THE ROLE OF HYDROGEN AS AN ELECTRICITY SYSTEM ASSET

WP8 REPORT - FINAL

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Introduction

WP8

SYNOPSIS

This report aims to outline the methodology and approach made to calculate input calculations and data to support BID3 redispatch modelling.

The core aims are to:

- Assess the BID3 calculation of short run marginal cost for electrolysers
- Develop a methodology to estimate the offer/bid price for electrolysers to participate in redispatch
- Estimate range of subsequent factors to allow calculation of the offer/bid price
- Provide qualitative insight on the key elements that may impact participation of electrolyser in re-dispatch the prices required to participate.

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Glossary of terms

AEM
Anion-Exchange Membrane

BM
Balancing Market

H2
Hydrogen

PEM
Polymer Electrolyte membrane

Stack
Part of the electrolyser that reacts with electricity to create hydrogen

VC
Value chain

SOE(C)
Solid Oxide Electrolyser Cell

SRMC
Short run Marginal Cost

Contents

Summary of overall Project Scope & Approach 1/2

Overall project scope:

To increase understanding of the future development of hydrogen markets and how targeted investment can more effectively support the electricity system

Project scope

- Outline possible future low carbon hydrogen landscapes under a range of scenarios
- Define interactions between the hydrogen vector and the electricity system operations and markets
- Identify the potential roles of hydrogen take in supporting and optimising the electricity system
- Understand the opportunities for National Grid to best engage with the hydrogen sector across both the system and transmission parts of the business
- Assess how National Grid can best include the impacts of hydrogen in their forecasting and scenario planning including FES development and economic models

Outputs

- ❑ WP2/3: Final Report
- ❑ WP4: Final Report
- ❑ WP5: Final Report – including associated datasets, where applicable
- ❑ WP6: Final Summary Report
- ❑ WP8: Final Report – including associated datasets, where applicable

A six work-package approach

WP1 is mobilisation (complete)

Stage 1: Exploration
- **WP2:** Identification of H2 value chains and pathways
- **WP3:** Analysis of H2 value chains and pathways
- **WP4:** Analysis of interactions between H2, National Grid, and the broader electricity system

Stage 2: Analysis
- **WP5:** Impact analysis
- **WP6:** Summary Report

Stage 3: Support Redispatch
- **WP8:** Input to Redispatch Power2X development and data requirements

This Report is for WP8

Summary of overall Project Scope & Approach 2/2

Overall project approach:

An initial exploration stage followed by a more in-depth analysis stage. This will capture the breadth of potential hydrogen interactions, and provide in-depth analysis on a sub-set of impacts which are most pertinent to National Grid and FES 2022

Project approach

- **Stage 1** will involve an in-depth literature review, interviewing of industry experts and in-house modelling. This mixed methodology will be used to develop different use cases and value chains, which will then be long-listed and then short-listed.

- **Stage 2** will involve in-depth analysis of the impacts of the short-listed value chains from stage 1. During the second stage of work, several topics will be explored in more detail. This analysis will provide evidence to inform the FES scenario development for 2022, and inform the assumptions and datasets used within the BID3 modelling to further develop the Hydrogen modelling capability. The nature and type of analysis conducted during stage 2 will vary depending on the topics explored but we anticipate a range of quantitative analysis, including runs of the model developed in stage 1 and additional qualitative research, such as an interactive webinar with key stakeholders to inform the analysis.

- **Stage 3** will be to support National Grid (in collaboration with AFRY) on the Redispatch Power2X module development in WP8. We understand that the Redispatch module of BID3 will enable simulation of Hydrogen value chains. We will provide additional evidence to support the development of the Redispatch module. This will include data associated with balancing mechanism actions taken by hydrogen related technology including bid and offer spreads, as well as flexible demand. Final methodology and outputs for stage 3 are to be confirmed.

Introduction and Scope

Aims for WP8

Stage 3:

WP8 will draw on the analysis in WPs 2 –6, and supplementing this with further analysis provide additional research to support the development of the Redispatch module and the datasets and assumptions which drive it.

1. Short Run Marginal Costs (SRMC) for Redispatch:

Logical output from **internal modelling** completed during **WP5**. We will include load factors and costings for how the electrolysers will operate. Observations will be made compared to the SRMC calculation approach proposed by AFRY for BID3 for different Value Chains that have been developed in **WP3**.

2. Adders/multipliers for Redispatch:

Overview of how hydrogen electrolysers will operate in a similar way to generators currently bidding/offering within the BM, based on information provided by NG (proxies). Our hydrogen expertise, project findings will enable us to work collaboratively with NG and AFRY **to propose possible ranges for bid/offer prices** and calculation approach to support the finalisation of inputs by NG. This will be an collaborative process with NG and AFRY.

Output: **Excel spreadsheet** showing how bidders/multipliers have been calculated, compatible with the BID3 methodology.

3. Qualitative insight for Dispatch/Redispatch:

This will include assumptions around how and when the hydrogen market is likely to interact with the BM. Work will logically build on work already completed in the previous work packages. The value chains analysis will inform the most likely use cases for electrolysers. As above, this will be an **iterative process with NG**, who will ultimately decide how to use our findings within BID3.

WP Deliverable: **WP8 report** with explanations of SRMC and bidders/multipliers.

Executive Summary

Key findings

Overview

A methodology for calculating bid and offer prices and the necessary adders for BID3 modelling of re-dispatch has been presented.

A range of adders have been calculated based on the value chains analysed in WP5 as part of this analysis.
The prices calculated shows a significant range in potential prices.

The prices that operators are likely bid or offer will be highly dependant on:

- Long term average electricity prices
- Hydrogen market conditions and structure
- Hydrogen storage conditions.

Short Run Marginal Cost

Short run marginal cost approach proposed by AFRY within BID3 appropriately capture the major pricing dynamics for electrolysers with regard to the potential income from hydrogen sales in relation to electricity price.

However, there are variable operating costs that are not included when using this approach, notably other consumable costs such as water and stack degradations costs.

Within this analysis an appropriate methodology to include these within the adder factor has been developed to ensure they are accounted for in the final bid and offer prices.

Bid and Offer Adders

A methodology for calculating Bid and offer prices at three different levels.

- Minimum pricing
- Breakeven pricing
- Preferential pricing

There remains uncertainty on the exact prices that operators will require in different use cases and market scenarios.

This range or prices enables further analysis and system modelling to understand the potential impact these prices ranges may have on the operation of these electrolysers in redispatch.

WP8: Input to Redispatch Power 2X Development and Data requirements

Utilising outputs from WP5 to provide data to support the redispatch modelling in BID3.

Short Run Marginal Cost (SRMC)

Commentary on the SRMC methodology used by National Grid and AFRY and relationship to this analysis.

Short Run Marginal Cost (SRMC)

Calculation methods for Electrolysers

The SRMC modelling approach proposed by AFRY captures the core dynamic costs for electrolysers in relation to hydrogen price and electricity cost.

Other variable costs can be captured within the adder/ multiplier part of BID 3 modelling.

BID 3 – SRMC Method assessment

The AFRY approach to estimating the SRMC for electrolysers in BID3 utilises the following formula:

SRMC (£/MWh) = Electrical efficiency (%) * Hydrogen Price (£/MWh)

This approach links the SRMC to the current sale price of hydrogen. This means the main cost of electrolyser operation, which is the electricity cost, is linked directly to the hydrogen price. The opportunity cost of operating the electrolyser or not can therefore be determined in terms of hydrogen generated per MWh electricity.

However, this approach does not include other variable operating costs for the electrolysers.

Some variable operating costs, such as water feedstocks, are much smaller costs relative to the electricity cost. However, the degradation of the electrolyser stack is proportional to the operational system hours and can be a significant factor of overall costs operational costs.

An alternative method could be to include an additional factor for variable operating costs:

SRMC (£/MWh) = Electrical efficiency (%) * Hydrogen Price (£/MWh) + operating costs(£/MWh).

The operating costs would include:

- Water and other consumable costs
- Proportion of stack operating costs

Water and stack operating costs can be extracted from levelised cost calculation on a static (£/MWh); these do not vary with the electricity cost.

However, as these are static costs, they could alternatively be included within the adder or multiplier factor as part of the offer or bid.

Bid/Offer Price estimation

Adders are applied to electrolysers bids/offers and multipliers are applied to power generation from hydrogen bids/offers.

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Methodology
Value chains

There is no single approach to estimating the operating cost for all electrolysers.

The operating costs and commercial arrangements will vary significantly by value chain.

This approach builds on the levelised cost modelling from WP5 based on the value chains developed in WP2-4.

VCs 4,5,6,7 and 10 were used for the calculation, as these provide a wide range of different scenarios, costs, technologies and use cases.

The specifics of each VC will impact the general economics of operating the electrolysers. However, the business case for each VC should also be considered, as the priorities will differ depending on the use case. This could significantly change the level of interest and costs associated with participating in the balancing market. The use of flex and ancillary services has already been analysed in detail in WP4.

No.	Value Chain	Detail
VC4	Centralised nuclear hydrogen for injection into hydrogen networks (smaller scale)	Covers the installation of electrolysers at existing or new nuclear built in the 2020s - i.e. large scale nuclear in isolated locations. Helps provide nuclear base loading and provides hydrogen.
VC5	Electrolysis for curtailment mitigation	Covers use case of electrolysis for avoiding curtailment of renewable assets (networked and non-networked); curtailment may occur due to electricity supply/demand imbalances and network constraints.
VC6	Centralised green hydrogen at onshoring point for transport near industrial clusters or ports	Covers HGV, trains and things like distribution centres (forklifts) that tend to be near industry clusters or ports that need high purity hydrogen and therefore can't easily use blue hydrogen.
VC7	Decentralised green hydrogen production for use in heavy road and rail transport	Distributed electrolysers that will be collocated with refuelling stations / transport hubs.
VC10	Centralised green hydrogen production for industrial use in a cluster	Hydrogen storage will be a key aspect for this value chain to decouple potentially intermittent hydrogen production from industrial output.

Adder vs Multiplier

Two options to calculate the Bid/Offer prices were considered

The Adder is used, as the marginal costs for an electrolyser are generally fixed per MWh.

The established SRMC approach already accounts for variability in hydrogen price.

Adder:

Price = SRMC(efficiency*hydrogen price) + Adder

Adder provides a static uplift, regardless of the marginal operating costs.

The primary variables in the operating margin for electrolysers are the electricity price and the hydrogen price.

The adder is well suited to cover investment, fixed and variable operating expenses, in a way that is most consistent with the SRMC approach.

An Adder is therefore used and calculated in this analysis.

Multiplier:

Price = SRMC(efficiency*hydrogen price) + SRMC*Multiplier.

Multiplier provides an uplift proportional to running costs.

The use of a multiplier was trialled, but a static multiplier was found to provide inconsistent price, requiring a more complex approach to achieve a reasonable result.

Therefore a multiplier was deemed unsuitable for the approach in this analysis.

Calculation of Adders
Key costs and Pricing breakdown

For each value chain the cost of operating per MW of electrical power consumed is broken down by:

- **Planned investment recovery**
  - Includes the necessary additional income required to generate minimum return on investment.
- **Fixed Operational expenses**
  - Annual operational maintenance costs unrelated to operational hours.
- **Variable Operational expenses**
  - Water and stack replacement costs.

For each VC these costs are defined by the expected average electricity price over their life time and the resulting average levelised cost of hydrogen required to recover the project investment as well additional return. The baseline calculations from WP5 have been used to generate values for this analysis.

These factors allow the calculation of the operating margins for the electrolyser, but they are highly proportional based on the assumptions made in WP5.

There are a number of factors that will impact the ability and capability of electrolysers to operate within the balancing market, such as:

- Marginal operational costs
- Planned operation (is the electrolyser currently available?)
- Annual utilisation targets
- Loss of hydrogen income
- Current hydrogen storage reserves
- Current customer demand requirements, forecasted demand and contractual commitments.
- Forecasted future electricity costs.

The aim of this analysis is to estimate the minimum prices for bid or offers that the electrolyser operators would accept.

Calculation of Adders

Factors to consider to estimate bid and offer price

When considering Bids or Offers, the other factors to consider include:

Bids (Turning on/up, increasing demand)

This is generally a good situation for electrolysers as it is an opportunity to operate when they were not otherwise planning to. In order to place a Bid:

- **Electrolyser must be available** (off) to provide this capability. If excess electricity is available (low price) the electrolyser is likely to already be operating (on).
- **Hydrogen generated needs somewhere to go.** Is there storage/demand available at the time of additional operation by the electrolyser?

Offers (Turning off/down, decreasing demand)

Turning off an electrolyser is counter to its planned operation. Placing an Offer will mean:

- Loss of hydrogen sales
- Potential for missing opportunity to operate at same costs in the future.
- Demand and storage requirements will be lower and contractual agreements will not be met.

There is a high level of uncertainty of what that status of electrolysers could be at any given time (on/off) as the hydrogen market develops. Therefore, this analysis provides a range of possible offers and bid prices to cover a range of electrolyser use cases.

- Minimum pricing
- Breakeven pricing
- Preferential pricing

Minimum pricing
Proposed lowest cost for operation which partially compensates operators so they still receive some income, but less than normal operation.

Breakeven pricing
In this case, calculate the bid/offer price such that the electrolysers will generate sufficient income/MWh to meet the levelised cost target.

Preferential pricing
This uplifted price considers the potential complications for electrolysers to change their operation and includes this in the bid/offer price. Operators are likely to require a premium in certain conditions, this study assumes this to be +50% over the breakeven pricing.

BID and OFFER Calculations

Electrolysers may use different pricing approaches during their lifetime and the current market status.

These calculations aim to provide a range of potential prices with a consistent approach.

BID

Buying electricity and selling hydrogen

Minimum pricing

Adder = -Fixed operating costs - Variable operating costs

Breakeven pricing

Adder = -Fixed operating costs - Variable operating costs – investment recovery costs

Preferential pricing

Adder =(-Fixed operating costs - Variable operating costs – investment recovery costs)*150%

OFFER

Selling electricity, but losing hydrogen sales

Minimum pricing

Adder = 50%*(Fixed operating costs + investment recovery costs) - Variable operating costs

Breakeven pricing

Adder = Fixed operating costs + investment recovery costs

Preferential pricing

Adder =(Fixed operating costs + investment recovery costs)*150%

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Results and Conclusion

Indicative bid and offer adders values for 5 value chains defined in WP5.

Results Summary

Initial adder values to calculate bid and offers

Initial results based on baseline calculation from WP5.

A range of adders values have been calculated for five value chains, including Minimum, Breakeven and Preferential values.

These values are tied directly to the assumptions made in WP5 on the baseline input assumptions. In particular they are very sensitive to the assumed average project electricity price and the average annual electrolyser load factor.

	BID			OFFER		
	Minimum	Breakeven	Preferential	Minimum	Breakeven	Preferential
VC4 - Nuclear	-17.9	-29.6	-44.5	7.0	24.4	36.6
VC5 - Curtailed wind	-12.3	-15.9	-23.9	7.5	15.6	23.4
VC6 - Centralised transport	-7.1	-11.9	-17.9	4.3	10.8	16.2
VC7 - Decentralised transport	-8.5	-13.2	-19.9	5.2	12.3	18.5
VC10 - Centralised industrial	-5.2	-9.8	-14.7	3.0	8.6	12.8

Observations on Value Chain preferences

General observations on possible approach to re-dispatch for value chains in 2050.

No.	Value Chain	Electrolyser type	Average annual load factor	Observations on suitability for re-dispatch
VC4	Centralised nuclear hydrogen for injection into hydrogen networks (smaller scale)	SOEC	50%	**BID**: start up time can be long when cold – could reduce opportunities to bid. **OFFER**: likely to offer as primary aim is to generate electricity – however may limit duration to ensure SOEC remains available to quickly operate if required.
VC5	Electrolysis for curtailment mitigation	PEM	25%	**BID**: highly likely to want to operate whenever economical. **OFFER**: unlikely to want to turn down unless economically advantageous, due to need to maintain minimum generation and output
VC6	Centralised green hydrogen at onshoring point for transport near industrial clusters or ports	PEM	50%	**BID**: highly likely to want to operate whenever economical, , significant storage expected. **OFFER**: highly dependant situational storage profile – expected to delivered highly consistent hydrogen for industry, therefore supply management critical.
VC7	Decentralised green hydrogen production for use in heavy road and rail transport	PEM	40%	**BID**: likely to want to operate when ever economical, but local hydrogen storage likely to limited, reducing capacity to operate when unplanned. **OFFER**: unlikely to want to turn down unless economically advantageous, due to need for frequent operation to maintain storage.
VC10	Centralised green hydrogen production for industrial use in a cluster	PEM	75%	**BID**: likely to want to operate whenever economical, however operating most of the time, therefore unable to BID. **OFFER**: highly dependant situational storage profile – expected to delivered highly consistent hydrogen for industry, therefore limited interest in turning down.

Conclusions

Final observations

A methodology for calculating bid and offer prices and the necessary adders for BID3 modelling of re-dispatch has been presented.

A range of adders have been calculated based on the value chains analysed in WP5 as part of this analysis.

The prices calculated shows a significant range in potential prices. The prices that operators are likely bid or offer will be highly dependant on:

- Long term average electricity prices
  - these define the overall electrolyser economics.
- Hydrogen market conditions and structure
  - Defining the hydrogen price, price elasticity and the flexibility of delivery contracts
- Hydrogen storage conditions.
  - The ability to manage short, medium and long perturbations in hydrogen supply and demand.

There remain key uncertainties on how electrolyser operators plan to interact with this market mechanism, the information in this analysis aims to support further system modelling to understand if their impact can have significant benefit on the future electricity system.

Appendix

Datasheet has been uploaded by the Delta-EE Team to National Grid's Sharepoint

WP8 – Adders and Multipliers

Sheet showing calculation of bid and offer calculations for each of the 5 value chain.

An editable calculation has been included to allow the assessment of the bid and offer prices versus different electricity and hydrogen market prices.