MARANDA – Marine application of a new fuel cell powertrain validated in demanding arctic conditions
Grant agreement no: 735717

D9.3 Report on business analysis tool design and use

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<tr><td colspan="2">A business analysis tool has been developed during the first year of the project to support dissemination activities. After a first attempt to develop an excel based tool, it was decided to build a web based tool including a few algorithms and a fleet database in order to emphasize the main advantages of FCH based vessels, e.g. reduction in emission, future cost reduction would the marine sector commit to the technology. The tool has been developed in an agile mode and was tested with a few marine stakeholders (ship owners, ship captain, FCH integrators) and is now approaching its final version.</td></tr>
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1. Introduction

Presentation of scope of work

The scope of activity of PersEE in terms of business analysis tool encompasses the FCH vessel and the H2 delivery chain from existing energy sources to the FCH vessels. These two analysis are developed in separate tools which are interdependent, the junction between the two being the cost of hydrogen.

This report focuses on the first tool, which is aimed at ship owners and operators to assess the technical and economic impact of adopting fuel cells and hydrogen. It supports preliminary reflection and pedagogy. It is not meant for vessel engineering design and detailed studies.

General approach

The tool is conceived based on a 3 steps process:

- Definition of marine mobility need
- Identification of FCH solution
- Evaluation of adoption of FCH solution (economic and environmental)

<u>1 – definition of the need</u>

A vessel is almost a unique piece of equipment. Unlike buses, very well known to the FCH world, a vessel has unique characteristics which makes generalist analysis often irrelevant.

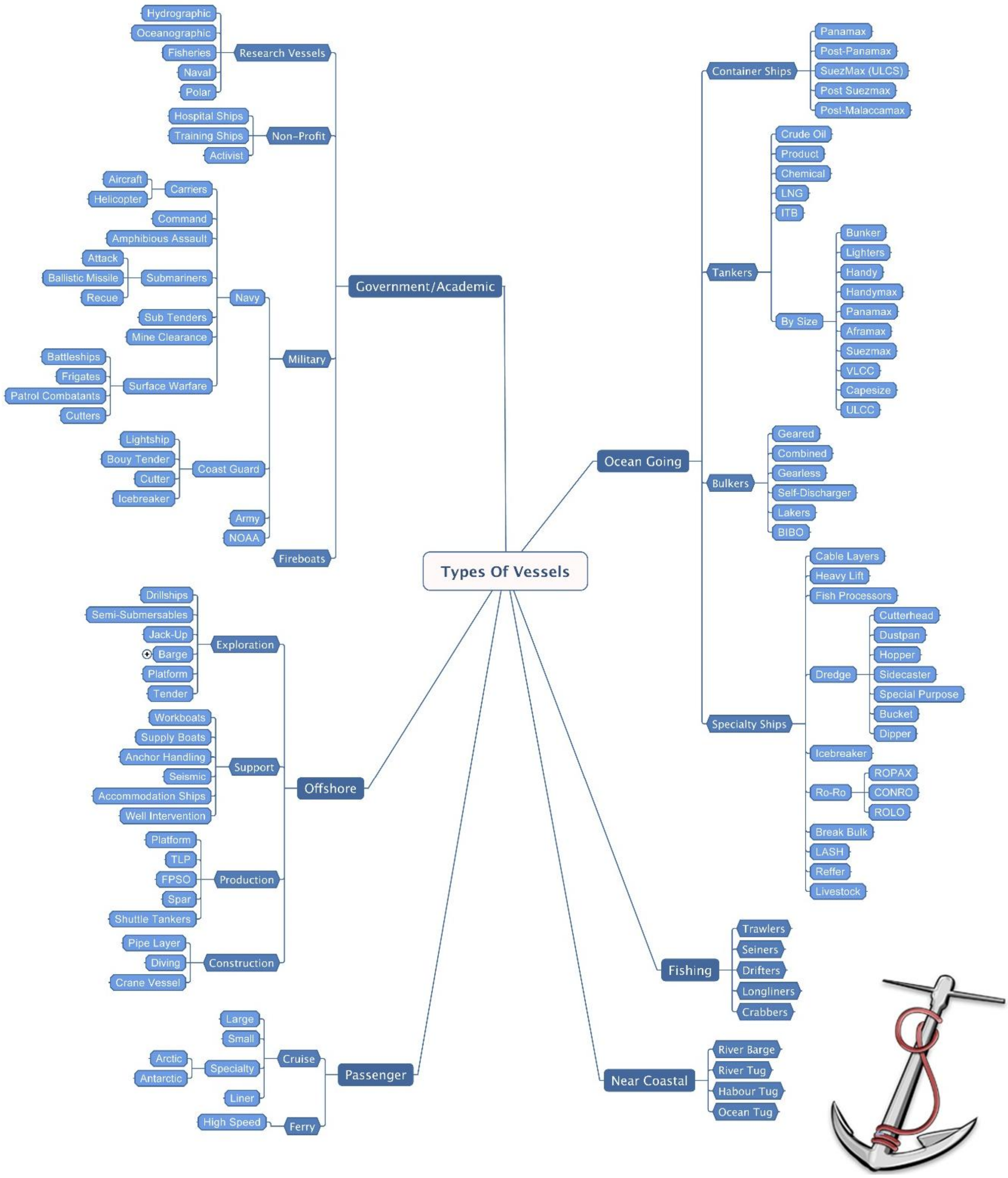
Hence our approach was twofold.

A) Define and characterise vessel main vessel categories:

   We performed a preliminary high-level classification according to the main application of the vessel and within which vessels would have relatively similar characteristics. For this, we analysed various existing categorisations either from the class agencies or marine engineers such as the one presented below. We came up with a "home made" categorisation.

B) Identify and quantity main vessel characteristics

   We researched main characteristics of a ship (speed, main engine power,…). For each category, we tried to quantify these characteristics and build our vessel database accordingly.



C) Enable the user to input his own vessel characteristics and/or overwrite prefilled data coming from a selected category.

2- Identification of FCH solution

In the case of marine application there is no standard solution.

For H2 storage liquid and gaseous forms being mature technologies were selected; The solution would have to be built based on a combination of fuel cells and storage vessels.

The dimensioning of the FC is based on the power requirement and the hybridisation and the storage based on the autonomy.

3- Evaluation of adoption of FCH solution

The economic assessment includes CAPEX of the new FCH components (and the battery) and the OPEX essentially made of maintenance and H2 purchase.

We gave up on quantifying the full electrification (e.g. the engine) as through our discussions with ABB marine we could not derive a model which would connect technical parameter need (such as speed) with dimensioning of the engines and related costs.

Regarding the environmental impact, we decided to assess CO_2 (even though marine is not in the scope of Paris Agreement, the sector is very well aware it needs to progress in the direction set by COP21), NO_x (Norway has set a NO_x fund for marine activities in its waters), SO_x (ECA zones).

2. Initial design approach using excel

Following the general approach described above, a first tool was designed using excel.

2.1 Presentation of the excel tool

This excel file would include, on the user side, 5 tabs described below

- **Tab 1: Existing ship (project) description**
- Describes general information about the ship concerned. It can be provided by choosing the vessel type (option 1) or directly provided by the user (option 2).

NEED		
Use description	Amount	Unit
Vessel type	fishing vessel	
Passengers	N/A	passengers
Speed peak	12	knots
Speed -Average*	10	knots
Trip duration - Max	24	h
Trip duration - Average*	12	h
# trips*	-	/day
working days/year*	240	days
# trips *	240	/year
Autonomy needed*	24	h
Load - Weight	3 000	kg
Load - Volume	3 000	m3
Ship lifetime*	30	years
Route details	time (h)	Load profile
maneuvering*	0,25	25%
Crossing*	11,5	90%
Assistance	0	N/A
Dynamic positioning	0	N/A
maneuvering*	0,25	25%

Tab 2: Power need of the ship under consideration.

Just as the previous tab, data regarding the powering of the ship can either be pre-filled by selecting the vessel type (option 1) or entered by the user (option 2).

VESSEL INPUTS		
Vessel description	Amount	Unit
Vessel type	fishing vessel	
Propulsion Power peak*	200	kW
Propulsion Power demand average*	175	kW
APU - Power need*	10	kW
APU functioning	100%	
power hybridation rate	95%	
energy hybridation rate	95%	
number of RCS gap topics		

Tab 3: Energy tab

This tab allows to select the energy inputs for the ship.

It also serves for the user to check the energy requirement of the ship based on the data he/she entered in the previous tabs. Notably the energy required in the different phases of a trip is estimated, as each of these phase will trigger different FC need and utilization profile.

ENERGY AVAILABILITY		
Energy prices	Amount	Unit
Electricity	0,12 €	/kWh
H2 350b*	0,27 €	/kWh
LH2*	0,33 €	/kWh
Route details	**Power demand**	**Energy (kWh)**
Loading/maneuvering	8	0,69
Crossing	83	68,89
Assistance		
Dynamic positioning		
maneuvering/unloading	8	0,69
Total		70,27
Energy need kWh/kW/trip		**0,64**
Energy need kWh/kW/h		**0,64**

Tab 4: FCH offer description

This tab presents generic data on FC technologies, hydrogen storage or battery technologies.

The technology description is based here rather on theoretical techno economic parameters rather than using real life products.

TECHNOLOGY OFFER		
FC system	Amount	Unit
CAPEX Power	1 000 €	/kW
Maintenance Power	2,5%	of FC CAPEX power
Maintenance Energy	10 €	/10 ans/kWh
Accounting lifecyle	20	years
DOD	10%	
# hours POWER	15 000	h
stack lifetime	12	yr
stack replacement	411	/kW/year
# cycles for DOD	N/A	
power loss	10%	
System efficiency	53%	
Self discharge	0,001%	
FC system gravimetric power	0,154	kW/kg
FC system volumetric power	0,074	kW/dm3
stack/cell price	50%	of FC/battery system

Different types of storage are available with specificities.

Liquid hydrogen	Amount	Unit	Comment
storage gravimetric density	3,1	kWh/kg	
storage Volume density	1,3	kWh/dm3 @LH2	
boil-off	N/A		negligible : consumption is too fast
CAPEX Energy	21 €	/kWh	checked

350 bar compressed hydrogen	Amount	Unit	Comment
storage volume density	1,8	kWh/kg	
storage spec density	1,3	kWh/dm3 @GH2	
boil-off	N/A		negligible : consumption is too fast
CAPEX Energy	150 I	/kWh	type 3/4 storage

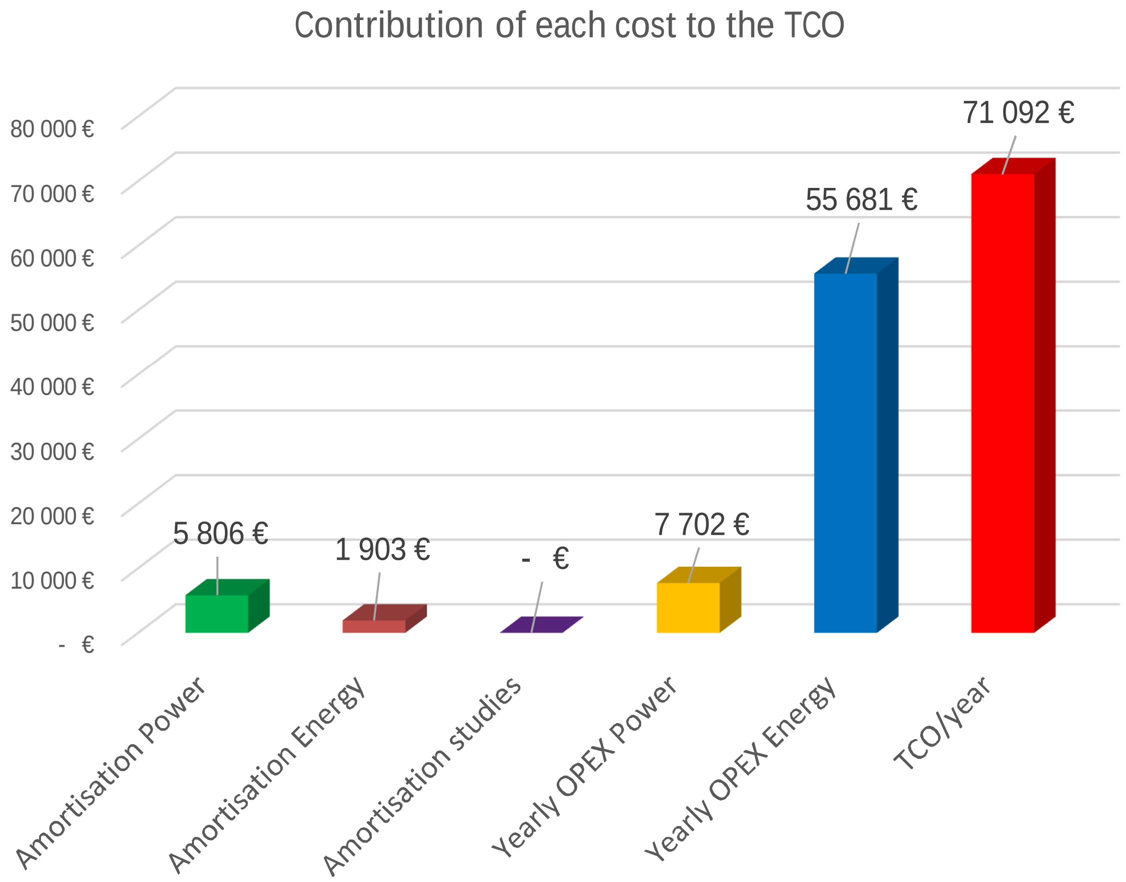
As for hydrogen storage, we used 2 generic battery technologies (LA, Li-ion) as the most common kinds of batteries.

Lithium-ion battery system	Amount	Unit
CAPEX Power		/kW
CAPEX Energy	1000 I	/kWh
Maintenance Power		/an/kW
Maintenance Energy	30 I	/an/kWh
Accounting lifecyle	20	years
battery lifetime	10	years
DOD	20%	
# hours POWER		h
# cycles for DOD	5 000	
System efficiency	95%	
Self discharge	N/A	
gravimetric energy density	150	Wh/kg
volumetric energy density	300	Wh/L
replacement	50 I	/kWh/year
cell price	50%	of battery system price

Lead-gel batteries	Amount	Unit
CAPEX Power		/kW
CAPEX Energy	150 I	/kWh
Maintenance Power		/an/kW
Maintenance Energy	30 I	/an/kWh
Accounting lifecyle	20	years
battery lifetime	5	year
DOD	50%	
# hours POWER		h
# cycles for DOD	1250	
System efficiency	95%	
Self discharge	N/A	
specific energy density	50	Wh/kg
volumetric energy density	100	Wh/L
replacement	15 I	/kWh/year
stack/cell price	50%	of FC/battery system price

Tab 5 and 6: TCO computation

From the previous tabs, the TCO of the new possible FCH solutions are computed and presented to the user for comparison.



2.2 Lessons learnt from this approach

A very large number of vessels is overpowered. Therefore, asking a vessel owner to describe his current solution is unfavourable to fuel cells, which would benefit from being dimensioned to fit the need. As the power need can't be reasonably derived from speed and other parameters (unless entering into detailed calculation per vessel category, costly to develop) it has been decided to user power need as a primary input. As speed is a major influencer of engine power rating, it has been decided to add in the final tool recommendation to reduce the speed requirement and consequently to reassess power need.

The hybridisation itself has proved as a 2nd level optimisation. A more straightforward approach to the dimensioning of the FC was to request from the user an average power need. The fuel cell would be dimensioned to fit this need after end of life (although this is subject to optimisation as well) and taking into account a conservative electric engine efficiency which was confirmed to us by several stakeholders (ABB, ENAG,….).

Overall this approach was viewed as putting too much emphasis on the engineering of the FCH solution which in the end proved too complex to achieve for the vast majority of the vessels. On the other hand, the environmental benefit of the fuel cell was not enough emphasized.

3. Final design approach, web-based

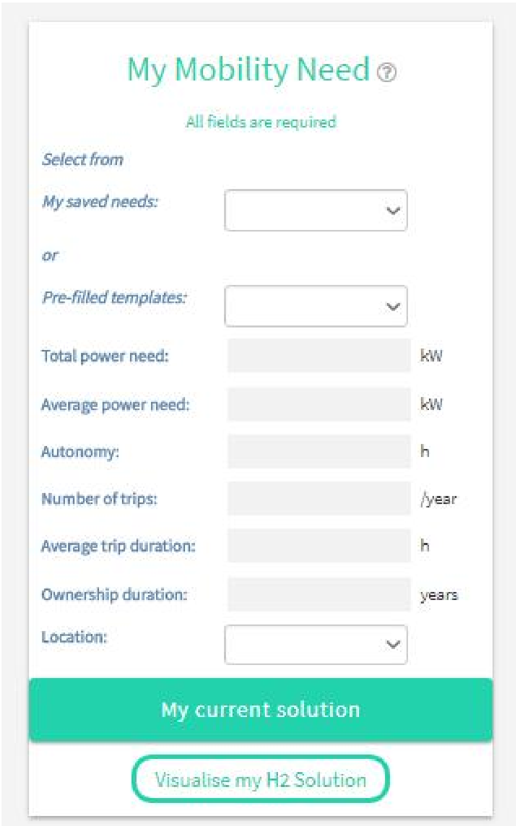
3.1 Presentation of web-based tool

The web-based tool is also following the 3-step approach defined in introduction;

However, the user experience is designed to be more high level.

1. Need definition

A more straightforward approach was adopted using below parameters

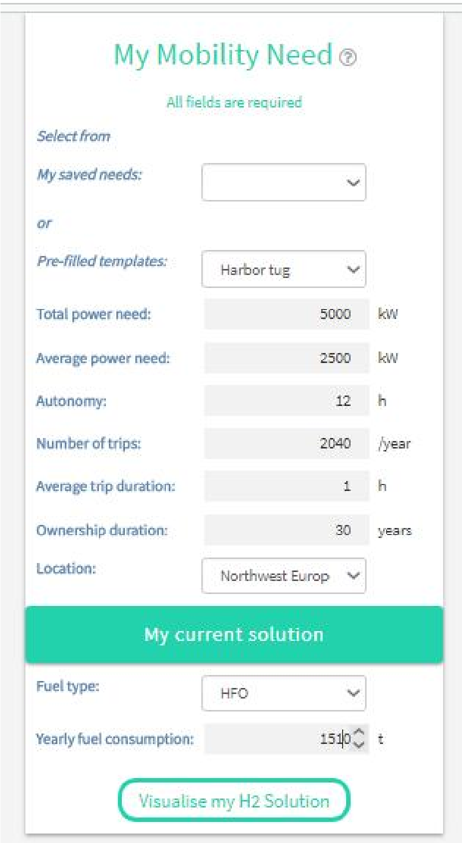


- Profile: the profile should best describe the type/function of the vessel. This selection will automatically populate the template with data which can be overridden.
- Total power need: Power required at full speed (100% MCR) covering ME and AE output
- Average power need: Power required at cruise speed, covering ME and AE output
- Autonomy: Maximum number of hours of activity expected between 2 refuelling
- Number of trips: Typical voyage between 2 port stops
- Average trip duration: Average number of hours of activity during one trip

- Ownership duration: Number of years before major overhaul, sale or disposal of vessel
- Location: Main port of call
- Fuel type: Main fuel consumed
- Yearly fuel consumption: Yearly cumulated tonnage of all fuel consumption

This approach forces the user to think in terms of real average power need.

In case the user would not be able to characterise his need, he could still use a pre-filled template from the categorisation which we have kept from the initial approach.



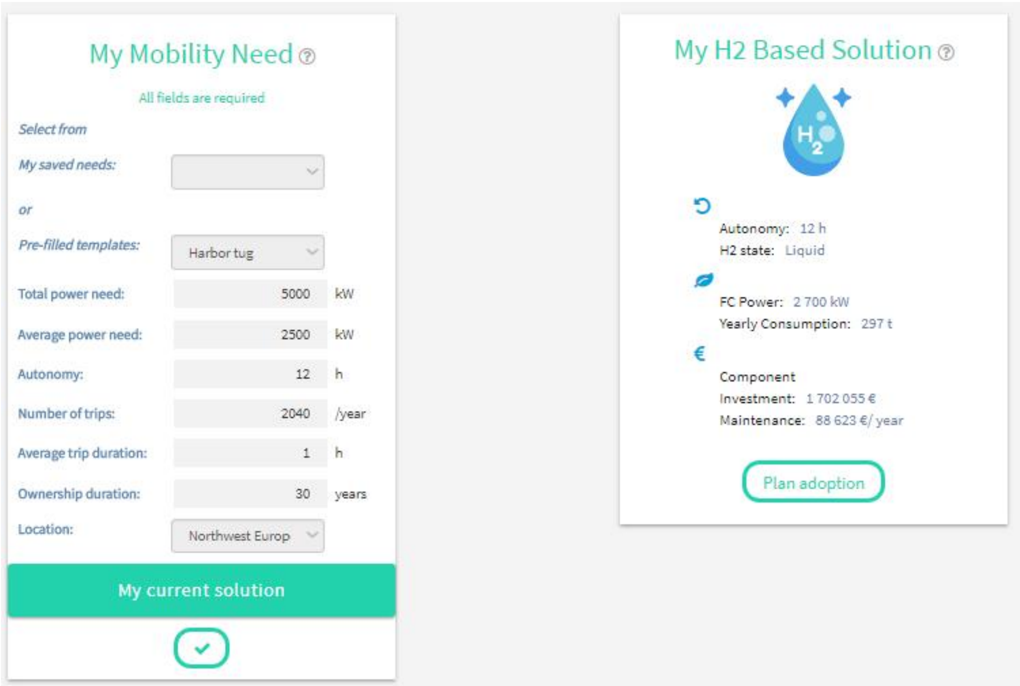
2. <u>FCH solution</u>

The FCH solution is identified using existing products or products about to be approved.

A light algorithm is computing the best technology fit which is then presented using below characteristics:

- Autonomy: Maximum autonomy to be expected from below hydrogen solution
- Pressure: Recommended pressure or state for H2 storage on-board
- Component Investment: Cumulated investment in fuel cells, hydrogen storage, including integration costs but excluding the electrical engine, batteries, the AC or DC bus specific arrangements and the EMS/PMS

- Maintenance: Yearly average maintenance cost of the different components: fuel cells, hydrogen storage and batteries
- FC Power: Max rated power of the Fuel cell upon installation (expected to decrease by 10% at the end of life)
- Yearly Consumption: Annual hydrogen consumption
- Weight Total weight of the hydrogen solution components
- Volume Total volume of the hydrogen solution components



3. FCH adoption

The FCH adoption process was separated into a simple parameterisation and the visualisation of brief business plan + environmental KPIs.

The adoption plan parameters include:

- Vessel deployment Number of H2 based vessels expected to be developed in the short term
- Hydrogen Availability Feasibility for the vessel to refuel on existing hydrogen infrastructure
- Number of vessels converted in 2020
- Hydrogen Price: Expected price of hydrogen for refuelling at the desired pressure
- Hydrogen CO2 Content: CO2 content of the hydrogen for refuelling
- Cost of financing: Total cost of financing of the new components

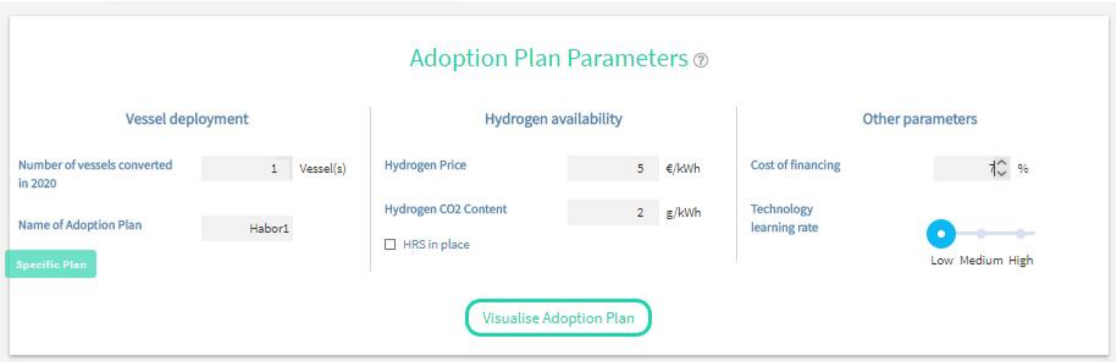
· HRS in place A hydrogen refuelling station exists at the Port of call and is dimensioned for the refuelling of the vessel

· HFC learning rate Expected speed of technology progress regarding hydrogen and fuel cells

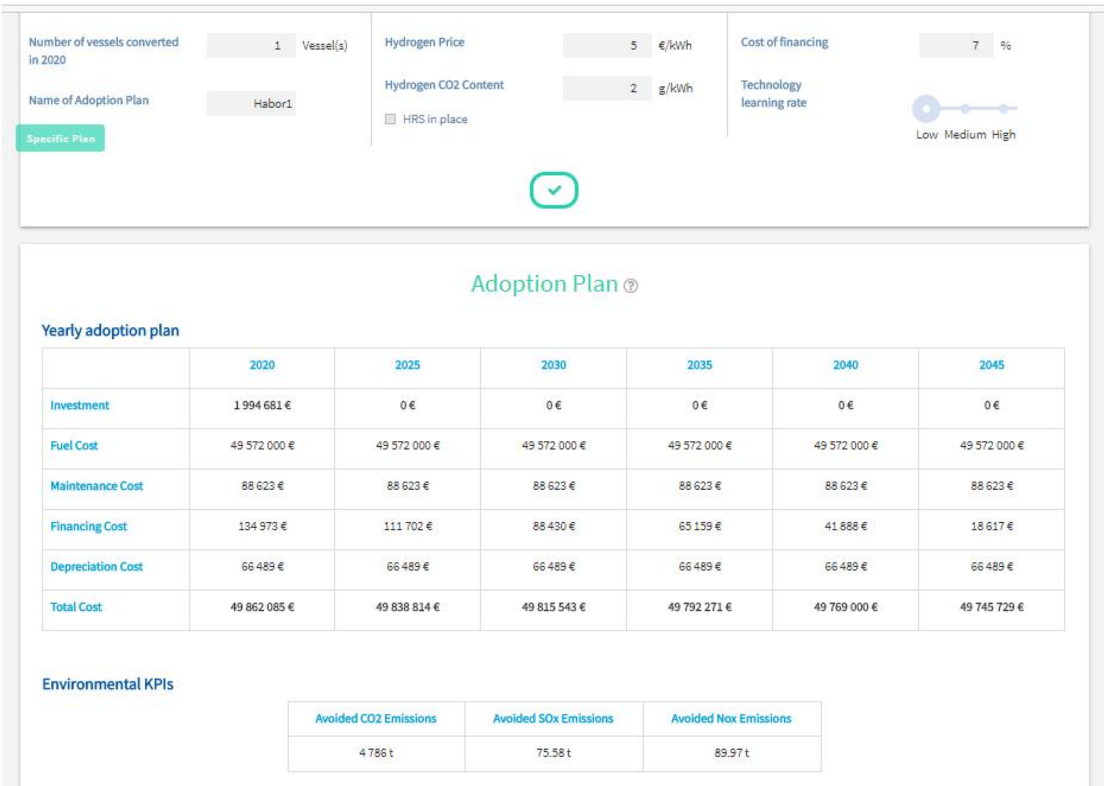
  o Low Hydrogen and fuel cell technologies are expected to progress at the current speed

  o Medium Hydrogen and fuel cell technologies are expected to progress at a faster pace

  o High A step change is expected in Hydrogen and fuel cell technologies



The resulting adoption plan is presented below:



	2020	2025	2030	2035	2040	2045
Investment	1 994 681 €	0 €	0 €	0 €	0 €	0 €
Fuel Cost	49 572 000 €	49 572 000 €	49 572 000 €	49 572 000 €	49 572 000 €	49 572 000 €
Maintenance Cost	88 623 €	88 623 €	88 623 €	88 623 €	88 623 €	88 623 €
Financing Cost	134 973 €	111 702 €	88 430 €	65 159 €	41 888 €	18 617 €
Depreciation Cost	66 489 €	66 489 €	66 489 €	66 489 €	66 489 €	66 489 €
Total Cost	49 862 085 €	49 838 814 €	49 815 543 €	49 792 271 €	49 769 000 €	49 745 729 €

Avoided CO2 Emissions	Avoided SOx Emissions	Avoided Nox Emissions
4 786 t	75.58 t	89.97 t

3.2 Main benefits of a web-based tool

The web-based tool turns the user experience from designing a FCH solution into testing parameters. The philosophy is then less of offering a precise solution with all required technical, economic and environmental parameters and more a process by which the user can experience the levers for making FCH a solution.

Indeed, this web-based tool allows the user to enter into a process by saving adoption plans, reworking them, accessing them at a later stage.

This also gives PersEE the possibility to track users and apprehend how they go about assessing the adoption of FCH. The tool is expected to be launched at the Navigate expo in May. Assuming that it will be effectively used, more than 2 years of user activity could be analysed for the project.

4. Use of Business analysis tool

4.1 Internal use

Internally, the tool is used to deliver on task 9.2 objectives and more specifically

- Assess H2 need from various vessel types which is a primary input to the delivery chain analysis
- Automatically identify vessels for which no HFC solution fits
- Assess the target cost for H2 for various vessels and vessel location (based on the tax regime on emissions)
- Fine tune the level of learning rate which would be required to achieve some economic relevance.

4.2 External use

Externally, the tools is used to deliver on task 9.1 dissemination objectives but also to support the collection of real life data which can fuel task 9.2 related work

At this stage, the tool still being in its design phase, has been tested with 2 'real' users (although its general approach had been discussed with more).

1- Ile de Batz

First user was Ile de Batz. This ship is a cable liner operating around the world and coming every few months to its base the port of Calais.

The captain of the vessel was keen enough to welcome us on board and go through the tool experience.

Main outcome:

Key interest:

- the potential of the fuel cell to meet the dynamic power demand of the ship when cabling

Although not a quantitative parameter, we decided to add it as a qualitative remark at the end of the adoption plan.

Key challenges:

- Size of the storage system
- WW possibilities to bunker (which is addressed in the delivery chain analysis)
- Overall investment needed

These challenges where anticipated. However, we had not anticipated that the size of the storage could be a primary need. Consequently, we increased emphasis on this characteristic.

2- Lighter boats

We also visited in Switzerland one of the previous crew coordinator from Race for Water who is, consequently, in regular contacts with owners or shipbuilders of lighter systems.

Main outcome:

Key interest:

- the possibility to automatically compute FCH requirements

Key challenges:

- not enough targeted at the luxury yacht sector which could be a prime user of the technology
- refuelling options for this sector are not straightforward enough

These remarks are currently being addressed.