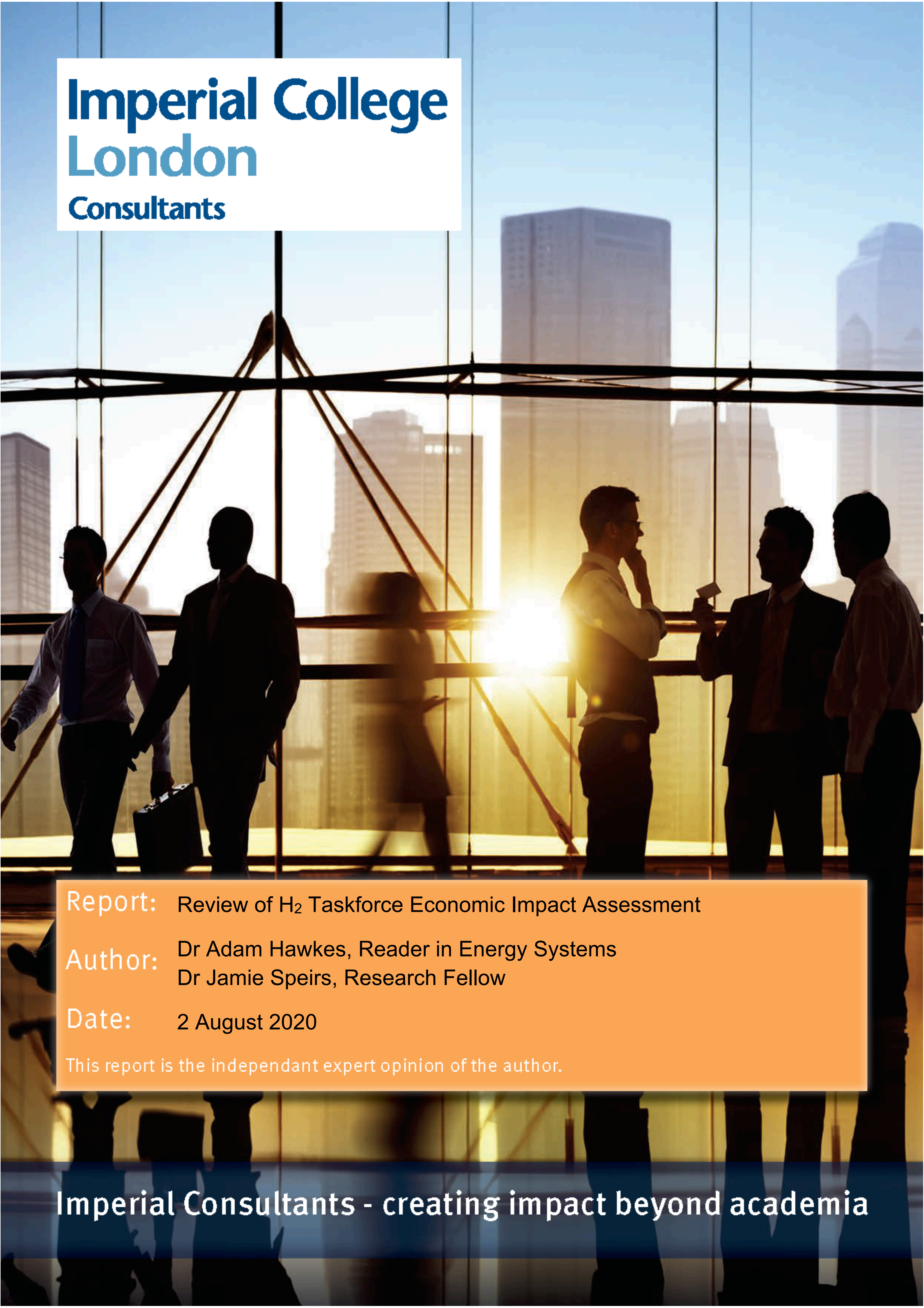

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Report: Review of H_2 Taskforce Economic Impact Assessment

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This report is the independant expert opinion of the author.

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Contents

Hydrogen Taskforce
Economic Impact Assessment

Revised analysis review comments

Imperial College Consultants were commissioned to undertake a review of the methodology and results for the Economic Impact Assessment of hydrogen uptake to 2035 in the UK for the Hydrogen Taskforce. The review was limited to three excel workbooks detailing the methodology and calculations for an Economic Impact Assessment of hydrogen uptake and an accompanying short overview of the methodology applied. No assessment has been made of the synthesis of results into the final report. The review was performed by Dr Adam Hawkes and Dr Jamie Speirs. This report is the independent expert opinion of the authors.

1. Revised analysis review

Following the original review comments presented in Section 2 below, the analysis has been revised to address issues raised. This page presents additional review feedback on those changes, and a revised overall assessment of the analysis undertaken.

a) Overall assessment

In response to the original review comments, the analysis has been revised to address key issues. The resulting analysis approximately halves the GVA and jobs attributable to the hydrogen pathway investigated, relative to the original analysis.

Specifically, the presentation of macroeconomic modelling has been reworded to clarify that impacts estimated are not net impacts; they are gross impacts. To accurately assess the net macroeconomic impact of a H_2 future pathway one would need to also assess the alternative pathways, which is outside the scope of the analysis undertaken. This should be made clear in the final report and in presentations of the material.

With regard to demand, infrastructure and supply modelling, which in the original analysis led to a high estimation of future H_2 demand and related supply chain, a number of changes have been made which significantly revise the projection downwards. The revised estimation is more realistic, but is still ambitious in some respects and should be characterised as such in the final report. Further assessment of specific changes are listed below.

b) Review comments on changes made in response to initial review

End-use demand estimates

Demand estimates in all three demand sectors investigated have been revised downwards as recommended in the original review. In transport, annual growth rates have been halved. In industry, the uptake of H_2 boilers has been revised downwards significantly. In buildings, a Committee on Climate Change (CCC) scenario has been adopted. These assumptions are central among literature estimates with the exception of transport, where the demand forecast still relies on a UKH2 mobility projection which is significantly above other frequently referenced works such as that of the National Grid.

Supply and infrastructure

The revised analysis has also responded to concerns on the level of green hydrogen production, and on the level of uptake of hydrogen in the power generation sector.

With regard to green hydrogen production, the analysis is now based on a CCC scenario, plus an uplift to take account of perceived recent developments in price and availability of electrolysers. This projection is reasonable but should be noted that it still represents an ambitious outcome at the higher end of expectations. In general, we would expect an initial reliance on blue hydrogen, transitioning towards more green hydrogen as the related technology becomes more competitive.

With regard to power generation, the analysis has been revised to remove hydrogen use as a replacement for new baseload nuclear power generation in future. Therefore, the revised analysis is much more realistic.

Other corrections

The revised analysis has also addressed the possible errors identified in the review below.

2. Original analysis review

c) Summary and recommendations

The reviewed Economic Impact Assessment has applied an overall methodology that uses various existing projections of the uptake of hydrogen technologies and the markets within which they will compete to build a "bottom-up" projection of hydrogen uses and associated expenditure across buildings, transport and industry end-use sectors. The figures emanating from that analysis are then fed into a macroeconomic input-output model to derive the results for national economic impact, primarily Gross Value Added and Additional Jobs created by 2035. Overall this is a common methodology for this type of analysis and is an appropriate one to use for the task, subject to a range of considerations and caveats.

With regard to the **macroeconomic input-output modelling**, the review had two primary concerns:

- Firstly, the characterisation of one of the key outputs as "additional jobs" does not appear to be accurate. The study has not estimated the employment impact of any counterfactual scenario, and it needs to be recognised that any such counterfactual will have an impact on employment. The net impact on jobs, therefore, is the difference between the hydrogen scenario and the counterfactual scenario. Therefore, the analysis here simply presents the 'hydrogen-related jobs created" rather than "additional jobs". A similar argument applies to GVA, where this reports gross GVA rather than the net change in GVA between two decarbonisation scenarios. **We recommend clarifying this in the text of the final report and making sure no results imply that the jobs are necessarily additional, or that GVA for the hydrogen scenario is necessarily any greater than GVA for any alternative scenario.**

- Secondly, and a less pressing point, is that the macroeconomic modelling appears to not consider induced economic effects (only direct and indirect numbers are reported). If this is correct, the results are ignoring what is potentially more positive impacts of the creation of the hydrogen economy in the UK. **The authors should consider whether these can be included, or how clarifying statements can be included to acknowledge that these effects exist and further support the case for hydrogen.**

With regard to the **bottom-up estimation of the scale of a hydrogen supply chain** in the UK by 2035, which ultimately drives the overall macroeconomic impacts, the review noted some important concerns that need to be addressed:

- Firstly, across all end-use demand sectors, the projected uptake of hydrogen is very optimistic. It appears to selectively take high estimates of hydrogen uptake from the reviewed literature, often relying on industry estimates rather than more impartial estimates in the academic or government literature. The overall result is a projection of the use of hydrogen, and related expenditure, which is very much an "upper bound" relative to the body of evidence in the literature overall. **We recommend that demand estimates in all three sectors are revised downwards to be more in line with analyses from organisations such as the CCC, BEIS, and academic studies.** Specific areas for attention are listed in the notes below. The current scenario could still be present but should be labelled as an "upper bound".

- Secondly, when supply and infrastructure needs are calculated based on the derived demand, some optimistic assumptions have been included. These include the assumptions about the potential for green hydrogen in the UK based largely on an industry study, the assumption that hydrogen-based power generation could displace all baseload nuclear power new build in future, and that energy efficiency improvements will have no influence on average building heat demand to 2035. **We recommend that all of these assumptions are revisited to be more in line with available independent assessment of likely changes in supply chains as a result of decarbonisation. We do not think that the present scenario could remain, even when labelled as an "upper bound", because it is extreme.**

- Thirdly, there is possibly some errors in the supply and infrastructure workbook which need investigation. These include the assumption that hydrogen demand in 2035 is 196TWh (see details below), but it appears from previous calculations that this is the cumulative demand to that point in time, rather than the annual demand, which is estimated to be 30TWh in 2035. **We recommend that this issue is investigated and corrected if necessary (alternatively an explanation showing that it is correct should be provided).** Additionally, there are some negative values for the uptake of blue hydrogen in one of the worksheets, apparently because of the way in which the green hydrogen uptake is calculated. As above the green hydrogen uptake should be reassessed, which will ideally lead to more reasonable value and may resolve this.

When the issues listed above are addressed, we expect that the analysis will provide a useful guide as to the economic impact of the hydrogen economy in the UK in 2035. We do expect headline numbers to be significantly lower than those currently reported, but we also expect that hydrogen can make a strong contribution to the UK energy system in that timeframe, particularly in relation to building heating, industrial heat and processes, heavy transport (including shipping), and possibly some power generation (but would not displace baseload nuclear power generation).

d) Overview of review notes

The team preparing this economic impact assessment have pursued a valid approach to answering the question at hand. They have prepared a detailed bottom-up projection of hydrogen demand and related expenditure across three end-use sectors (buildings, industry and transport) and related supply and infrastructure assets. Results from this effort have then been fed into a macroeconomic input-output model, which is used to calculate direct and indirect impacts on GVA and jobs. A great deal of work has been put in to deliver outputs, particularly with regards to the macroeconomic modelling.

Future projection of uptake of any technology is a challenging task, as is assessment of its impact on value and job creation. This is even more challenging in the context of the UK's net zero target, where radical non-marginal change in the way that energy is produced, converted, processed, transported and consumed is needed. Several methodologies exist to attempt to do this, and there are many reports and accompanying analyses of various options for the whole system for the UK, Europe, other regions, and worldwide. Reviewing and selecting from this body of work is challenging, and decisions must be made regarding which sources to rely upon, which inevitably influence the outcome of the work at hand.

While the broad methodology applied in this study is appropriate, this review drew out some issues regarding how results are communicated with respect to the macroeconomic modelling, and some issues related to the possible extent of hydrogen rollout in the years to 2035. On the latter point, we are of the opinion that these should be revisited to create a more realistic "central" scenario, and possible re-labelling the current scenario as an "upper bound". The following sections present our review notes to enable the team to address these points.

Review notes on macroeconomic modelling

The excel file titled "Macroeconomic Model_FINAL_v2" presents an input/output (I/O) model covering the key sectors adjacent to the hydrogen economy in the UK, and global input/output assumptions to support calculations of net exports from the UK. This is a common approach used to analyse a number of different market sectors in the past, including other energy supply chains [1-8]. There are a number of recognised features of I/O modelling that are worth acknowledging. While the approach is entirely valid, it will be important to give the reader a sense of the limits of the research approach and to defend the findings against criticism.

The comments below are referenced where appropriate, though a useful critique of I/O modelling, and comparison to CGE and econometrics as alternative approaches, is provided by Allan et al (2012) [9].

- **Correctly acknowledging snapshot aspect of I/O modelling.** I/O modelling captures a 'snapshot' in time, following the immediate impacts of money spent in specific parts of the economy on the activity in all other parts [9]. As such it does not capture dynamics over time. While this 'snapshot' is still a very informative tool, other approaches, such as econometrics or CGE modelling, could provide those dynamic aspects. It will be helpful to make the reader aware of these issues.
- **Induced effects.** The analysis appears to make no reference to Type 2 multipliers or induced effects. These are potentially additional to the economic impacts presented in the modelling at present. This may be a deliberate scoping decision. If so the report might like to highlight this explicitly and may even want to give some indication of the typical difference between Type 1 and Type 2 multipliers seen in other studies or when analysing other sectors [9, 10].
- **Counterfactual scenarios, net jobs and opportunity cost.** The results of the modelling in terms of both GVA and jobs appear to be gross estimates and do not account for a counterfactual scenario or the opportunity cost of investment elsewhere [11, 12]. For example, if all the investments in the hydrogen sector were instead invested in the electricity sector then there would be an impact on GVA and a number of jobs would be created. The difference between these two scenarios is considered net GVA or net jobs [11]. To address this comment, it is not necessary to conduct a net GVA or net jobs analysis. It is important, however, to make clear to readers that the GVA and jobs calculated are gross, not additional jobs created as a result of hydrogen investment that would otherwise disappear.
- **Global exports.** Global exports, as calculated in the model, seem to assume the UK will be as competitive in hydrogen as it is currently across UK exports as a whole. However, there is some uncertainty regarding the role the UK could have in international hydrogen development. Acknowledging this uncertainty in the presentation of these result would be useful. For example, if the UK became an expert in hydrogen deployment domestically then exporting this experience globally might afford the UK a competitive advantage, and the share of global hydrogen value

captured by the UK might be greater than the share of value captured across the whole economy. Mentioning this uncertainty, or exploring it though scenarios or sensitivity assumptions might be informative [8].

- **I/O demand -driven assumption.** I/O models assume a demand-driven economy, with the outcome that no displacement of other activities is assumed [9]. The validity of this assumption in the specific case of the future hydrogen economy is worth some investigation. For example, the hydrogen economy is ultimately to deliver energy to consumers who currently get energy through a more carbon intensive energy supply chain. The displacement of one energy supply chain for another will presumably be accompanied by a similar displacement in the direct, indirect and induced macroeconomic impacts of that supply chain displacement.

Review notes on demand modelling

- **The methodology is sound but assumptions lead to an overly optimistic outlook.** This excel workbook makes demand projections for end-use technologies that consume H2 in transport, industry and buildings sectors for the UK. It draws on a range of published sources and then makes further calculations to arrive at a "central" estimate of demand. The approach is sound, but the choice of studies to draw upon, and some assumptions, lead to a projection of hydrogen demand that is very high.
- **Transport.** The transport demand projection draws primarily on a UKH2 Mobility presentation from October 2019, which shows very rapid uptake of H2 vehicles from early-to-mid 2020s. It combines this with percentage growth rate in vehicles from the National Grid Future Energy Scenarios 2-degree scenario from 2030 onwards. This result is extremely ambitious in terms of deployment on H2 vehicles, and likely to be a "very high" scenario instead of a "central" scenario. The general consensus is that passenger mobility is much more likely to be served by electrification then hydrogen, especially in the near-to-medium term. We recommend that the team re-label the central scenario as an "upper bound" scenario, and produce a complementary analysis that reflects CCC analysis of the likely role of H2 in transport.
- **Industry.** The industrial demand projection is also optimistic, with an assumed potential of 96TWh in 2040. The Element Energy report that this is drawn from states that half of this potential only becomes available after 2030, so it seems unlikely that 58% of it would be utilised by 2035. The Element Energy report also states that biomass and waste sources are cheaper than H2 (though subject to supply constraints), but this work assumes that all switching is to H2, which is an unlikely outcome. The work also assumes that the entire 25% of oil and coal boilers switches instantly to H2 from 2025 onwards, which is an extreme assumption. Overall once again we recommend that the central scenario here is re-labelled as an upper bound, and a new central scenario is created with more realistic assumptions.
- **Buildings.** Similarly, the buildings H2 demand projection is optimistic, in the sense that it uses the average of a "Full H2" scenario and a "Hybrid H2" scenario from CCC work to find the percentage of H2 uptake. It is possible that there is some double-counting in this demand projection as well, because gas boiler stock from National Grid projections is used to calculate H2 uptake in "existing building" stock, but then "boiler replacement" numbers are added to this to calculate annual sales and total stock. Similarly, with the other sectors, we recommend that this scenario is renamed from "central" to "upper bound", and that a new central scenario is created using the Hybrid H2 scenario only and avoiding any double counting.

Review notes on supply and infrastructure modelling

- **The methodology applied is sound but assumptions lead to an overly optimistic outlook.** This excel workbook calculates hydrogen supply and infrastructure requirements and their costs, based on the demand calculations in the demand workbook. The precise method varies by part of the supply chain, but each approach represents a reasonable simple estimation of capacities, flows and costs.
- **The team should consider assumptions around building energy efficiency.** On the Output_Capex_Opex sheet the assumption that energy efficiency measures will not decrease the average consumption per dwelling between now and 2035 is not realistic. Historically energy efficiency gains tend to balance out demand increase, and given that net zero ambitions involve substantial action on energy efficiency one would expect average consumption per dwelling to decrease.
- **Some possible errors should be investigated.** The sheet Upstream_Prod there appears to be a minor error with some negative numbers in for example cell N11. This seems to be a result of using disparate sources for demand and supply calculations, and in particular the rate of growth of green H2 supply (see point below). It may be possible to address this whilst addressing the issue in the point immediately below this one.
- **The projections for uptake of green hydrogen are very optimistic, and the balance between blue and green hydrogen does not appear to be in line with current thinking.** While there is some uncertainty with regards to the rate of capital cost reduction of electrolyser technology, it does not seem likely that it will outcompete blue hydrogen in the near term. However, the projected uptake of the two technologies here show green H2 taking a large market share in the early period, only later for blue H2 to take over. I would expect blue H_2 to have the larger market share consistently until 2030 at least, possibly with green H_2 catching up slightly (but not overtaking) after that. I think the reason for this is that this work relies on the Hydrogen Europe report which is very optimistic on electrolyser uptake. I do agree that the UKs renewable resources put it in a good position to produce green H2, but I think this work is too optimistic for the period to 2035, and should be altered to reflect alternative view of the balance between blue and green H2 production (and thus capital expenditure etc, which feed through to final results here).
- **Some possible errors should be investigated.** The Midstream T&D sheet assumes at cell C15 that H2 demand in 2035 is 196TWh. However according to the Upstream_Prod sheet this is the cumulative demand, not the annual demand, which is approx. 30TWh. Also cell G19 appears to make this error. This has a large impact on the calculations on these sheets. Likewise the Midstream_EnergyS sheet relies on the 196TWh figure.
- **Assumptions on hydrogen use in power generation are extreme.** The Downstream_Powergen sheet assumes that all nuclear and gas plants are replaced with H2 plants from 2029 onwards. This is not realistic. It may be reasonable to assume that gas plants only are replaced with H2 plants, and the scenario should be revised accordingly. We do not agree that new nuclear baseload generation is likely to be replaced with H2 power generation.

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