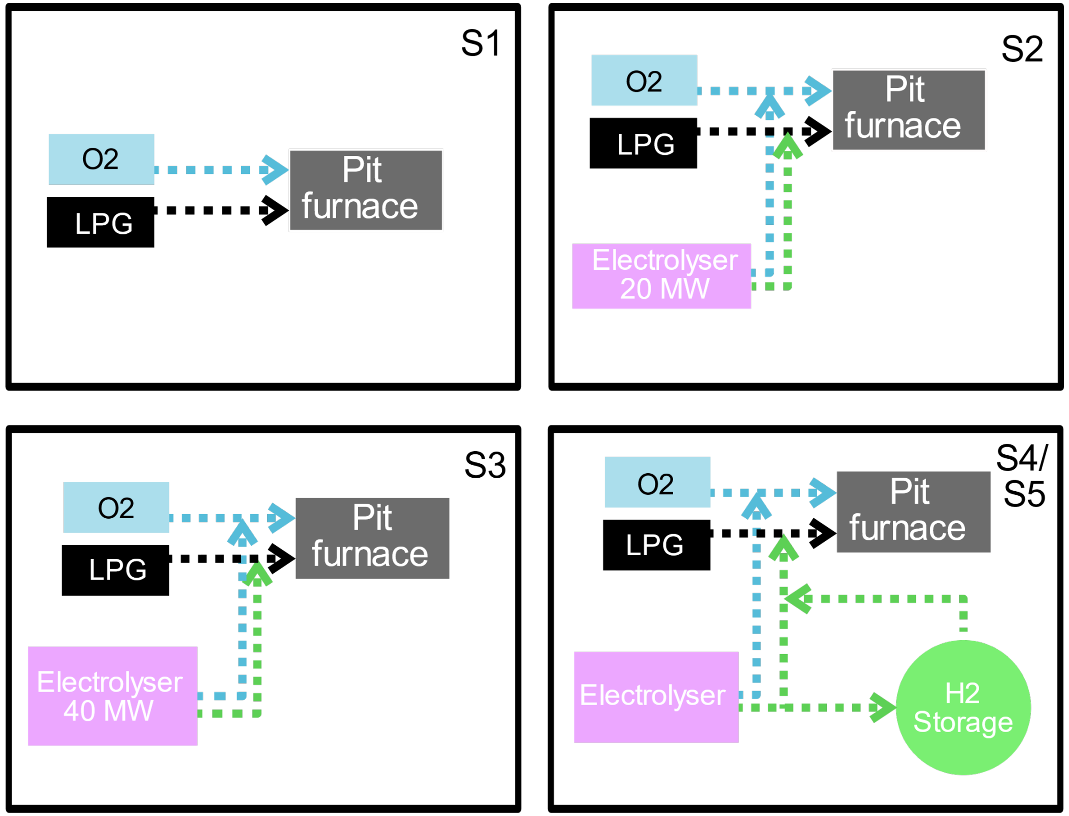
FCR-D Type	Electrolyser Action	Buffer Tank Role
Up Regulation	Reduce electrolyser load	Buffer tank supplies production needs
Down Regulation	Increase electrolyser load	Excess hydrogen goes into tank

Benefits

- **Revenue Generation** : Earn from both availability and activation.
- **Asset Optimization** : Monetize downtime or idle capacity.
- **Energy Cost Reduction** : Offset operating costs through grid services.
- **Higher availability factor:** more capacity payments
- Enhances **qualification probability** with TSO.

Application study

Scenarios for the application study



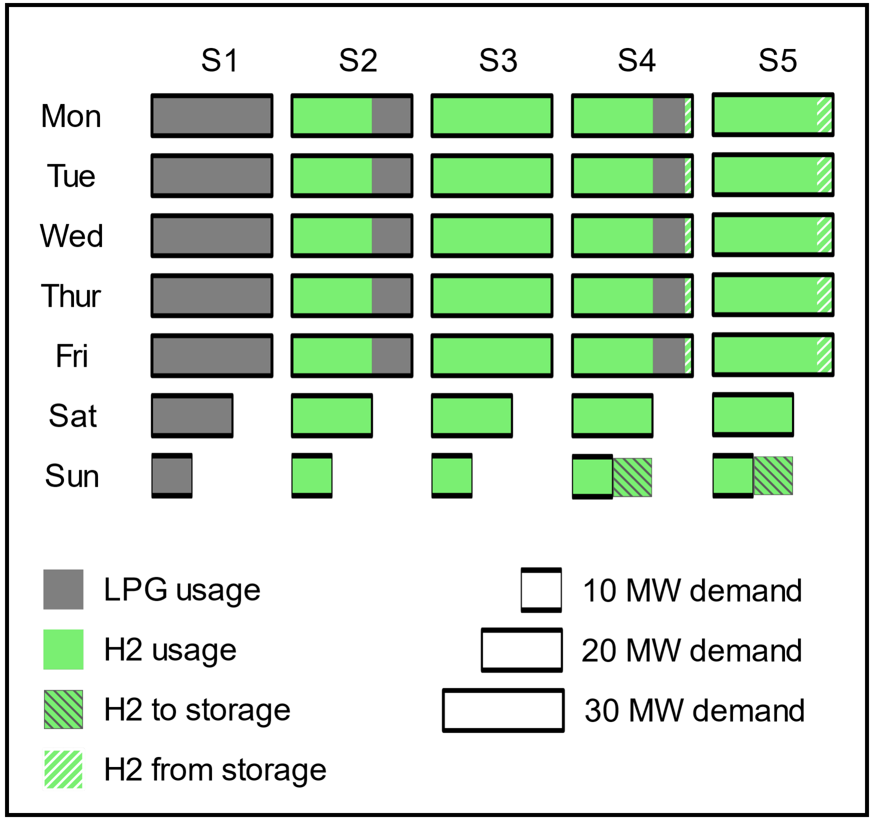


Fig: Amended from Elmfeldt et al. 2024

Assumptions

Description	Parameter
Capacity of Electrolyser	Scenarios: 0/20/40 MW
Storage capacity of H2	Scenarios: 0/120/240 MWh
Efficiency of Electrolyser	0.613%
Production active	All year except July
Price cap to change from H2 to LPG	2 SEK/kWh
Price cap to turn off production	3 SEK/kWh
Demand of heat for district heating	All year except June, July and August
kg of CO2 saved for each kg of H2 use	7.7 kg CO2 / kg H2
CO2 emission price	900 SEK/tonne CO2
Percentage of FCR-D up/down market price	0.85%

Description	Parameter
Energy density of H2	33 kWh/kg *
Energy density of LPG	12.8 kWh/kg *
Density of LPG	0.5 kg/L *
Price of LPG	14 kr/L (simplification)
District heating capacity	1.8 MW / 19 MW production
Generated O2	2 MW/19 MW production
Capacity available for FCR-D up	max(0, production - 0.15 capacity)
Capacity available for FCR-D down	min(0.2 capacity, max(0, capacity - production))
Electricity market price	Historical data, 2018 to October 2023
FCR-D up and down market price	Historical data

Table: Elmfeldt et al. 2024

Results for scenarios

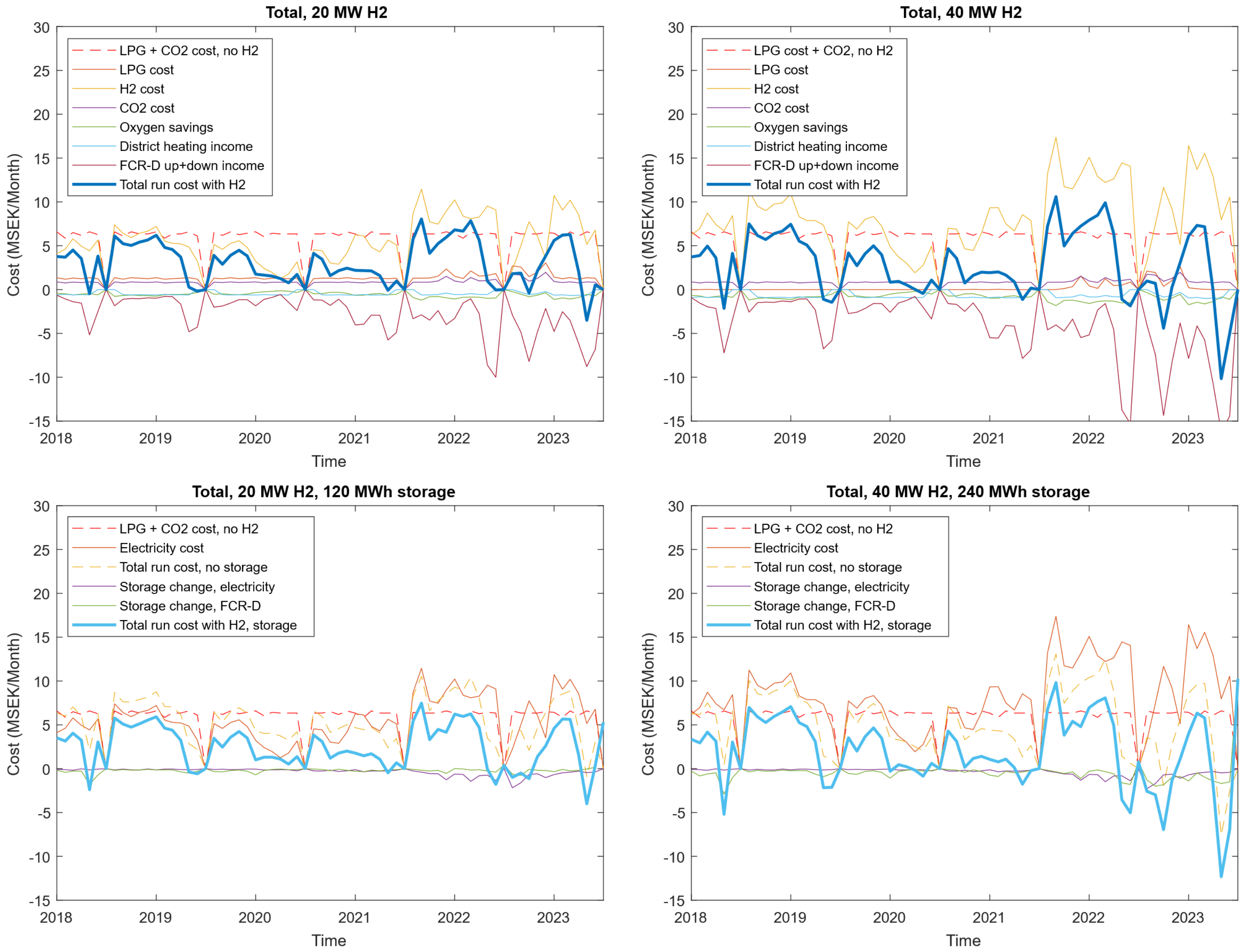


Fig: Elmfeldt et al. 2024

Key Findings

Total Operating Costs – LPG vs. Electrolyser

- **Most months**, the **electrolyser is cheaper to operate** than an LPG-based system.
- A few months show higher costs due to **electricity price spikes**.
- Overall, **system benefits from FCR-D participation** significantly improve cost-efficiency.

Key Role of FCR-D Market Participation

- **FCR-D prices and available capacity** have a **substantial impact** on monthly operating costs.
- Especially for **Scenario S3**, the large **FCR-D down regulation capacity** offsets high electricity costs.
- Participation in frequency regulation markets enables **revenue generation**, helping to balance or reduce net power costs.

Key Findings

Limited Impact from Hydrogen Storage

- **Hydrogen storage** plays a **lesser role** in reducing operating costs compared to FCR-D participation.
- While it provides operational flexibility, **returns on storage investment are relatively low**.
- Cost-benefit ratio of additional storage is **not as favorable** as other optimization strategies.

Trade-Offs in Electrolyser Sizing – 40 MW Case Study

- Operating a **40 MW electrolyser** system:
  - Slightly **more expensive** during months with high electricity prices.
  - But **significantly cheaper** in lower-cost months due to **greater access to FCR-D revenues**.
- Larger systems benefit from **economies of scale** in frequency regulation participation.

Conclusion

Maximizing Economic Performance

- **System benefits from grid services** (FCR-D) are crucial for minimizing operating costs.
- **Storage alone does not provide substantial cost reductions.**
- **Larger electrolyser systems** enable deeper market participation, improving economic viability—especially in favorable electricity pricing conditions.

Ongoing studies

Phase 2: Funded byVinnova

Ongoing Studies (Phase 2)

Research team members	Year	Focus Area
Prof. Lina Bertling Tjernberg **(Project Co-Ordinator/Leader)** Dr. Yasir Arafat **(Researcher)** Paula Muñoz Peña **(Visiting PhD student from UP** Heramba Ganesh Elango **(Master thesis student)**	April 2025 to July 2025	**Electrolyser for grid support services, and Industrial Hub for hydrog as fuel for hydrogen-based heavy truck transportation route** ❑ Analysis of operational data (e.g., unused capacity of the electrolyser, efficiency, and electrolyser's ramping behaviour) of the Electrolyser system at Ovako Hofors ❑ The models and results from phase 1 will be updated and refine actual data. ❑ Knowledge will be gathered regarding the operation of transform the rectifier operation at different load conditions. ❑ Application for next phase

Thank You!