P2X Methanol Analysis Tool V1.0

Released for Stakeholder Consultation

Background

The Australian Research Council (ARC) Training Centre for the Global Hydrogen Economy (GlobH2E) is an international consortium of research institutions, industry partners, government agencies and hydrogen start-ups. The training center acts as a collaborative focal point between world-class teams in the areas of chemical, safety and manufacturing engineering; materials science and theoretical modeling; social science; and energy market analysis. GlobeH2E engages PhD candidates and hydrogen researchers to develop technologies, business skills and supporting innovations to aid the world's transition to renewable energy. For more details of the training center visit https://www.globh2e.org.au.

The P2X Methanol Analysis Tool is part of a series of open-source and open-access tools developed to assess the viability of Power-to-X projects and supply chains. Previously released tools include outputs from HySupply Australia Germany collaboration, and include Hydrogen, Ammonia, and Shipping tools. More details and access to these tools can be found in https://www.globh2e.org.au.

This open-source tool will be released 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 P2X Methanol Analysis tool is being released for further consultation with stakeholders and to support and facilitate discussions regarding the development and deployment of green hydrogen and Methanol supply chains.

Disclaimer

UNSW Sydney 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 for 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 P2X Methanol Analysis 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.

J. Van Antwerpen, R. Daiyan, R. Amal, *P2X Methanol Analysis Tool V1.0.*, UNSW, 2023

Feedback and Queries

We welcome any queries and seek stakeholder feedback on the model. Please feel free to contact Dr Rahman Daiyan (r.daiyan@unsw.edu.au) to discuss further.

P2X Methanol Analysis Tool V1.0

User Manual and Documentation

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Executive Summary

The P2X Methanol Analysis Tool is a Microsoft Excel Workbook developed to model and cost methanol production via hydrogenation of captured CO_2 process, using renewable energy (solar PV and wind) as a key power source and green hydrogen from an electrolyser. The tool extends beyond current state-of-the-art models, by providing the user the complete freedom to define their desired plant capacities and design a wide variety of configurations to integrate the renewable energy power source, dispatchable balancing power (e.g., battery), electrolyser and methanol production process. Solar and wind traces for various locations around Australia are preloaded into the model but the user has the option to upload their own trace data which allows the tool to be used to assess green methanol production in any location around the world. The hourly resolution of the solar and wind trace data is used to model the entire process from hydrogen generation via electrolysis through to the methanol production process. The tool also considers generally under-explored electrolyser and power plant operating factors such as variation of electrolyser efficiency with load, electrolyser/power plant efficiency degradation with operating life, and using hydrogen storage as a buffer to maintain reliable operation. Furthermore, the tool integrates several types of balancing technology (battery, hydrogen Fuel cell, methanol fuel cell and grid power) which is used to provide dispatchable power to maintain system reliability when the renewable power generation is insufficient to meet the power demand.

A subsequent cost model then establishes the capital and operating costs associated with generating the methanol, which is then used to estimate the levelised cost of methanol through a discounted net present value analysis. Complete user control also extends to these features, allowing for their own project-specific cost assumptions. These include options for the user to set their own electrolyser and power plant system cost, with additional opportunities to explore economies of scale. These costs are then complemented with options to include additional costs or include engineering, procurement, and construction (EPC) and land development cost.

The tool is a living tool with additional features expected to be added after consultation with various stakeholders (the next steps of the tool development are summarized in **Section 5**). We also encourage feedback from the user to help us improve the tool. Feedback can be provided to Dr. Rahman Daiyan (r.daiyan@unsw.edu.au) and further updates on the tool will be provided at https://www.globh2e.org.au/ .

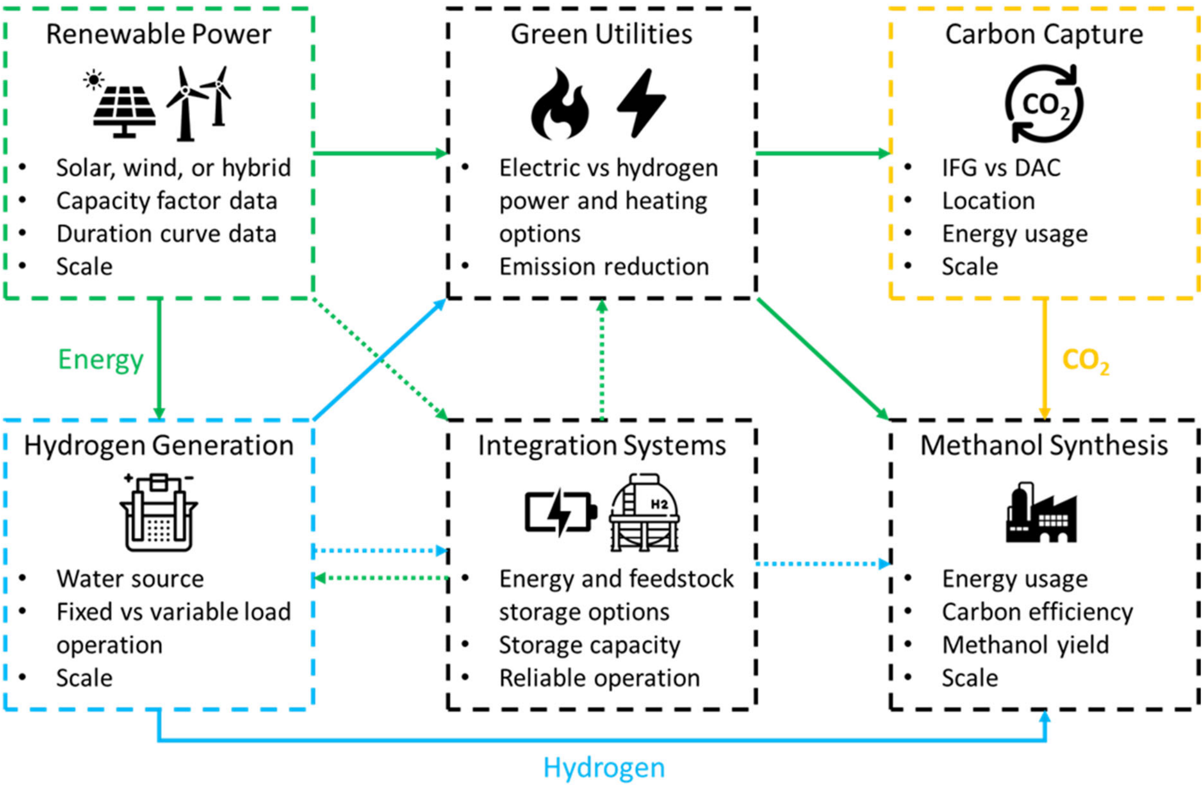


Figure 1: Overview of P2X Methanol Analysis Tool V1.0 showing the three major stages of the Power-to-Methanol Pathway.[1]

1 User Manual

1.1 Outline

The current iteration of the P2X Methanol Analysis Tool comprises of eleven worksheets. The first three sheets are the **Index**, **Project Title**, and **Project Description**. The **Inputs** sheet is the primary sheet that is used to define the variables to be used for analysis. This sheet also contains the '**Calculate**' button which must be used each time the inputs are changed to run the analysis. The **Results** sheet presents the outcomes of the model. The next four sheets contain the **Levelised Cost Analysis**, **User Raw Data**, **Raw Data** and **Working Data**. These sheets are for calculations and data only, and do not contain any inputs apart from the option to add user defined generation traces in the **User Raw Data** sheet. The **Electrolyser Parameters** sheet allows the user to adjust the electrolyser operating profile. The last sheet the **Ranges** sheet which contains the various drop-down list options throughout the tool. The tool worksheet data flow is represented below in **Figure 2.**

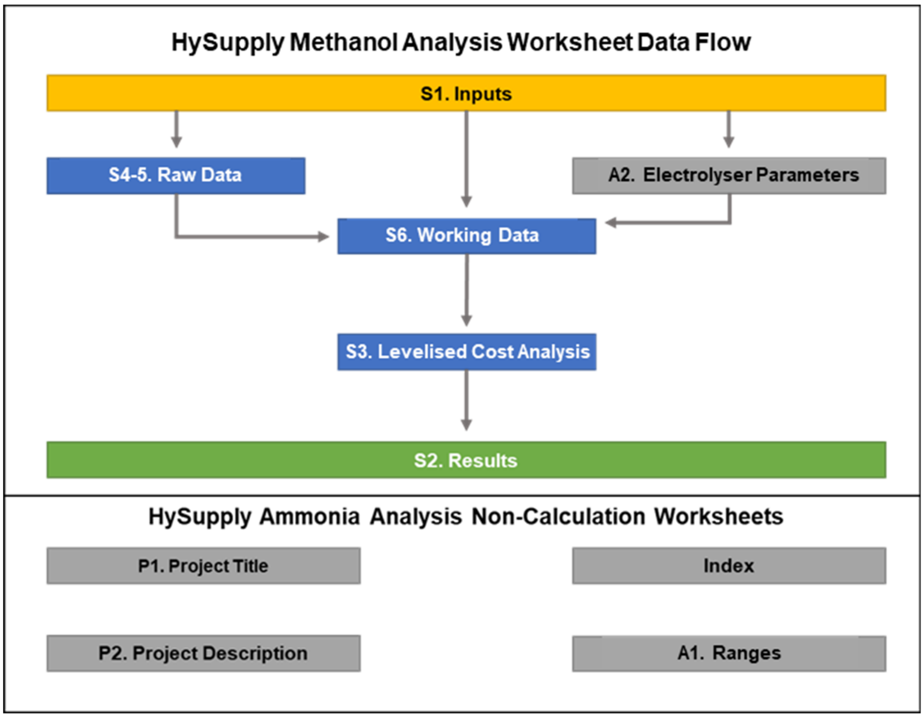


Figure 2: P2X Methanol Analysis Tool worksheet data flow

1.2 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. Inputs'** 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 power plant-based parameters are grouped under the "Power Plant Parameters" heading), as shown in **Figure 3** and **Figure 4**. Under the Scope of Analysis, the user can choose a location from the drop-down list or enter their own hourly electricity generation data in the **'User Raw Data'** sheet (further explained in **Section 2**).

Next, select from the options for the Power Plant Configuration. This cell contains a dropdown list with the configurations that can be modelled. This includes a solar only, wind only or hybrid (solar and wind) generator as well as options for a grid connected system without a PPA and grid connected system with a solar, wind or hybrid PPA. Users will also define the type of balancing technology to use which provides additional power to the system to increase reliability. The main types of balancing technology include a utility scale battery, hydrogen or methanol powered fuel cell or a grid connection that can provide balancing power. There is also the option to have no balancing technology. The source of carbon capture can also be selected which will impact the energy consumption and economic parameters associated with that unit. The next variable is water source, in which the user specifies whether water is purchased at a wholesale rate or whether it is procured and treated by an integrated onsite process. The Final element of the Scope of the analysis is Feedstock storage. While balancing technology provides backup power to process utilities, feedstock storage is the method by which hydrogen feedstock supply can be backed up during periods of low power generation. Two options are provided here including hydrogen storage, and large-scale battery storage to back up the electrolyser. Depending on the selection in the Scope of Analysis, different cells under the various parameter headings may become grey to indicate they will not be used in the model.

Under the System Sizing heading the project scale should be entered as the methanol Plant Capacity in TPD (tonnes per day). The electrolyser and power plant size will be automatically calculated based on the methanol plant capacity. The remaining inputs that can be specified under the system sizing heading are the oversizing of the electrolyser and renewable energy plant, and the hydrogen storage capacity. If a hybrid power plant configuration is selected, the solar: wind split can also be specified. At this point it is possible to run a quick analysis by pressing the green 'Calculate' button and using the default operating and cost parameters specified in the model.

S1. Inputs Sheet				
Scope of Analysis				
Location	**Southern NSW Tablelands**		Choose preloaded locations from the dropdown list or select custom to use a user specified location	
Power Plant Configuration	**C3. Standalone Hybrid Generator**		Select configuration from the options in the list. The different power plant configurations that can be evaluated using the tool have been elaborated on in the documentation	
Balancing Technology	**BT1. Battery**		Select Balancing Technology	
Carbon capture source type	**Cement Plant**		Select carbon capture point source type	
Water Source	**Integrated**		Select type of water source	
Feedstock storage	**Hydrogen storage**		Select hydrogen supply buffer stratergy	
Note: The choices provided for the power plant configuration are used to determine which input cells are marked as inactive below. The scope will also be summarised in the results, which the user can then print/copy				
Note: Once the scope and inputs are ready, please click the green calculate button to initiate the calculation. The calculation button needs to be clicked again to recalculate the result each time the location, power plant configuration, balancing technology parameters, system sizing parameters, type of electolyser, electrolyser performance, and solar/wind performance parameters are changed. The cost parameters can be changed without the need to recalculate via the green claculate button.				
Parameter	**Value**	**UOM**	**Note**	**Default Value**
System Sizing				
Methanol Plant Parameters				
Carbon Capture Plant Parameters				
Electrolyser and Hydrogen Storage Parameters				
Power Plant Parameters				
Transmission Parameters				
Balancing Technology Parameters				
Revenue Streams				
Additional Costs				
Financing Parameters				
Post Project Cash Flows				
Lifecycle Emission Intensity				

Figure 3: Summary of **'S1. Inputs'** sheet

To specify a more detailed analysis, the user can expand each heading as shown in **Figure 4**, to reveal all the relevant operating and cost parameters for the key components of the system. Change the orange 'input' cells relevant to the scope of analysis specified and then click the green **'Calculate'** button. This will start the calculation of the annual methanol production which can take up to 2 minutes to process. The user will then be automatically taken to the **'S2. Results'** sheet which provides a summary of the results in both tabular and graphical formats.

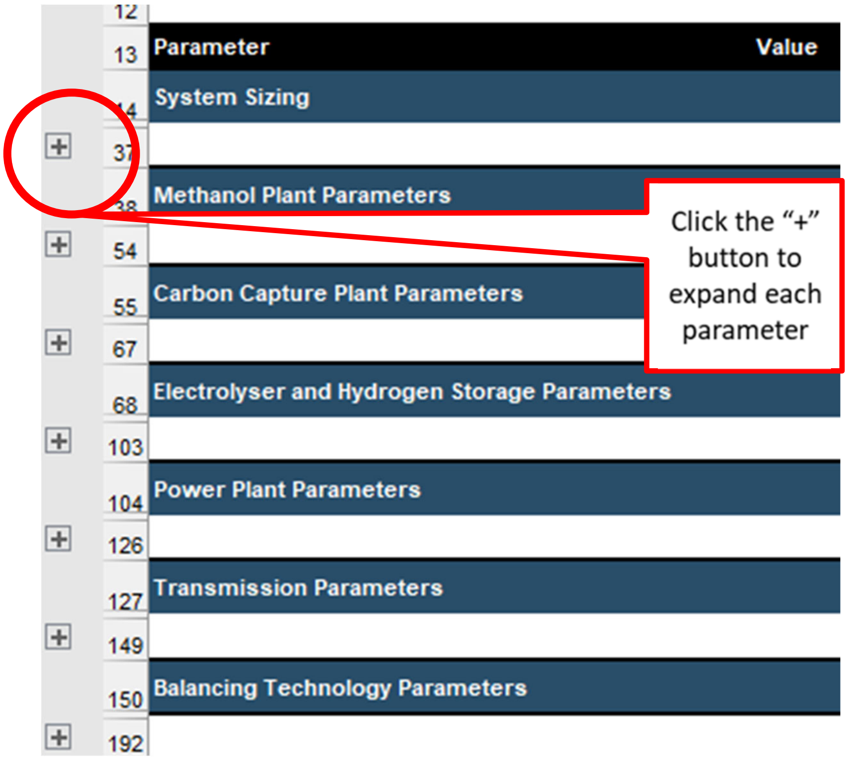


Figure 4: Expand function to help manage input of technical and economic parameters.

The outputs are given in a table on the **'S2. Results'** sheet, as in **Figure 5**. Additional figures detailing capacity factors, duration curves and cost breakdowns are also included in the results and these figures are explained in **Section 2**.

Key Input Summary		
Location	-	Southern NSW Tablelands
Power Plant Configuration	-	C3. Standalone Hybrid Generator
Balancing Technology	-	BT1. Battery
Power Plant Capacity	MW	1883.500887
Battery Capacity	MWh	375.9314015
Electrolyser Type	-	PEM
Electrolyser Capacity	MW	1,076
H2 Storage Capacity	kg	500,000
Methanol Plant Design Capacity	TPD	1,000
	kTPA	365
Carbon capture Capacity	TPD	1,446
Key Results Summary		
Capacity Factors		
Power Plant Capacity Factor	%	34%
Time Electrolyser is at Max Capacity	% of 8760 hrs/yr	0%
Total Time Electrolyser is Operating	hrs/yr	7,482
Electrolyser Capacity Factor Achieved	%	50%
Methanol Plant Capacity Factor	% of 8760 hrs/yr	89%
Methanol Plant Capacity Factor	% of 8000 Op hrs/yr	97%
Energy Results		
Total power generation	MWh / 8760 hrs	5,634,784
Energy Consumed by Electrolyser	MWh / 8760 hrs	4,730,423
Energy Consumed by Methanol Plant (MWh/yr)	MWh / 8000 hrs	116,815
Energy Consumed by CC Plant (MWh/yr)	MWh / 8000 hrs	365,952
Energy Used to Charge Battery (MWh/yr)	MWh / 8000 hrs	6,591
Excess Power Generated (Curtailed or Sold to Grid) (MWh/yr)	MWh / 8760 hrs	421,595
Carbon Balance Results		
Methanol Carbon Intensity Farm-to-Gate	gCO_{2e}/kg_{MeOH}	-907
Methanol Carbon Intensity Farm-to-Grave	gCO_{2e}/kg_{MeOH}	466
Emission Reduction	%	87%
Production Results		
Hydrogen Production	t / 8760 hrs	78,617
CO_2 Captured	t / 8000 hrs	468,209
Methanol Production (Net)	t / 8000 hrs	323,820
Excess hydrogen Generated curtailed or sold	t / 8760 hrs	15,033
Plant Operation Results		
Longest uninterupted Methanol production	hrs	2,712
Methanol Plant Uptime (Intermittency related)	%	97%

Target uptime Achieved	True/False	TRUE
Intermittent hydrogen supply annual downtime	hrs/yr	242
Intermittent energy supply annual downtime	hrs/yr	8
Levelised Cost Results		
Levelised Cost of Hydrogen (AUD/kgH2)	A$/$kg_{H2}$	4.85
Levelised Cost of Methanol (AUD/kgMEOH)	A$/$kg_{MeOH}$	1.08

Figure 5: The Outputs section of the **'Results'** sheet

1.3 Tips

- It is recommended to save an additional copy of the file before modifying any cells to make it easier to revert 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 GlobH2E website: https://www.globh2e.org.au
- Do not type values into cells with drop-down menus. Select only from the options in the menu.
- The tool uses macros to perform calculations, so macros will need to be enabled in Excel to use the tool. **NOTE:** The macros are pre-programmed to write onto set columns, which are indicated by blue shading and text. Please ensure that these columns are not moved or altered such as by adding or removing rows and columns (above or to the left of the blue cells), as this will impact on the macro function.
- Throughout the model, cells have been colour-coded based on the following conventions **(Figure 6).** 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 6: The colour coding key given in the **'Index'** sheet

- Make sure to click the green **'Calculate'** button every time the inputs are changed since the results will not update automatically.

2 Worksheets

2.1 P1. Project Title

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

2.2 P2. Project Description

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

2.3 Index

Contains the table of contents and a key for the colour coding used throughout the workbook (Figure 6).

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.	**Inputs**	The input sheet is provided for the user to select the analysis location and define the design, performance and cost parameters for the power plant, electrolyser system and Methanol unit.
S2.	**Results**	The results sheet provides a summary of key metrics and a graphical results of the analysis including duration curves for the power plant, electrolyser system and Methanol unit, breakdown of the levelised cost components and hourly capacity factor data for the power plant, electrolyser system and Methanol unit.
S3.	**Levelised Cost Analysis**	The levelised cost analysis sheet computes the capital (CAPEX) and operating (OPEX) costs of each system component, develops a discounted net present value analysis to eventually determine the levelised cost of Methanol and hydrogen.
S4.	**User Raw Data**	Optional user defined power generation data. Allowing analysis of more site locations.
S5.	**Raw Data**	The raw data sheet holds the preloaded generation data for each site available to choose from.
S6.	**Working Data**	The working data sheet establishes the hourly energy balance between the power plant, electrolyser system, carbon capture plant, Methanol unit, and balancing technologies to evaluate the mass of hydrogen, Carbon Dioxide and Methanol generated.
Appendices		
A1.	**Electrolyser Parameters**	Defines the specific energy consumption profile of the electrolsyer as a function of load
A2.	**Ranges**	The ranges sheet contains all the options in the drop down lists

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 7: The contents of the P2X Methanol Analysis Tool as defined in the **"Index"** sheet.

2.4 S1. Inputs

This sheet is where the majority the model inputs are stored. The inputs are separated into categories starting with the basic scope of analysis and followed by the system sizing, methanol plant parameters, electrolyser and hydrogen storage parameters, power plant parameters, balancing technology parameters, additional costs, and financing parameters. 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 battery costs which varies with the duration of storage. **NOTE:** Once all the parameters are defined, click the green **'Calculate'** button to activate the calculation. The calculations may take up to 2 minutes, and once the calculation is complete the user will be automatically taken to the '**Results'** sheet. If changes are made to the inputs after the active calculation is completed, the **'Calculate'** button must be clicked again for the changes to reflect in the results.

1	**S1. Inputs Sheet**				
2					
3	**Scope of Analysis**				
4	Location	**Southern NSW Tablelands**		Choose preloaded locations from the dropdown list or select custom to use a user specified location	
5	Power Plant Configuration	**C3. Standalone Hybrid Generator**		Select configuration from the options in the list. The different power plant configurations that can be evaluated using the tool have been elaborated on in the documentation	
6	Balancing Technology	**BT1. Battery**		Select Balancing Technology	
7	Carbon capture source type	**Cement Plant**		Select carbon capture point source type	
8	Water Source	**Integrated**		Select type of water source	
9	Feedstock storage	**Hydrogen storage**		Select hydrogen supply buffer strartegy	
10	**Note:** The choices provided for the power plant configuration are used to determine which input cells are marked as inactive below. The scope will also be summarised in the results, which the user can then print/copy				
11	**Note:** Once the scope and inputs are ready, please click the green calculate button to initiate the calculation. The calculation button needs to be clicked again to recalculate the result each time the location, power plant configuration, balancing technology parameters, system sizing parameters, type of electolyser, electrolyser performance, and solar/wind performance parameters are changed. The cost parameters can be changed without the need to recalculate via the green claculate button.				
12					
13	**Parameter**	**Value**	**UOM**	**Note**	**Default Value**
14	**System Sizing**				
15	Methanol Capacity	**1000**	TPD	Enter Methanol Plant Capacity	100 - 5000 TPD
16	Methanol Power demand	15.00	MW	Power demand from methanol production process. Custom value can be specified in Methanol Plant Parameters	
17	Carbon Capture Plant Capacity	1,446	TPD	Calculated Capacity of carbon capture process	
18	Carbon capture Power Demand	46.99	MW	Power demand from methanol production process. Custom value can be specified in carbon Capture Plant Parameters	
19	Hydrogen Output	198.7	TPD		
20		8,279	kg/h		
21	Electrolyser Rated Capacity	1,614.43	MW		
22	Electrolyser Oversizing	**200%**	%	Oversizing to allow for storage of Hydrogen (Must be greater than calculated minimum oversizing)	
23	Optional - User defined electrolyser capacity		MW	User defined electrolyser capacity (Optional - will ignore Electrolyser sizing calculations). Leave empty if not used.	
24	Water Required	82.79	m3/h		
25	Water Plant Power Demand	0.32	MW		
26	Generator Type	Hybrid			
27	Solar Farm Capacity	1677	MW	Input solar farm capacity	
28	Wind Farm Capacity	1677	MW	Input wind farm capacity	
29	Total Nominal Power Capacity	3355	MW	Total RE plant capcity	

Figure 8: The Scope of Analysis and System Sizing Sections in Sheet **'S1. Inputs.'**

13	**Parameter**	**Value**
14	**System Sizing**	
37		
38	**Methanol Plant Parameters**	
54		
55	**Carbon Capture Plant Parameters**	
67		
68	**Electrolyser and Hydrogen Storage Parameters**	
103		
104	**Power Plant Parameters**	
126		
127	**Transmission Parameters**	
149		
150	**Balancing Technology Parameters**	
192		
193	**Revenue Streams**	
198		
199	**Additional Costs**	
202		
203	**Financing Parameters**	
206		
207	**Lifecycle Emission Intensity**	
227		
228	**Hiden variables for calculation**	
246		

Figure 9: Summary of categories in the **'Inputs'** sheet that can be expanded and further defined by the user

2.5 S2. Results

The Results sheet provides a concise summary of the model's key inputs and results (**Figure 5**), represented as a table with the following parameters.

The summary of the key inputs include:

- **Location:** the location selected from the dropdown list in the **'Inputs'** sheet.
- **Power Plant Configuration:** depicts the configuration of the power plant.
- **Balancing Technology:** defines the type of technology used as a source of balancing power for the system.
- **Carbon Capture Source Type:** The carbon capture source selected from the dropdown list in the **'Inputs'** sheet. The selection applies preloaded operating and costing parameters to relevant fields which can be altered using custom values.
- **Feedstock Storage:** Specifies whether hydrogen storage or large scale battery storage is to be used to back up hydrogen generation reliability.
- **Power Plant Capacity:** the capacity of the power plant is copied from the **'Inputs'** sheet, based on the nominal capacity calculated.
- **Battery Power (Capacity):** if a battery is selected as the balancing technology, this is the battery rated power and capacity in parentheses.
- **Electrolyser Type:** the type of electrolyser specified in the **'Inputs'** sheet will be repeated here i.e., AE or PEM type electrolysers.
- **Electrolyser Capacity:** the capacity of the electrolyser is translated over from the **'Inputs'** sheet, based on the calculated capacity.
- **H2 Storage Capacity:** the hydrogen storage capacity defined in the **'Inputs'** sheet is repeated.
- **Methanol Capacity:** the methanol plant capacity defined in the **'Inputs'** sheet under system sizing is repeated here in tonnes per day (TPD) and thousands of tonnes per annum (kTPA).
- **Carbon Capture Capacity:** the calculated carbon capture unit capacity from the **'Inputs'** sheet is repeated.

The summary of the key results include:

- **Average Power Plant Capacity Factor (%):** The power plant capacity factor is evaluated as the ratio of the total energy that the power plant generates over the year to the energy the power plant would generate if it operated at full capacity. This capacity factor is evaluated based on the solar and wind traces.
- **Average Time Electrolyser is at Max Capacity (% of 8760 hrs/yr):** represents the number of hours in a year that the electrolyser operates at its maximum capacity (which is defined by the user in the **'Inputs'** sheet), as a percentage of the total hours in a year.
- **Average Total Time Electrolyser is Operating (hrs/yr):** represents the number of hours in a year the electrolyser operates (over its complete load range, which is defined by the user in the **'Inputs'** sheet) as a percentage of the total hours in a year.
- **Electrolyser Capacity Factor Achieved (%):** represents the ratio of the total energy input to the electrolyser over the total energy that would be required to run the electrolyser at its maximum capacity for the full year.
- **Energy Consumed by Electrolyser (MWh/yr):** represents the average energy consumed by the electrolyser in each year over the project life.
- **Energy Consumed by Methanol / Carbon Capture Plant (MWh/yr):** represents the

average energy consumed by the methanol plant in each year over the project life.

- **Energy Used to Charge the Battery (MWh/yr):** if a battery is selected as the balancing technology in the **'Inputs'** sheet, this value represents the amount of energy used in one year to charge the battery. The battery can only be charged when there is excess energy available and requires oversizing of the renewable energy plant to achieve this.
- **Time Methanol Plant is at Max Capacity (% of 8760 hrs/yr):** represents the number of hours in a year that the methanol plant operates at its maximum capacity, as a percentage of the total hours in a year.
- **Methanol Plant Capacity Factor Achieved (%):** represents the ratio of the total energy input to the methanol plant over the total energy that would be required to run the methanol plant at its maximum capacity for the whole year.
- **Average Total Time Methanol Plant is Operating (hrs/yr):** represents the number of hours in a year the methanol plant operates (over its complete load range, which is defined by the user in the **'Inputs'** sheet) as a percentage of the total hours in a year.
- **Methanol Carbon Intensity Farm-to-Gate (gCO2e/kgMeOH):** Represents the net lifecycle carbon emissions per kg of methanol product as produced from renewable energy from through to methanol production prior to use, combustion or transport.
- **Methanol Carbon Intensity Farm-to-Grave (gCO2e/kgMeOH):** Represents the approximate net lifecycle carbon emissions per kg of methanol from energy farm through to end of product life assuming complete oxidation.
- **Emission Reduction (%):** Net reduction in lifecycle emission intensity compared to fossil derived methanol.
- **Hydrogen Production (TPA):** represents the average amount of hydrogen generated per year of the plant life.
- **Carbon Capture Rate (TPA):** represents the average amount of Carbon Dioxide produced from the carbon capture unit per year of the plant life.
- **Methanol Production (TPA):** represents the average amount of methanol produced per year of the plant life.
- **Excess Power Generated (Curtailed or Sold to Grid) (MWh/yr):** represents the average additional annual energy output from the power plant which is not consumed by any of the units within the system that would otherwise need to be curtailed or sold if a grid connection was present.
- **Longest uninterrupted methanol production (Hrs):** Indicator of plant operation and the impact of intermittency on operational reliability
- **Methanol Plant Uptime (Intermittency related):** Percentage of time the designed methanol plant is operational accounting for outages due to intermittency.
- **Target uptime achieved:** Calculated uptime performance against target uptime set by user.
- **Intermittent hydrogen and power supply annual downtime:** breakdown of the annual downtime by hours related to both hydrogen supply and power supply. Providing more detail of backup power and feedstock balancing technology systems.
- **Levelised Cost of Hydrogen (A$/kg$_{H2}$):** represents the levelised cost of hydrogen
- **Levelised Cost of Methanol (A$/kg$_{MEOH}$):** represents the levelised cost of methanol

There are also several plots showing the power plant, electrolyser and methanol plant annual duration curves **(Figure 10),** hourly capacity factors (**Figure 11**), hourly battery state of charge (**Figure 12**), hourly hydrogen storage level (**Figure 13**). For the financial aspects there is a plot showing the breakdown of costs that make up the Levelised cost of methanol **(Figure 14), and**

a breakdown of the costs making up the capital expenditure (Figure 15). At the far right of the **'Results'** sheet is the result for each year of operation, which only vary if degradation of the power plant and/or electrolyser is included in the model. These results are automatically generated by the macro.

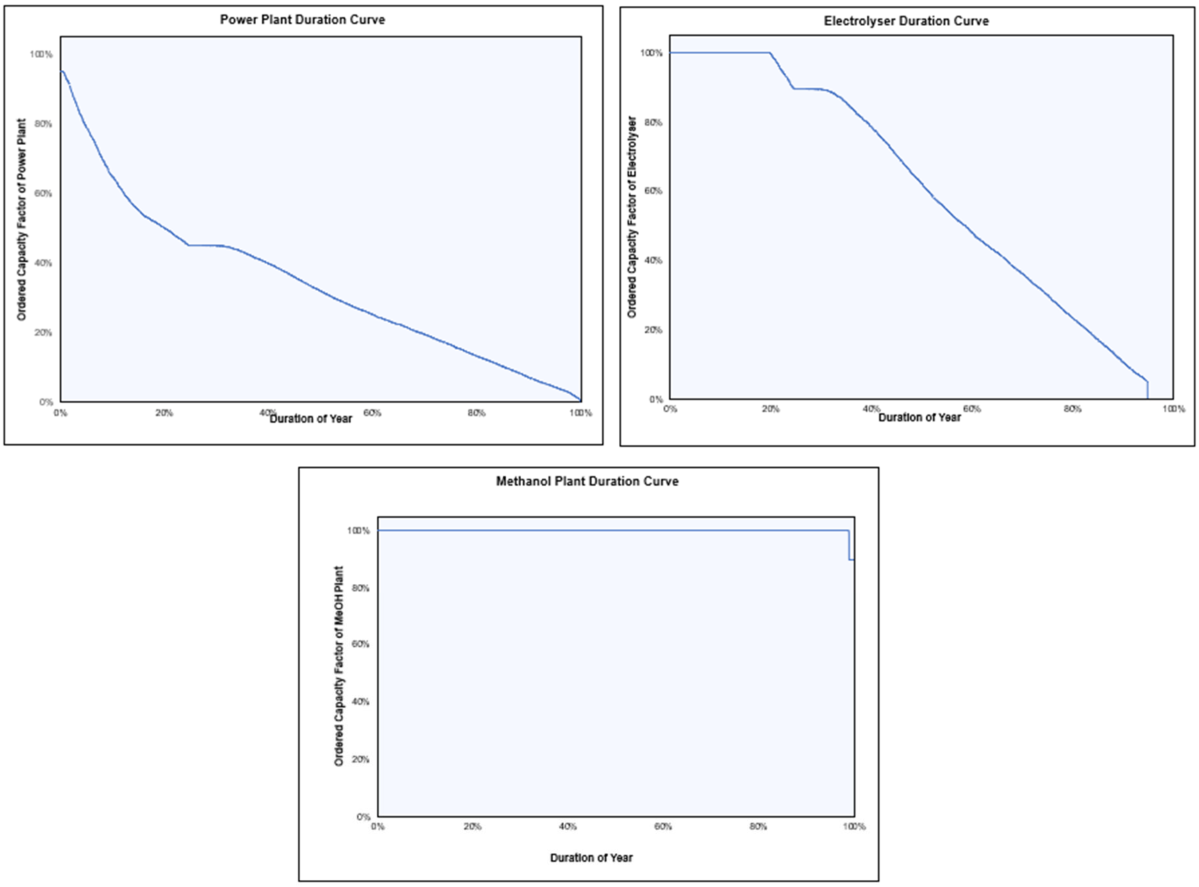


Figure 10: Annual duration curves for the power plant, electrolyser system and methanol unit from sheet **'S2. Results.' NOTE:** The values in the figures are for illustrative purposes and will change based on user defined inputs

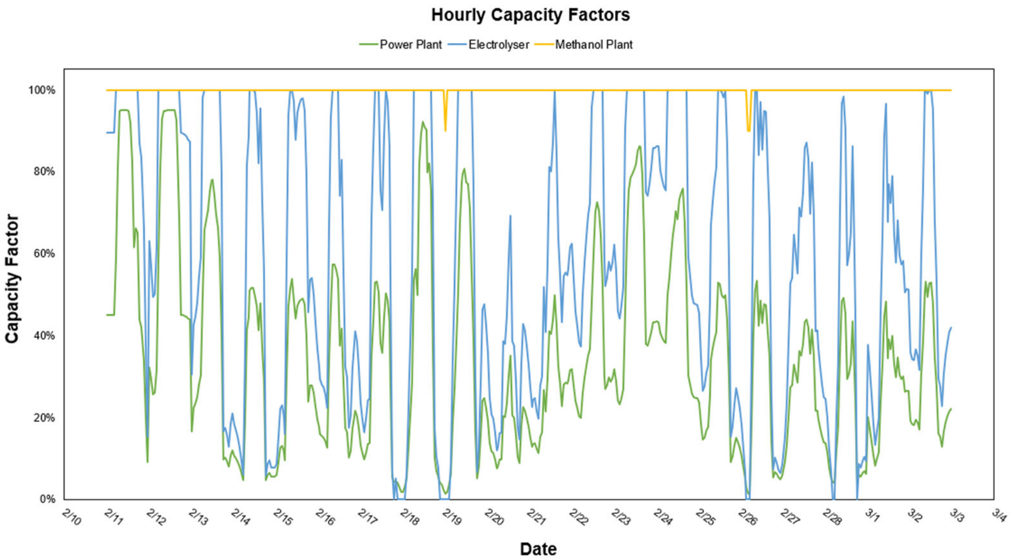


Figure 11: Interactive plot showing the hourly capacity factors of the power plant, electrolyser system and methanol unit from sheet **'S2. Results'. NOTE:** The values in the figures are for illustrative purposes and will change based on user defined inputs

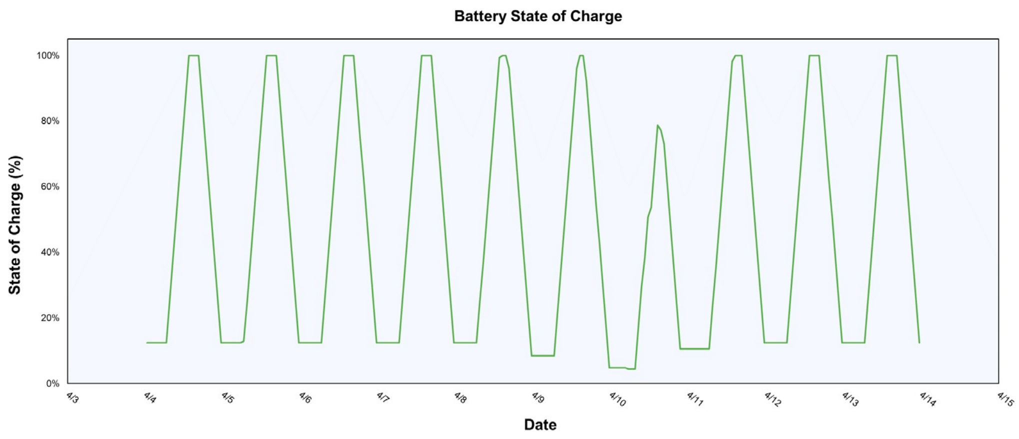


Figure 12: Interactive plot showing the hourly battery state of charge of the battery energy storage system from sheet **'S2. Results'. NOTE:** The values in the figures are for illustrative purposes and will change based on user defined inputs

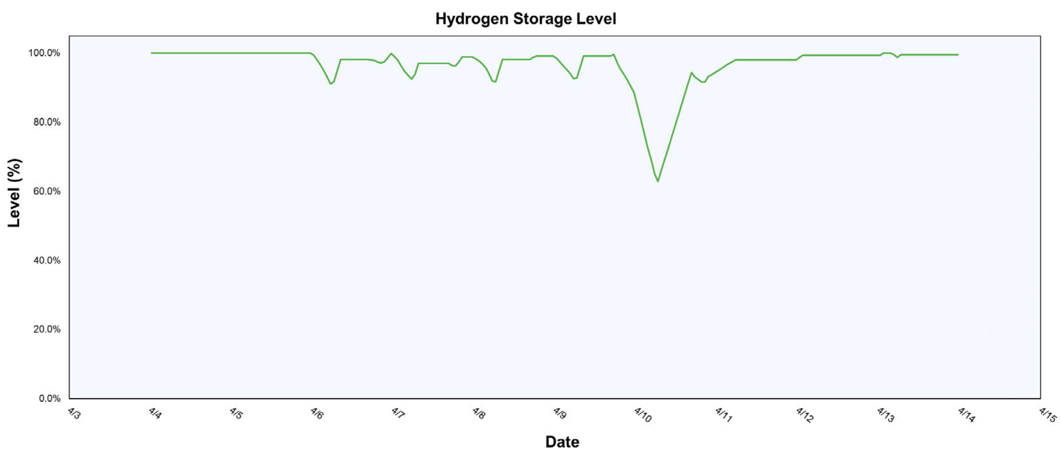


Figure 13: Interactive plot showing the hourly hydrogen storage level from sheet **'S2. Results'. NOTE:** The values in the figures are for illustrative purposes and will change based on user defined inputs

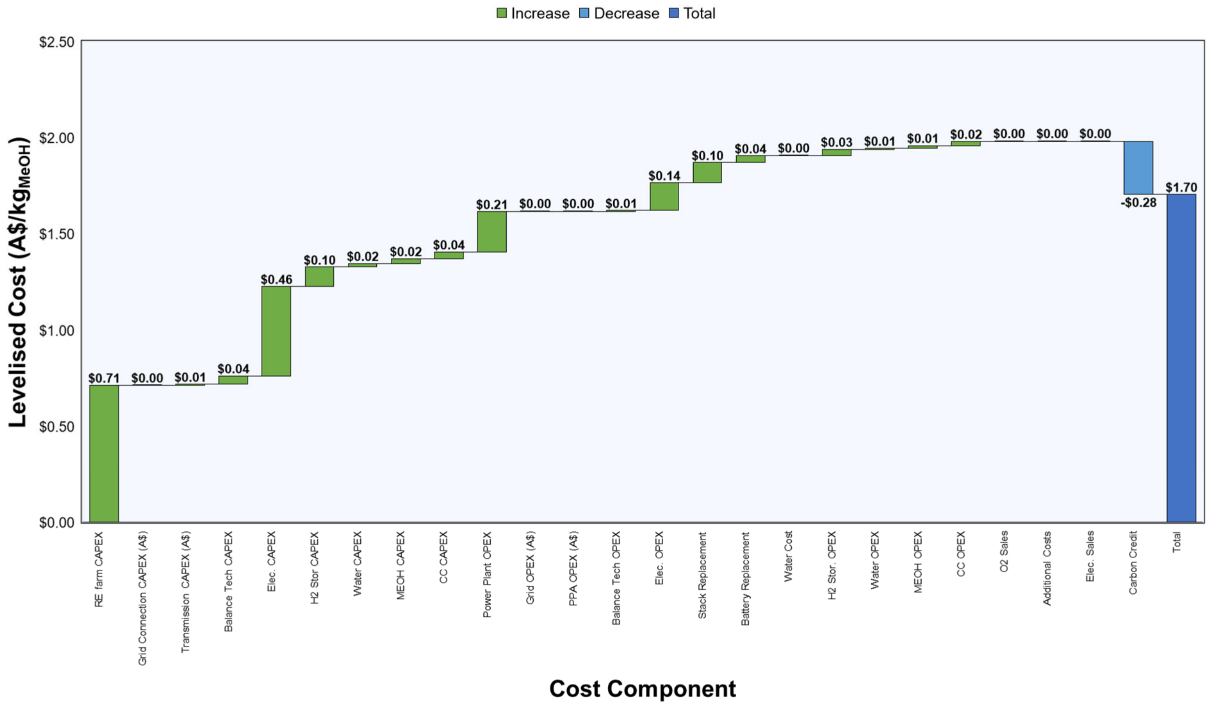


Figure 14: Waterfall plot showing the relative components of the LCOA from sheet **'S2. Results'. NOTE:** The values in the figures are for illustrative purposes and will change based on user defined inputs.

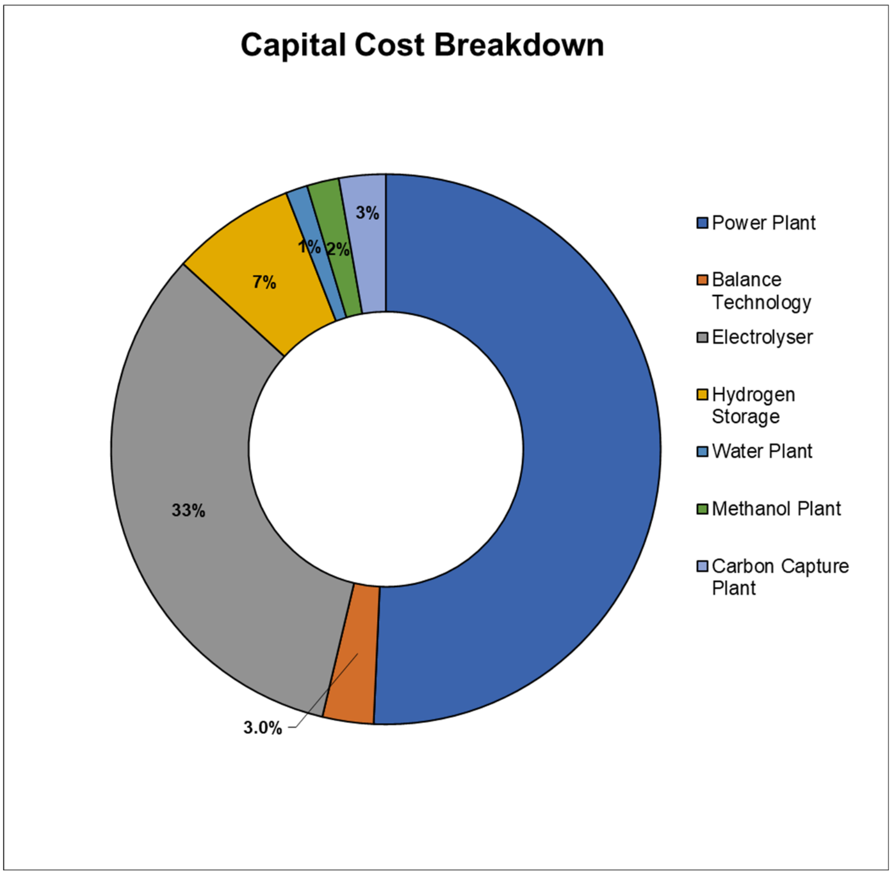


Figure 15: Breakdown of the components of the capital costs from sheet **'S2. Results'. NOTE:** The values in the figures are for illustrative purposes and will change based on user defined inputs.

2.6 S3. Levelised Cost Analysis

This sheet calculates the capital and operating costs for each component of the methanol model. It presents the annual operational profile for each year up to the lifetime as well as the discounted and non-discounted cash flows. **NOTE:** All these cells are automatically generated once the **"Calculate"** button is activated. The values are based on the user inputs and background calculations from the **'S6. Working Data'** sheets. Please do not change any values in this sheet. If changes to the inputs are required, please do so in the **'S1. Input'** sheet and click the **"Calculate"** button again.

S3. Levelised Cost Analysis

S3. CAPEX and OPEX Summary

Parameter	Value	Unit
Power Plant		
Solar Farm		
Capacity	1677	MW
Reference Capacity	1000	kW
Refrence Solar PV Farm Cost	1176	AUD/kW
Solar PV Cost Reduction with Scale	10%	%
Reference Fold Increase	10	
No. of fold increase in Capacity	3.22	
Capital Cost Reduction Factor	29%	%
Scaled Purchase Cost of Solar PV	837	AUD/kW
Solar Farm Equipment Cost	1,404,397,555	AUD
Installation Cost	-	
Land Procurement Cost	-	
Solar Farm Capital Cost	1,404,397,555	AUD
Solar Farm O&M	17,000	AUD/MW/yr
Solar Farm OPEX	28,515,620	AUD/yr
Wind Farm		
Capacity	1677	MW
Reference Capacity	1000	kW
Reference Wind Farm Cost	1289	AUD/kW
...ith Scale	10%	%

S3. LCMEOH Net Present Value

Annual Operational Profile

Year	Electricity Produced (MWh/yr)
Plant Installation/Startup	
1	9158733
2	9158733
3	9158733
4	9158733
5	9158733
6	9158733
7	9158733
8	9158733
9	9158733
10	9158733
11	9158733
12	9158733
13	9158733
14	9158733
15	

Figure 16: Sheet **'S3. Levelised Cost Analysis'** which includes a summary of the capital and operating costs and an annual summary of the actual and discounted operating costs. NOTE: The values in the figures are for illustrative purposes and will change based on user defined inputs

2.7 S5. Raw Data

To calculate the annual hydrogen production, the tool relies on hourly electricity generation profiles in the form of capacity factor traces. The '**Raw Data'** sheet currently contains hourly solar and wind traces for 2019 for 41 locations across Australia, though this will be expanded in the future. The user may also input their own project-specific solar and wind trace data to run the tool for a location other than those already included. These traces could include solar and wind potential trace data or the historical generation profile of an actual solar or wind farm in that location. To do this, copy a column of hourly capacity factor data into the appropriate space in the '**User Raw Data**' sheet shown as the orange cells **Figure 18.** Then select the 'Custom' option from the locations drop down on the **'S1. Inputs'** sheet.

S5. Raw Data

	Technology	Solar PV		
	Site ID	REZ-W1	REZ-W1	RE Ninja W1
	Location	Geraldton WA	Ashburton WA	Port Hedland WA
	Annual Capacity Factor (CF)	**31%**	**29.91%**	**26.08%**
Month of the Year	**Local Time**	**Generation (MWh/MW)**	**Generation (MWh/MW)**	**Generation (MWh/MW)**
1	1/01/2019 0:30	0.00%	0.00%	0.00%
1	1/01/2019 1:30	0.00%	0.00%	0.00%
1	1/01/2019 2:30	0.00%	0.00%	0.00%
1	1/01/2019 3:30	0.00%	0.00%	0.00%
1	1/01/2019 4:30	0.00%	0.00%	0.00%
1	1/01/2019 5:30	0.00%	0.00%	0.22%
1	1/01/2019 6:30	8.05%	0.00%	9.44%
1	1/01/2019 7:30	50.65%	3.57%	25.75%
1	1/01/2019 8:30	70.72%	10.91%	44.84%
1	1/01/2019 9:30	79.65%	72.65%	62.83%

Figure 17: Sheet **'S5. Raw Data'** contains solar and wind traces for 41 locations across Australia.

S4. User Raw Data

Note:
a) The generation data (hidden from view) for the pre-programmed locations are selected from the input sheet
b) Additional solar and wind traces for a custom location can be included by providing data in the columns below
c) Global databanks of wind and solar traces can be accessed through Renewables Ninja (https://www.renewables.ninja)

User defined RE data		Solar	Wind
Month of t	**Local Time**	**Generation (MWh/MW)**	**Generation (MWh/MW)**
1	1/01/2019 0:30		
1	1/01/2019 1:30		
1	1/01/2019 2:30		

Figure 18: Sheet '**S4. User Raw Data**' with the additional option to include solar and/or wind traces for a custom location.

2.8 S6. Working Data

The Working Data sheet **(Figure 19)** is where the hourly electrolyser operation and outputs are calculated. **NOTE:** These cells are automatically generated once the **'Calculate'** button is activated. The values are based on the user inputs and background calculations from the **'S5. Raw Data'** sheets. Do not change any values in this sheet. If changes to the inputs are required, please do so in the **'S1. Input'** sheet and click the **'Calculate'** button again.

S6. Working Data

Note:
a) Do not change the values in this worksheet
b) All parameters are calculated automatically based on provided solar/wind traces (Sheet S4. Raw Data) and the electrolyser/power plant design parameters from Sheet S1. Inputs

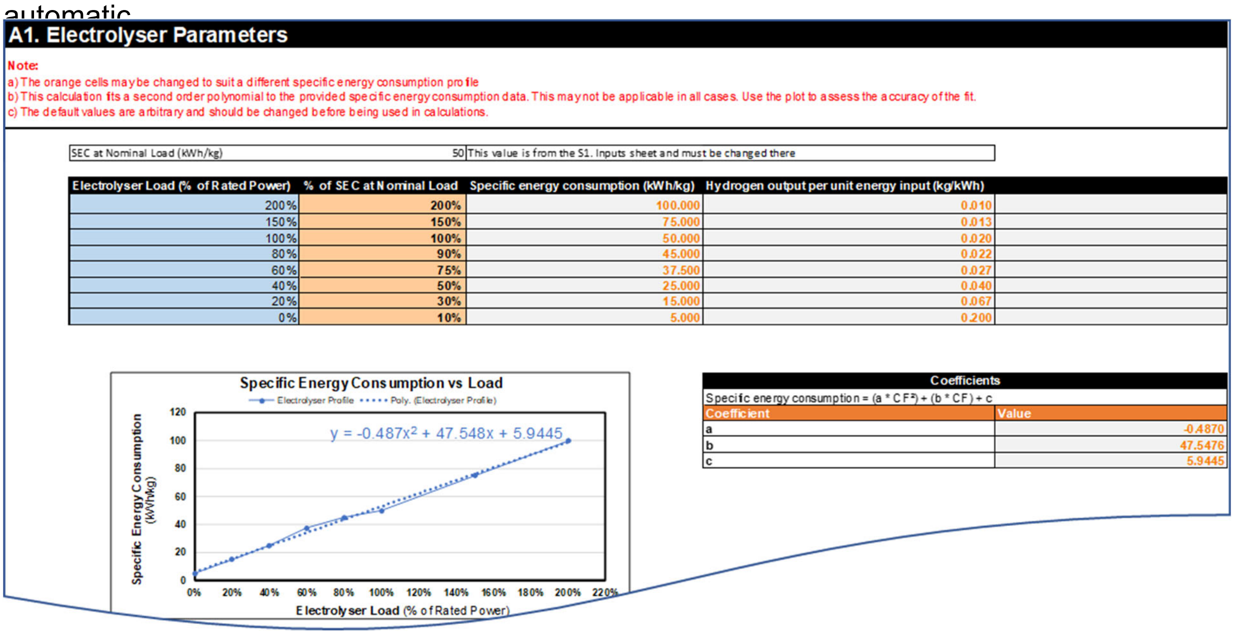
	Powerplant Operation		Capacity Factors		
Parameter	Generator Capacity Factor	Actual Power Generated(MWh)	Ordered Generator Capacity Factor	Ordered Electrolyser Capacity Factor	Ordered MEOH Plant Load (%)
Average Values	34%		34%	60%	99.9%
Totals		10,028,812			Total modelled (hrs/yr):
Occurences					
Maximum					

Date and Time	Powerplant Operation		Capacity Factors		
Local Time	Generator Capacity Factor	Actual Power Generated(MWh)	Ordered Generator Capacity Factor	Ordered Electrolyser Capacity Factor	Ordered MEOH Plant Load (%)
1/01/2019 0:30	14%	473			
1/01/2019 1:30	13%	437			
1/01/2019 2:30	16%	543			
1/01/2019 3:30	19%				

Figure 19: Sheet 'S6. Working Data' where the hourly operation is calculated. **NOTE:** The values in the figures are for illustrative purposes and will change based on user defined inputs.

2.9 A1. Electrolyser Parameters

The Specific Energy Consumption (SEC) for both the AE and PEM electrolyser, which is elaborated in **Section 3**, are known to vary based on the operational load of the electrolyser at any given time.[2] This functionality has been included in the tool as an advanced feature, which can be activated by selecting the 'variable' option from the drop down list (SEC vs Load Profile) present in cell **B71** of the **'S1. Inputs'** Sheet. Once the option has been selected, further inputs are required on the **'A1. Electrolyser Parameters'** sheet. In this sheet, the user must define the SEC (as a percentage of the SEC at nominal load), across the load range of the electrolyser (in cell **C7** onwards as shown in **Figure 20**). The SEC vs Load profile is then plotted automatically, and a second order polynomial equation is defined as a best fit that passes through up to 7 manually selected points. The coefficients used for the calculation are displayed in cells **F21 to F23**. This polynomial function is used to determine the SEC at any given load of the electrolyser, which is passed into the **'S6. Working Data'** sheet to determine the amount of hydrogen generated based on the available energy from the power plant in each hour. **NOTE:** The SEC profile vs load (orange shaded cells) are the only inputs required from the user. All other calculations on this sheet are automatic.



A1. Electrolyser Parameters

Note:
a) The orange cells may be changed to suit a different specific energy consumption profile
b) This calculation fits a second order polynomial to the provided specific energy consumption data. This may not be applicable in all cases. Use the plot to assess the accuracy of the fit.
c) The default values are arbitrary and should be changed before being used in calculations.

SEC at Nominal Load (kWh/kg)	50	This value is from the S1. Inputs sheet and must be changed there

Electrolyser Load (% of Rated Power)	% of SEC at Nominal Load	Specific energy consumption (kWh/kg)	Hydrogen output per unit energy input (kg/kWh)
200%	200%	100.000	0.010
150%	150%	75.000	0.013
100%	100%	50.000	0.020
80%	90%	45.000	0.022
60%	75%	37.500	0.027
40%	50%	25.000	0.040
20%	30%	15.000	0.067
0%	10%	5.000	0.200

Coefficients	
Specific energy consumption = (a * CF²) + (b * CF) + c	
Coefficient	Value
a	-0.4870
b	47.5476
c	5.9445

Figure 20: Sheet **'A1. Electrolyser Parameters'** defines the electrolyser specific energy consumption vs load profile.

Actual SEC profiles of AE and PEM electrolysers established in literature are also provided as a reference to guide the user in defining their own profiles **(Figure 21** and **Figure 22**). [3, 4] **NOTE:** Further profiles will be provided in due course after engagements with technology stakeholders through updated versions of the tools, which will be made available at the GlobH2E website: https://www.globh2e.org.au/

AE Electrolyser			
Reference - SEC at Nominal Load (kWh/kg)		49	Note: This just represents the electrolyser stack
Electrolyser Load (% of Rated Power)	% of SEC at Nominal Load	Specific energy consumption (kWh/kg)	Hydrogen output per unit energy input (kg/kWh)
100%	100%	49.000	0.020
80%	91%	44.545	0.022
60%	85%	41.761	0.024
40%	82%	40.091	0.025
20%	81%	39.534	0.025
Reference:	Beerbuhl et al. 2015		

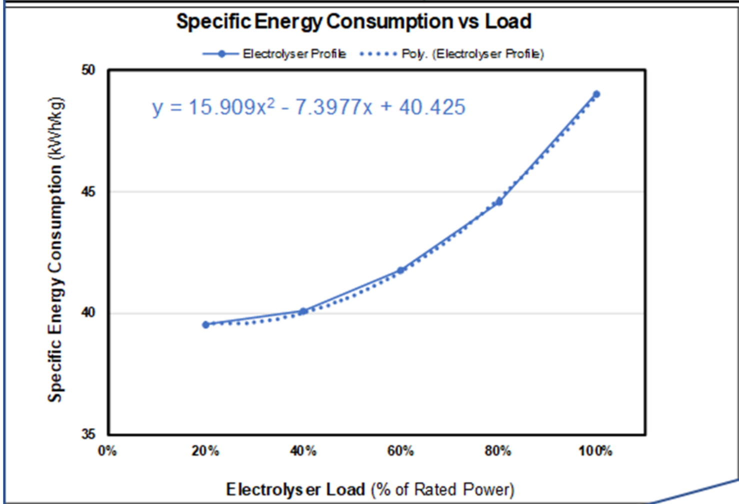


Figure 21: Preloaded SEC vs Load Profile of AE electrolyser adopted from literature[3]

PEM Electrolyser			
ence - SEC at Nominal Load (kWh/kg)		66	Note: This just represents the electrolyser system
Electrolyser Load (% of Rated Power)	% of SEC at Nominal Load	Specific energy consumption (kWh/kg)	Hydrogen output per unit energy input (kg/kWh)
100%	101%	66.663	0.015
80%	93%	61.478	0.016
60%	90%	59.282	0.017
40%	86%	56.749	0.018
20%	84%	55.330	0.018
Reference:	Kopp et al. 2017		

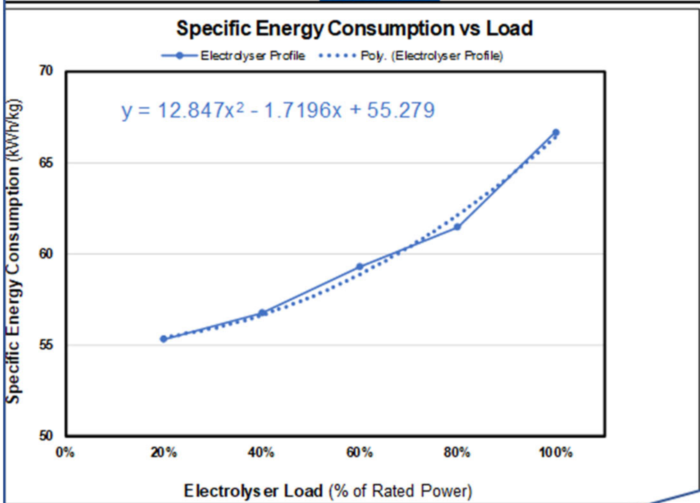


Figure 22: Preloaded SEC vs Load Profile of PEM electrolyser adopted from literature[4]

3 Scope of Analysis and Inputs

3.1 System Boundary

The system boundary (**Figure 23**) of the P2X Methanol Analysis Tool builds on the HySupply Hydrogen Cost Model previously released[5] to include hydrogen storage and conversion to methanol. The key components within the boundary are the solar and/or wind power plant, balancing technology system e.g., battery energy storage system, the electrolyser system (including its balance of plant - BoP) and hydrogen storage, and the methanol plant and the carbon capture process. The water supply source to drive the electrolyser is assumed outside the scope of the analysis, however, to represent the associated costs of the water used, the user has been provided an option to input the wholesale water price, and if known, the capital and operating costs of onsite water treatment and processing. Further functionality is provided for the user to enter additional upfront and annual costs to the project.

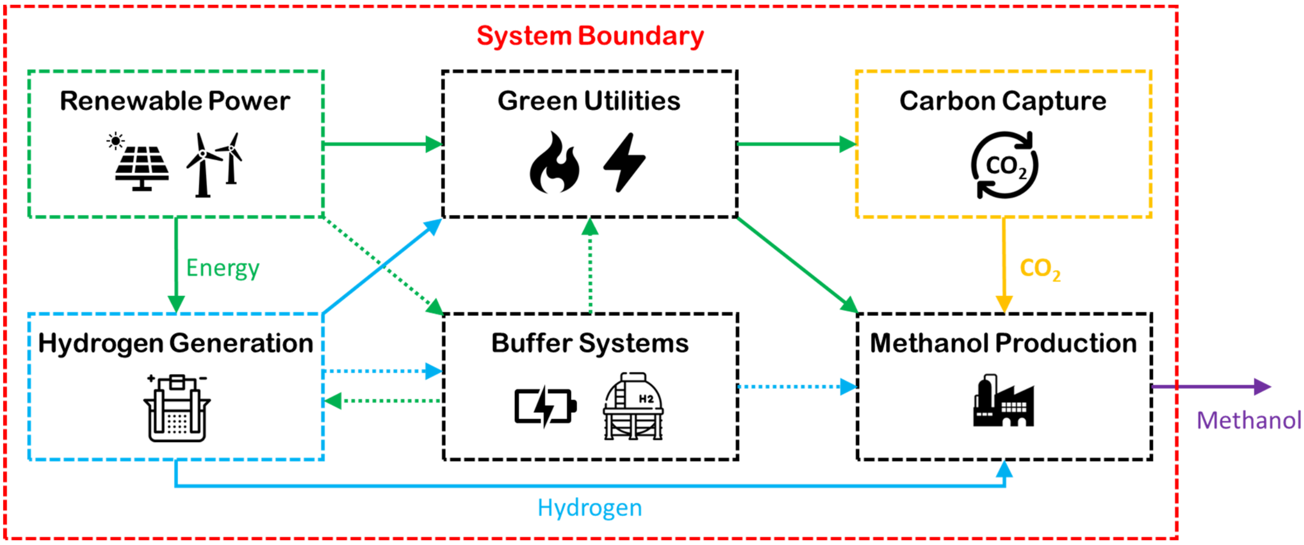


Figure 23: System boundary for the P2X Methanol Analysis Tool

3.2 Scope of Analysis

To define the analysis scope the user must set the following parameters:

3.2.1 Location

The P2X Methanol Analysis Tool is designed for a spatial analysis of methanol production costs, based on the solar and wind resources across Australia. In its present iteration, the tool includes several pre-determined sites within Australia, which contain solar and wind traces that are representative of a year of renewable resources for each renewable generation technology type. For sites within the Australian National Electricity Market (NEM), historical Australian Energy Market Operator's (AEMO) solar and wind data from the 2020 Integrated System Plan (ISP) have been used. Non-NEM sites have been represented by modelled solar and wind data obtained via the "Renewables Ninja" open-source tool. The sites that have been included in the tool can be categorised as such:

- NEM sites
  - New South Wales (NSW)
  - Queensland (QLD)
  - Victoria (VIC)
  - South Australia (SA)

    - Tasmania (TAS)
- Non-NEM sites
    - Northern Territory (NT)
    - Western Australia (WA)

The NEM sites have been chosen with reference to the Renewable Energy Zones (REZ) as documented by the AEMO's 2022 Integrated System Plan (ISP).[6] AEMO defines REZs as follows:

"REZs are areas in the NEM where clusters of large-scale renewable energy can be developed to promote economies of scale in high-resource areas and capture geographic and technological diversity in renewable resources."

For non-NEM locations, the selected sites have taken into consideration the renewable energy resources that are available as well as the site's proximity to infrastructure such as roads, railways, gas pipelines, and ports. Reports such as the Western Australian Renewable Hydrogen Strategy(ref) have also informed the site selection, aligning the P2X Methanol Analysis Tool with sites that are of interest to the relevant state government and the private sector for their renewable energy/green methanol potential.

The location can be set through the drop-down list in Cell B4 as shown in **Figure 24**. Custom locations can be defined in the **'S4. User Raw Data'** Sheet, and that will appear in the drop-down list as **'Custom'**. The full list of preloaded locations is provided in **Appendix A**.

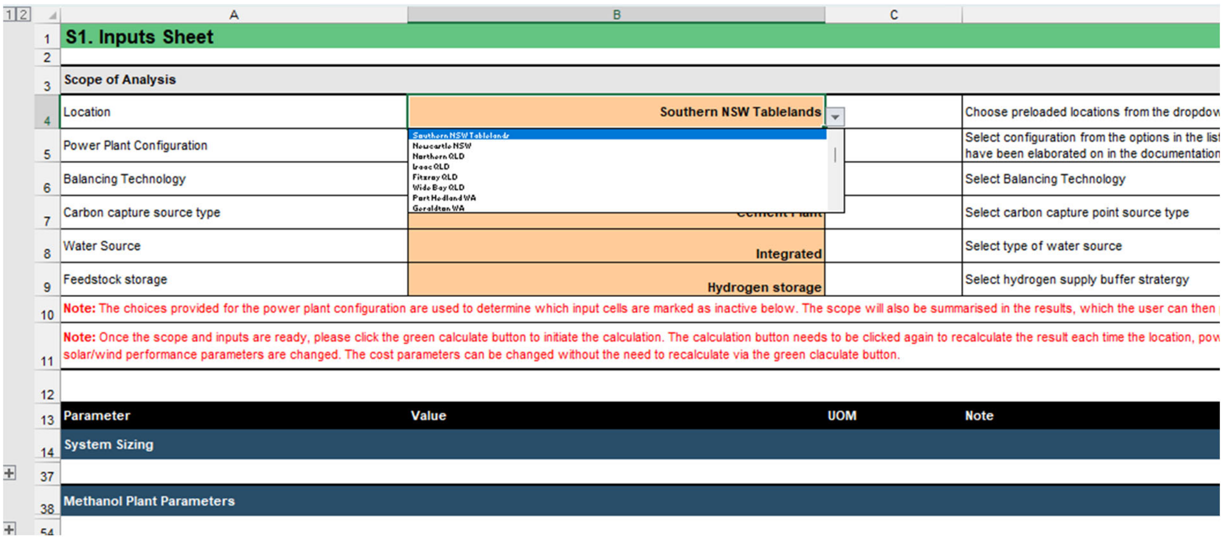


Figure 24: Site selection drop down list

3.2.2 Solar and Wind Traces

To calculate the electricity generation, the P2X Methanol Analysis Tool relies on time- sequential, hourly observations of the solar and wind data at each specific location. The NEM sites in QLD, NSW, VIC, TAS, and SA use traces that are sourced from AEMO's 2020 ISP database.5 The trace data that has been obtained through AEMO for NEM sites is for the reference year of 2019 and has been modelled by the market operator to reflect observed historical patterns. The non-NEM sites of NT and WA use traces were produced using the open-source tool "Renewables Ninja".6 The data obtained from this tool uses inputs from NASA's Modern-Era (MERRA) Retrospective Analysis (Reanalysis), and CM-SAF's The Surface Solar Radiation Data Set - Heliosat (SARAH) dataset pertaining to 2019.

In addition, the user has the option to include their own solar and wind traces for a custom analysis, these traces could either be based on potential solar and wind resources at a particular region not included in the analysis or actual outputs from existing solar and wind farms. This can be done in Sheet 'S5. Raw Data' (refer to **Section 2**).

Process for Extracting Additional Solar and Wind Traces from Renewables Ninja:

Additional Solar and Wind traces can be extracted using Renewables Ninja (https://www.renewables.ninja/). Requests for data can be made anonymously or by registering for a free account within the website. Anonymous users are limited to 5 retrieval requests per day for data from the year 2014, whereas registered users are limited to 50 retrieval requests per hour for data between 2000-2019.

The Renewables Ninja website interface allows for specific solar PV and wind system setups, as well as a choice between MERRA-2 (global data) and CM-SAF SARAH (European data) data sets as seen in **Figure 25**. Sites can be selected either by entering the location name, by latitude and longitude, or by dropping a pin on the map.

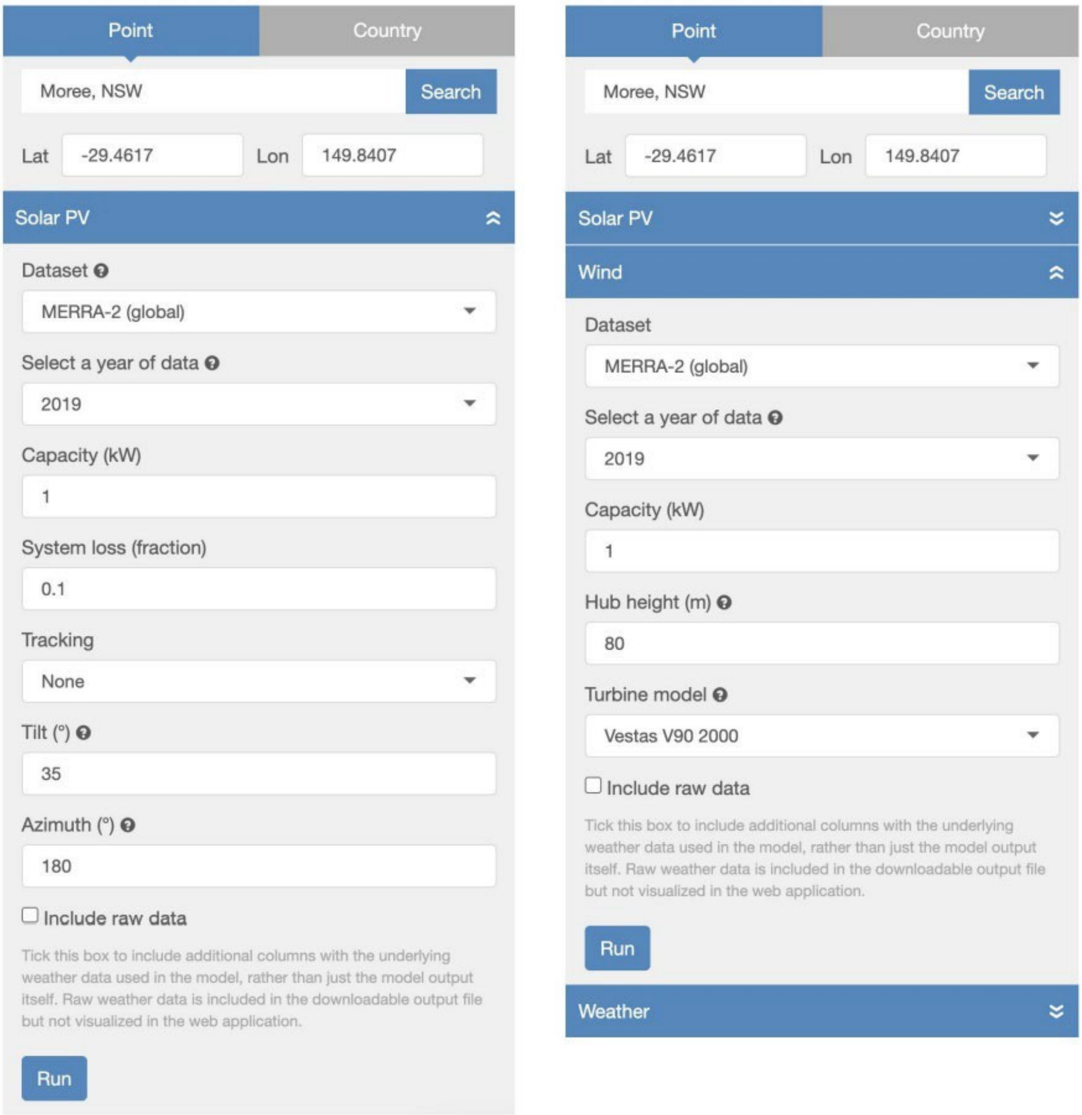


Figure 25: Renewable Ninja user input fields

For solar PV, user inputs can be made for:

- Capacity (kW) – the default input is 1 kW. The data retrieved from Renewables Ninja in the HCAT tool uses a capacity of 1000 kW.
- System Loss (fraction) – the default input is 0.1. The data retrieved from Renewables Ninja in the HCAT tool uses a system loss of 0.
- Tracking – tracking setups will be dependent on the specific project parameters of the solar farm. The data retrieved from Renewables Ninja in the HCAT tool uses single axis tracking.
  - Fixed tilt (None)
  - 1-axis (azimuth)
  - 2-axis (tilt and azimuth)
- Tilt (°) – This field defines how far a panel is inclined from the horizontal plane. If using a fixed tilt system (no tracking), the tilt of the system should be equal to the latitude of the site to maximise the solar farm's yield. For single and dual axis tracking, setting a tilt angle in this field will not affect the yield.
- Azimuth (°) – This field defines the compass direction in which the solar farm is facing. To maximise yields in the southern hemisphere, solar farms should be facing north, defined by 180° in Renewables Ninja. To maximise yields in the northern hemisphere, solar farms should be facing south, defined by 0° in Renewables Ninja.

For Wind, user inputs can be made for:

- Capacity (kW) – the default input is 1 kW. The data retrieved from Renewables Ninja in the HCAT tool uses a capacity of 1000 kW.
- Hub height (m) – this field defines the height of the turbine's tower and will be dependent on the specific turbine model that will be used on the wind farm
- Turbine Model – this field allows for the selection of the make and model of the wind turbines. Model names typically will include the manufacturer, the blade diameter in meters, and the rated capacity in kW or MW.

Once all fields have been defined, clicking on run will begin the retrieval process and clicking on "Save hourly output as CSV" will allow for the downloading of the data

3.2.3 Power Plant Configuration

The P2X Methanol Analysis Tool allows the user to model the entire methanol production operation based on certain power plant configuration scenarios. These scenarios allow for the choice between a Solar PV, Wind, or Hybrid power plant which can be standalone (within the system boundary) or outsourced (via a power purchase agreement). In addition, there is also the option to select a fully grid connected system as the power source which removes the variability associated with standalone renewable energy.

These power plant configurations are summarised below:

- **C1.** Standalone Solar PV Generator
- **C2.** Standalone Wind Generator
- **C3.** Standalone Hybrid Generator
- **C4.** Solar PPA
- **C5.** Wind PPA
- **C6.** Hybrid PPA
- **C7.** Grid Powered System

These options can be selected using the drop-down list in Cell B5 of the **'Inputs'** sheet as shown in **Figure 26**. **NOTE:** The drop-down list has an additional feature, whereby the selected configuration dictates which inputs need to be populated (orange cells) and which cells do not (grey cells).

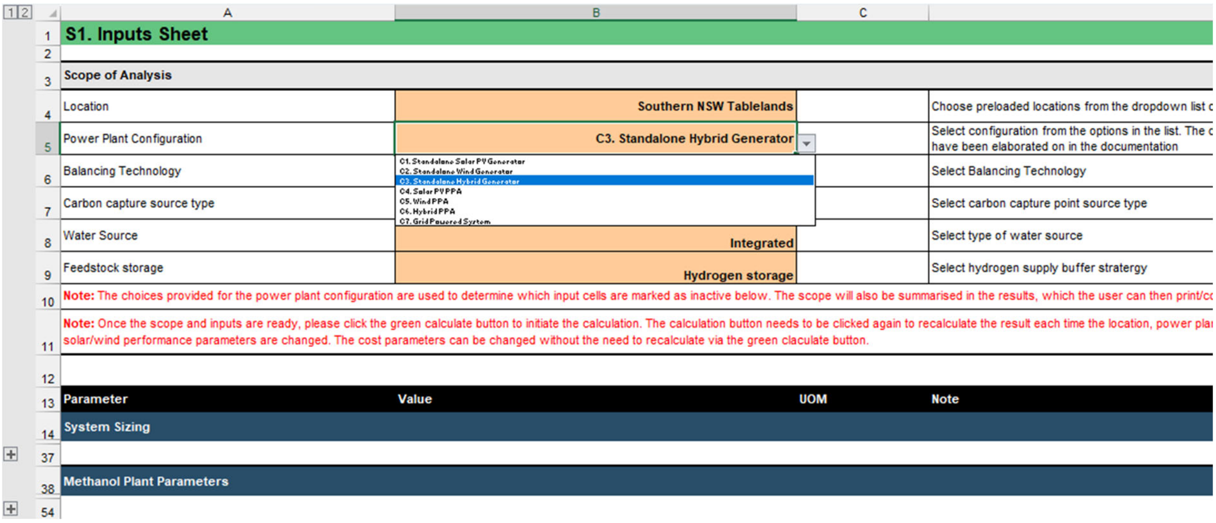


Figure 26: Drop down list of power plant configurations

The above scenarios can be categorised into the following configurations:

Standalone Configuration:

For the standalone system, the renewable power plant is assumed to be built within the boundary of the methanol facility. The key features of this scenario are:

- The electricity output from the power plant is used directly by the electrolyser unit to generate hydrogen, the carbon capture unit to generate Carbon Dioxide and the methanol unit to produce methanol. Any surplus electricity generated is used to charge a battery (if selected as the balancing power technology) or is assumed to be curtailed.

For this scenario, the capital and operating costs of the power plant, electrolyser and methanol plant are directly passed on to the project proponent

Of the above, **C1-C3**, fall into this configuration.

- **PPA Configuration:**

The second option is to purchase the electricity from a 3rd party through a Power Purchase Agreement (PPA). The key features of this scenario are:

- The generator type, capacity and the generation profile of the power plant are defined by the user. Elaborated in **Section 3.6.**
- The PPA contract could be tailored to provide enough power to operate the electrolyser and methanol facilities, or it could be oversized to provide additional power for charging a battery energy storage system as a back-up power source
- The PPA can be configured as a dedicated on-site facility where the project purchases electricity from the renewable energy developer or it can be supplied through a grid connection (i.e., connected to the NEM) whereby the renewable energy plant could be in a different location to the methanol plant.
- The electricity sourced is then costed as a fixed unit cost of electricity (A$/MWh), that is defined by the user. If the PPA contract is supplied through the grid, a grid connection

cost is also defined by the user.

The configuration options: **C4-C6** fall into the PPA category.

- **Grid Configuration**:
  As an alternate to the standalone and PPA system, the methanol facility can be connected directly to the grid. This provides constant power to the system without the variability associated with a renewable power source and allows the user to assess this type of power configuration. **NOTE:** This option is provided for analysis purposes only and does not imply the methanol produced is free from carbon emissions. Further analysis must be conducted by the user to fully understand the carbon footprint associated with sourcing power from the grid.
  The configuration options: **C7** falls into the grid connected category.

3.2.4 Balancing Technology

The reliability of the methanol system is improved using a balancing power source which can provide dispatchable electricity during periods of low renewable energy generation. The user is provided with three broad categories of balancing power in the form of a battery, or fuel cell.

The balancing power technology is summarised below:

- **BT1:** Battery
- **BT2.** Hydrogen Fuel Cell
- **BT3.** Methanol Fuel Cell
- **BT4.** No Balancing Technology

These options can be selected using the drop-down list in Cell **B6** of the **'Inputs'** sheet as shown in **Figure 27**. **NOTE:** The drop-down list has an additional feature, whereby the selected configuration dictates which inputs need to be populated (orange cells) and which cells do not (grey cells).

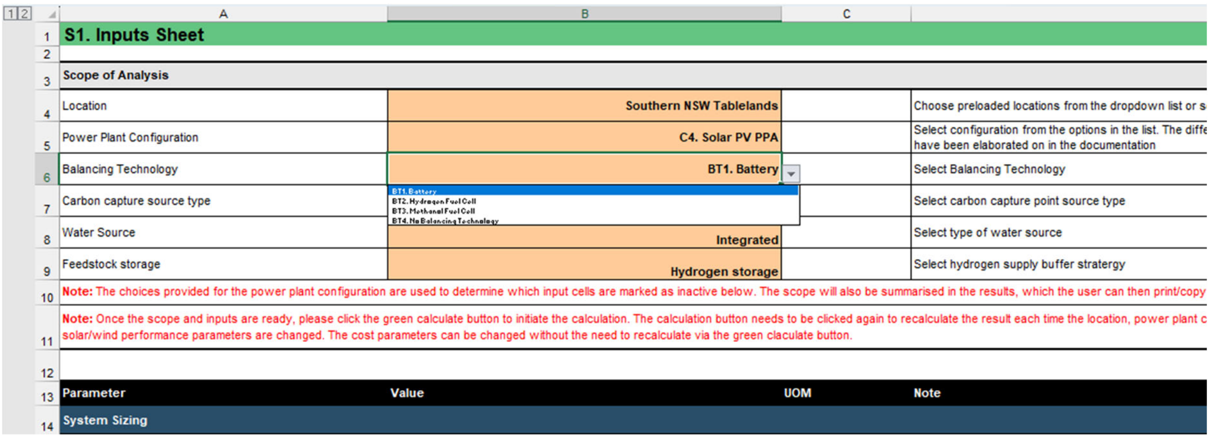


Figure 27: Drop down list of balancing technology options

The above balancing technology options can be categorised into the following:

- **Battery Energy Storage System:**
  The user is provided the option to use a battery to provide balancing power to the system. Utility scale batteries are commercially available and provide a viable option for the user

to model this within the methanol system. The key features of this balancing technology are:

- The battery provides back-up power to the carbon capture unit and methanol plant to maintain reliable operation.
- Rated power is automatically scaled to match the required energy demand of the methanol and carbon capture plants.
- The battery operation is constrained by the parameters set by the user i.e., duration of storage, total capacity, minimum and maximum state of charge and round-trip efficiency.

This option relates to **BT1** from the balancing technology drop down list

- **Fuel Cell System:**
  The user can select to use a hydrogen or methanol powered fuel cell as a back-up power source. methanol and hydrogen fuel cell technologies have been used for backup power source applications such as in the telecommunications industry for over a decade, and producers include (Siemens, PlugPower, Mitsubishi, etc.). Although large scale systems are still under development. Early analysis can provide the user with an insight into the potential benefit this type of technology can bring to the methanol production system. The key features of this balancing technology are:

  - The option to select between methanol fed and hydrogen fed fuel cells.
  - The fuel cell provided backup power to the carbon capture unit and methanol plant using fuel from either the hydrogen storage or from the methanol storage tanks.
  - The fuel cell operations are controlled by the parameters set by the user i.e., efficiency, and turndown.
  - Rated capacity is automatically set to the size of downstream demand from methanol and carbon capture plants as with the battery backup.

  This option applies to **BT2-BT3** from the balancing technology drop down list.

3.3 System Sizing

This section of the 'Inputs' sheet (**Figure 28**) requires the user to define up to five key parameters depending on the power plant configuration selected.

	Parameter	Value	UOM	Note
13	Parameter	Value	UOM	Note
14	System Sizing			
15	Methanol Capacity	1000	TPD	Enter Methanol Plant Capacity
16	Methanol Power demand	15.00	MW	Power demand from methanol production process. Custom value can be specified in Methanol Plant Parameters
17	Carbon Capture Plant Capacity	1,446	TPD	Calculated Capacity of carbon capture process
18	Carbon capture Power Demand	46.99	MW	Power demand from methanol production process. Custom value can be specified in carbon Capture Plant Parameters
19	Hydrogen Output	198.7	TPD	
20		8,279	kg/h	
21	Electrolyser Rated Capacity	1,614.43	MW	
22	Electrolyser Oversizing	200%	%	Oversizing to allow for storage of Hydrogen (Must be greater than calculated minimum oversizing)
23	Optional - User defined electrolyser capacity		MW	User defined electrolyser capacity (Optional - will ignore Electrolyser sizing calculations). Leave empty if not used.
24	Water Required	82.79	m3/h	
25	Water Plant Power Demand	0.32	MW	
26	Generator Type	Hybrid		
27	Solar Farm Capacity	1677	MW	Input solar farm capacity
28	Wind Farm Capacity	1677	MW	Input wind farm capacity
29	Total Nominal Power Capacity	3355	MW	Total RE plant capcity
30	Hybrid Generator Split	50%	% Solar	parts solar energy
31		50%	% Wind	parts wind energy
32	Oversizing of renewable energy	100%	%	Oversizing of renewable energy Pmax*(1+REoversize)
33	Hydrogen Storage Capacity	500,000	kg	Specify H2 storage capacity
34	Balancing Technology Capacity	55.79	MW	
35	Target Methanol Plant Uptime	96%	%	Enter target plant uptime accounting for energy and feedstock related availability and intermittency. Downtime due to scheduled and unscheduled maintanance activities is accounted for seperately in Methanol Plant Parameters
36	Operational warnings	No Action Required		Warnings are based on the specified target plant uptime. Warnings include: **Low hydrogen supply** - Indicates that the current electrolyser and power plant configuration does not meet the stoichiometric hydrogen demand for operation of the methanol plant. **Production intermittency** - While the stoicheometric supply of hydrogen can be achieved with the current configuration, the degree of intermittency in hydrogen and power supply exceeds the capabilities of the current configuration and balancing technologies.
37				

Figure 28: System sizing input parameters in the **'Inputs'** sheet.

The parameters included in the system sizing section are summarized below:

- **Methanol Plant Capacity (TPD):** The annual production of the methanol plant is defined by the user in tonnes per day (TPD). The user can define this as any number, however as a guide it is recommended to use a capacity between 100 – 5000 TPD to mimic the output of a small scale to large scale methanol facility.
- **Methanol Plant Power Demand (MW):** Based on the methanol plant capacity specified above and the default or user defined Methanol plant specific energy consumption in cell **B39**, the power demand for the methanol plant is automatically calculated.
- **Carbon Capture Unit Capacity (TPD):** Based on the methanol plant capacity and the CO_2 to methanol yield defined by the user in cell **B42**, the carbon capture unit daily production capacity is automatically calculated.
- **Carbon Capture Unit Power Demand (MW):** Based on the carbon capture unit capacity and default or user defined carbon capture unit specific energy consumption in cell **B54**, the power demand for the carbon capture unit is automatically calculated.
- **Hydrogen Output (TPD):** Based on the methanol plant capacity defined by the user, the hydrogen daily production capacity is automatically calculated.
- **Nominal Electrolyser Capacity (MW):** Based on the hydrogen output required to satisfy the methanol plant capacity, the default or user defined electrolyser specific energy consumption in cell **B7**, the power demand for the electrolyser is automatically calculated.
- **Electrolyser System Oversizing (%):** The user can define the extent to which the electrolyser is oversized. When oversizing is applied, at 100% capacity the electrolyser will produce more hydrogen than the minimum required to satisfy the methanol plant and under these conditions the hydrogen can be stored for future use or curtailed if the hydrogen storage is full. The amount of oversizing can be tuned by the user to optimize the quantity of hydrogen stored for periods when the renewable energy generation is insufficient to meet the methanol plant demand.
- **Generator Type:** Based on the power configuration selected in the scope of analysis, the generator type is summarized here as either solar, wind, hybrid, or grid.
- **Nominal Solar Farm Capacity (MW):** If the power configuration contains an element of solar PV as a power source (i.e., **C1, C3, C4 or C6**) the solar farm capacity will be automatically calculated based on the methanol plant capacity, carbon capture unit capacity, electrolyser capacity, hybrid generator split (if applicable) and the renewable energy plant oversizing.
- **Nominal Wind Farm Capacity (MW):** If the power configuration contains an element of wind as a power source (i.e., **C2, C3, C5 or C6**) the wind farm capacity will be automatically calculated based on the methanol plant capacity, carbon capture unit capacity, electrolyser capacity, hybrid generator split (if applicable) and the renewable energy plant oversizing.
- **Hybrid Generator Split (%):** If a hybrid power configuration is selected (i.e., **C3** or **C6**), the user must define the percentage of solar within the hybrid system. The wind percentage is then automatically adjusted.
- **Renewable Energy Plant Oversizing (%):** The renewable energy plant oversizing is specified by the user and defined as the additional renewable energy capacity required above the minimum required to meet the demand of the electrolyser, carbon capture unit and methanol plant. i.e., at 0% there is no oversizing and at 100% the renewable energy plant is double the minimum capacity required. Oversizing the renewable energy plant is a key strategy to improve the capacity factor of the electrolyser and methanol plant.
- **Total Nominal Power Plant Capacity (%):** The total power plant capacity is automatically calculated based on the power configuration selected and extent of oversizing.

- **Hydrogen Storage Capacity (kg):** The hydrogen storage capacity is specified by the user in kilograms and is independent of the type of storage facility used. i.e., the user can use their own assumption on the type of compressed gas hydrogen storage facility used e.g., Type I vessel or underground hydrogen system. Utilising hydrogen storage is another key strategy used within a renewable energy driven methanol production process to provide a buffer capacity of hydrogen when the renewable energy plant cannot satisfy the minimum energy demand of the system.
- **Balancing Technology Capacity (MW):** The Balancing technology capacity is calculated based on the configuration selected as well as parameters in the system sizing, methanol, and carbon capture parameter sections.
- **Target Methanol Plant Uptime (%):** Enter target plant uptime. This factor considers the percentage of time that the plant could operate accounting for energy and feedstock related availability and intermittency. Downtime due to scheduled and unscheduled maintenance activities is accounted for separately in methanol Plant Parameters. Lower targets represent a methanol plant with the ability to handle frequent and sporadic startups and shutdowns due to lack of power and or hydrogen availability. For reference, 96% represents a shutdown frequency of around 1 per day on average.
- **Operational Warnings:** Warnings are based on the specified target plant uptime. These warnings are accompanied by suggested actions which include adjusting 1 or more of the following, Electrolyser oversizing, Powerplant oversizing, Hydrogen storage, Balancing technology Capacity. Warnings include:
    - **Low hydrogen supply** - Indicates that the current electrolyser and power plant configuration does not meet the stoichiometric hydrogen demand for operation of the methanol plant.
    - **Production intermittency** - While the stoichiometric supply of hydrogen can be achieved with the current configuration, the degree of intermittency in hydrogen and power supply exceeds the capabilities of the current configuration and balancing technologies.

3.4 Methanol Plant and Carbon Capture plant Parameters

This section of the 'Inputs' sheet requires the user to specify the methanol and carbon capture operating and cost parameters.

38	**Methanol Plant Parameters**			
39	Methanol Plant SEC	0.36	kWh/kg MEOH	SEC based on simulation
40	Operating Hours	8000	Hours/year	Enter number of operating hours per year accounting for downtime due to scheduled and unscheduled maintanance
41	Methanol Plant Minimum Turndown	90%	%	Enter min CH3OH plant load
42	CO2 to Methanol Yield	95%		
43	**Planned Maintanance**			
44	Major Shutdown Frequency	3	years	
45	Major Shutdown Duration	23.0	Days	
46	**Methanol Plant Cost**			
47	**Capital Costs**			
48	Methanol Synthesis Plant Costs	272	AUD/TMEOH/year	User defined CAPEX
49	Methanol Synthesis plant Costs	$ 99,280,000	AUD	
50	Installation Costs	10%	% of Equipment cost	Includes engineering, procurement and construction costs
51	Land Procurement Costs	0%	% of Equipment Cost	Costs incurred for procurement of land
52	**Operating Costs**			
53	Methanol plant O&M	5.0%	% of CAPEX	
54				
55	**Carbon Capture Plant Parameters**			
56	Carbon Capture Specific Energy Consumption (SEC)	0.78	kWh/kg CO2	Estimated SEC based on literature
57	Optional - Custom Carbon Capture SEC		kWh/kg CO2	
58	**Carbon Capture Plant Cost**			
59	**Capital Costs**			
60	Carbon Capture Plant Cost	275	$A\$/T_{CO2}/a$	
61	Optional - Custom Carbon Capture Plant Cost		AUD/TCO2/year	User defined CAPEX
62	Carbon Capture plant Costs	$ 145,131,209	AUD	
63	Installation Costs	10%	% of Equipment cost	Includes engineering, procurement and construction costs
64	Land Procurement Costs	0%	% of Equipment Cost	Costs incurred for procurement of land
65	**Operating Costs**			
66	Maintanance cost CC	5.0%	% of CAPEX	
67				

Figure 29: Methanol parameters specified in the **'Inputs'** sheet.

The parameters included in the methanol section are summarized below:

3.4.1 Methanol Plant and Carbon Capture Operating Parameters

- **Specific Energy Consumption (SEC):** The SEC for the methanol plant is split into two subsections as detailed below. The values specified are used to calculate the methanol plant and carbon capture unit power demand.
  - *Methanol Plant SEC (kWh_e/kg_{MEOH}):* This represents the kWh of electricity required per kg of methanol produced by the methanol plant independent of the load. The scope of this SEC includes the methanol synthesis unit and balance of plant. This value is specified by the user and guide values from literature are provided in cell **E39.**
  - *CARBON CAPTURE SEC (kWh_e/kg_{CO2}):* This represents the kWh of electricity required per kg of Carbon Dioxide produced by the carbon capture unit independent of the load. This value is specified by the user in cell **E54** and guide values from literature are provided as default based on the selected carbon capture source in cell **E53.**
- **Methanol Plant Load Range:** The load range of the methanol plant determines how flexible the process can be to adjust to variable nature of the renewable energy power source. It is assumed the carbon capture unit load range is directly proportional to the methanol plant load range.
  - *Methanol Plant Minimum Turndown (%):* The user specifies the minimum methanol plant turndown.

3.4.2 Methanol Plant and Carbon Capture Plant Costs

- **Capital Costs**
  - *Methanol Synthesis Unit Cost (A$/$T_{MEOH}$/yr):* The methanol synthesis unit cost specified by the user covers the CAPEX for the feed compression train, reactor system, recycle compressor system and balance of plant. A guide range for the CAPEX is provided in cell **E45.**
  - *Carbon Capture Unit Cost (A$/$T_{CO2}$):* The carbon capture unit cost specified by the user covers the CAPEX for the entire carbon capture unit regardless of technology used (e.g., cryogenic distillation or pressure swing adsorption. A guide range for the CAPEX is provided in cell **E57**
  - *Installation Cost (%of CAPEX):* The installation costs for the methanol plant including the carbon capture are specified by the user as a percentage of the CAPEX and covers the cost of engineering, procurement and construction activities.
  - *Land Procurement Cost (% of CAPEX):* The cost of procuring the land to locate the methanol plant is specified by the user as a percentage of the CAPEX.
- **Operating Costs**
  - *Methanol Synthesis Unit Operation and Maintenance Costs (% of CAPEX):* The annual operating and maintenance costs for the methanol synthesis unit must be specified by the user
  - *Carbon Capture Unit Operation and Maintenance Costs (% of CAPEX):* The annual operating and maintenance costs for the carbon capture unit must be specified by the user

3.5 Electrolyser & Hydrogen Storage Parameters

The tool is currently tailored for the Alkaline Electrolyte (AE) Electrolyser and Polymer Electrolyte Membrane (PEM) Electrolyser.

68	**Electrolyser and Hydrogen Storage Parameters**			
69	Hydrogen Production	**PEM**		Select type of electrolyser for producing hydrogen
70	Maximum Load	**100%**	%	Enter maximum electrolyser load
71	Minimum Load	**5%**	%	Enter minimum electrolyser load
72	**Electrolyser Specific Consumption - SEC**			
73	SEC H2 Electrolyser	**65.0**	kWh/kg H2	Specify Electrolyser SEC
74	SECvsLoad	**Fixed**		
75	SEC Water Plant	3.9	kWh/m3 H2O	Estimated SEC based on literature
76	User Defined SEC Water Plant	**3.9**		
77	Minimum hydrogen storage level	**10%**		
78	Minimum H2 Storage Capacity	50,000	kg	Specifiy minimum H2 Storage Capacity
79	Starting Storage	**500,000**	kg	Specifiy if storage commences full or is filled
80	**Other Operational Factors**			
81	Stack Replacement Type	**Cumulative hours**		What stack replacement is based upon - cumulative hours of operation or cumulative level of degradation.
82	Stack Lifetime	**60000**	hrs	Enter stack lifetime before replacement
83	Electrolyser Degradation Rate	**1.0%**	%/yr	Enter electrolyser degradation rate
84	Maximum Degradataion Before Replacement		%	Maximum allowable degradation before stack must be replaced. **Note:** Provide this only when the 'maxiumum degradation level' stack replacement type is selected
85	Water Requirement	**10**	L/kg.H2	Enter water requirement for electrolyser (Stack)
86	Minimum Hydrogen Storage	**10.00%**	%	

Figure 30: Electrolyser and Hydrogen Storage operating parameters specified in the **'Inputs'** sheet.

The user is provided with the option to define the following electrolyser parameters:

- **Electrolyser Type:** The user may select either AE or PEM from a drop-down list (Cell **B66**), the choice then reflects in the project summary (in the **'Results'** sheet).
- **Electrolyser Specific Energy Consumption (SEC).** The SEC is defined as a combination of the following components:
  - *SEC at Nominal Load (kWh_e/kg_{H2}):* This represents the kWh of electricity required per kg of H_2 output by the electrolyser at the nominal load. This value must be provided by the user. This value is assumed to include the power required by the stack and balance of plant.
  - *SEC vs Load Profile:* This function allows the user to select the profile of how the SEC varies with load. The fixed profile assumes that the SEC is independent of the load. In comparison, the variable profile assumes that the SEC varies for load to mimic the more realistic nature of electrolyser operations. The tool can account for both fixed and variable specific energy consumption with electrolyser load. For the variable case, the relationship between the specific energy consumption of the electrolyser and the electrolyser load is based on a curve fit to a set of input points provided by the user (SEC as a function of the % of the electrolyser load). This is available to view and edit in sheet **'A2. Electrolyser Parameters'** as highlighted earlier.
- **Electrolyser Load Range:** The user also needs to define the electrolyser load range as a maximum and minimum percentage of the electrolyser's nominal capacity that the electrolyser can operate at within at any given time. **NOTE:** In practice, the minimum operating value of the electrolyser is dictated by the electrolyser's operational safety limit, which varies depending on electrolyser type. Literature suggests the low-end load range of AE as 10 – 40% of nominal capacity and of 0 – 10% for PEM electrolyser.[7]
- **Stack Replacement Type:** A key parameter of an electrolyser operation is the need for stack replacement. Our model allows the user to manage this option in either of the following ways:
  - *Cumulative hours (hours):* In this option, the user provides stack lifetime, which is then compared with the cumulative operational hours of the electrolyser, and once these hours exceed the stack lifetime the stack must be replaced.
  - *Maximum degradation level (%):* In this option, the user can provide a maximum degradation level. The stack is expected to be replaced when the cumulative

degradation per year adds up to the maximum degradation level. **NOTE:** for this scenario, the user must provide the annual degradation rate.

- **Electrolyser Degradation (%/year):** Both the AE and PEM electrolyser are susceptible to degradation which leads to loss of efficiency, performance, and durability of the system. The degradation rate is conventionally represented as a loss in voltage per hour of operation (usually represented in micro volt lost per hour - μV/hr). Degradation of any level leads to an increase of electrical consumption to achieve the same hydrogen output. Our model caters for this scenario by providing the user the option to define the degradation rate as a set percentage loss of hydrogen per year. E.g., by setting a degradation of 1% per year would mean that the electrolyser generating 1000 tonne/yr in year 1 would generate 990 tonne/yr in year 2.
- **Water Requirement of Electrolyser (L/kg):** The water requirement represents the water consumed for driving the electrolyser in terms of litres of water consumed per kg of hydrogen output. The user can define this value and if deemed necessary increased to include water required for cooling purposes.
- **Minimum Hydrogen Storage (%):** The minimum hydrogen storage specified by the user is representative of the cushion gas volume i.e., the quantity of gas that is intended as permanent inventory in a storage facility to maintain adequate pressure and ability to release hydrogen at the required rate on demand. A typical value of 10% is used as a default.

87	**Electrolyser Costs**			
88	**Electrolyser Capital Costs**			
89	Reference Electrolyser Capacity	10000	kW	
90	Reference Electrolyser CAPEX	1500	AUD/kW	Assuming that CAPEX includes indirect costs
91	Electrolyser Cost Reduction with Scale	10%	%	
92	Refrence Fold Increase	10		
93	Installation Costs	0%	% of Equipment cost	Includes engineering, procurement and construction costs
94	Land Procurement Costs	0%	% of Equipment Cost	Costs incurred for procurement of land
95	H2 Storage CAPEX	848	AUD/kg	
96	Water Plant CAPEX	21,000	AUD/(m3/d)	Estimated from literature
97	**Electrolyser Operating Costs**			
98	O&M Electrolyser	2.5%	%	2.5% of Fixed Capital
99	Electrolyser Stack Replacement	20%	%	
100	Wholesale water cost	5	AUD/kL	
101	Water Plant Operating Costs	2.5%	%	
102	O&M H2 Storage	2.5%	% of Capex	Calculated from Literature
103				

Figure 31: Electrolyser capital and operating cost parameters specified in the **'Inputs'** sheet. **NOTE:** The values in the figures are for illustrative purposes and will change based on user defined inputs

3.5.1 Electrolyser Capital and Operating Costs

For the cost analysis of the electrolyser (**Figure 31**), the tool considers the following parameters:

- **Electrolyser Capital Cost:** The electrolyser capital cost is based on the direct cost associated with the purchase of the equipment (electrolyser CAPEX) and the indirect costs which include the land and engineering, procurement, and construction costs (EPC). This capital cost is evaluated as:
    - *Electrolyser CAPEX:* The electrolyser CAPEX is evaluated using two methods which the user can select from the drop-down menu. The first method is **'self-defined'** where a reference cost (A$/kW) is provided for a specific scale (kW) which is then used to establish the scaled purchase cost of the electrolyser (A$/kW) at the calculated capacity of the electrolyser. The following logarithmic function is used to scale up or down the CAPEX (**Eq.1**):

$$C_B\left(\frac{A\$}{kW}\right) = C_A \times (1 - C_r)^{Log_{Ref}\left(\frac{S_B}{S_A}\right)}$$ **Eq. 1**

- Here the C_B is the evaluated cost at the nominal electrolyser scale S_B, C_A is the cost at the reference scale S_A (both of which are provided by the user), C_r is the percentage scale reduction in CAPEX per set fold increase in capacity (Ref). This set number of fold increase in capacity dictates when the economies of scale are triggered. E.g., if the reference electrolyser CAPEX is set to be A$1,000/kW at 1,000 kW scale with a 10% reduction in CAPEX at every 10-fold increase in capacity (Ref), then if the desired scale (S_B) is set to be 100 MW, then the factor $\log_{Ref=10}$ (S_B/S_A) will become 2 and this will lead to an overall 19% reduction in capital cost and C_B will become A$810/kW.

  The second method uses a generic economy of **'scale index'** to evaluate the capital cost. The user must specify a scale index which is then used to calculate the scaled purchase cost of the electrolyser based on the reference cost specified by the user using **Eq. 2**:

$$C_B(A\$/kW) = \frac{(C_A \times S_A) \times \left(S_A \times \frac{1000}{S_B}\right)^{SI}}{S_A \times 1000}$$ **Eq. 2**

  Here, SI is the scale Index specified by the user and all other parameters are the same as for **Eq. 1**.

- *Hydrogen Storage Capital Cost(A$/kg):* The hydrogen storage cost is based on a dollar per kg basis. A guide storage costs is provided in cell **E92**
- *Electrolyser Indirect Cost (% of CAPEX):* The indirect costs include the installation cost (covering engineering, procurement and construction), and the land procurement cost. Both as a percentage of the CAPEX calculated.

- **Electrolyser System Operating Costs:** The electrolyser operating costs (OPEX) includes the fixed operating and maintenance costs (O&M), cost of stack replacement and the water consumption costs. These can be defined as:
  - *Electrolyser Operating and Maintenance Costs:* The tool allows the user to specify the operation and maintenance cost of the electrolyser unit as a percentage of the electrolyser CAPEX per year
  - *Hydrogen Storage Operating and Maintenance Costs:* The tool allows the user to specify the operation and maintenance cost of the hydrogen storage unit as a percentage of the electrolyser CAPEX per year
  - *Electrolyser Stack Replacement Costs:* The cost associated with the electrolyser stack replacement can be represented as a % of the electrolyser CAPEX per replacement.
  - *Water Costs:* The water cost is evaluated based on the user defined wholesale price which is then correlated with the water requirement (L/kg H_2) required to determine the annual cost to the project.

3.6 Power Plant Parameters

3.6.1 Power Plant Capacity and Operating Parameters

- **Degradation Rates of Solar PV and Wind Farm (%): Will be made available in future versions of the tool.** Just like the electrolyser, the user can define the degradation rate of the solar and wind farms (**Figure 32**). This input is provided as a percentage reduction in output and is multiplied by the capacity factor figures to get the power plant output per unit capacity for each hour of each year. **NOTE:** For the hybrid scenario, the degradation rate should be provided for both the solar and wind farm.
- **Excess Electricity:** The user has the option to either curtail excess electricity generated or sell it to the grid. If the **'Sold to Grid'** option is selected, the user will need to enter further data under the grid connection heading (e.g., Grid connection cost, spot price for electricity and transmission charges). See further details below.

87	Power Plant Parameters				
88	Solar Degradation	0.1%	%/yr	Decrease in solar farm output per year	0.1%/yr (Aurecon AEMO Parameters 2020)
89	Wind Degradation	0.1%	%/yr	Decrease in wind farm output per year	0.1%/yr (Aurecon AEMO Parameters 2020
90	Excess Electricity	Curtailed		Select between curtailing excess electricity or selling it back to the grid	
91	Power Plant Costs	Curtailed Sold to the Grid			

Figure 32: Power plant performance parameters specified in the **'Inputs'** sheet.

3.6.2 Power Plant Capital and Operating Costs

The power plant capital and operating costs depend on whether the plant is owned and built by the project proponent or sourced through the electricity grid

- **Standalone Configuration:** For the standalone configuration, depending on the operational scenario defined by the user (**Section 3.2.3**) the capital and operating cost of the individual solar and wind farm must be defined by the user. This is done in an equivalent way to the electrolyser using the reference cost of a specified capacity and the cost reduction with scale methods available in a drop-down list. The tool evaluates these in the following manner:
  - *Power Plant CAPEX:* The power plant CAPEX is evaluated based on the similar economies of scale model used for the electrolyser, in which a reference cost (A$/kW) that is provided at a reference scale (kW) is scaled up or down to determine the CAPEX at the nominal capacity of the power plant through Eq.2 or Eq. 3.
  - *Power Plant Indirect Cost:* The power plant indirect costs include the cost of land and installation. In the tool, the user is given the option to define these values as a percentage of the individual solar/wind power plant CAPEX.
  - *Hybrid Power Plant Costs:* When a hybrid power plant is chosen, the aggregate of the capital of the individual solar and wind farm proportional to their share in the total capacity of the hybrid power plant is taken to represent the capital costs of hybrid systems (**Eq. 3**).

$$Hybrid\ Power\ Plant\ Cost = \frac{P_S \times C_S + P_W \times C_W}{P_S + P_W} \qquad \textbf{Eq. 3}$$

  - Here, CS is the cost component of solar farm, CW is the cost component of the wind farm, while PS is the capacity of the solar PV in the hybrid system, and PW is the capacity of the wind farm.
  - While the operating costs of the power plant in the standalone configuration include:
  - *Fixed and Variable O&M Costs (A$/MW/year)*: The tool provides the option to include

the fixed and variable operation and maintenance cost of the power plant as an aggregate A$/MW/year value based on the nominal capacity of the power plant. These can be individually defined for both the solar and wind farm.

  - *Hybrid Power Plant OPEX:* For the Hybrid system the individual operating cost of solar and wind farm are aggregated in the same manner as the capital costs using **Eq. 3**

108	**Power Plant and Transmission Costs**			
109	**Solar Capital Costs**			
110	Reference Capacity of Solar Farm	**1000**	kW	
111	Reference Solar Farm Cost	**1176**	AUD/kW	
112	Cost Reduction with Scale	**10%**	%	
113	Reference Fold Increase	**10**		
114	Installation Costs	**0%**	% of Equipment cost	Includes engineering, procurement and construction costs. Set to 0 if included in above plant cost
115	Land Procurement Costs	**0%**	% of Equipment Cost	Costs incurred for procurement of land
116	**Wind Farm Capital Costs**			
117	Reference Capacity of Wind Farm	**1000**	kW	
118	Reference Wind Farm Cost	**1289**	AUD/kW	
119	Cost Reduction with Scale	**10%**	%	
120	Reference Fold Increase	**10**		
121	Installation Costs	**0%**	% of Equipment cost	Includes engineering, procurement and construction costs. Set to 0 if included in above plant cost
122	Land Procurement Costs	**0%**	% of Equipment Cost	Costs incurred for procurement of land
123	**Power Plant Operating Costs**			
124	O&M Solar	**17000**	AUD/MW/yr	
125	O&M Wind	**25000**	AUD/MW/yr	

Figure 33: Standalone power plant capital and operating parameters specified in the **'Inputs'** sheet.

- **PPA Configurations:** For the PPA Configurations, the capital and operating costs of the power plant are typically integrated within the PPA cost as follows:
  - *Principal PPA Cost (A$/MWh):* Selecting the PPA option allows for the operation of the system based on electricity sourced from the grid. The PPA price represents the cost per unit of electricity consumed by the system. It is assumed in this case that the entire system still follows the hourly operational profile of the generator, but capital and operating costs are simplified into a single per unit cost. **NOTE:** When the PPA power configuration is selected, the user must include a grid connection cost if the PPA contract is set up to provide the power through the grid. If the PPA contract is set up to provide an on-site renewable energy facility, the user can define if any additional costs are applicable by adding them to the **'Additional Costs'** section (detailed below).
  - *Additional Transmission Charges (A$/MWh):* If the PPA contract is set up to provide power through the grid, additional grid usage charges can be defined by the user.
  - *Total PPA Cost (A$/MWh):* The principal PPA cost, and the additional transmission charges are summed to represent the total PPA cost as shown in **Figure 34**.
- **Sale of Excess Electricity to the Grid:** For standalone and PPA configurations, there is an option to sell excess electricity to the grid which provides an option for the project to reduce the overall levelised cost. When the **'Sold to Grid'** option is selected as the strategy for excess electricity, the grid connection cost (Cell **B135**) Spot Price of Electricity Sold to the Grid (Cell **B143**) and transmission charges (Cell **B144**) will need to be populated.

127	**Transmission Parameters**			
128	Transmission Distance	25.00	km	Distance between renewable energy plant and electrolyser/carbon capture and methanol unit site
129	Losses	0.00%	%/km	Power losses along transmission line
130	**Transmission Capital Costs**			
131	Transmission Equipment Cost	$ 910,000	A$/km	Cost per km of transmission line. Includes lines and supporting infrastructure
132	Installation Cost	10%	% of CAPEX	
133	Land Procurement Cost	0%	% of CAPEX	
134	**Transmission Operating Costs**			
135	Annual Transmission Operating Costs	1%	% of CAPEX	
136				
137	**Grid Connected Systems**			
138	**Costs for Grid Connected Systems**			
139	Grid Connection Cost	$ 132.00	A$/kW	Capital cost for transmission connection which includes between 5-10km of transmisison line
140	Cost of Electricity from the Grid	$ 50.00	A$/MWh	Fixed price for electricity purchased from the Grid
141	Additional Transmission Charges	$ 10.00	A$/MWh	Any additional charges for using grid services, e.g. Transmission Use of System (TUOS) Charges
142	**Power Purchase Agreement Price**			
143	Principal PPA Cost	$ 55.00	A$/MWh	Fixed price for electricity purchased through the PPA
144	Additional Transmission Charges	$ 10.00	A$/MWh	Any additional charges for using grid services, e.g. Transmission Use of System (TUOS) Charges
145	Total PPA Cost	$ 65.00	A$/MWh	**Note:** Please do not change, the value is automatically evaluated based on above inputs
146	**Sale of Excess Electricity to the Grid**			
147	Spot Price for Electricity Sold to the Grid	$ 55.00	A$/MWh	Average Spot price for excess electricity sold back to the grid
148	Transmission Charges	$ 10.00	A$/MWh	Any additional charges for using grid services, e.g. Transmission Use of System (TUOS) Charges
149				

Figure 34: Transmission, Grid Connected and PPA parameters specified in the **'Inputs'** sheet.

3.7 Balancing Technology Parameters

The balancing technology parameters are broken down into the 2 main categories. Battery and fuel cell.

- **Battery Capacity and Operating Parameters:** The battery is defined by both its size and a set of operational parameters when selected as the balancing technology (**Figure 35**). The operating parameters can be changed to suit different battery types.
  - *Battery Rated Power (MW):* This represents the maximum energy the battery can store or discharge at any given time in MW and is calculated to match the downstream demand from methanol and carbon capture plants.
  - *Duration of Storage (Hrs):* The tool currently caters for 1, 2, 4 and 8 hours of storage and these can be selected by the user using the drop-down list.
  - *Nominal Battery Capacity (MWh):* The battery capacity is based on the battery's rated power and the duration of storage as specified by the user.
  - *Round Trip Efficiency (%):* Proportion of energy retained after a charge and discharge cycle of the energy storage system.
  - *Minimum State of Charge (%):* Minimum level of battery charge for safe operation, given as a proportion of the battery rated power capacity
  - *Maximum State of Charge (%):* Maximum level of battery charge for safe operation, given as a proportion of the battery rated power capacity.
  - *Battery Lifetime (Years):* The operational life of the battery before it must be replaced.

150	**Balancing Technology Parameters**			
151	**Battery Operating Parameters**			
152	Battery Rated Power	56	MW	Input Rated power capacity of the battery
153	Duration of Storage	8	hours	Number of hours that the battery takes to charge/discharge at its max power level
154	Nominal Battery Capacity	446	MWh	Calculated battery capacity based on rated power and duration of storage
155	Minimum State of Charge	0%	%	Section only applies when battery is sellected as Balancing technology
156	Maximum State of Charge	100%	%	
157	Starting charge state	100%		
158	Round Trip Efficiency	85%	%	
159	Battery Lifetime	10	Yrs	

Figure 35: Battery Energy Storage System parameters specified in the **'Inputs'** sheet.

- **Battery Capital Costs**: The battery capital costs are based on the following user defined values:
  - *Battery CAPEX (A$/kWh)*: The capital cost of the battery system per unit of battery energy capacity.

- *Battery Indirect Costs (% of CAPEX):* These costs include the installation costs and land procurement costs as a percentage of the CAPEX

- **Battery Operating Costs:** The operating costs of batteries considered in the tool include:
  - *Battey OPEX (A$/MW/year):* The OPEX is the fixed and variable operation and maintenance cost of the battery as an aggregate A$/MW/year value, based on the power capacity.
  - *Battery Replacement Cost (%):* Defines the percentage of the CAPEX to be spent each time the battery is replaced. This may be less than the original CAPEX since the infrastructure is already in place and the battery cells need replacing more often than the rest of the system. **NOTE:** The model assumes that this cost is incurred as an additional operating expense in the annual cost summary when the battery life expires.

171	**Battery Capital Costs**			
172	Cost of Battery	368.00	AUD/kWh	Assume CAPEX
173	Cost of Battery Interface	184.00	AUD/kW	
174	**Battery Operating Costs**			
175	Battery Replacement Cost	100%	% of CAPEX	
176	Battery O&M Costs	39314	AUD/MW/yr	

Figure 36: Battery capital and operating cost parameters to specify in the **'Inputs'** sheet.

- **Fuel Cell Capacity and Operating Parameters**
  - *Fuel Cell Type:* The Fuel Cell type selected in the balancing technology drop down list under the scope of analysis is repeated here.
  - *Fuel Cell Capacity (MW):* Fuel Cell capacity determines the maximum instantaneous power output achieved my the fuel cell system. This is calculated by based on the calculated downstream demand by the methanol and carbon capture units.
  - *Efficiency (%):* The fuel cell efficiency is required to be defined by the user. Guide values are provided in the cell **E158** and **E163**

160	**H2 Fuel Cell Operating Parameters**			
161	H2 Fuel Cell Rated Power	55.79	MW	
162	Fuel cell efficiency	50%	% of fuel LHV	https://www.californiahydrogen.org/wp-content/uploads/files/doe_fuelcell_factsheet.pdf
163	Converter efficiency	95%	%	
164	Specific energy production H2 fuel cell	15.83	kWh/kgH2	
165	**MeOH Fuel Cell Operating Parameters**			
166	H2 Fuel Cell Rated Power	55.79	MW	
167	Fuel cell efficiency	40%	% of fuel LHV	https://doi.org/10.1007/s11356-020-12231-8
168	AC/DC convertesion efficiency	95%	%	
169	Specific energy production H2 fuel cell	2.40	kWh/kgMeOH	

Figure 37: Fuel cell operating parameters specified in the **'Inputs'** sheet

- **Fuel Cell Capital Cost:**
  - *Fuel Cell CAPEX (A$/kW):* The Fuel Cell CAPEX is specified by the user and a guide on the costs is provided in cell **E174** and **E180**
  - *Indirect Costs:* The indirect costs cover the installation and land procurement costs as a percentage of the CAPEX, which the user must specify.
- **Fuel Cell Operating Costs:**
  - *Fuel cell operating costs:* Specified as a percentage of fuel cell capital costs.

177	**H2 Fuel Cell Capital Cost**			
178	Cost of fuel cell	6500.49	AU$ / kW	
179	**H2 Fuel Cell Operating Cost**			
180	Stack replacement cost	50%	% of Capex	
181	Fuel cell lifetime	10.00	years	
182	O&M costs	2.5%	% of CAPEX	
183	**MeOH Fuel Cell Capital Cost**			
184	Cost of fuel cell	8000.00	AU$ / kW	
185	**MeOH Fuel Cell Operating Cost**			
186	Stack replacement cost	50%	% of Capex	
187	Fuel cell lifetime	10.00	years	
188	O&M costs	2.5%	% of CAPEX	

Figure 38: Fuel Cell capital and operating costs specified in the **'Inputs'** sheet

3.8 Secondary Revenue Streams

- **Oxygen sales:** The user can specify a price for oxygen to be sold as a byproduct of electrolysis to supplement the cost of methanol production.
- **Carbon Credit:** The user can specify a price of carbon credits applicable to emission reduction achieved by the green methanol product as compared to a fossil fuel derived methanol baseline.

193	Secondary Revenue Streams			
194	Oxygen Sales		AUD/T	
195	Carbon Credit	100	AUD/tCO2 abated	Advise setting to 0 when using grid connected system
196				

Figure 39: Secondary revenue streams in the **'Inputs'** sheet

3.9 Additional Costs

- **Additional Upfront Costs:** The user can include any unaccounted-for upfront costs if required as a lump sum amount in Cell **B195** of the **'S1. Inputs'** sheet.
- **Additional Annual Costs:** The user can include any unaccounted annual costs if required as in Cell **B196** of the '**S1. Inputs'** sheet.

180	Additional Costs			
181	Additional Upfront Costs		A$	Any additional costs to include as a once off in the levelised cost calculation
182	Additional Annual Costs		A$/year	Any additional costs to include as an annual expenditure in the levelised cost calculation
183				

Figure 40: Additional cost options in the 'Inputs' sheet.

3.10 Financing Parameters

The key inputs for the financial analysis include:

- **Plant Life (Years):** The user has the option to define the plant life. Currently the plant life of the electrolyser (including multiple stack replacements), the power plant and methanol plant are all assumed to be the same. The user can set the plant life to up to 50 years if required.
- **Discount Rate (%):** The user is required to provide the discount rate for the Net Present Value analysis. **NOTE:** This must be provided to calculate the levelised cost of methanol and hydrogen.

184	Financing Parameters			
185	Plant Life	25	years	Total plant life to evaluate, assuming power plant, electrolyser and ammonia plant have equal plant life
186	Discount Rate	7%	% p.a.	Discount rate for the net present value analysis and levelised cost calculation
187				

Figure 41: Financing parameters in the 'Inputs' sheet.

3.11 Lifecycle Emission Intensity

The lifecycle emissions intensity inputs include both direct process emissions and indirect and embedded emissions associated with each major plant section.

- **Direct process emissions:**
  - *Solar PV Generator (gCO_{2e}/kWh):* Direct process emission intensity per kWh of power generation for solar PV generator can be specified by the user. This value is

set to 0 by default.
  - *Wind Generator (gCO_{2e}/kWh):* Direct process emission intensity per kWh of power generation for wind generator can be specified by the user. This value is set to 0 by default.
  - *Electrolyser (gCO_{2e}/kg_{H2}):* Direct process emission intensity per kg of hydrogen produced can be specified by the user. This value is set to 0 by default.
  - *Methanol Plant (gCO_{2e}/kg_{MeOH}):* Direct process emission intensity per kg of methanol produced is calculated based on inputs specified under methanol plant parameters. This value is correlated to the specified yield of methanol from the CO_2 feed.
  - *Carbon Capture Plant (gCO_{2e}/kg_{CO2}):* Direct process emission intensity per kg of CO_2 captured can be specified by the user. This value is set to -1000 by default.
  - *Balancing Technology (gCO_{2e}/kg_{MeOH}):* Direct process emission intensity per kg of methanol consumed in the case of methanol fuel cell backup power and is assumed to be zero for battery, and hydrogen fuel cell options.
- **Embedded and indirect emissions:**
  - *Solar PV Generator (gCO_{2e}/kWh):* Embedded and indirect emission intensity per kWh of power generation for solar PV generator can be specified by the user.
  - *Wind Generator (gCO_{2e}/kWh):* Embedded and indirect emission intensity per kWh of power generation for wind generator can be specified by the user.
  - *Electrolyser (gCO_{2e}/kg_{H2}):* Embedded and indirect emission intensity per kg of hydrogen produced can be specified by the user.
  - *Methanol Plant (gCO_{2e}/kg_{MeOH}):* Embedded and indirect emission intensity per kg of methanol produced can be specified by the user. This value is assumed to be negligible unless specified otherwise.
  - *Carbon Capture Plant (gCO_{2e}/kg_{CO2}):* Direct process emission intensity per kg of CO_2 captured can be specified by the user. This value is assumed to be negligible unless specified otherwise.
  - *Balancing Technology (gCO_{2e}/kg_{MeOH}):* Embedded and indirect emission intensity per kWh of power generation by fuel cell options, or per kWh of battery capacity. This value is assumed to be negligible unless specified otherwise.
  - *Grid Usage (gCO_{2e}/kWh):* Indirect emission intensity of grid power usage per kWh.

4 Methods and Evaluation

4.1 Hourly Energy Flows

4.1.1 Power Plant Capacity Factors

The generation data is sourced as a ratio of the potential energy (MWh) generated by the power plant to the installed capacity of the power plant. These ratios vary hourly, daily, and seasonally based on the solar and wind traces, between a minimum (0%) and maximum level (100%), with 0% representing no energy output from the power plant and 100% representing the maximum energy output. The average of this yearly distribution of the ratios represents the power plant capacity factor.

Currently, for simplification it is assumed that the performance of the generator is independent of its size, and so the same traces are used for all nominal capacities of solar and wind farm. **NOTE:** This functionality will be improved after consulting with stakeholders

4.1.2 Hybrid Power Plant – Combination of Solar and Wind

For the hybrid power plant, the capacity factors from a solar farm and a wind farm in the same location are added in a weighted sum based on the solar and wind capacities. This is described in **Eq. 4.**

$$CF_h(t) = \frac{P_S \times CF_S(t) + P_W \times CF_W(t)}{P_S + P_W} \quad \textbf{Eq. 4}$$

Where $CF_h(t)$ is the capacity factor of the hybrid system at any given time t, in hours, $CF_S(t)$ and $CF_W(t)$ are the capacity factor of the individual solar PV and wind farm respectively, while P_s is the capacity of the solar PV in the hybrid system, and P_W is the capacity of the wind farm.

4.1.3 Operating Region Determination

The power generated by the renewable energy power plant is allocated to the various units that make up the entire system, with the quantity allocated defined by five operating regions as described in the table below:

Table 1: Description of five operating regions to allocate the power generated.

Operating Region	Operation	Electrolyser	CC/MEOH Unit
1. $P > P_{MAX}$	Store excess hydrogen/charge battery (if applicable)	P_{R_Elec}	$P_{R\_CC/MEOH}$
2. $P_{MAX} > P > P_{STOIC}$	Store excess hydrogen/charge battery (if applicable)	$P_{R\_Elec} - (P_{MAX} - P)$	$P_{R\_CC/MEOH}$
3. $P_{STOIC} > P > P_{R\_CC/MEOH}$	Draw down from hydrogen storage if necessary	$P_{R\_Elec} - (P_{MAX} - P)$	$P_{R\_CC/MEOH}$
4. $P_{R\_CC/MEOH} > P$	Make up power deficit from balancing power sources and draw down from hydrogen storage	0	$P_{R\_CC/MEOH} - (P_{R\_CC/MEOH} - P)$
5. $P_{STOIC} > P$, AND: H_2 Storage < min OR Battery Chg. < P_{min}	Temporary Shutdown due to insufficient hydrogen feedstock or power supply.	0	0

In Table 1, the parameters are defined as:

- P = Power generated from the renewable power plant
- P_{MAX} = The maximum power required to operate all units at 100% capacity
- P_{STOIC} = The power required to operate the electrolyser, carbon capture unit and methanol plant at the stoichiometric flow rate i.e., the rate at which the methanol is operating at its design capacity. If the electrolyser is not oversized, this value will be equal to P_{MAX}.
- $P_{R\_CC/MEOH}$ = The power required to operate the carbon capture unit and methanol plant at 100%
- P_{R_Elec} = The power required to operate the electrolyser at 100%
- P_{MIN} = The minimum power required to operate the carbon capture unit and methanol plant at turndown

4.1.4 Balancing Technology Model

- **Battery Operations:** When the battery is selected as the balancing technology, the unit has two operating modes as described below:
    - *Battery Charging Mode:* The battery will charge when there is excess electricity available and sufficient capacity within the battery system. The amount of power allocated to the battery for charging is determined by the minimum of:
        - *Battery rated power*
        - *Excess electricity available beyond stoichiometric operation*
        - *Available capacity within the battery system*
    - *Battery Discharge Mode:* The battery will discharge to the electrolyser, carbon capture Unit and methanol plant when there is a power deficit from the renewable energy power plant.
        - *If the power generated is in region 4 (as described in Table 1), the amount of power discharged to the carbon capture unit and methanol plant is the minimum of the battery rated power, available power in the battery or the amount of power required to operate the carbon capture unit and methanol plant at the minimum turndown.*

- **Fuel Cell Operations:** When the fuel cell is selected as the balancing power source, the operation is determined by the fuel cell capacity, efficiency and turndown specified by the user. The fuel cell will become operational when:
    - The total power allocated (P) is less than the stoichiometric power (P_{MIN})
    - The quantity of power allocated to the carbon capture Unit and methanol plant from the Fuel Cell will be the minimum of:
        - *Fuel Cell Capacity*
        - *The power deficit required to bring the carbon capture unit and methanol plant back up to its rated or minimum power demand ($P_{R\_CC/MEOH}$)*
        - *Rated power demand of the carbon capture Unit and methanol plant ($P_{R\_CC/MEOH}$)*

4.1.5 Electrolyser System Operations

Given that the electrolyser takes the largest load of the power plant, the electrolyser capacity factors will directly be influenced by that of the power plant. Moreover, the electrolyser capacity factor is constrained by the inherent maximum and minimum operating loads of the electrolyser. Modern electrolyser systems are being designed to be highly adaptive and flexible to enable their operation with variable renewable energy supply. However, due to safe operating limits intrinsic to each class of electrolyser, a lower load range (higher than 0% of nominal load) must always be maintained while operational.

The total power allocated to the electrolyser is the sum of the power allocated from the renewable power plant and the power allocated from the balancing power source. The electrolyser energy rating is then subsequently corelated with the electrolyser's specific energy consumption (SEC), that is the energy consumed by the electrolyser to generate a unit of hydrogen (usually represented as a kWh/kg of H2) to determine the amount of hydrogen generated during that hour (**Eq. 5**).

$$Hydrogen\ Produced\ \left(\frac{kg}{hr}\right) = Total\ Power\ Allocated\ (MWh) \times \frac{1}{SEC\left(\frac{kWh}{kg}\right)} \qquad \textbf{Eq. 5}$$

NOTE: If the variable profile for the SEC is selected, the tool adjusts the SEC to match the operating load of the electrolyser in each hour using the polynomial function (Defined in **'A1. Electrolyser Parameters'** Sheet).

4.1.6 Hydrogen Storage Operations

The hydrogen storage operation is determined by an excess or deficit of hydrogen produced from the electrolyser. The hydrogen storage operates in two modes as described below:

- **Hydrogen to Storage:** When there is an excess of hydrogen produced from the electrolyser and sufficient capacity available in the hydrogen storage facility, the excess hydrogen will be directed to the hydrogen storage
- **Hydrogen from Storage:** When there is a hydrogen deficit and the quantity available in the hydrogen storage is above the minimum operational quantity (i.e., the cushion volume), the quantity discharged from the hydrogen storage facility is the minimum of:
  - *The hydrogen deficit*
  - *The available quantity from the hydrogen storage to maintain the minimum hydrogen storage volume specified in the* ***'Inputs'*** *sheet*

4.1.7 Carbon Capture Unit/Methanol Plant Operations

The total power allocated to the carbon capture unit and methanol plant from the renewable power source and balancing power determines the plant load. If this power allocated is greater than the minimum power required (P_{MIN}) the quantity of methanol will be calculated. The plant load determined by the power allocation is directly proportional to the quantity of Carbon Dioxide generated and by adding this quantity to the mass of hydrogen produced, we get the hourly quantity of methanol produced.

4.2 Levelised Cost Analysis

The levelised cost of methanol was used as the key metric for our analysis. To evaluate the levelised costs, the annual methanol output per year (inclusive of effects of degradation and overloading) is fed into a cost model to determine the levelised cost of methanol (LCOA) for the input configuration in A$/kg. Here, T is the total number of years of operation, r is the discount rate, and P_{MEOH} is the production of methanol in year t. $Costs_t$ is the system costs in year t, which is inclusive of year 0 capital costs for the renewable energy generation, electrolyser and hydrogen storage, balancing technology, carbon capture unit and methanol plant, and all operation and maintenance costs, including stack replacement costs and water costs. Lastly, ES_t is the revenue generated through the sale of excess electricity to the grid if this option is selected. **Eq. 6** summarizes the levelised cost calculation.

$$LCOM = \frac{\sum_{t=0}^{T} \frac{Cost_t - ES_t}{(1+r)^t}}{\sum_{t=0}^{T} \frac{P_{MeOH}}{(1+r)^t}} \qquad \textbf{Eq. 6}$$

5 Tool Limitations and Next Steps

The tool currently has the following limitations:

- The scope of the tool is currently limited to farm-gate methanol production and does not include inland transport or export to international markets. However, for users interested in costing up the export of methanol (assuming the methanol plant modeled with this tool is located close to a port), the HySupply Shipping Tool V1.1 can be used.[9]
- The preloaded solar and wind traces are based on time-sequential, hourly observations of the solar and wind data at each specific location (through historical data). These do not include solar and wind outputs from existing power plants in the area, however data from the existing solar and wind farms can be added as a custom analysis (**Section 3.2.1**). The traces for existing power plants connected to the NEM can be accessed from our other open-source tool NEMOSIS (available here)
- The battery energy storage system model and fuel cell model are currently simplistic, further room for optimising the battery operation remains.

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

- A python-based optimisation code to evaluate the high-capacity factor and least cost operation parameters.

We welcome feedback from the user to help us improve the tool, feedback can be provided to 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 Locations

1. Port Hedland, WA
2. Geraldton, WA
3. Ashburton, WA
4. Tennant Creek, NT
5. Baines, NT
6. McArthur, NT
7. North West NSW
8. New England
9. Central West NSW
10. Southern NSW Tablelands
11. Broken Hill, NSW
12. South West NSW
13. Wagga Wagga, NSW
14. Tumut, NSW
15. Cooma Monaro, NSW
16. Far North QLD
17. Clean Energy Hub North QLD
18. Northern QLD
19. Isaac, QLD
20. Barcaldine, QLD
21. Fitzroy, QLD
22. Wide Bay, QLD
23. Darling Downs, QLD
24. South East, SA
25. Riverland, SA
26. Mid North SA
27. Yorke Peninsula SA
28. Northern SA
29. Leigh Creek, SA
30. Roxby Downs SA
31. Eastern Eyre Peninsula, SA
32. Western Eyre Peninsula, SA
33. North East Tasmania
34. North West Tasmania
35. Central Highlands
36. Ovens Murray, VIC
37. Murray River, VIC
38. Western VIC
39. South West VIC
40. Gippsland, VIC
41. Central North VIC

Appendix B: List of Default Operating & Cost Assumptions

Methanol Plant Parameters

Parameter	Default Values	Reference
Methanol Plant SEC	0.30 - 0.50 kWh_e/kg_{MEOH}	
Carbon Capture Unit SEC	0 – 1.535 kWh_e/kg_{CO2}	
Methanol Synthesis Unit Cost	A$250 - A$450/T_{MEOH} (CO_2 hydrogenation)	
Carbon Capture Unit Cost	A$0 - A$1610/T_{CO2}	
Methanol Synthesis Unit O&M	5% of CAPEX	
Methanol Storage O&M	3% of CAPEX	
Carbon Capture Unit O&M	2% of CAPEX	

Electrolyser & Hydrogen Storage Parameters

Parameter	Default Values	Reference
Electrolyser SEC at Nominal Load	55 - 60 kWh/kg	10
Electrolyser Minimum Load	10% for PEM and AE	
Stack Lifetime	80,000 Hours for PEM and AE	
Stack Degradation	1%/year	
Water Requirement of Electrolyser	15-20 L/kg H2	
Ref. Electrolyser Purchase Cost	For AE: A$1,333 - 1,513/kW For PEM: A$2,438 - 2,501/kW	11
Hydrogen Storage Purchase Cost	A$750 - A$2000/kg_{H2}	12
Land Procurement Costs	8-10% of CAPEX (Aurecon AEMO Parameters 2021)	10
Electrolyser O&M	3% of CAPEX	
Hydrogen Storage O&M	1% of CAPEX	12
Electrolyser Stack Replacement Costs	40% of CAPEX	
Water Cost	Current Wholesale Prices in Australia: - Fresh Water: A$1.1 - 3.4/kL (Avg: 2.5) - Recycled Water: A$1.1 - 2.1/kL (Avg: 1.6) - Desalinated Water: A$1 - 5/kL (Avg: 2.5)	

Power Plant Parameters

Parameter	Default Values	Reference
Solar Degradation	0.4%	10
Wind Degradation	0.1%	
Reference Solar PV Farm Cost	A$1,441/kW (2021-22)	11
Land Procurement Cost	10% of CAPEX	10
Solar PV OPEX	A$17,000/MW/Year	
Reference Wind Farm Cost	Onshore: A$1,700/kW Offshore: A$4,330/kW	10
Land Procurement Cost	3% of CAPEX	
Wind OPEX	A$25,000/MW/Year	

Transmission Parameters

Parameter	Default Values	Reference
Losses	0.003%/km for HVDC and 0.04%/km for HVAC	13
Transmission Cost Equipment	A$0.86M to A$1.35M/km of overhead HVAC line A$1.3M to A$2.05M/km of overhead HVDC line	14
Transmission OPEX	1% of CAPEX	

Grid Connected Systems

Parameter	Default Values	Reference
Grid Connection Costs	A$103 - A$227/kW	14

Balancing Technology Parameters

Parameter	Default Values	Reference
Round Trip Efficiency	83-85%	10
Battery Lifetime	20 years	
Cost of Battery	1 Hr Storage = A$790/kWh 2 Hr Storage = A$527/kWh 4 Hr Storage = A$407/kWh 8 Hr Storage = A$357/kWh	11
Battery OPEX	1 Hr Storage = A$4,833/MW 2 Hr Storage = A$9,717/MW 4 Hr Storage = A$19,239/MW 8 Hr Storage = A$39,314/MW	10

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