Djewels

Delfzijl Joint development of green Water Electrolysis at Large-Scale

Deliverable D2.1: Electricity procurement and balancing services optimisation study

Fuel Cells and Hydrogen Joint Undertaking (FCH JU)
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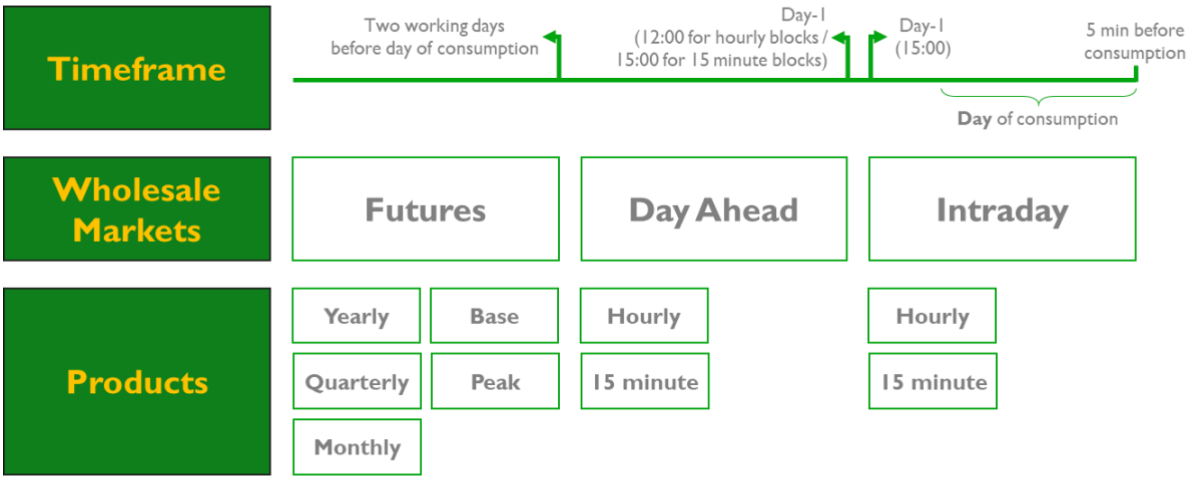
Table of Contents

1. Electricity Procurement

In the Dutch electricity market, electricity is traded between generators, traders, suppliers and customers via bilateral agreements or through standardized products in forward and/or spot markets (day ahead and intraday).

The forward markets involve trading of long-term contracts to be fulfilled on a future date, whereas spot products provide the opportunity to trade day-ahead or intraday. On the forward markets, parties can trade different calendar products: Year(s) Ahead, Quarter(s) Ahead and Month(s) Ahead, where one can choose a base or peak contract. A base contract refers to the entire period (all-day), while a peak contract only has the peak hours (from 08:00-20:00 during working days) in scope.

Volumes that are not bought on the forward market can be bought on the anonymous day ahead auction coordinated every day by market operator EPEX SPOT. When the day ahead auction is closed, additional volumes can be bought and sold on the intraday market. On the day ahead and intraday market, parties can buy/sell hourly blocks and / or 15 minute blocks.

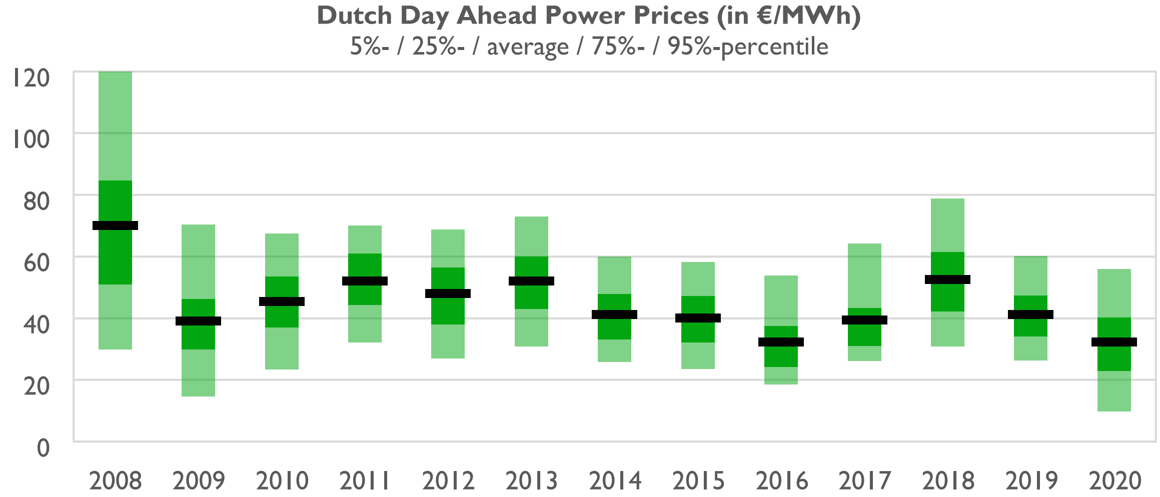


Products traded on the forward markets are limited to the next few Month(s) / Quarter(s) / Year(s), as these offer sufficient liquidity. To secure supply and pricing for a longer term, Parties can enter into a so-called Power Purchase Agreement (PPA). In a PPA, the following conditions can be agreed: the amount of electricity to be supplied, price structure, accounting, and penalties for non-compliance. Since it is a bilateral agreement, a PPA can take many forms and is usually tailored to the specific application. Electricity can be supplied physically or on a balancing sheet.

Within a PPA for renewable energy, parties can agree on a different profile of power delivery, basically ranging from '*as produced*' to a '*baseload*' profile. Electrolyser operators can lower input costs if they follow the renewable production profile.

In PPAs, for assets without subsidies, you typically see that producers of renewable electricity (wind turbines and solar PV) require pricing structures securing returns for the renewable asset. Those renewable electricity producers have high investment costs and low operating costs. With payment for the electricity already secured to a certain extent, plant operators and financing banks can feel more confident that proceeds from electricity sales will indeed cover investment costs.

Regarding market price risks, it is important to note that power markets are rather volatile with annual averages fluctuating largely over the years, as can be seen in the graph below. These power prices are mainly depending on power demand (following economic development), (de)coupling of market areas via interconnections to neighbouring countries and the availability and marginal costs of power generating capacity. In the end, the power price is determined by the marginal costs of the generation unit that is needed to meet the power demand, so the relevance of low-cost renewable capacity (absence/ presence of wind and sun) becomes more important over time.



2. Renewable electricity (Guarantees of Origin)

The only way to proof that you consume electricity produced from renewable sources is via Guarantees of Origins (GOs). One cancelled GO can be used to claim the consumption of 1 (one) MWh of electricity that has been generated from renewable sources (as defined in RES Directive 2018/2001/EC and its predecessor 2009/28/EC), specifying

- the source of the energy;
- the dates when it was produced;
- the identity, location, type and capacity of the production facility;
- whether the GO relates to electricity or heating or cooling;
- whether and to what extent the installation has benefited from support;
- the date when the installation became operational; • the date and country of issue; and
- an unique identification number.

There is no fixed price for a GO, and their value depends on market demand. There is no wholesale market for Guarantees of Origin. Trades are done Over The Counter (OTC) or as part of a Power Purchase Agreement when the power and associated guarantees of origin from a renewable project are sold as one complete package.

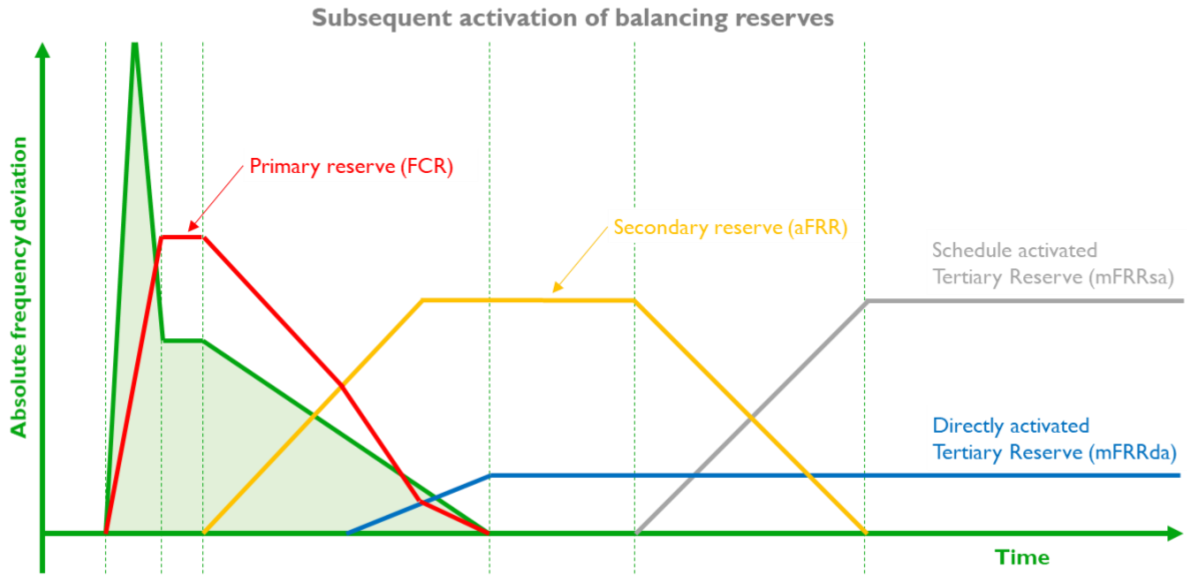
The above list of characteristics of a GO directly lead to a wide variety on price levels. If the source / location / etc. doesn't matter, a GO costs 0.0x €/MWh though very specific GOs might cost in the range of 3-10 €/MWh. For this reason, it is important to mention the revision of the Renewable Energy Directive (RED II) by the European Commission that is currently ongoing. This is accompanied with the current and ongoing process of establishing GO's for green Hydrogen. Which could impact the GO market from electricity in the overall chain. In these processes, some important parameters are under discussion that might become obliged for producing fuels in order to qualify for sustainable premiums via the electrolysis process:

- **Additionality**: This term refers to the date when the installation becomes operational, meaning that the renewable production delivering the GOs for a consumption facility should be commissioned after a certain date (i.e. "after Financial Investment Decision of the consumption facility to be build" or "after commissioning date of the consumption facility").
- **Geographical correlation**: Any prescription towards the location of the production facility, either referring to a specific country, region or ultimately towards a direct connection between the production and consumption facility.
- **Temporal correlation**: So far, GOs are issued in the month after production and they remain valid for a year. In other words, consumption in March 2022 can be covered by GOs from renewable electricity production in March 2021. The RED II might require a closer temporal correlation with the ultimate situation being that the cancelled GOs match the consumption on an hourly / 15-minute basis.

3. Flexibility Markets

The flexibility of an electrolyser to ramp up and down can be exploited on the aforementioned day ahead auction and intraday market, i.e. by producing less hydrogen than previously anticipated in hours / 15-minute blocks with a high power prices and/or producing more hydrogen at times with a low power price.

Another option which can be chosen additionally to the wholesale markets or separately is to offer the flexibility on the balancing markets operated by the Transmission System Operator (TSO) TenneT. In order to fulfil their responsibility for ensuring the stability of the Dutch electricity transmission system, TenneT uses a combination of Frequency Containment Reserve (FCR) and Frequency Restoration Reserve (FRR).



- **FCR** is mainly procured via the cross-border FCR Cooperation, although in the Netherlands 30% of the FCR requirement is domestic.
- **Automatic Frequency Restoration Reserve (aFRR)**, known as Regelvermogen (Regulation Capacity), is achieved through the continuous activation of particular generating units or portfolios by TenneT. aFRR is the main instrument that TenneT uses in the event that Frequency Containment Reserve is unable to resolve an imbalance.
- **Manual Frequency Restoration Reserves directly activated (mFRRda)**, known as Noodvermogen (Emergency Capacity), is activated via manual and discrete instructions by TenneT in case of substantial long-lasting power deviations.
- **Manual Frequency Restoration Reserves scheduled activated (mFRRsa)**, known as Reservevermogen (Reserve Capacity), is similar to mFRRda, but with a call time of one Imbalance Settlement Period (ISP) of 15 minutes instead of a ramp rate.

The main characteristics of these balancing reserves are summarized in the following table.

	FCR	aFRR	mFRR
Regulation direction	Symmetrical	Up OR Down	Up OR Down
Ramp up / down speed	100% of capacity to be changed within 30 seconds	At least 7% per minute	100% to be delivered within 10-15 minutes after request
Reaction speed		Within 30 seconds after setpoint change	
Expected availability	100% during contract period, though *transfer of obligation* possible	Minimal 97%	
Minimal capacity	1 MW (or multiple of 1 MW)	Integer value between 1/999 MW	20 MW (lower volumes can join within a portfolio)

Remuneration	Capacity fee for daily contracts No activation fee	Capacity fee for daily contracts and/or Activation fee for delivered MWh's	Capacity fee for daily contracts + Activation fee for delivered MWh's
NL market size	45 MW (lot of competition)	310 MW (up) and 405 MW (down)	955 MW (up) and 635 MW (down)
Average contract price	575 €/MW/day	250 (up) or 100 €/MW/day (down)	125 (up) or 60 €/MW/day (down)

[*Sources: TenneT's Product Requirements, ENTSO-E Transparency Platform*]

A last option of flexibility worth mentioning is imbalance management. Imbalance is the difference between actual consumption in an Imbalance Settlement Period (ISP) of 15 minutes and the nominated consumption volume for that ISP. This imbalance is settled against the imbalance price, being the marginal price of regulation capacity (aFRR) and reserve capacity (mFRR) used in that ISP to counteract the imbalance. TenneT does publish details on actual imbalance volumes on its website with a few minutes delay. That imbalance signal that TenneT publishes could be used to help reduce the imbalance by voluntarily creating more imbalance opposite to the system imbalance. However, there is a risk of imbalance shifting the other direction in the same ISP, meaning that your actions have been in the wrong direction.

4. Flexibility Value of Water Electrolysis

The flexibility value is determined by the following parameters. In the next paragraphs, these parameters will be discussed in general and specifically for Djewels.

- Technology Constraints
  - Ramp rate limitations of the electrolyser
  - Turndown limitations of the electrolyser
  - Electrical power factor and harmonic constraints
  - Implications for the auxiliary equipment: Reliability of the plant (a minimum reliability is required to qualify for contracting capacity on balancing markets)
- Customer constraints
  - Customer offtake flexibility and predictability
  - Integration of a H_2 buffer will give the opportunity to offer more flexibility
  - Green H_2 pricing structure (i.e. fixed or indexed to power price / penalties for not delivering)

5. Technology Constraints

Operation of a chemical production facility is historically done with a baseload production pattern and characterized by slow changes and minimal stops. This is key to upkeep high throughput and high production levels with high availability and a predictable reliability of the installation. For Djewels, a novel water electrolysis plant, it is desirable to deviate from this historically proven operational philosophy. By operating the unit flexibly and delivering grid balancing services the levelized cost of hydrogen can be positively influenced. As also studied in the Alkali Flex Eindrapportage[1], several constraints are identified in the water electrolysis plant.

Ramp rate limitations of the electrolyser

As concluded in the study of Haug et al. (2017)[2] the gas hold-up in an electrolyser varies with current density and hence the applied load. Assuming bubbles coalesce quickly, a gas phase may arise at the top of cells when quickly ramping down the load on an electrolyser. It is unclear if the gas separation performance of the diaphragm reduced when the top of the diaphragm is exposed to a gas phase, however this potential effect should be considered carefully when validating the performance of an electrolyser to ensure a safe operating window. The effect is dependent on the electrolyser type and operating conditions.

Turndown limitations of the electrolyser

Based on the study of Trinke et al. (2018)[3], it can be concluded that the hydrogen in oxygen concentration is higher at low load operation compared to high load operation.

Furthermore, the gas cross over is expected to rise over the lifetime of the electrolyser. At end of life under low load conditions, operation should remain outside of the explosion limits.

Electrical power factor and harmonic constraints

Large scale hydrogen production process requires large direct currents and, hence, make use of large current rectifiers. The main requirement for these large current rectifiers from the load side (electrolysers) is that it must have the capability to deliver a controlled direct current in a range of 0%–100% of rated value. The main requirements and specifications regarding the interaction of these large rectifiers with the power supply are: (I) high power factor (PF) which originates the need to use compensation of reactive power in rectifiers with thyristors and (II) the input current harmonics must comply with the demands of the local grid owner. The electrical grid requirements influence the choice of electrical equipment (technology and ratings) for transformer rectifiers, harmonic filters and reactive power compensation system. The complete system must be designed integrally to meet the

[1] https://pure.tue.nl/ws/portalfiles/portal/148942878/Publieke_eindrapportage_Alkaliflex.pdf

[2] P. Haug, B. Kreitz, M. Koj, T. Turek, Process Modelling of an alkaline water electrolyzer, Int. J. of Hydrogen Energy Vol 42, 2017

[3] P. Trinke, P. Haug, J. Brauns, B. Brensmann, R. Hanke-Rauschenbach, T. Turek, Hydrogen Crossover in PEM and Alkaline Water Electrolysis: Mechanism, Direct Comparison and Mitigating Strategies, J. of the Electrochemical Society, Vol 165, 2018

local grid requirements at the grid connection point over the entire rectifiers' operating range.

Implications for the auxiliary equipment:
Compressors, cooling systems, de-oxo and drying units need to all be designed to operate efficiently over a large capacity range. Here the inefficiency of operation at low load with traditional equipment needs to be balanced with the additional investment required to improve that efficiency over the whole operating range. Furthermore, a smooth load change is required to avoid issues in equipment downstream the electrolysers. Limited experience with flexible operation of electrolysis industry is available from the chlor-alkali industry.[4]

Technology Limitations in Djewels

Due to the above each technology and installation will have its own typical ramp-up and ramp-down rate.

- In general, pressurized systems are more flexible due to the smaller gas over liquid fraction in the system. Hence McPhy technology is more flexible than atmospheric technology.
- Also, a reasonable turndown (~20%) is specified making it possible to flexibly operate over a large range of the operating window.
- In order to deliver grid balancing services, the system needs to be sufficiently reliable. This is achieved by reliability studies and design optimizations according to good engineering practices.

Technically, the electrolyser is able to qualify to act upon all balancing markets and the cost of overcoming the above technical challenges are outweighed by the gains from delivering grid balancing services. The qualification itself shall take place as part of or after the Site Acceptance Test (SAT).

Customer constraints

When producing hydrogen at a large scale, storage of hydrogen is no longer attractive due to the associated risks, investment costs and variable cost due to compression. Up until large scale storage is developed in e.g. salt caverns, the flexibility of the customer to consume the hydrogen is leading for the flexibility window that the production unit can valorise. In case of Djewels1 the customer BioMCN produces methanol in such large quantities that the supplied hydrogen is only a fraction of the total required hydrogen. By making some adjustments in its production process, BioMCN is able to accommodate a significant flexibility window that can be utilized and valorised by delivering grid balancing services next to the delivery of hydrogen to BioMCN. The level of fluctuations in the hydrogen production of Djewels1 that allows acting on the aFRR market, but limits acting on FCR market.

[4] T.F. O'Brien, T.V. Bommaraju, F. Hine, Handbook of Chlor-Alkali Technology, 2005

6. Energy Souring Strategy Djewels

The strategy for (renewable) electricity sourcing is depending on the requirements as formulated in the dedicated project subsidies and potential requirements from the Renewable Energy Directive (under revision). Developments around those REDII requirements will be followed closely and the following strategy may be adjusted as a result. But based on currently known guidelines, the Djewels project will procure renewable electricity via a PPA with one/more renewable production facilities (including wind energy) in The Netherlands. Guarantees of Origin will be used as proof to produce the renewable electricity, and those guarantees are used as input to claim green hydrogen production conform the CertifHy methodology.

Regarding flexibility, own (early project phase) studies led to the conclusion that the aFRR is the most promising balancing market, because the size and prices of the aFRR market are more interesting than other flexibility markets and the aFRR market has the benefit of combination between a capacity fee for reserving capacity (€/MW's) and/or the payments for delivering the regulating power (€/MWh's). Furthermore, the plant and customer BioMCN can respectively produce and consume hydrogen flexible, meaning that a bidding price can be chosen in such a way that a lot of regulating power can be delivered with associated revenues.

A market consultation and RFP among several Balancing Service Providers supported this view, but also led to the conclusion that additional value can be generated when the flexibility of the electrolyser is optimized over all different flexibility markets, extracting the value from the market that is expected to be most profitable that (part of the) day. In order to maximize learnings how to optimize over the various evolving and volatile balancing markets, the Djewels project will cooperate with a third party as contracted Balancing Service Provider.

Based on the above-mentioned studies, market consultation and RFP, the Djewels electrolysis plant is expected to reduce energy procurement costs in the range of 10-35%. This is realized by price advantages of a PPA compared to buying on the wholesale market, revenues from contracting balancing capacity and the actual activation of offered flexible capacity. The large variety in expected annual revenues is primarily caused by the final customer BioMCN contract details (i.e. offtake flexibility), technical performance of the plant and market uncertainties (price development of balancing products).