UNSW SYDNEY

HySupply Shipping Tool V1.1

Released for Stakeholder Consultation

User Manual and Documentation

September 2021

Background

HySupply is a collaboration between Germany and Australia to investigate the feasibility of exporting renewable energy in the form of hydrogen from Australia to Germany and identify how this partnership can be facilitated. For Australia, the consortium is led by UNSW Sydney and is funded by the Department of Foreign Affairs and Trade (DFAT) and the Department of Industry, Science, Energy and Resources (DISER). More details can be found in https://www.globh2e.org.au/hysupply.

As part of the feasibility study, HySupply Australia is developing a series of open-source and open-access costing tools to assess the viability of this supply chain. These open-source tools will be released as an asset of the HySupply project with the intent to iteratively improve existing functionalities and data sets to provide holistic, high-level, pre-feasibility assessments for possible hydrogen projects, as we build towards a complete value chain assessment tool. The HySupply Shipping Tool is being released as *Beta* version for further consultation, to facilitate discussion regarding the development of an Australia-Germany green hydrogen supply chain.

Disclaimer

UNSW Sydney, consortium members and the Australian Government do not take responsibility arising in any way from reliance placed in this report. Any reliance placed is that party's sole responsibility. We shall not be liable to any losses, claims, expenses, demands, damages, liability, or any other proceedings out of reliance by any third party on this report.

License

Citation

While the HySupply Shipping Tool is published under the conditions of the open source MIT license making sure that the code can be used, edited, and re-distributed by others, we would appreciate if the tool developers are acknowledged by using the following citation.

R. Daiyan, I. MacGill, C. Johnston, M.H. Khan (2021). *HySupply Shipping Tool V1.1*., UNSW

Feedback and Queries

We welcome any queries and seek stakeholder feedback on the model. Please feel free to contact either Dr Rahman Daiyan (r.daiyan@unsw.edu.au) or Associate Professor Iain MacGill (I.macgill@unsw.edu.au) to discuss further.

HySupply Shipping Analysis Tool V1.1

User Manual and Documentation

Figures 1

1. Executive Summary 2

2. User Manual 3

2.1. Outline 3

2.2. Quick Start Guide 3

2.3. Tips 5

3. Worksheets 6

P1. Project Title 6

P2. Project Description 6

Index 6

S1. Model 7

3.1.1. Inputs 7

3.1.2. Calculations 8

3.1.3. Results 9

S2. Graphical Results 9

S3. Route Data 10

4. Scope of Analysis and Inputs 11

4.1. System Boundary 11

4.2. Inputs – ‘Universal Inputs & Assumptions’ 12

4.2.1. Financial Assumptions 12

4.2.2. Ship Assumptions 12

4.2.3. Port and Canal Assumptions 12

4.2.4. Shipping Route 13

4.2.5. Custom Shipping Route Inputs 13

4.2.6. Custom Fuel Inputs 13

4.3. Inputs – ‘Other Inputs & Assumptions’ 14

4.3.1. Transport Medium Assumptions 14

4.3.2. Ship Assumptions 14

4.3.3. Export Terminal Storage Assumptions 14

4.3.4. Additional Costs 15

4.4. Inputs – Values Used 16

5. Methods and Evaluation 18

5.1. Economic Analysis 18
5.1.1. Route Calculations 18
5.1.2. Capital Costs 18
5.1.3. Operating Costs 18
5.1.4. Total Costs 19
6. Validation of Shipping Model 21
7. Tool Limitations and Next Steps 22
Appendix A. List of Preloaded Routes 23
Appendix B. References 24

Figures

Figure 1. The '**S1. Model'** sheet. 3
Figure 2. The outputs section of the **Results** section. 4
Figure 3. The **'S2. Graphical Results'** sheet. 5
Figure 4. The colour coding key given in sheet **'Index'**. 5
Figure 5. The contents of the tool as defined in sheet **'Index'**. 6
Figure 6. The financial, ship, canal and port, custom shipping route and shipping input sections of sheet **'S1. Model'**. 7
Figure 7. The route calculations, capital costs, operating costs, BOG cost and delivered quantity sections of **'S1. Model'** 8
Figure 8. The route calculations, capital costs, operating costs, BOG cost and delivered quantity sections of **'S1. Model'**. 8
Figure 9. The outputs sections of **'S1. Model'**. 9
Figure 10. The **'S2. Graphical Results'** sheet 9
Figure 11. The shipping route data in **'S2. Route Data'**. 10
Figure 12. System boundary for Version 1.1 of the shipping tool. 11
Figure 13. 'Shipping Route' Inputs Section with **'Custom'** option shown. 13
Figure 14. Option to include additional costs in the **'Additional Costs'** section. 15

1. Executive Summary

The HySupply Shipping Analysis Tool is a Microsoft Excel Workbook developed to model the cost of shipping hydrogen (as liquid hydrogen (LH_2) and hydrogen carriers (ammonia, methanol, methane (LNG) and LOHC (as toluene / methylcyclohexane (TOL/MCH)). Users input all relevant shipping costs and can either select a shipping route from list of pre-determined routes linking major Australian and global ports to those in Europe and Asia, or can define their own shipping route data, hence enabling users to cost shipping transport via any route.

The tool includes a comprehensive range of costs designed to emulate a close to reality analysis for shipping transportation of hydrogen and hydrogen carriers (transport mediums). These costs include ship investment, storage investment, additional capital costs, labour, canal, port, maintenance, miscellaneous, insurance, storage operating costs, additional operating costs, fuel, carbon emissions and boil-off gas (BOG) costs. To best enable comparison between transport mediums the levelised cost of transport via shipping is calculated by adding the total annual costs and dividing by the annual total energy delivered. This levelised cost is presented per kilogram (kg) of hydrogen, per gigajoule (GJ) of transport medium and per tonne (t) of transport medium.

Total energy delivered is dependent on the storage capacity of the ship (in tonnes) and the number of trips made per year, which in turn is influenced by the ship speed, shipping route length, time spent docked at port and ship availability (days per year the ship is available for operation). Total annual costs are a summation of capital and operating costs. Annual capital costs were calculated using a capital recovery factor for the ship capital costs (outright cost of buying the ship). Annual operating costs were given through the addition of labour, canal use charges, port service charges, maintenance, miscellaneous, insurance, storage operating cost,

fuel, carbon emissions and boil-off gas (BOG) costs. Users are also given the option to incorporate any other additional capital and operating costs into the model if required.

The tool is a living tool with additional features being and expected to be added after consultation with various stakeholders (the next steps of the tool development are summarized in **Section 7**). We also encourage feedback from the user to help us improve the tool. Feedback can be provided to Associate Professor Iain MacGill (i.macgill@unsw.edu.au) and Dr. Rahman Daiyan (r.daiyan@unsw.edu.au) and further updates on the tool will be provided at https://www.globh2e.org.au/.

2. User Manual

2.1. Outline

The current iteration of the HySupply Shipping Analysis tool comprises of six worksheets. The first three sheets are the '**P1. Project Title'**, '**P2. Project Description'**, and the '**Index'**. The '**S1. Model'** sheet is the primary sheet used to input variables for the analysis and contains the calculations and outputs of the model. The '**S2. Graphical Results'** sheet breaks down the model results per unit of transport medium (the hydrogen carrier) and displays these results graphically. The final sheet, '**S3. Route Data',** contains data on the shipping route distances used in the calculations, which are selected as inputs in the **Model** sheet.

Note: There are no inputs required from the user in the **Route Data** sheet and any required changes to the variables should be done in the **Model** Sheet.

2.2. Quick Start Guide

The tool opens by automatically loading the **Index** sheet. The **Index** sheet summarises the functionality of each of the sheets and hyperlinks are provided to each sheet (activated by clicking on the sheet number). The tool inputs are stored in the **'S1. Model'** sheet. Each input relevant to key aspects of the tool have been summarised under a pertinent heading to assist the user in navigating the tool (e.g. all ship-based parameters are grouped under the '**Ship Assumptions**' heading), as shown in **Figure 1**. The user can choose the shipping route from a list of predefined shipping routes included as drop-down list or enter their own shipping route data in the '**Custom Shipping Route Inputs'** section of the sheet (as shown in **Figure 1**). The preloaded shipping routes are listed in **Appendix A**.

S1. Shipping Model

Universal Inputs & Assumption	Unit	Value	Note	Default Value
Financial Assumptions				
AUD-USD Conversion Rate	-	0.7		0.7
Interest Rate	%	5	Annual Interest Rate	5
Economic Life	years	20	Economic life of the ship and additional capital costs	20
CRF	%	8.024	Capital Recovery Factor	8.024
Ship Assumptions				
Fuel Cost	$ USD/tonne	500		500
Ship Speed	knots	18		18
Days per year in operation	days	350		350
Maintenance Cost	% of CAPEX	4		4
Miscellaneous Cost	% of OPEX	10		10
Insurance Cost	% of OPEX	10		0.95
Labour Cost	$ Million USD/year	2.5		2.5
Carbon Price	$ USD/tonne	0		20
Canal and Port Assumptions				
Suez Canal Cost	$ Million USD	0.4	One-way canal cost	0.4
Panama Canal Cost	$ Million USD	0.35	One-way canal cost	0.35
Port Days	days to load/unloa	1.5	Time taken to load/unload ship at port	1.5
Port Charges	$ Million USD/day	0.2	Cost to dock at port (including cost to load and unload	0.2
Shipping Route				
Port of Departure	N/A	Geraldton (WA)	If "Custom" is selected for both ports, model will take	N/A
Port of Arrival	N/A	Rotterdam (the	values from "Custom Shipping Route Inputs" table	N/A

Custom Shipping Route Inputs			
Input	Unit	Value	Note
Distance	Nautical Miles	-	Route Distance
Suez Canal	yes/no	-	Input "YES" if route passes Suez Ca
Panama Canal	yes/no	-	Input "YES" if route passes Panama

Custom Fuel Inputs			
Input	Unit	Value	Note
Fuel Energy Content	MJ/kg	60	
Carbon Emissions	g CO2 / g Fuel	1.2	

Other Inputs & Assumptions	Unit	LNG	Ammonia	Methanol	LOHC (TOL/MCH)	Hydrogen	Note	Default Value LNG	Default Value Ammonia	Default Value Methanol	Default Value LOHC (TOL/MCH	Default Value Hydrogen
Transport Medium Assumptions												
Lower Heating Value (LHV)	MJ/kg	48.6	18.6	19.9	0	120		48.6	18.6	19.9	0	120
Density	kg/m^3	450	682	792	769	71		450	682	792	769	71
Mass Conversion	$kg_{H2}/kg_{transportmedium}$	0.250	0.177	0.125	0.0616	1.000		0.250	0.177	0.125	0.0616	1.000
Market Price	$ USD/GJ	9.81	22.90	16.30	-	12.00		9.81	22.90	16.30	-	12.00

Figure 1. The '**S1. Model'** sheet.
Note: These values are representative and are subject to change based on user input

A column has been included in the far right of the section to show the default values used in the initial cost analysis. The cells highlighted in "orange" represent the input cells which should be defined to run the tool. If changes are made to the inputs, the tool will automatically update the results.

Outputs:

The outputs are given in a table on the **'S1. Model'** sheet, as shown in **Figure 2** below. The key outputs are highlighted in "green", these include the levelised cost of shipping transport cost represented per tonne and per GJ of hydrogen carrier, as well as the cost per kg of hydrogen delivered. The calculation method is elaborated in **Section 5.**

Capital Costs						
Ship Capital Cost	$ Million USD/year	15.41	13.00	9.63	5.22	17.33
Storage Capital Cost	$ Million USD/year	19.27	8.71	12.90	12.90	34.19
Additional Capital Cost	$ Million USD/year	0.00	0.00	0.00	0.00	0.00

Operating Costs (excluding BOG & Fuel Costs)						
Labour Cost	$ Million USD/year	2.50	2.50	2.50	2.50	2.50
Canal Costs	$ Million USD/year	5.99	5.99	5.99	5.99	5.99
Port Costs	$ Million USD/year	4.50	4.50	4.50	4.50	4.50
Maintenance Cost	$ Million USD/year	7.68	6.48	4.80	2.60	8.64
Miscellaneous Cost	$ Million USD/year	3.03	2.38	2.42	2.20	3.87
Insurance Cost	$ Million USD/year	3.03	2.38	2.42	2.20	3.87
Storage Operating Cost	$ Million USD/year	9.60	4.34	6.43	6.43	17.05
Additional Operating Cost	$ Million USD/year	0.00	0.00	0.00	0.00	0.00

BOG & Fuel Costs						
Required Fuel	tonnes/year	14,385	14,385	14,385	14,385	14,385
Ship Fuel Source	N/A	Hydrogen	Hydrogen	Hydrogen	Hydrogen	Hydrogen
BOG during transportation	tonnes/year	37,692	1,431	675	40,298	7,452
Additional Forced BOG/ dehydrogenation for ship fuel	tonnes/year	19,847	79,838	114,402	193,219	6,933
Total BOG	tonnes/year	57,539	81,269	115,077	233,518	14,385
BOG per trip	tonnes	7,679	10,846	15,357	31,163	1,920
BOG Source	N/A	LNG	Ammonia	Methanol	Hydrogen	Hydrogen
Fuel Cost	$ Million USD/year	27.43	34.62	37.33	20.71	20.71
Carbon Emissions	tonnes/year	157,829	-	158,001	-	-
Carbon Emissions Cost	$ Million USD/year	-	-	-	-	-
BOG during storage (export termir	tonnes/year	-	-	-	-	4,146
BOG during storage (import termir	tonnes/year	-	-	-	-	4,146
Shipping BOG	$ Million USD/year	0.00	0.00	0.00	0.00	0.00
Storage BOG	$ Million USD/year	0.00	0.00	0.00	0.00	11.94

Total Capital & Operating Costs						
Capital Costs	$ Million USD/year	34.67	21.71	22.53	18.11	51.53
Operating Costs	$ Million USD/year	63.76	63.19	66.39	47.14	79.07

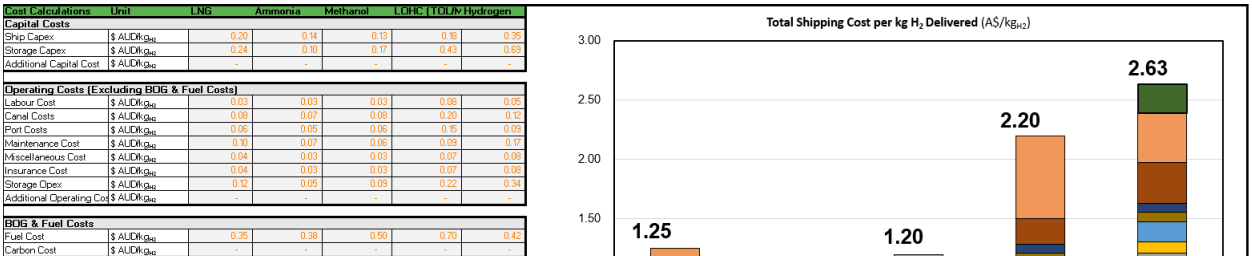
Delivered Quantity						
Delivered Quantity	kg	449,728,357	737,359,694	850,060,817	688,459,249	70,859,208
Delivered Energy	GJ	21,856,798	13,714,890	16,916,210	-	8,503,105

Total Costs (USD)	**Unit**	**LNG**	**Ammonia**	**Methanol**	**LOHC (TOL/MCH)**	**Hydrogen**
Total Annual Costs	$ Million USD/year	98.43	84.89	88.92	65.25	130.59
Cost/GJ Transport Medium	**$ USD/GJ**	**4.50**	**6.19**	**5.26**	**N/A**	**15.36**
Cost/kg Tranport Medium	$ USD/kg	0.22	0.12	0.10	0.09	1.84
Cost/tonne Transport Medium	**$ USD/tonne**	**218.88**	**115.13**	**104.60**	**94.78**	**1,843.01**
Cost/kg H2	**$ USD/kg$_{H2}$**	**0.88**	**0.65**	**0.84**	**1.54**	**1.84**

Total Costs (AUD)						
Total Annual Costs	$ Million AUD/year	140.62	121.28	127.03	93.22	186.56
Cost/GJ Transport Medium	**$ AUD/GJ**	**6.43**	**8.84**	**7.51**	**N/A**	**21.94**
Cost/kg Tranport Medium	$ AUD/kg	0.31	0.16	0.15	0.14	2.63
Cost/tonne Transport Medium	**$ AUD/tonne**	**312.68**	**164.48**	**149.43**	**135.40**	**2,632.87**
Cost/kg H2	**$ AUD/kg$_{H2}$**	**1.25**	**0.93**	**1.20**	**2.20**	**2.63**

Figure 2. The outputs section of the **Results** section.
Note: These values are representative and are subject to change based on user input

The results are also displayed graphically in the **'S.2 Graphical Results'** sheet. In the sheet, the levelised costs are presented as a breakdown of the key cost drivers (ship investment,



storage investment, additional capital costs, labour, canal, port, maintenance, miscellaneous, insurance, storage operating costs, additional operating costs, fuel, carbon and BOG costs) to the final shipping transportation cost. The breakdown is represented per tonne and per GJ of transport medium, as well as the cost per kg of hydrogen delivered.

Figure 3. The **'S2. Graphical Results'** sheet.
Note: These values are representative and are subject to change based on user input

2.3. Tips

— It is recommended to save an additional copy of the file before modifying any cells to make it easier to revert back if the workbook returns errors or if you need to revert to the default values and formulas. A fresh copy of the tool can always be downloaded from the GlobeH2 website: https://www.globh2e.org.au/hysupply

— Do not type values into cells with drop-down menus. Select only from the options in the menu.

— Throughout the model, cells have been colour-coded based on the following conventions (**Figure 4**). Please adhere to these to avoid running into errors.

Cell Colour Coding		
Note: The cells have been colour coded based on the following rules		
Name	**Representation**	**Function**
Input	XXX	Cells that can be changed
Output	XXX	Computed key outputs that should not be changed
Calculation	XXX	Represent intermediate calculations to achieve key outputs. Do not change these cells.
Important Note	XXX	Used to highlight important instructions
Value not in use	XXX	Cell is not used in calculations based on the set configuration

Figure 4. The colour coding key given in sheet **'Index'**.

3. Worksheets

P1. Project Title

Introduces the project including the project name, developers, acknowledgements, affiliations, contact information, copyright information and citation.

P2. Project Description

Provides a summary of the tool including the project statement, project scope, tool competencies and methodology.

Index

Contains the table of contents and a key for the colour coding used throughout the workbook (**Figure 5**).

Table of Contents

Sheet #	Sheet Name	Sheet Function
Intro Sheets		
P1.	**Project Title**	Introduction to the project; includes the project name, developers, acknowledgements, affiliations and copyright information
P2.	**Project Description**	Project Description: contains the project statement, project scope, tool competencies and a summary of the methodology
Main Tool Sheets		
S1.	**Model**	The **Model** sheet is provided for the user to input their chosen route and cost parameters to evaluate the cost of shipping for hydrogen and hydogen carriers.
S2.	**Graphical Results**	The **Graphical Results** sheet contains calculations and bar chart representations of the shipping route costed.
S3.	**Route Data**	The **Route Data** sheet holds the distances and canal use data for the various shipping routes costed.

Cell Colour Coding

Note: The cells have been colour coded based on the following rules

Name	Representation	Function
Input	XXX	Cells that can be changed
Output	XXX	Computed key outputs that should not be changed
Calculation	XXX	Represent intermediate calculations to achieve key outputs. Do not change these cells.
Important Note	XXX	Used to highlight important instructions
Value not in use	XXX	Cell is not used in calculations based on the set configuration

Figure 5. The contents of the tool as defined in sheet **'Index'**.

S1. Model

This sheet contains the shipping cost model. Inputs to the model are inserted in this sheet, intermediary calculations are undertaken, and results presented to the user.

3.1.1. Inputs

The inputs are separated into separate categories: financial, ship, canal/port, shipping route, transport medium, export/import storage and additional costs. Some inputs are applied universally to all transport mediums (for example, labour costs) while others are unique to each transport medium (for example, ship capital cost).

The financial category contains currency conversion assumptions as well as the interest rate and economic life of the ship. The ship category contains relevant inputs for the ship, including fuel cost, ship speed, days per year in operation, maintenance cost, miscellaneous cost, insurance cost, labour cost, carbon price, ship capital cost, ship capacity, ship engine capacity and efficiency, ship fuel source and BOG rates. The canal and port category contains the cost of passing through relevant canals (one-way) and the time and cost associated with docking at a port and loading/unloading. The transport medium input section includes energy content, density, hydrogen content and the market price of each hydrogen carrier. Finally, the export and import terminal storage inputs includes storage reference cost, storage reference capacity, nominal capacity, scale coefficient, storage O&M rate and storage BOG rates. All inputs are described in detail in **Section 4.**

Each input has a name, value, unit, notes and default value. The defaults are suggested values and some of these may depend on a formula such as the capital recovery factor (CRF) which varies with the interest rate and economic life inputs. Note that users may select a shipping route with pre-entered distance and canal input values via a drop-down list in the **'Shipping Route'** table, or if they wish to cost a custom shipping route they can select **'Custom'** as the **'Port of Departure'** and **'Port of Arrival'** and input their own distance and canal data into the **'Custom Shipping Route Inputs'** table. A similar rule applies for the ship fuel choice, which can be chosen from a drop-down list or custom inputs, which are used when the 'custom' input is chosen from the drop down, can be input in the **'Custom Fuel Inputs'** table.

S1. Shipping Model

Universal Inputs & Assumptions	Unit	Value	Note	Default Value
Financial Assumptions				
AUD-USD Conversion Rate	-	0.7		0.7
Interest Rate	%	5	Annual Interest Rate	5
Economic Life	years	20	Economic life of the ship and additional capital costs	20
CRF	%	8.024	Capital Recovery Factor	8.024
Ship Assumptions				
Fuel Cost	$ USD/tonne	500		500
Ship Speed	knots	18		18
Days per year in operation	days	350		350
Maintenance Cost	% of CAPEX	4		4
Miscellaneous Cost	% of OPEX	10		10
Insurance Cost	% of OPEX	10		0.95
Labour Cost	$ Million USD/year	2.5		2.5
Carbon Price	$ USD/tonne	20		20
Canal and Port Assumptions				
Suez Canal Cost	$ Million USD	0.4	One-way canal cost	0.4
Panama Canal Cost	$ Million USD	0.35	One-way canal cost	0.35
Port Days	days to load/unload	1.5	Time taken to load/unload ship at port	1.5
Port Charges	$ Million USD/day	0.2	Cost to dock at port (including cost to load and unload s	0.2
Shipping Route				
Port of Departure	N/A	Geraldton (WA)	If "Custom" is selected for both ports, model will take	N/A
Port of Arrival	N/A	Rotterdam (the N	values from "Custom Shipping Route Inputs" table	N/A

Custom Shipping Route Inputs			
Input	Unit	Value	Note
Distance	Nautical Miles	5,000	Route Distance
Suez Canal	yes/no	YES	Input "YES" if route passes Suez Can
Panama Canal	yes/no	-	Input "YES" if route passes Panama C

Custom Fuel Inputs			
Input	Unit	Value	Note
Fuel Energy Conte	MJ/kg	60	
Carbon Emissions	g CO2 / g Fuel	1.2	

Figure 6. The financial, ship, canal and port, custom shipping route and shipping input sections of sheet **'S1. Model'**.
Note: These values are representative and are subject to change based on user input

3.1.2. Calculations

Once users have inserted their inputs to the model, the model will automatically calculate all costs and update the outputs accordingly. The intermediate calculations are separated into route calculations, capital costs, operating costs (excluding BOG & fuel costs), BOG & fuel costs, total capital & operations costs and delivered quantity. The physical formulas used for the calculations are contained in **Section 5.**

Cost Calculations	Unit	LNG	Ammonia	Methanol	LOHC (TOL/MCH)	Hydrogen
Route Calculations						
Distance	Nautical Miles	9441.00	9441.00	9441.00	9441.00	9441.00
Days (one way)	days	21.85	21.85	21.85	21.85	21.85
Total Trip Days	days	46.71	46.71	46.71	46.71	46.71
Trips per year	trips/year	7.49	7.49	7.49	7.49	7.49
Sailing Days	days	327.52	327.52	327.52	327.52	327.52
Suez Canal	yes/no	YES	YES	YES	YES	YES
Panama Canal	yes/no	NO	NO	NO	NO	NO
Suez Canal Cost	$ Million USD	0.40	0.40	0.40	0.40	0.40
Panana Canal Cost	$ Million USD	0.00	0.00	0.00	0.00	0.00
Capital Costs						
Ship Capital Cost	$ Million USD/year	15.41	13.00	9.63	5.22	17.33
Storage Capital Cost	$ Million USD/year	19.27	8.71	12.90	12.90	34.19
Additional Capital Cost	$ Million USD/year	0.00	0.00	0.00	0.00	0.00
Operating Costs (excluding BOG & Fuel Costs)						
Labour Cost	$ Million USD/year	2.50	2.50	2.50	2.50	2.50
Canal Costs	$ Million USD/year	5.99	5.99	5.99	5.99	5.99
Port Costs	$ Million USD/year	4.50	4.50	4.50	4.50	4.50
Maintenance Cost	$ Million USD/year	7.68	6.48	4.80	2.60	8.64
Miscellaneous Cost	$ Million USD/year	3.03	2.38	2.42	2.20	3.87
Insurance Cost	$ Million USD/year	3.03	2.38	2.42	2.20	3.87
Storage Operating Cost	$ Million USD/year	9.60	4.34	6.43	6.43	17.05
Additional Operating Cost	$ Million USD/year	0.00	0.00	0.00	0.00	0.00
BOG & Fuel Costs						
Required Fuel	tonnes/year	14,385	14,385	14,385	14,385	14,385
Ship Fuel Source	N/A	Hydrogen	Hydrogen	Hydrogen	Hydrogen	Hydrogen
BOG during transportation	tonnes/year	37,692	1,431	675	40,298	7,452
Additional Forced BOG/ dehydrogenation for ship fuel	tonnes/year	19,847	79,838	114,402	193,219	6,933
Total BOG	tonnes/year	57,539	81,269	115,077	233,518	14,385
BOG per trip	tonnes	7,679	10,846	15,357	31,163	1,920
BOG Source	N/A	LNG	Ammonia	Methanol	Hydrogen	Hydrogen
Fuel Cost	$ Million USD/year	27.43	34.62	37.33	20.71	20.71
Carbon Emissions	tonnes/year	157,829	-	158,001	-	-
Carbon Emissions Cost	$ Million USD/year	-	-	-	-	-
BOG during storage (export termin	tonnes/year	-	-	-	-	4,146
BOG during storage (import termin	tonnes/year	-	-	-	-	4,146
Shipping BOG	$ Million USD/year	0.00	0.00	0.00	0.00	0.00
Storage BOG	$ Million USD/year	0.00	0.00	0.00	0.00	11.94
Total Capital & Operating Costs						
Capital Costs	$ Million USD/year	34.67	21.71	22.53	18.11	51.53
Operating Costs	$ Million USD/year	63.76	63.19	66.39	47.14	79.07
Delivered Quantity						
Delivered Quantity	kg	449,728,357	737,359,694	850,060,817	688,459,249	70,859,208
Delivered Energy	GJ	21,856,798	13,714,890	16,916,210	-	8,503,105

3.1.3. Results

The results of the model are contained in the Total Costs (USD) and Total Costs (AUD) sections of the sheet. The outputs (levelised cost of shipping) are given per kilogram (kg), per tonne and per gigajoule (GJ) of transport medium, as well as per kg of hydrogen delivered, as shown

Total Costs (USD)	**Unit**	**LNG**	**Ammonia**	**Methanol**	**LOHC (TOL/MCH)**	**Hydrogen**
Total Annual Costs	$ Million USD/year	98.43	84.89	88.92	65.25	130.59
Cost/GJ Transport Medium	**$ USD/GJ**	**4.50**	**6.19**	**5.26**	**N/A**	**15.36**
Cost/kg Tranport Medium	$ USD/kg	0.22	0.12	0.10	0.09	1.84
Cost/tonne Transport Medium	**$ USD/tonne**	**218.88**	**115.13**	**104.60**	**94.78**	**1,843.01**
Cost/kg H2	**$ USD/kg$_{H2}$**	**0.88**	**0.65**	**0.84**	**1.54**	**1.84**

Total Costs (AUD)						
Total Annual Costs	$ Million AUD/year	140.62	121.28	127.03	93.22	186.56
Cost/GJ Transport Medium	**$ AUD/GJ**	**6.43**	**8.84**	**7.51**	**N/A**	**21.94**
Cost/kg Tranport Medium	$ AUD/kg	0.31	0.16	0.15	0.14	2.63
Cost/tonne Transport Medium	**$ AUD/tonne**	**312.68**	**164.48**	**149.43**	**135.40**	**2,632.87**
Cost/kg H2	**$ AUD/kg$_{H2}$**	**1.25**	**0.93**	**1.20**	**2.20**	**2.63**

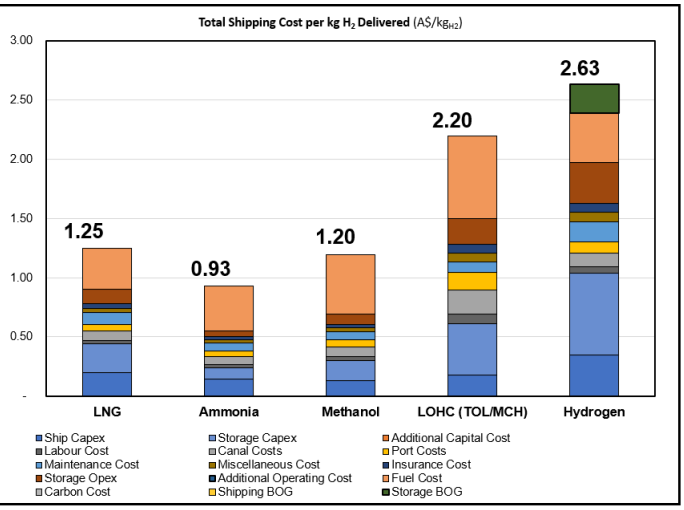
Figure SEQ Figure * ARABIC 9. The outputs sections of **'S1. Model'**.
Note: These values are representative and are subject to change based on user input

below.

S2. Graphical Results

The **Graphical Results** sheet contains all costs calculated on a per unit basis, with results given per kg of hydrogen, per tonne of transport medium and per GJ of transport medium. The results are also presented in graphical form (as a bar chart) to aid user understanding of the results. **Note:** This sheet is automatically populated with data from the **Model** sheet, so does not need any input from users

Cost Calculations	Unit	LNG	Ammonia	Methanol	LOHC (TOL/M	Hydrogen
Capital Costs						
Ship Capex	$ AUD/kg$_{H2}$	0.20	0.14	0.13	0.18	0.35
Storage Capex	$ AUD/kg$_{H2}$	0.24	0.10	0.17	0.43	0.53
Additional Capital Cost	$ AUD/kg$_{H2}$	-	-	-	-	-
Operating Costs (Excluding BOG & Fuel Costs)						
Labour Cost	$ AUD/kg$_{H2}$	0.03	0.03	0.03	0.08	0.05
Canal Costs	$ AUD/kg$_{H2}$	0.06	0.07	0.08	0.20	0.12
Port Costs	$ AUD/kg$_{H2}$	0.06	0.05	0.06	0.15	0.09
Maintenance Cost	$ AUD/kg$_{H2}$	0.10	0.07	0.06	0.09	0.17
Miscellaneous Cost	$ AUD/kg$_{H2}$	0.04	0.03	0.03	0.07	0.08
Insurance Cost	$ AUD/kg$_{H2}$	0.04	0.03	0.03	0.07	0.08
Storage Opex	$ AUD/kg$_{H2}$	0.12	0.05	0.09	0.22	0.34
Additional Operating Cost	$ AUD/kg$_{H2}$	-	-	-	-	-
BOG & Fuel Costs						
Fuel Cost	$ AUD/kg$_{H2}$	0.35	0.38	0.50	0.70	0.42
Carbon Cost	$ AUD/kg$_{H2}$	-	-	-	-	-
Shipping BOG	$ AUD/kg$_{H2}$	-	-	-	-	-
Storage BOG	$ AUD/kg$_{H2}$	-	-	-	-	0.24
Total Cost						
Total Cost	$ AUD/kg$_{H2}$	1.25	0.93	1.20	2.20	2.63



S3. Route Data

The final sheet, **Route Data,** contains data on the shipping route distances and canal usage used in the calculations, which are selected as inputs in the **Model** sheet. The routes costed are from two major ports in every state and territory in Australia (except the Australian Capital Territory, which has zero ports, and the Northern Territory, which has one port (Darwin)) to either Venice (representing the Adriatic LNG port) (Italy), Rotterdam (the Netherlands), Montoir-de-Bretagne (France), Barcelona (Spain), Tokyo (Japan), Incheon (South Korea), Singapore (Singapore) and Shanghai (China), and are given in nautical miles. Shipping distances for ports of potential competitors to Australia for hydrogen export are also provided, including Doha (Qatar), Dubai (UAE), Cape Town (South Africa), Valparaíso (Chile), Jeddah (Saudi Arabia), Houston (US), Algiers (Algeria) and Reykjavik (Iceland).

All the routes with provided shipping distances also need canal usage inputs, which are provided in the subsequent tables in the **Route Data** sheet. An input of **YES** indicates the shipping route goes through the canal mentioned. This data is used for the canal costs calculation in the **Model** sheet.

Note: The data in the **Route Data** sheet is drawn on by the model according to the route choice of the user, so no changes to this sheet are needed by users. This includes for custom shipping routes, where the custom data is input in the **Model** sheet to be used for costing.

Assumption	Unit	Heavy Fuel Oil (HFO	Marine Gas Oil	Very Low Sulfur	LNG	Ammonia	Methanol	LOHC (TO	Hydrogen	Custom
Fuel Energy Content	MJ/kg	40.20	42.70	41.00	48.60	18.60	19.90	N/A	120.00	60.00
Carbon Emissions	g CO2 / g Fuel	3.11	3.21	3.18	2.74	-	1.37	-	-	1.20

Distances (Nautical Miles	Venice (Italy)	Rotterdam (the Neth	Montoir-de-Bre	Barcelona (Spair	Tokyo (Japan)	Incheon (Sou	Singapore (S	Shanghai	Custom	Notes
Geraldton (WA)	7,478	9,441	9,035	7,755	4,297	4,161	2,017	3,834		
Port Hedland (WA)	7,498	9,461	9,055	7,775	3,622	3,634	1,678	3,307		
Darwin (NT)	8,053	10,016	9,610	8,330	3,033	3,068	1,887	2,765		
Gladstone (QLD)	9,790	11,753	11,347	10,067	3,860	4,313	3,577	4,134		
Townsville (QLD)	9,383	11,346	10,940	9,660	3,739	3,982	3,170	3,733		
Port Kembla (NSW)	9,562	11,525	11,119	9,839	4,379	4,847	4,256	4,668		
Newcastle (NSW)	9,662	11,625	11,219	9,939	4,284	4,752	4,214	4,573		
Western Port (VIC)	9,128	11,091	10,685	9,405	4,861	5,320	3,822	5,137		
Portland (VIC)	8,951	10,914	10,508	9,228	4,990	5,458	3,645	5,279		
Port Pirie (SA)	8,870	10,833	10,427	9,147	5,474	5,719	3,564	5,392		
Port Lincoln (SA)	8,747	10,710	10,304	9,024	5,373	5,596	3,441	5,269		
Burnie (TAS)	9,181	11,144	10,738	9,458	4,851	5,319	3,875	5,140		
Bell Bay (TAS)	9,224	11,187	10,781	9,501	4,842	5,308	3,918	5,129		
Doha (Qatar)	4,380	6,343	5,937	4,657	6,512	6,160	3,608	5,845		
Dubai (UAE)	4,202	6,165	5,759	4,479	6,334	5,982	3,430	5,667		
Cape Town (South Africa)	6,657	6,163	5,757	5,605	8,363	8,017	5,611	7,699		
Valparaíso (Chile)	8,643	7,455	7,162	7,494	9,294	10,202	9,988	10,134		
Jeddah (Saudi Arabia)	2,034	3,997	3,591	2,311	7,225	6,873	4,321	6,558		
Houston (US)	6,392	5,012	4,745	5,243	9,226	10,015	12,022	10,138		Houston route
Algiers (Algeria)	1,256	1,773	1,367	279	9,421	9,069	6,517	8,754		
Reykjavik (Iceland)	3,591	1,182	1,305	2,442	11,758	11,406	8,854	11,091		
Custom									-	

4. Scope of Analysis and Inputs

4.1. System Boundary

The system boundary (**Figure 12**) of Version 1.1 of the HySupply Shipping Analysis Tool is restricted to the shipping route and storage at the import and export port. The key components within the boundary are the port storage and ship systems. The model, in this iteration, allows user to use a variety of ship fuel sources to power the ship, in contrast to Version 1.0 of the model which restricted the fuel source to be HFO only.

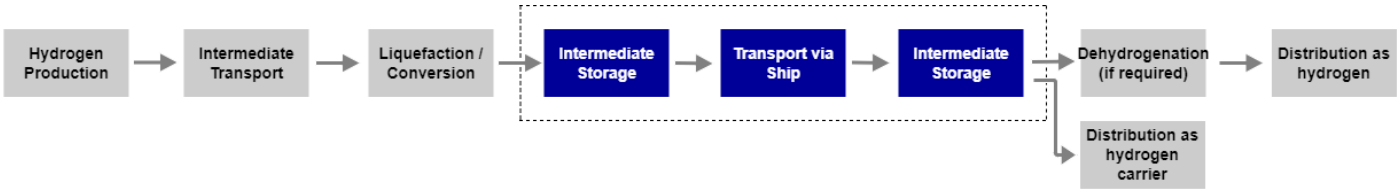


Figure 12. System boundary for Version 1.1 of the shipping tool.
Note: The system boundary is being expanded iteratively with more stakeholder input in the next stage of HySupply Project.

4.2. Inputs – 'Universal Inputs & Assumptions'

The **'S1.Model'** sheet contains a section of **'Universal Inputs & Assumptions'** which are inputs which apply equally to all transport mediums costed in the model (for example, labour cost). The following section **'Other Inputs & Assumptions'** contains inputs which are unique to each transport medium (for example, energy content of the transport medium). The **'Universal Inputs & Assumptions'** input section contains a number of subsections:

4.2.1. Financial Assumptions

- **AUD-USD Conversion Rate:** To ease analysis for stakeholders, all costs in the model are input in US dollars (USD) and then the final values are converted into Australian dollars (AUD) using the given conversion rate.
- **Interest Rate and Economic Life:** To calculate the annual capital costs, a capital recovery factor (CRF) is used, which requires an annual interest rate and economic life as an input. The CRF for an interest rate (*i*) and number of periods (*N*) is:

$$CRF = \frac{(i*(1+i)^N)}{((1+i)^N-1)} \qquad \textbf{Eq.1}$$

4.2.2. Ship Assumptions

This section requires a number of parameters about the ships used in the costing. The user has to provide the following options:

- **Fuel Cost ($ USD/ tonne):** The cost of fuel for the ship.
- **Ship Speed (knots)**
- **Days per year in operation (days):** This refers to the number of days in a year the ship is available for use. This is used to calculate the annual trips undertaken by the ship per year. The days available are used for both transportation or loading/unloading by the model.
- **Maintenance Cost (% of CAPEX):** Calculated as a percentage of the total ship investment cost (not as a percentage of the annual ship CAPEX).
- **Miscellaneous Cost (% of OPEX):** This cost is included to account for additional costs not explicitly encompassed in the model and to account for unknown cost contingencies, and is calculated as a percentage of all operating costs except 'BOG Costs', 'Fuel Costs' and 'Carbon Emissions Costs'.
- **Insurance Cost (% of OPEX):** Cost to insure the ship. It is calculated as a percentage of all operating costs except 'BOG Costs', 'Fuel Costs' and 'Carbon Emissions Costs'.
- **Labour Cost ($ Million USD/year):** Labour cost to operate the ship.

- **Carbon Price ($ USD/tonne):** Cost per tonne of CO_2 emitted.

4.2.3. Port and Canal Assumptions

- **Suez Canal Cost ($ Million USD):** The cost to pass through the Suez Canal (one-way).
- **Panama Canal Cost ($ Million USD):** The cost to pass through the Panama Canal (one-way).
- **Port Days (days to load/unload):** The time taken to load or unload the ship at port. This time is doubled to calculate the time for one round trip to account for both loading and unloading.
- **Port Charges ($ Million USD/day):** These include the cost to dock at the port and loading/unloading costs.

4.2.4. Shipping Route

- **Port of Departure/Arrival:** The two ports between which the ship is travelling. If the user selects 'Custom' for both ports, then the model will cost the shipping route inputs from the 'Custom Shipping Route Inputs' table.

Ship Assumptions				
Fuel Cost	$ USD/tonne	500		500
Ship Speed	knots	18		18
Days per year in operation	days	350		350
Maintenance Cost	% of CAPEX	4		4
Miscellaneous Cost	% of OPEX	10		10
Insurance Cost	% of OPEX	10		0.95
Labour Cost	$ Million USD/year	2.5		2.5
Carbon Price	$ USD/tonne	0		20

Canal and Port Assumptions				
Suez Canal Cost	$ Million USD	0.4	One-way canal cost	0.4
Panama Canal Cost	$ Million USD	0.35	One-way canal cost	0.35
Port Days	days to load/unload	1.5	Time taken to load/unload ship at port	1.5
Port Charges	$ Million USD/day	0.2	Cost to dock at port (including cost to load and unload sh	0.2

Shipping Route				
Port of Departure	N/A	Geraldton (WA)	"Custom" is selected for both ports, model will take	N/A
Port of Arrival	N/A	Rotterdam (the N	values from "Custom Shipping Route Inputs" table	N/A

Custom Shipping Route Inputs			
Input	Unit	Value	Note
Distance	Nautical Miles	-	Route Distance
Suez Canal	yes/no	-	Input "YES" if route passes Suez Can
Panama Canal	yes/no	-	Input "YES" if route passes Panama C

Custom Fuel Inputs			
Input	Unit	Value	Note
Fuel Energy Content	MJ/kg	60	
Carbon Emissions	g CO2 / g Fuel	1.2	

Figure 13. 'Shipping Route' Inputs Section with **'Custom'** option shown.

4.2.5. Custom Shipping Route Inputs

- **Distance:** Distance of the custom shipping route in nautical miles.
- **Suez Canal:** Whether or not the custom shipping route passes through the Suez Canal. Input "YES" if the routes passes through the Suez Canal or "NO" if it doesn't.
- **Panama Canal:** Whether or not the custom shipping route passes through the Panama Canal. Input "YES" if the routes passes through the Panama Canal or "NO" if it doesn't.

4.2.6. Custom Fuel Inputs

- **Fuel Energy Content (MJ/kg)**

- **Carbon Emissions (g CO_2/g Fuel)**

4.3. Inputs – 'Other Inputs & Assumptions'

The model contains a section of 'Other Inputs & Assumptions' which are inputs which apply uniquely to each transport medium costed in the model. The 'Other Inputs & Assumptions' section contains a number of subsections:

4.3.1. Transport Medium Assumptions

- **Lower Heating Value (MJ/kg):** Energy content of the transport medium.
- **Density (kg/m^3):** Density of the transport medium
- **Mass Conversion (kgH_2/ $kg_{transportmedium}$):** The proportional mass of hydrogen in the transport medium.
- **Market Price ($ USD/GJ):** The market price of the transport medium. Used to calculate the cost of boil-off gas in the model.

4.3.2. Ship Assumptions

- **Capital Cost ($ Million USD):** Capital cost of the ship.
- **Ship Capacity (m^3 & kg):** Capacity of the ship. The volume input (m^3) is purely so users can compare ship inputs, but it not used for any calculations. The mass input is used for calculations in the model.
- **Ship Engine Capacity (MW):** Energy demand of the ship engine.
- **Ship Engine Efficiency (%):** Efficiency of the ship engine.
- **Ship Fuel Source:** The fuel being used to power the ship. The fuel source options embedded in this model are Heavy Fuel Oil (HFO), Marine Gas Oil (MGO), Very Low Sulfur Fuel Oil (VLSFO), the specific hydrogen carrier (so an LNG ship can be powered by LNG and an ammonia ship can be powered by ammonia etc) and hydrogen. If the user selects 'Custom' for the fuel input then the model will cost the fuel inputs from the 'Custom Fuel Inputs' table.
- **Transportation BOG (%/day):** Boil-off gas rates for each transport medium (hydrogen carrier).

4.3.3. Export Terminal Storage Assumptions

- **Reference Cost ($ Million USD):** Capital cost of the reference storage tank used for the export terminal.
- **Reference Capacity (m^3):** Capacity of the reference storage tank used for the export terminal.
- **Nominal Capacity (m^3):** Capacity of the storage tank used for the export terminal in the model.
- **Scale Coefficient (N/A)**
- **Storage O&M (% of CAPEX)**
- **Storage BOG (%/day):** The BOG rate of the storage tanks.

4.3.4. Import Terminal Storage Assumptions

- **Reference Cost ($ Million USD):** Capital cost of the reference storage tank used for the import terminal.
- **Reference Capacity (m^3):** Capacity of the reference storage tank used for the import terminal.
- **Nominal Capacity (m^3):** Capacity of the storage tank used for the import terminal in the model.
- **Scale Coefficient (N/A)**
- **Storage O&M (% of CAPEX)**
- **Storage BOG (%/day):** The BOG rate of the storage tanks.

Note: The capital cost of the storage tanks used at the import/export terminals is given by:

$$StorageCapitalCost = ReferenceCost * \left(\frac{NominalCapacity}{ReferenceCapacity}\right)^{Scale\ Coefficient}$$

4.3.5. Additional Costs

- **Additional Capital Costs:** The user can include any unaccounted upfront cost if required as a lump sum amount in **Cells C69:G69** of the '**S1. Model'** sheet. This cost will be multiplied by the CRF to calculate the associated annual capital cost.
- **Additional Operating Costs:** The user can include any unaccounted operating costs if required as in **Cells C70:G70** of the **'S1. Model'** sheet.

Additional Costs						
Additional Capital Costs	$ Million USD	0	0	0	0	0
Additional Operating Costs	$ Million USD/year	0	0	0	0	0

Figure 14. Option to include additional costs in the **'Additional Costs'** section.

4.4. Inputs – Values Used

Note: These values are subject to change based on feedback from stakeholder engagement and the road mapping phase of the HySupply Feasibility Study. Additionally, the model is set up to encourage users to input their own values, but the values used for the model in this iteration are provided here for user convenience.

Assumptions for all transport mediums.

Assumptions	Unit	Value	Source
AUD-USD Conversion Rate	N/A	0.7	[1]
Interest Rate (Annual)	%	5	[2]
Economic Life of ships	Years	20	[2]

This gives a CRF of 8.024%, as per **Equation 1.**

Other assumptions for all transport mediums were:

Assumptions	Unit	Value	Source
Fuel Cost	$ USD/tonne	500	[3]
Ship Speed	knots	18	[2]
Days per year in operation	days	350	[1]
Maintenance Cost	% of CAPEX	4	[1]
Miscellaneous Cost	% of OPEX	10	[1]
Insurance Cost	% of OPEX	10	[2]
Labour Cost	$ Million USD/year	2.5	[1]
Carbon Price	$ USD/tonneCO_2	0	N/A
Suez Canal Cost	$ Million USD	0.40	[4]
Panama Canal Cost	$ Million USD	0.35	[5]
Port days to load/unload	days	1.5	[6]
Port charges	$ Million USD/day	0.2	[7]

Transport Medium Specific Assumptions Include:

Assumptions	Unit	LNG	Ammonia	Methanol	LOHC (TOL/MCH)	LH_2	Source
Lower Heating Value (LHV)	MJ/kg	48.6	18.6	19.9	N/A	120	[1, 8]
Mass Conversion	kg_{H2}/kg Transport Medium	0.25	0.177	0.125	0.0616	1	N/A

Market Price	$ USD/GJ	9.81	22.90	16.30	N/A	12.00	[1], [8-10]
Ship Capital Cost	$ Million USD	192	162	120	65	216	[1], [2]
Ship Volume	m^3	160,000	160,000	160,000	160,000	160,000	[1]
Ship Capacity	kg	67,696	109,248	128,800	123,040	11,376	[1]
Ship Engine Capacity	MW	30.5	30.5	30.5	30.5	30.5	[11]
Ship Engine Efficiency	%	50	50	50	50	50	[12]
Transportation BOG	% per day	0.170	0.004	0.0016	0.000	0.200	Based on discussions with industry partners
Additional Capital Costs	$ Million USD	0	0	0	0	0	N/A
Additional Operating Costs	$ Million USD/year	0	0	0	0	0	N/A

The export and import terminal tank storage assumptions are:

Assumptions	**Unit**	**LNG**	**Ammonia**	**Methanol**	**LOHC (TOL/MCH)**	**LH_2**	**Source**
Reference Cost	$ Million USD	85	25	42.35	42.35	106.03	[2, 13, 14]
Reference Capacity	m^3	180,000	87,977	110,000	110,000	100,000	[2, 13, 14]
Nominal Capacity	m^3	320,000	320,000	320,000	320,000	320,000	[15]
Scale Coefficient	N/A	0.6	0.6	0.6	0.6	0.6	N/A
O&M	% of CAPEX	4	4	4	4	4	[16]
Storage BOG	%/day	0	0	0	0	0.1	[16]

5. Methods and Evaluation

5.1. Economic Analysis

The model was adapted from [1] with a number of new features and changes to calculations based off feedback from industry partners.

5.1.1. Route Calculations

One round trip comprises of the ship travel time between ports (both ways) plus two times the days at port days (one period each to load and unload).

$$DaysOneWay = \frac{Distance}{Speed*24}$$

$$TotalTripTime = DaysOneWay * 2 + PortDays * 2$$

The days per year of operation is divided by total trip time to calculate trips per year.

$$AnnualTrips = \frac{DaysPerYearInOperation}{TotalTripTime}$$

$$AnnualSailingDays = AnnualTrips * DaysOneWay * 2$$

Annual sailing days is used to calculate yearly fuel and BOG costs.

5.1.2. Capital Costs

The annual CAPEX was calculated by multiplying the CRF and the ship capital cost. Also, any additional upfront costs input by the user are multiplied by the CRF to calculate their annual cost.

$$AnnualCAPEX = CRF * ShipCapitalCost + CRF * StorageCapitalCost + CRF * AdditionalCapitalCost$$

Note: The storage capital cost is calculated from:

$$StorageCapitalCost = ReferenceCost * \left(\frac{NominalCapacity}{ReferenceCapacity}\right)^{Scale\ Coefficient}$$

5.1.3. Operating Costs

Operating costs were given through the addition of labour, fuel, canal, port, maintenance, miscellaneous, insurance, additional operating costs and BOG costs.

$$ShipEnergyRequired\ \left(\frac{MWh}{day}\right) = \frac{ShipEngineCapacity*24}{ShipEngineEfficiency}$$

$$FuelUse\left(\frac{tonnes}{day}\right) = \frac{ShipEnergyRequired*3.6}{FuelEnergyContent}$$

$$RequiredFuel = AnnualSailingDays * FuelUse$$

$$AnnualFuelCost = RequiredFuel * FuelCost$$

If BOG is used as the fuel source (when the ship is propelled by the hydrogen carrier (e.g. LNG, ammonia, methanol) or by hydrogen – the annual fuel cost becomes:

$$AnnualFuelCost = AnnualBOG * LowerHeatingValue * HydrogenCarrierMarketPrice$$

The annual BOG is either equal to the amount of BOG that occurs naturally (if this amount is larger than the amount of BOG required for fuelling the ship) or, if forced BOG is required to fuel the ship, the BOG will be equal to the amount required to fuel the ship.

In this way the annual BOG is therefore calculated as:

$$AnnualBOG = AnnualSailingDays * TransportationBOG * ShipCapacity(kg) * \frac{1}{1000}$$

If this value is not big enough to fuel the ship requirements, the AnnualBOG is calculated as:

$$AnnualBOG = RequiredFuel$$

The remainder of the operating costs are calculated as follows:

$$AnnualCanalCost = (SuezCanalCost + PanamaCanalCost) * 2 * AnnualTrips$$

$$AnnualPortCost = AnnualTrips * Port\ Days * Port\ Charges * 2$$

$$AnnualMaintenanceCost = ShipCapitalCost * MaintenanceCost$$

$$AnnualMiscellaneousCost = (LabourCost + AnnualCanalCost + AnnualPortCost + AnnualMaintenanceCos$$

$$AnnualInsuranceCost = (LabourCost + AnnualCanalCost + AnnualPortCost + AnnualMaintenanceCost +$$

$$AnnualShippingBOGCost = AnnualSailingDays * TransportationBOG * ShipCapacity(kg) * \frac{LowerHeatingValue}{1000}$$

Note: If BOG is used as the fuel source for the ship – the BOG cost becomes zero and its cost is contained in the fuel cost.

$$AnnualStorageBOGCost = StorageBOGRate * \frac{NominalCapacity}{2} * Density * 365$$

Note: This applies to both import and export terminal storage.

$$AnnualCarbonCost = RequiredFuel * FuelCarbonEmissions * CarbonPrice$$

$$AnnualOPEX = LabourCost + AnnualCanalCosts + AnnualPortCost + AnnualMaintenanceCost + Annual$$

5.1.4. Total Costs

$$AnnualDeliveredQuantity(kg) = AnnualTrips * ShipCapacity$$

$$AnnualDeliveredQuantity(GJ) = AnnualDeliveredQuantity(kg) * \frac{LowerHeatingValue}{1000}$$

$$TotalAnnualCost = AnnualCAPEX + AnnualOPEX$$

$$CostPerGJTransportMedium = \frac{TotalAnnualCost}{AnnualDeliveredQuantity(GJ)}$$

$$CostPerKgTransportMedium = \frac{TotalAnnualCost}{AnnualDeliveredQuantity(kg)}$$

$$CostPerTonneTransportMedium = CostPerKgTransportMedium * 1000$$

$$CostPerKgH_2 = CostPerKgTransportMedium * \frac{1}{MassConversion}$$

6. Validation of Shipping Model

To validate the HySupply model, its outputs were compared to a number of results in existing literature, with the inputs used in literature used in the HySupply model to compare results. The results of the model validation are presented below:

Paper (Route costed)	**Result (their model)**	**Result (HySupply model using inputs from the source)**	**Notes**
[15] (Algiers – Hamberg)	0.7 €/kgH_2 (LOHC) 0.10 €/kgH_2 (LH_2)	0.7 €/kgH_2 (LOHC) 0.12 €/kgH_2 (LH_2)	Costs are similar however are small due to the short shipping distance, making it hard to discern differences in model performance.
[2] (Tokyo – Melbourne)	0.36 €/kgH_2 (LOHC) 0.41 €/kgH_2 (LH_2)	0.42 €/kgH_2 (LOHC) 0.42 €/kgH_2 (LH_2)	Costs were fairly similar. Due to the model in [2] including capital costs for the jetty and port, the 'Port Costs' assumptions from the HySupply model was included in comparative calculations.
[1] (Qatar – Japan)	\$0.14 USD / kgH_2 (LNG) \$0.11 USD / kgH_2 (Ammonia) \$0.11 USD / kgH_2 (Methanol) \$0.12 USD / kgH_2 (DME) \$0.39 USD / kgH_2 (LH_2)	\$0.15 USD / kgH_2 (LNG) \$0.12 USD / kgH_2 (Ammonia) \$0.11 USD / kgH_2 (Methanol) \$0.12 USD / kgH_2 (DME) \$0.41 USD / kgH_2 (LH_2)	It should be noted the model in [1] doesn't account for the return journey of the ship in its model. By inputting this assumption into the HySupply model similar outputs are obtained.
[11] (Japan – Patagonia)	1.13 €/kgH_2 (LH_2)	1.12 €/kgH_2 (LH_2)	
[16] (N/A – 3000 km)	\$1.33 US / kgH_2 (LH_2) \$0.19 USD / kgH_2 (Ammonia) \$0.23 USD / kgH_2 (LOHC)	\$1.24 US / kgH_2 (LH_2) \$0.18 USD / kgH_2 (Ammonia) \$0.26 USD / kgH_2 (LOHC)	

7. Tool Limitations and Next Steps

The tool currently has the following limitations:

— The scope of the tool is currently limited to the cost from port to port so does not account for any other parts of the supply chain.

The next steps of the tool development are expected to involve:

— This tool is part of larger project which aims to develop a feasibility framework for complete hydrogen value chain that includes generation, storage, transportation, conversion, and export of hydrogen/hydrogen carriers, which are in development.

We welcome feedback from the user to help us improve the tool, feedback can be provided to Associate Professor Iain MacGill (i.macgill@unsw.edu.au) and Dr. Rahman Daiyan (r.daiyan@unsw.edu.au) and further updates on the tool will be provided at https://www.globh2e.org.au/.

Appendix A. List of Preloaded Routes

Port of Departure

1. Geraldton (WA)
2. Port Hedland (WA)
3. Darwin (NT)
4. Gladstone (QLD)
5. Townsville (QLD)
6. Port Kembla (NSW)
7. Newcastle (NSW)
8. Western Port (VIC)
9. Portland (VIC)
10. Port Pirie (SA)
11. Port Lincoln (SA)
12. Burnie (TAS)
13. Bell Bay (TAS)
14. Doha (Qatar)
15. Dubai (UAE)
16. Cape Town (South Africa)
17. Valparaíso (Chile)
18. Jeddah (Saudi Arabia)
19. Houston (United States) – Note that Houston routes are costed from the 'Texas City' port
20. Algiers (Algeria)
21. Reykjavik (Iceland)

Port of Arrival

1. Venice (Italy)
2. Rotterdam (Netherlands)
3. Montoir-de-Bretagne (France)
4. Barcelona (Spain)
5. Tokyo (Japan)
6. Incheon (South Korea)
7. Singapore (Singapore)
8. Shanghai (China)

Appendix B. References

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