Wind Energ. Sci. Discuss.,
https://doi.org/10.5194/wes-2019-100-AC2, 2020
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Interactive comment on "Exploitation of the far-offshore wind energy resource by fleets of energy ships. Part A. Energy ship design and performance" *by* Aurélien Babarit et al.

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Received and published: 9 April 2020

Dear Shane McDonagh,

Thank you very much for your comments. Please find below our answers:

1. Introduction

You recommend to modify the structure of the introduction according to: - First energy ship concepts – Advances and alternative configurations – use of Flettner rotors and water turbines for maximum efficiency. We do not agree with your recommendation because the introduction has been written in a standard way. Indeed, the introduction

starts with the global contex: a rationale for the development of low-carbon fuel production from the far-offshore wind energy resource, which we believe is needed as it is a new concept for the wind energy community (which is the readership of this journal). Then, for sake of completeness, we mention the technological options (sailing wind turbines and energy ships); and we provide a brief review of the current scientific knowledge of energy ships, which includes discussions of energy storage options and wind propulsion options. Last, we present the FARWIND energy system as we think it should be. Please note that as it is the result of almost four years of research, it is not possible to explain and justify in just one paper the reasons for the all the choices we made for each of the subsystems.

Nevertheless, we acknowledge that it would be helpful to display pictures of the concept earlier than Figure 2. Therefore the structure of the introduction has been slightly modified to include the other energy ships concepts which have been proposed so far (new Figure 1).

2. Line 60-65 – hydrogen and methanol

You consider that the statement: "However, low volumetric energy density at ambient temperature and pressure conditions is a well-known challenge for hydrogen storage and transportation. In (Babarit et al., 2018), the energy cost and economic cost of hydrogen storage and transportation was estimated for far-offshore and land-based scenarios. It was found that energy losses directly related to storage and transportation would be in the order of 50% of the transported energy, and that storage and transportation costs would account for nearly half of the cost of the fuel." is not justified enough.

However, the top graph in Figure 7 (reproduced below) in reference (Babarit et al., International Journal of Hydrogen Energy, 2018) shows that whatever the option for hydrogen storage and transportation (compressed or liquid), the power-to-hydrogen delivered to customer efficiency is 51% at best (option 2, longer term).

With respect to cost, it is shown in table 5 of the same reference (option 1) that the hydrogen cost after the electrolysis stage is 5.11 €kg and 8.7 €kg at delivery to the end user short term (respectively 2.34 €kg and 4.4 €kg for the longer term). Thus, the processes associated to storage and transportation represent 41 to 47% of the total hydrogen cost. The results are similar for the other options (42 to 50% for option 2, 31% for option 3, 44% for option 4).

Therefore, the statements that nearly half of the cost of the fuel is directly related to storage and transportation costs, and that hydrogen storage and transportation correspond to a 50% energy loss are supported. However, the energy loss includes the electrolyzer's efficiency, which may have not be clear enough in the first version of the manuscript and which we will correct in the revised version: "It was found that energy losses directly related to hydrogen production, storage and transportation would be in the order of 50% of the generated power transported energy, and that storage and transportation costs would account for nearly half of the cost of the fuel."

With respect to the choice of methanol or other fuels, you recommend further exploration of the possible options and trade-offs. It is the topic of reference (Babarit et al., 2019) of the manuscript: "The additional conversion step decreases the overall energy efficiency and increases the size and complexity of the PtX plant. In a previous study (Babarit et al., 2019), we investigated whether these drawbacks could be compensated by the easier storage, transportation and distribution of the products, and found that methanol is the most promising solution; hence it is retained as the energy vector in this study." This reference can be downloaded here: https://www.researchgate.net/publication/336775079_Energy_and_economic_performance_offshore_wind_energy_resource

With respect to more consideration of end use, we think that it goes beyond the scope of the present paper. However, let us just comment that fuel for passengers cars represents only a fraction of fuel consumption. The majority of fuel consumption corresponds to fuel for heavy duty vehicles, trucks, ships, airplanes, for which electrification

is hardly an option. Therefore, even if 100% of passenger cars are EVs in the future, the demand for drop-in fuels can be expected to remain very significant. Moreover, note that the chemical industry uses 45 Mt of methanol each year (production of plastics, paints, ...), which is unlikely to decrease and which is currently obtained from natural gas. Finally, note that in principle it would be very easy to change the power-to-methanol plants aboard the energy ships to power-to-ammonia plants should it actually be the most relevant option.

Last but not least, thanks for pointing out the paper by Varone and Ferrari. We were not aware of it, and we are happy to see that they also selected methanol for the energy vector.

3. Axial induction factor

We would be delighted that our paper attracts attention of people outside of wind energy. However, it has been written for the readership of the Wind Energy Science journal, for which the axial induction factor is a basic concept. Moreover, there is a reference in the paper to a book in which this concept is detailed (Manwell et al., 2009). Therefore, we wish not to add more explanations about it. Nevertheless, we retain your comment for future publications in journal whose readership may have less knowledge of wind energy technology.

4. Electrolysis – lines 220 – 230

The data in the suggested reference (Schmidt et al., 2017, Fig. E.1.) indicates that, according to the industry expert, the system energy requirement of AEL will remain in the order of 5.2 kWh/m3H2 by 2030, which corresponds to an efficiency of 57%. According to the academic expert, it could increase to 67%. For PEM technology, the efficiency is expected to be in the range 57%-70%, thus similar to AEL technology. Therefore, we have kept 60% for the efficiency of the electrolyser in order to remain on the conservative side.

However, the following text will be added in the revised version of the manuscript to take into your comment:

“It can be noted that performance of water electrolysis technology is expected to improve in the coming decade. According to (Schmidt et al., 2017), the energy efficiency of AEL technology may increase up to 67%, and PEM technology may reach even greater efficiencies while achieving similar lifetime to AEL technology. Moreover, despite PEM would still be more expensive than AEL, it has been shown that the advantage in efficiency may lead to better overall financial performance (McDonagh et al., 2018). Therefore, the efficiency data used in this paper can be considered as conservative and PEM electrolyzers may eventually be a better option than AEL for the FARWINDERs.”

5. Water recycling

We think that it is hard to tell at the current concept level whether the benefits of water recycling could outweight the additional complexity (piping). Nevertheless, the following text has been added in section 2.4.3:

“Moreover, methanol synthesis also results in water production (see Equation (18)). Thus, a third of the freshwater needs could be met through water recycling. Although freshwater production does not contribute significantly to parasitic energy demande, freshwater recycling may improve system maintenance and lifetime.”

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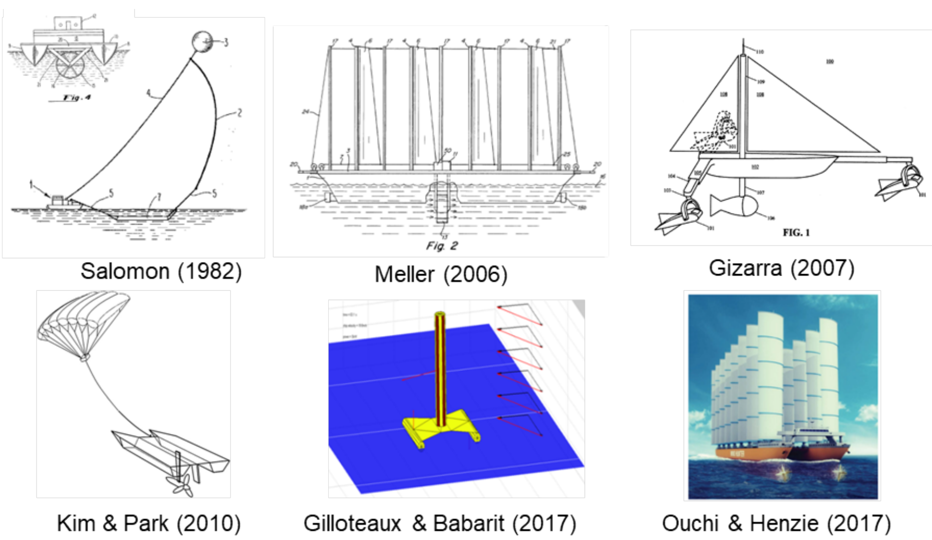

Fig. 1. New Figure 1: Pictures of technology proposals of energy ships.

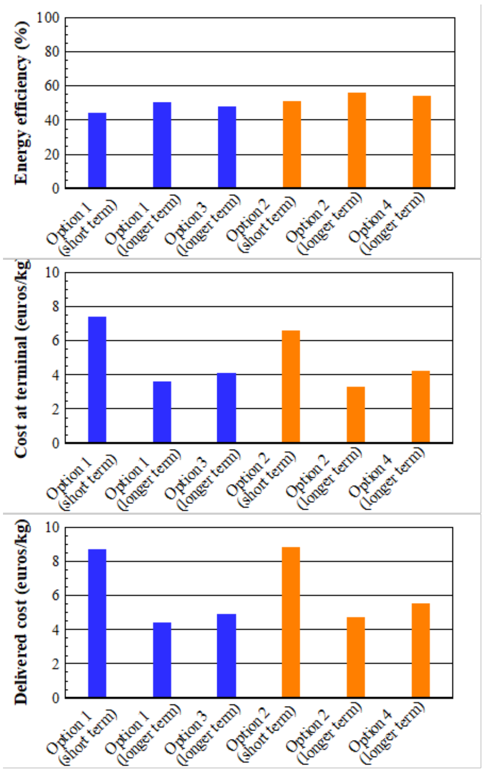

Fig. 2. Figure 7 of (Babarit et al., 2018)