Hydrogen Pathways – User Guide

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Introduction

Welcome to Hydrogen Pathways, our hydrogen supply chain tool, designed to help you estimate costs and emissions across the supply chain. As the world transitions towards a low-carbon economy, hydrogen is emerging as a promising energy vector that can play a significant role in decarbonizing various sectors, including transportation, industry and power generation. Our website provides a comprehensive and user-friendly platform to explore the different stages of the hydrogen supply chain, including production, storage, transport and utilisation, and to assess the environmental and economic impacts of each stage. Whether you are a policy maker, investor, or industry expert, our website can help you make informed decisions about the deployment of hydrogen in your operations.

Disclaimer

The information provided on this website is for educational and informational purposes only. The predictions are based on available data and assumptions and may not reflect the actual costs and emissions of specific hydrogen supply chain pathways.

The predictions on this website do not constitute professional advice or recommendation and should not be relied upon as the sole basis for making decisions related to hydrogen supply chain pathways. The user is responsible for verifying the accuracy and completeness of any information provided on this website before making any decisions.

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1. Terminology

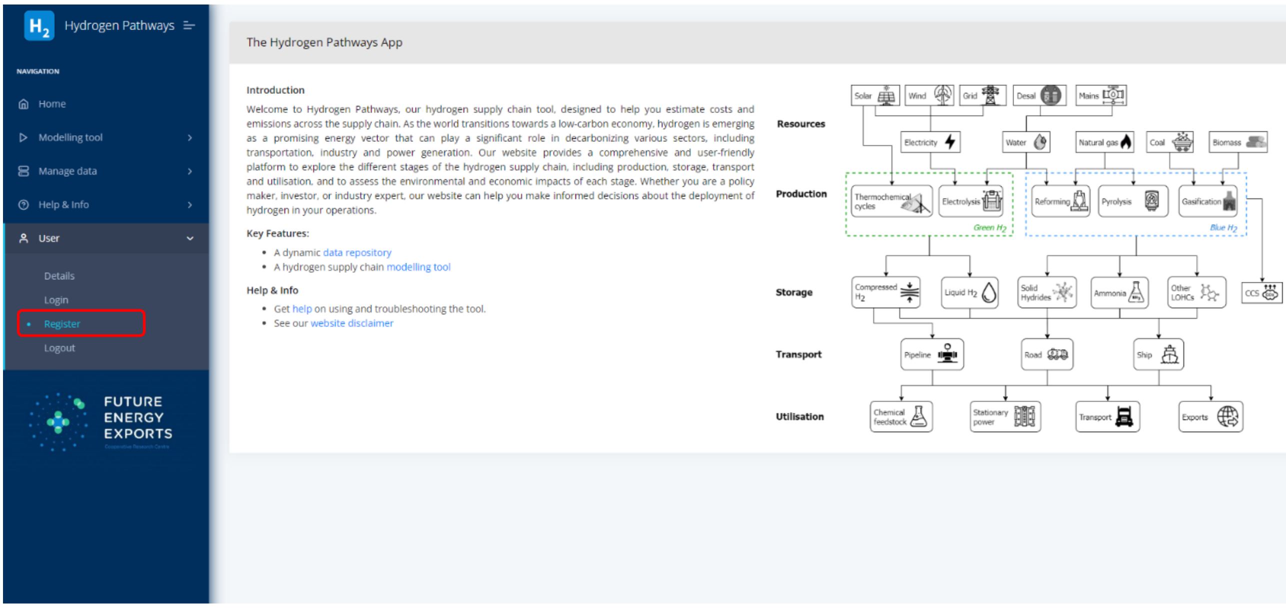
The following terminology is used throughout the app:

Scenario – a specific pathway through the hydrogen supply chain. A scenario consists of multiple modules linked together.

Module – a module is a specific element within the supply chain. A module represents an instance of a given technology (e.g. a PEM electrolyser located in Karratha).

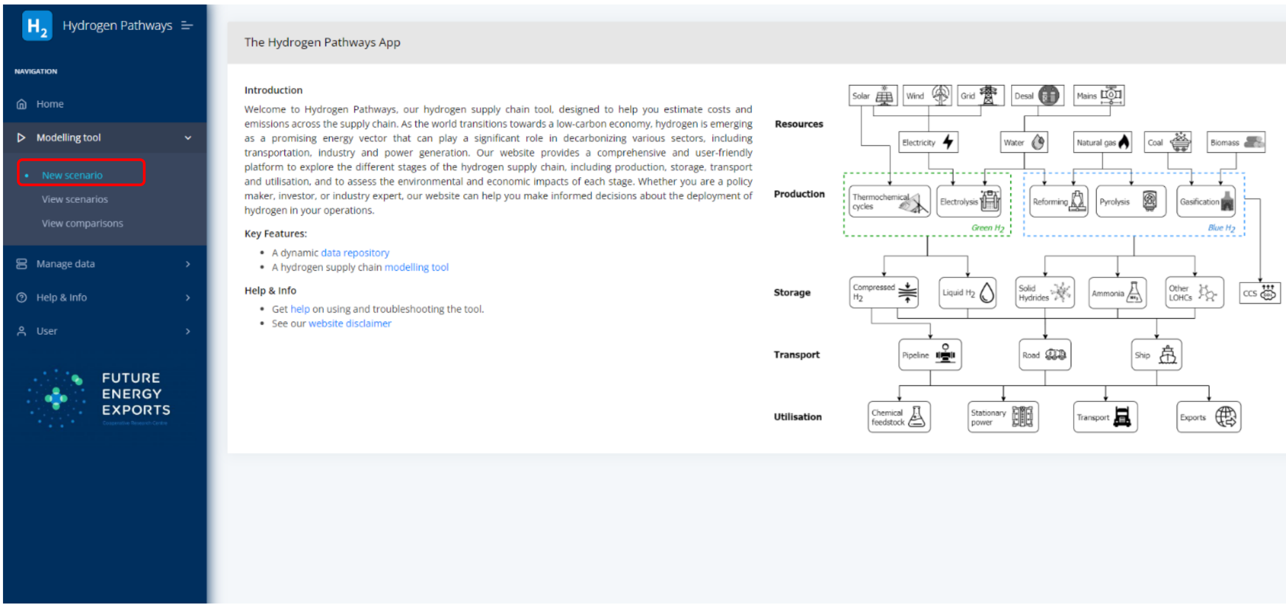
2. Scenario creation & analysis

The main aspect of the app is creating hydrogen supply chain scenarios. This section will outline how to create scenarios and get results. Note that in order to save scenarios (and view them again later) it is recommended to register a user. This can be found in the "User" dropdown of the navbar under "Register", or https://h2pathways.azurewebsites.net/user/register.

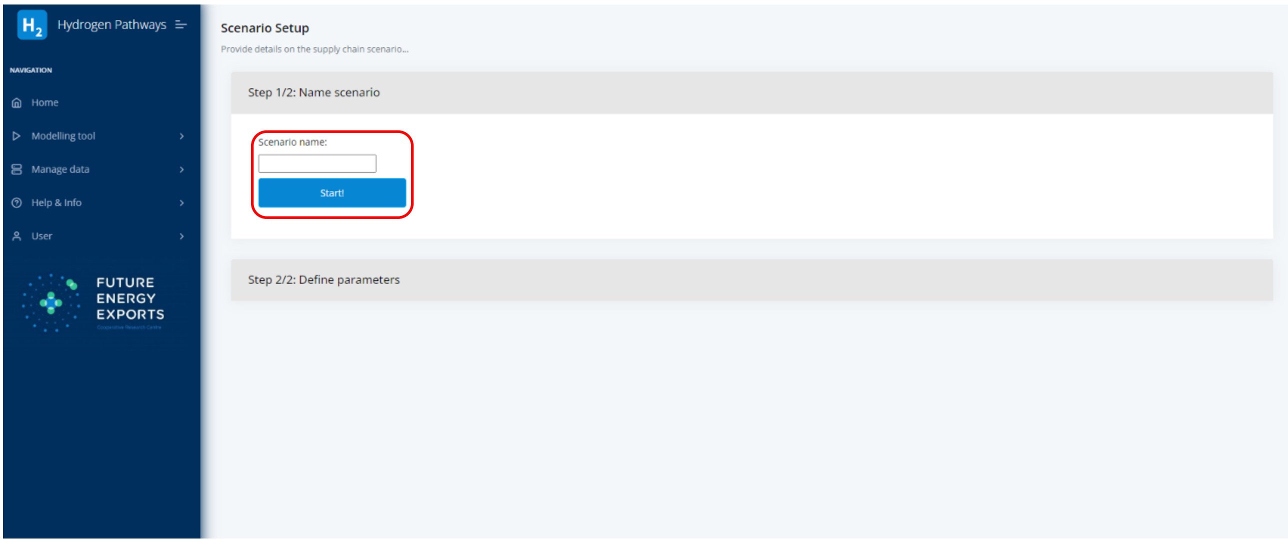


To create a scenario:

1. First select "New scenario" from the "Modelling tool" dropdown in the navbar, or at: https://h2pathways.azurewebsites.net/tool/scenarios/create.



2. Now input your scenario name, then click start:



3. The next screen provides a list of configurable parameters specific to the overall supply chain scenario. These are predominantly economic project parameters which impact the calculation of levelized cost. These include:

Lifetime – project lifetime (default is 30 years)

Project commencement – year of project start (default is the next calendar year)

Discount factor – the factor used to discount future cash flows back to present values (default is 8 %). Note that no correction for inflation is made, so this is essentially the "nominal discount factor"

Capex budget – an array which describes the outlay of capital expenditure (Capex) in the first years of the project. The first value represents fraction in first year, second value is fraction of capex in second year etc. For example:

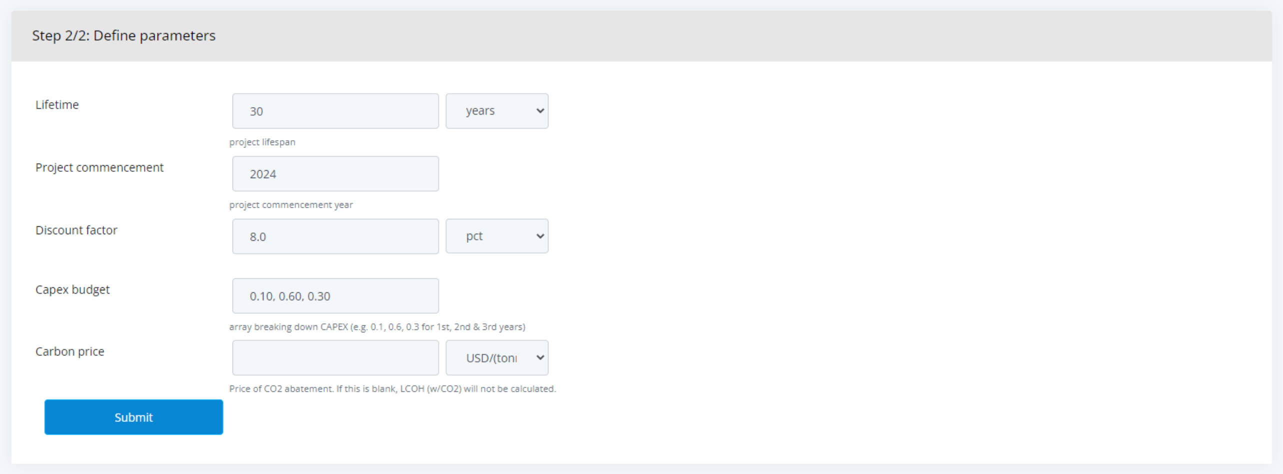
"0.10, 0.60, 0.30" represents 10% Capex spent in 1st year, 60% in 2nd year and 30% in 3rd year.

"0.20, 0.20, 0.20, 0.20, 0.20" represents 20% of Capex being spent in each of the first 5 years.

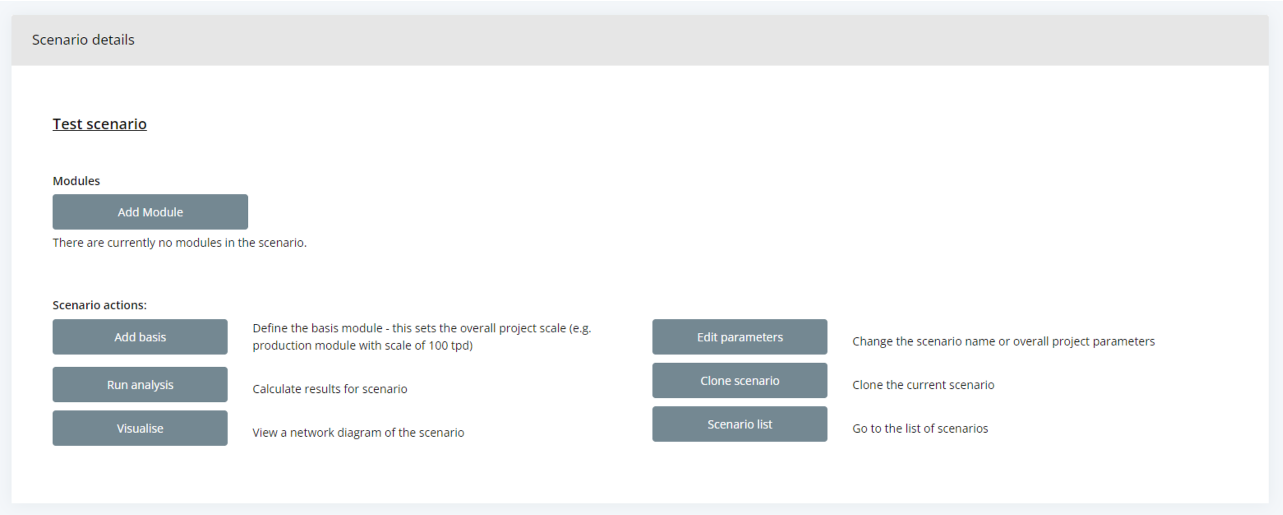
Please make sure this adds up to 1!

Carbon price – the cost of associated with CO_2 emissions or CO_2 abatement in (US$/tonne). This is included in OPEX and applied to the calculated "Well-to-gate" emissions of the scenario. If this is left empty, no carbon price is applied.

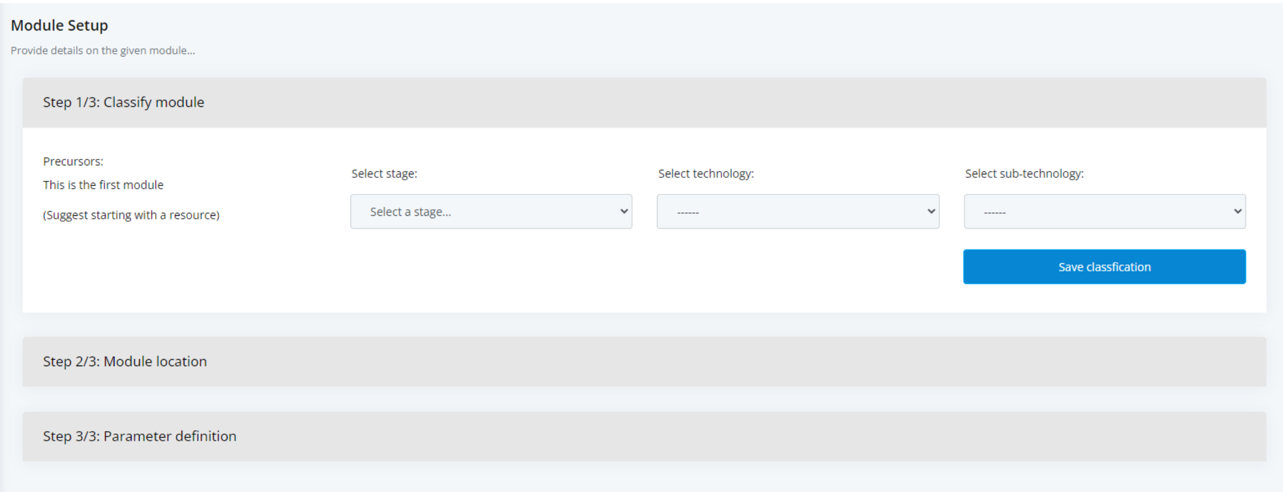
Click submit once you are happy with selected parameters.



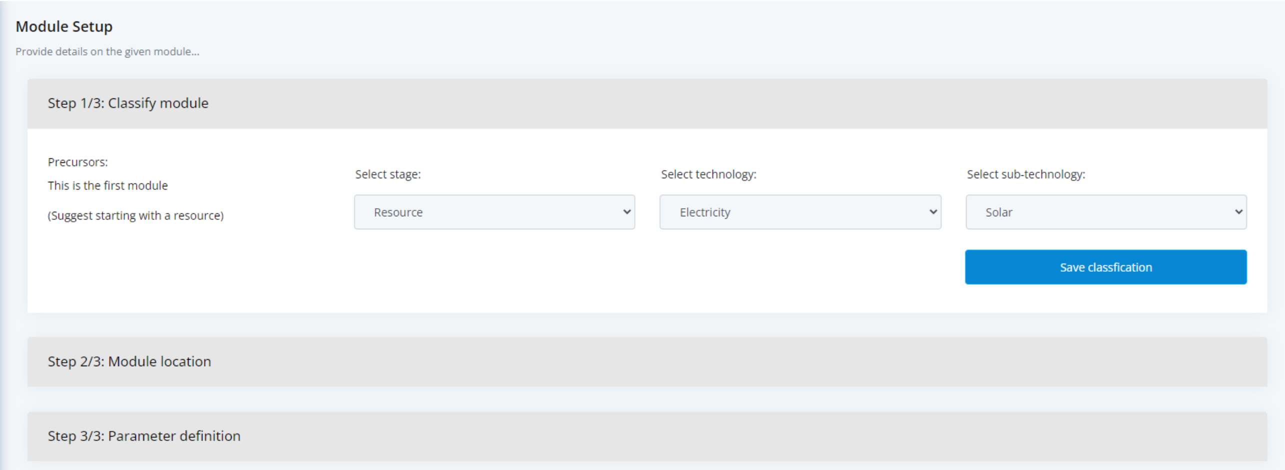
4. You then reach the "scenario detail page" (e.g. see below) from here you have multiple options. The first action is to add a module (click "Add module"): this is adding the first module into your scenario.



5. This will bring you to the module creation page (see below). There are 3 steps to module creation: (a) classification, (b) location and (c) parameter definition.



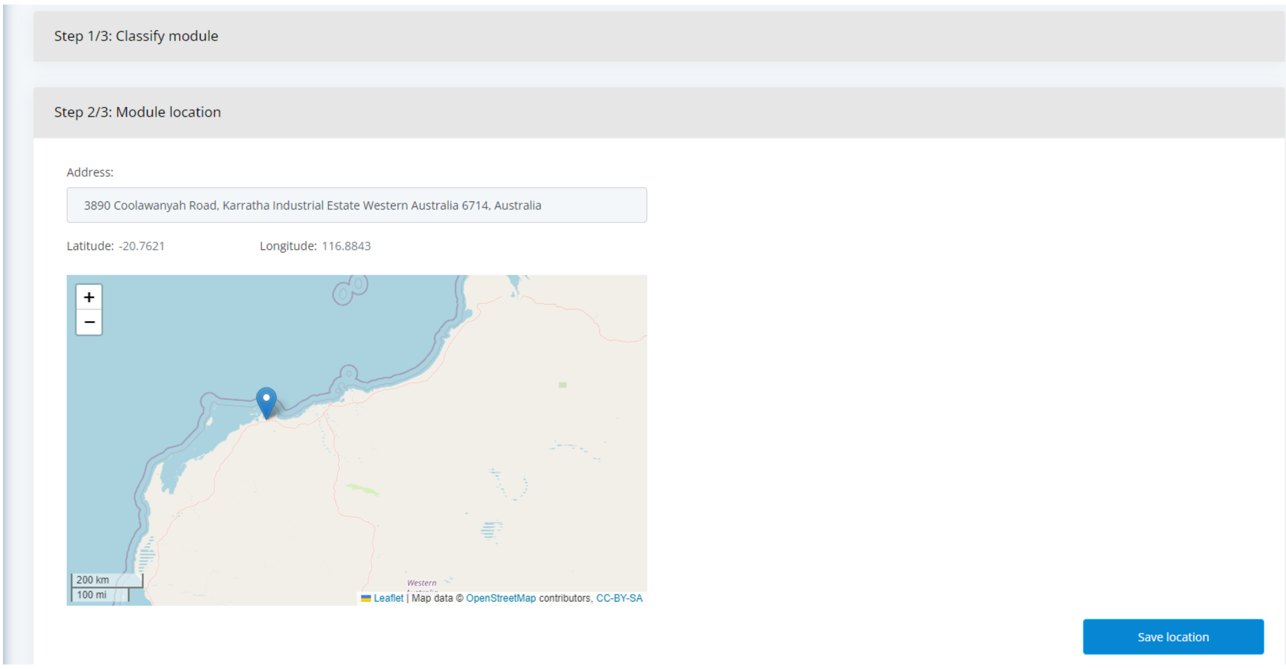
a. Module classification involves defining the "precursors", "stage", "technology" and (maybe) "subtechnology" of the module. For the first module there will be no precursors – details on linking precursors will be discussed in the next module. It is recommended to always begin with a "Resource". In the example scenario, we will begin with a solar module, thus select "Resource" as the stage, "Electricity" as the technology and "Solar" as the subtechnology. Click "save classification" once selected.
Have a flick through some of the different stage/technology/subtechnology options – a list of the currently available options is provided in Appendix A.



b. Now select the module location. This can be done by either clicking on the map at the relevant location or inputting an address (the alternate will update accordingly). The location is used for:

- In all modules, it determines the country-specific "location factor" applied to CAPEX and Fixed OPEX.
- For solar and wind modules (only in Australia), it determines the appropriate capacity factor to use (i.e. according to solar irradiation or wind speed data). This is used to determine the appropriate scale of the module.
- For modules which are the precursor to a "transport" module (typically this will be a "storage" module) – the location of this module is the "start-point" of the transit, e.g. if Liquid H2 tanks are followed by a Liquid H2 trucking module, the location of the Liquid H2 tanks is the start of transit, and the location of the trucking module is the end of the transit.
- For "transport" modules – the location determines the "end-point" of the transit.

For the solar module example, a location in the Karratha industrial estate will be used.

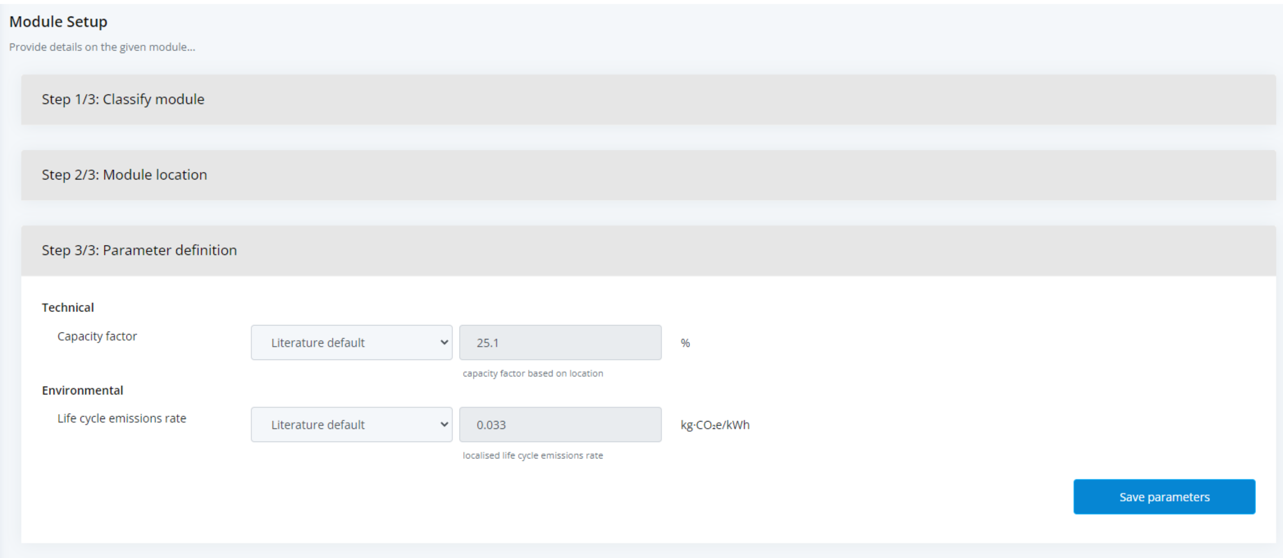


c. The final part of module creation is <u>parameter definition</u>. The parameters which are presented are dependent on the module classification (e.g. for a production module we might see electricity usage requirements, whereas for a road transport module we would see number of trailers and fuel usage).

For the solar module – the capacity factor is determined from solar irradiation data from the module location. The "life cycle emissions rate" is localised according to location data.

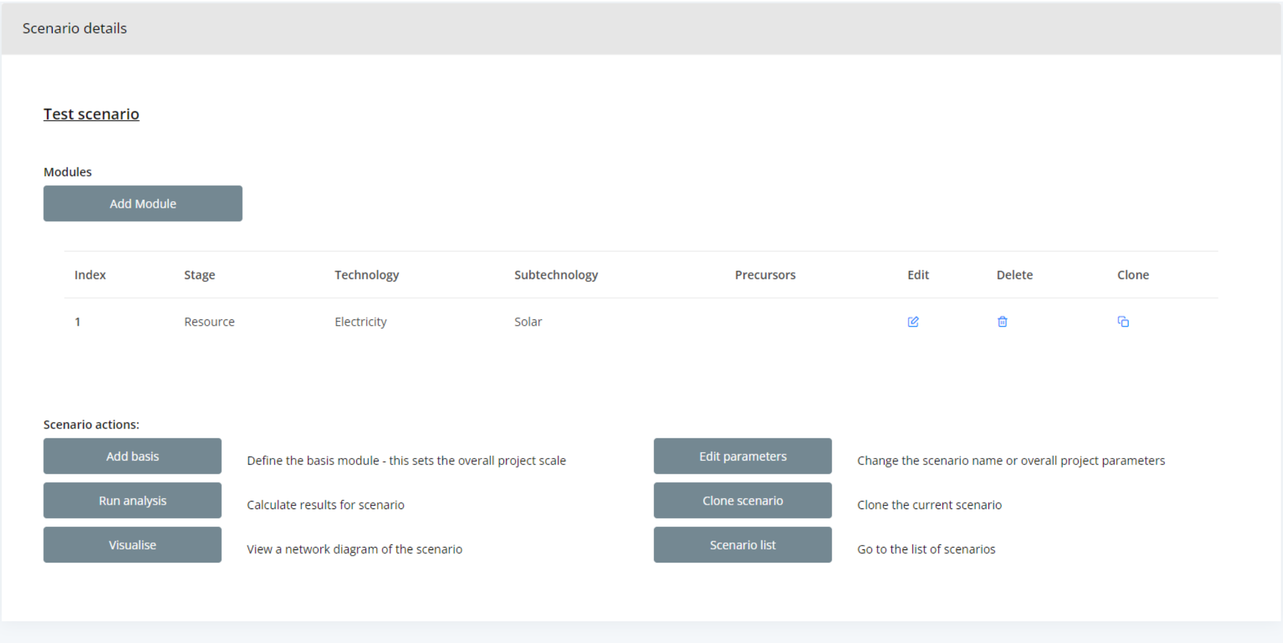
For any parameter, you can change the dropdown from "Literature default" to "User defined" in order to edit the parameter value & select your own value.

Literature default values are pulled from the app database & averaged.

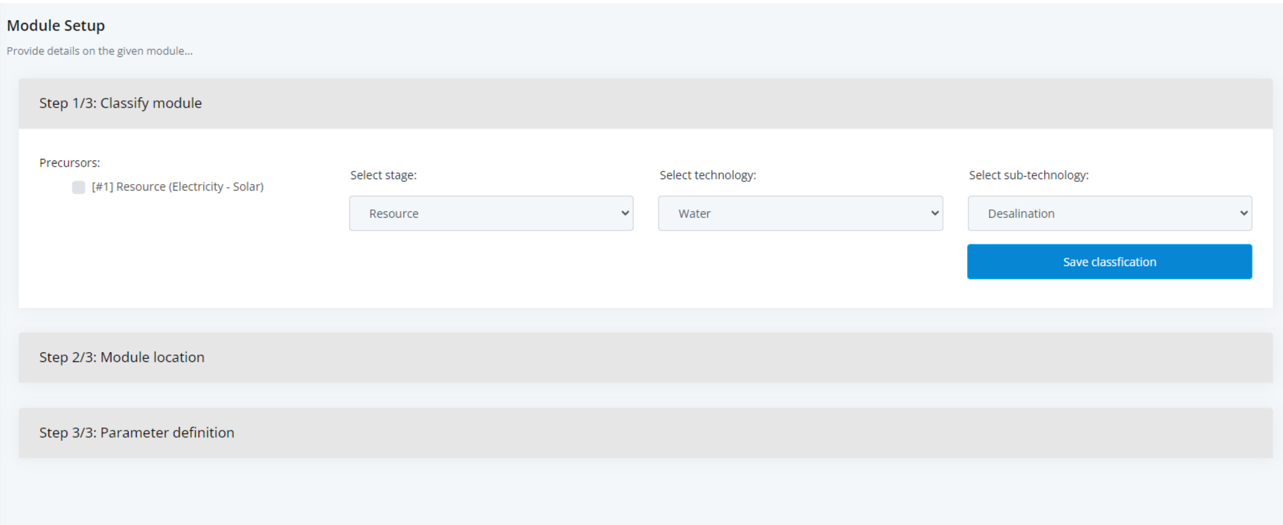


Once you are happy with the parameters, click save parameters.

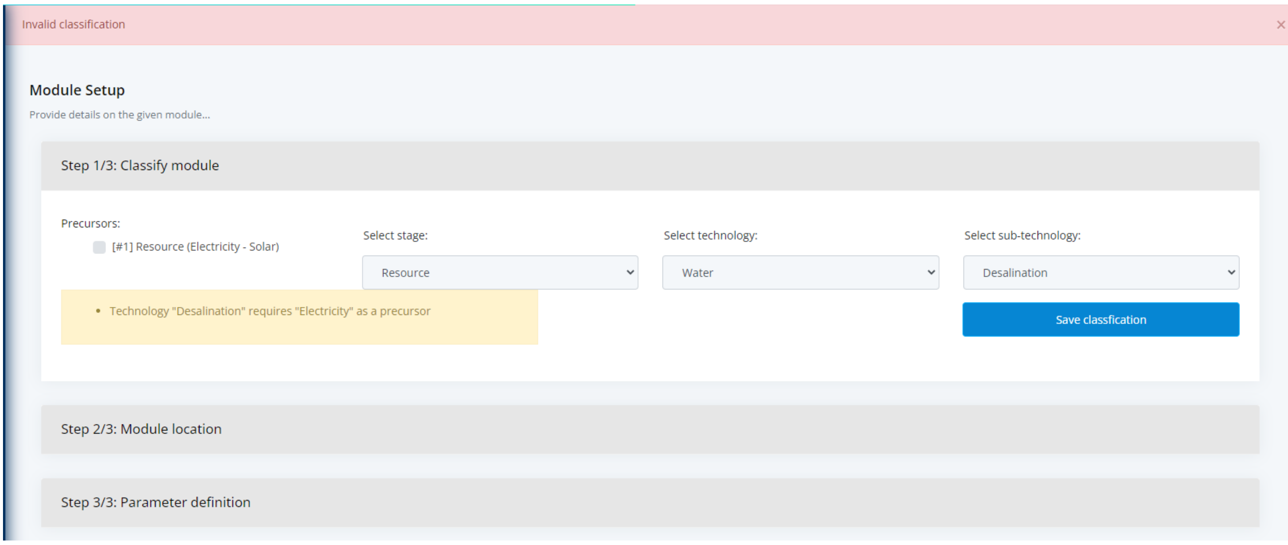
6. The module is now included in the “scenario details” page



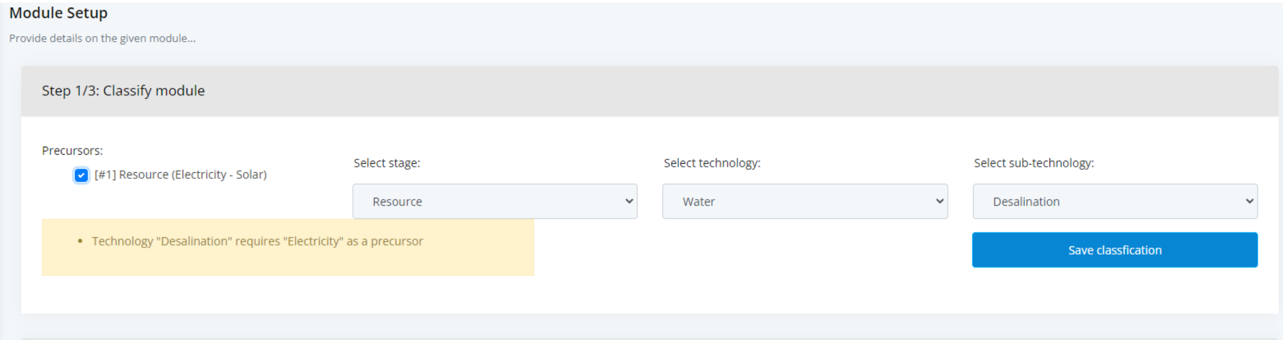
7. Now add a second module (click “add module” again). This time we are going to add a desalination plant.



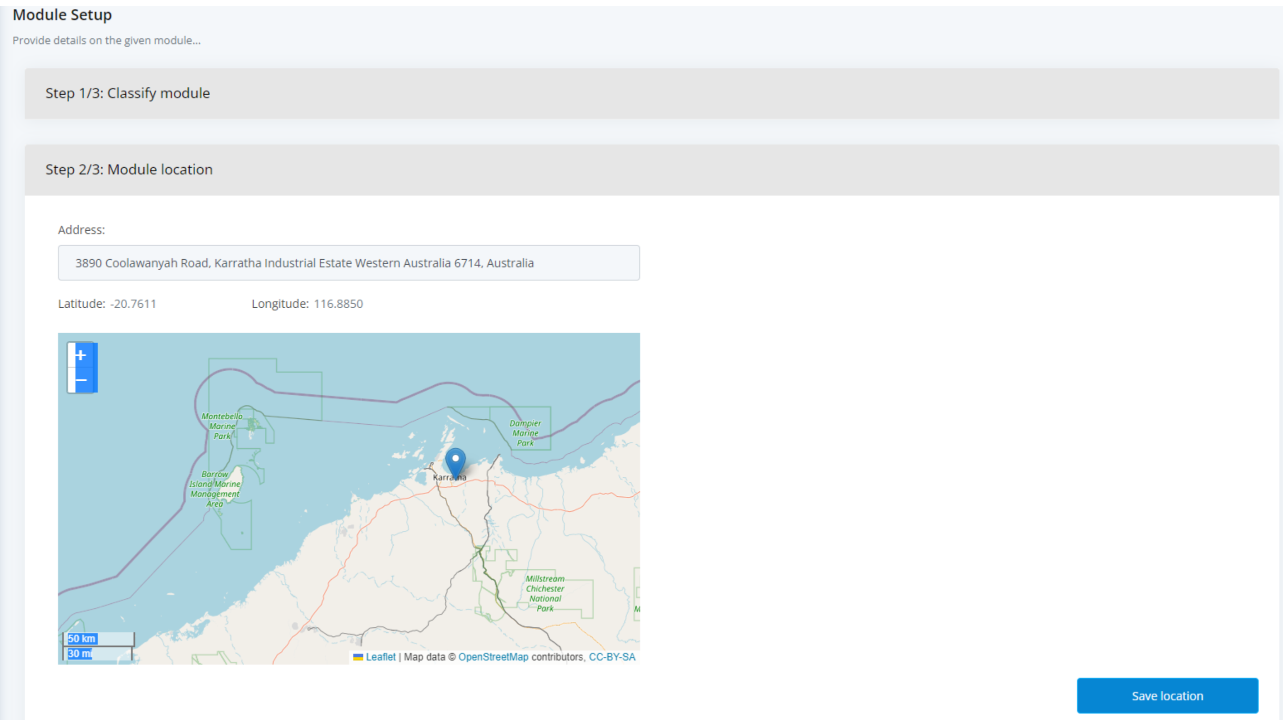
8. Desalination requires electricity, so we will need to select the solar module as an input. However, if you don’t the app should tell you it is required when you click save classification. This will happen for all module technologies – the app should tell you which precursors are required. If you don’t have that precursor created yet (e.g. if you had no electricity modules at this stage), you will have to create that module first.



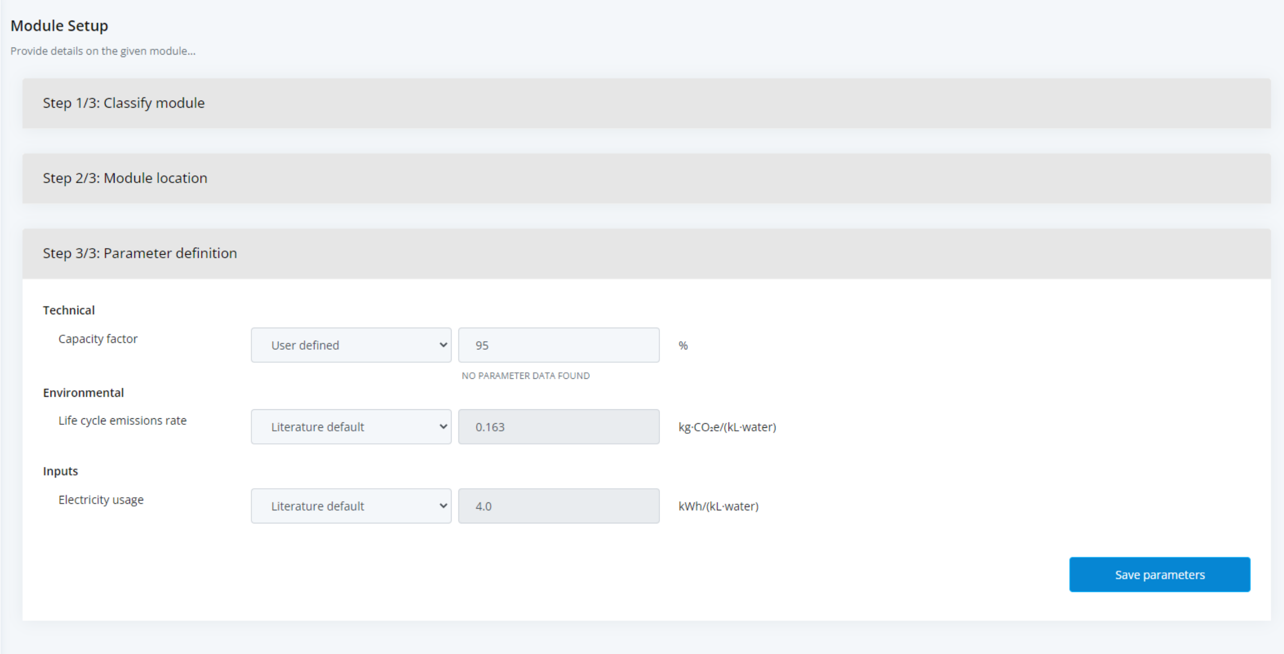
9. Select the solar module as the precursor (and keep the classification as Resource/water/desalination), then click save again.



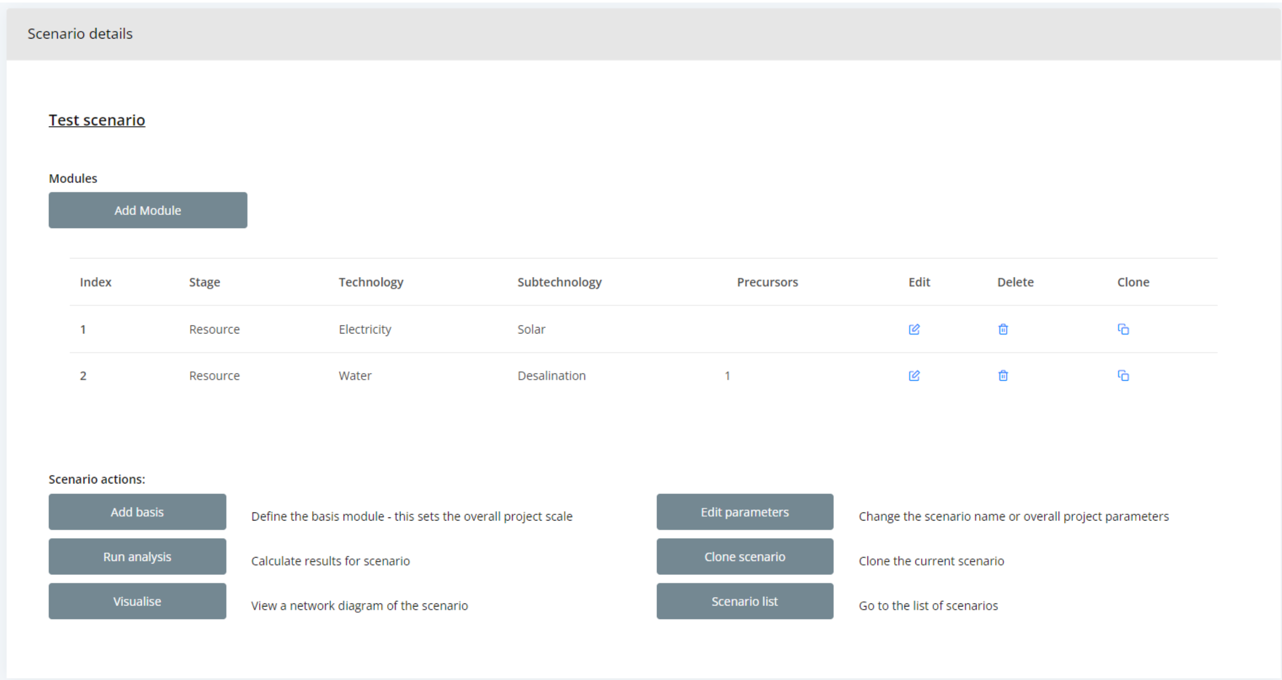
10. Set the same location for the desalination module.



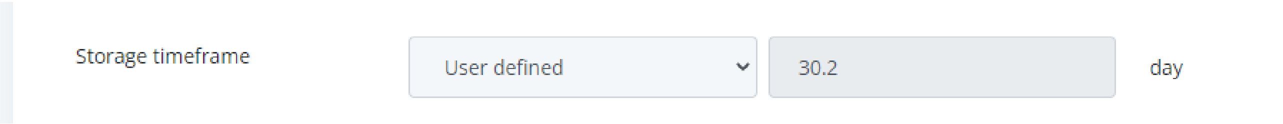
11. View the parameters associated with desalination – here we will set the capacity factor to be "User defined" as 95%. Click save parameters once happy



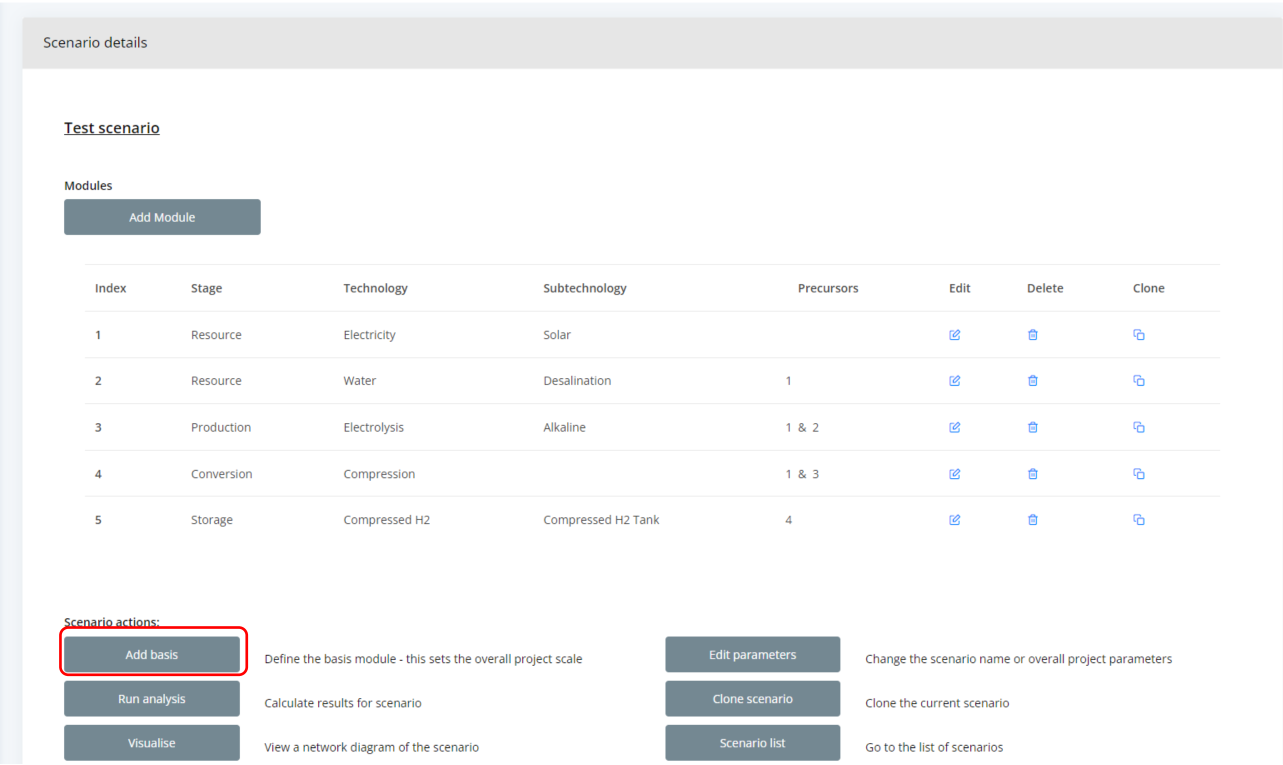
12. The scenario detail page now shows up as below. Note that desalination module has "1" in precursors to note that module #1 (i.e. Solar) is a precursor to it.



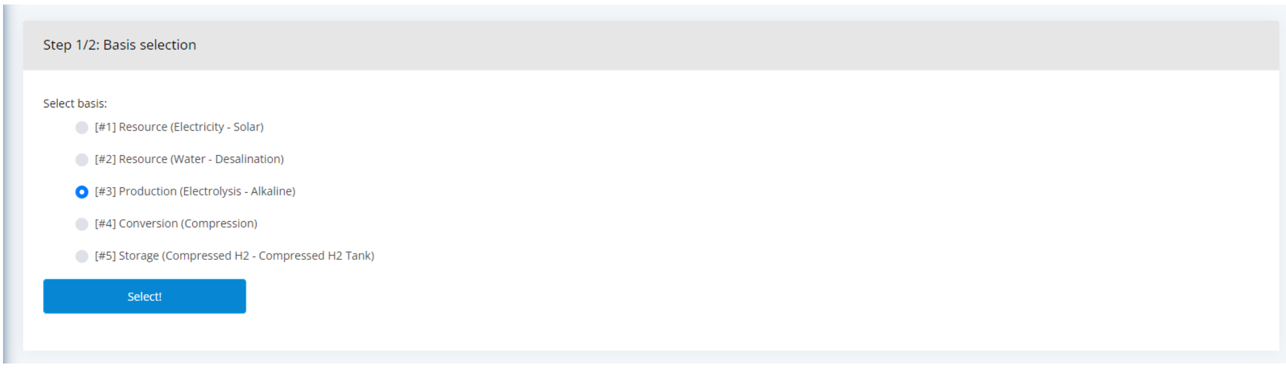
13. Run through a similar process in creating modules the following modules (all in same location, use the default parameters – except in storage as below):
    a. Production/Electrolysis/Alkaline – with both Solar & desalination as precursors
    b. Conversion/Compression – with both Solar & Alkaline as precursors
    c. Storage/Compressed H2/Tanks – with the conversion module as a precursor – <u>however set the "storage timeframe" to be 7 days</u> (user defined).



14. Once complete, the scenario detail page should look as follows. Now that we have all the relevant modules defined, the final thing to do before running analysis is to <u>define a scenario basis</u>. Click "add basis".

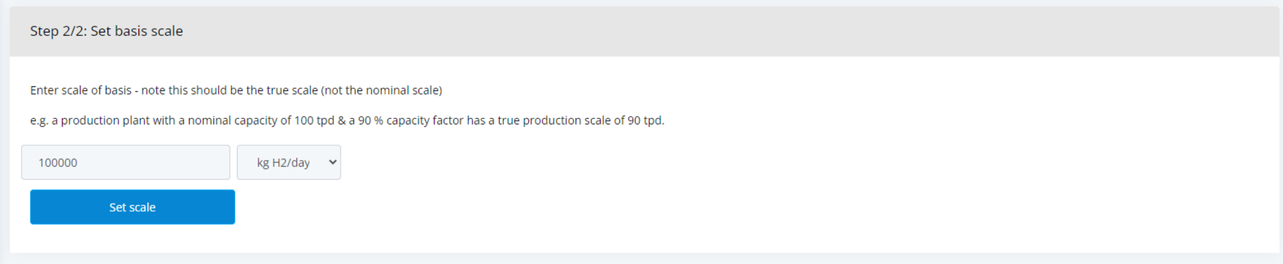


15. Choose which module you wish to specify as a basis. In this example, the production module (electrolysis/alkaline) will be selected.

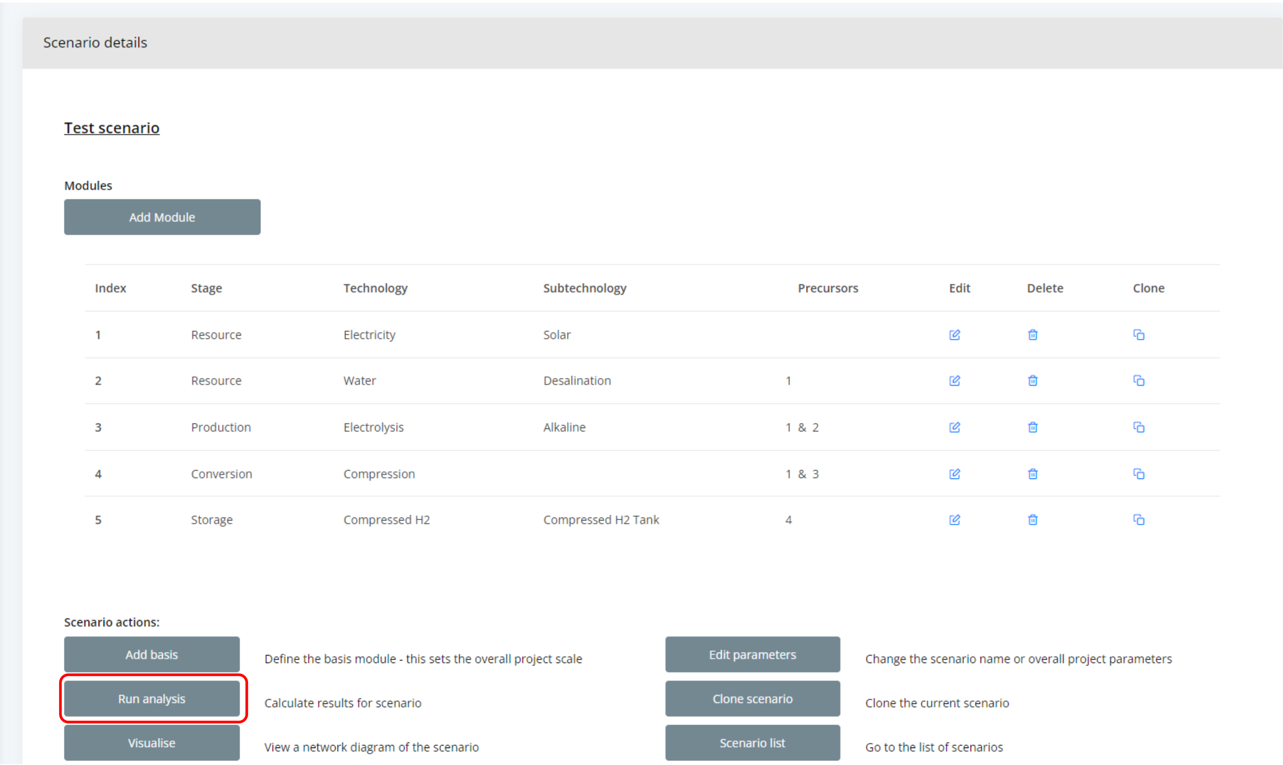


16. Then specify the scenario basis scale (this is the size of that given module). Please specify the true scale, not the nominal scale. In this case, the scale will be set to 100 tonne/day (100,000 kg/day). Note that the scale units will change depending on the module (e.g. scale is in MW for solar or wind and kL/day for water).

    The scale of all other modules is calculated from this.



17. Now click run analysis. If the basis has not been set, or there is an invalid precursor link – the analysis will fail (and the app will tell you this).



18. The app will present you with results for the scenario. This includes a breakdown of levelized cost of hydrogen (LCOH) on the left and emissions intensity (right).

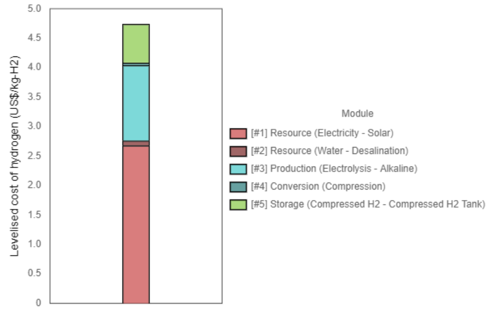
    The table at the bottom provides numeric values for the scenario (top row) and each module (subsequent rows).

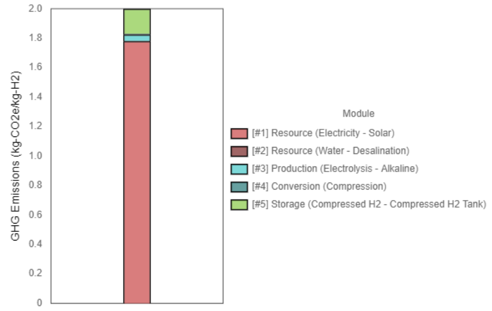
Scenario Results

Test scenario

back to scenario details

Costs & Emissions breakdown





Module results table

Index	Scenario/Module	Scale	LCOH	CAPEX	OPEX	GHG Emissions
Overall	Test scenario	100000 $kg \cdot H_2/day$	4.74 $US\$/(H_2 \cdot kg)$	1,503,700,000 US$	60,465,000 US$/year	2.00 $kg \cdot CO_2e/(kg \cdot H_2)$
1	[#1] Resource (Electricity - Solar)	225 MW	2.68 $US\$/(H_2 \cdot kg)$	903,000,000 US$	30,100,000 US$/year	1.78 $kg \cdot CO_2e/(kg \cdot H_2)$
2	[#2] Resource (Water - Desalination)	1090 kL·water/day	0.08 $US\$/(H_2 \cdot kg)$	36,300,000 US$	315,000 US$/year	0.00 $kg \cdot CO_2e/(kg \cdot H_2)$
3	[#3] Production (Electrolysis - Alkaline)	100000 $kg \cdot H_2/day$	1.28 $US\$/(H_2 \cdot kg)$	300,000,000 US$	24,400,000 US$/year	0.04 $kg \cdot CO_2e/(kg \cdot H_2)$

19. You can find further details on each individual module by clicking on the name of that module, e.g. clicking on "[#1] Resource (Electricity – Solar) brings up:

Module Details

[#1] Resource (Electricity - Solar)

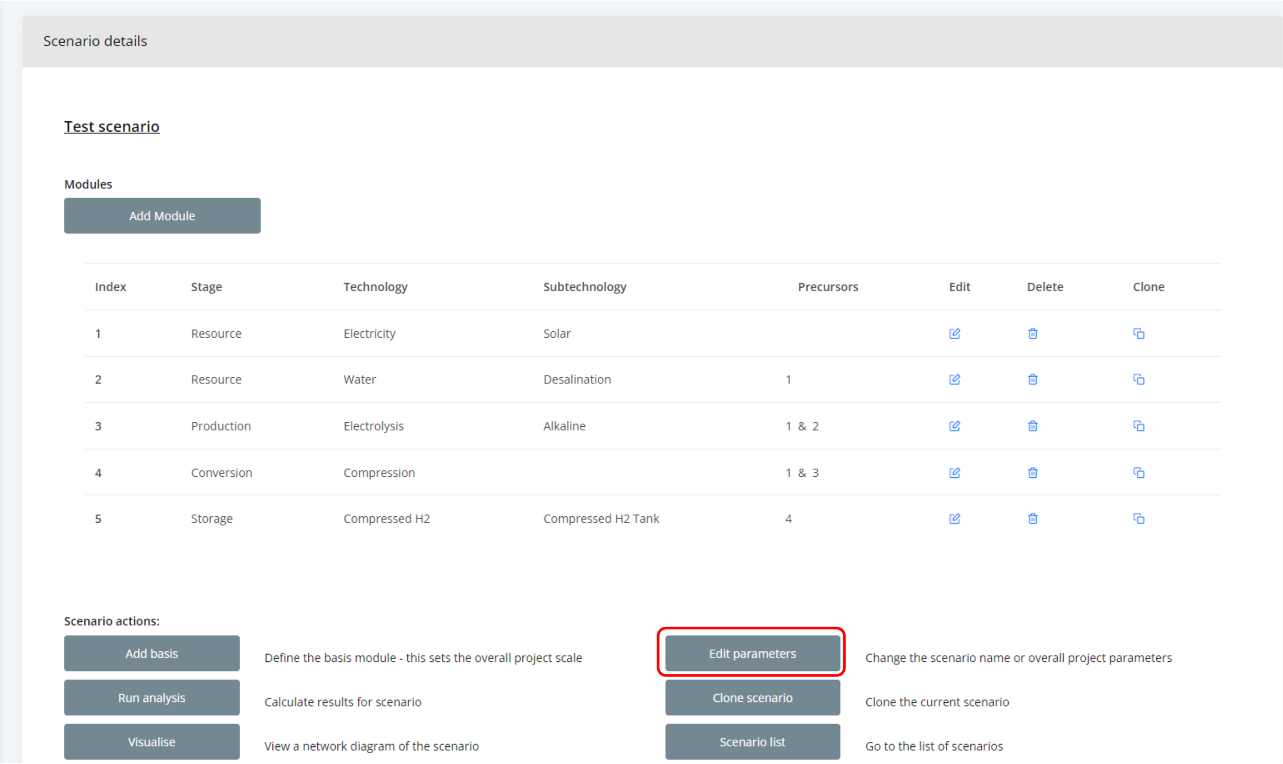
Scenario:	Test scenario
Stage:	Resource
Technology:	Electricity
Subtechnology:	Solar
Economics	
LCOH:	2.68 $US\$/(H_2 \cdot kg)$
LCOH (w/CO2):	
CAPEX:	903,000,000 US$
Variable OPEX:	0 US$/year
Fixed OPEX:	30,100,000 US$/year
Environmental	
Total_lca:	65000.0 $t \cdot CO_2e/year$
Total_w2g:	0.0 $t \cdot CO_2e/year$
Rate_lca:	1.78 $kg \cdot CO_2e/(kg \cdot H_2)$
Rate_w2g:	0.0 $kg \cdot CO_2e/(kg \cdot H_2)$
Technical	
Scale:	225.0 MW
Nameplate capacity:	896.0 MW
Resource usage:	225.0 MW

That's it! The scenario is now defined, and results have been calculated.

3. Scenario editing and cloning

3.1 Edit scenario parameters

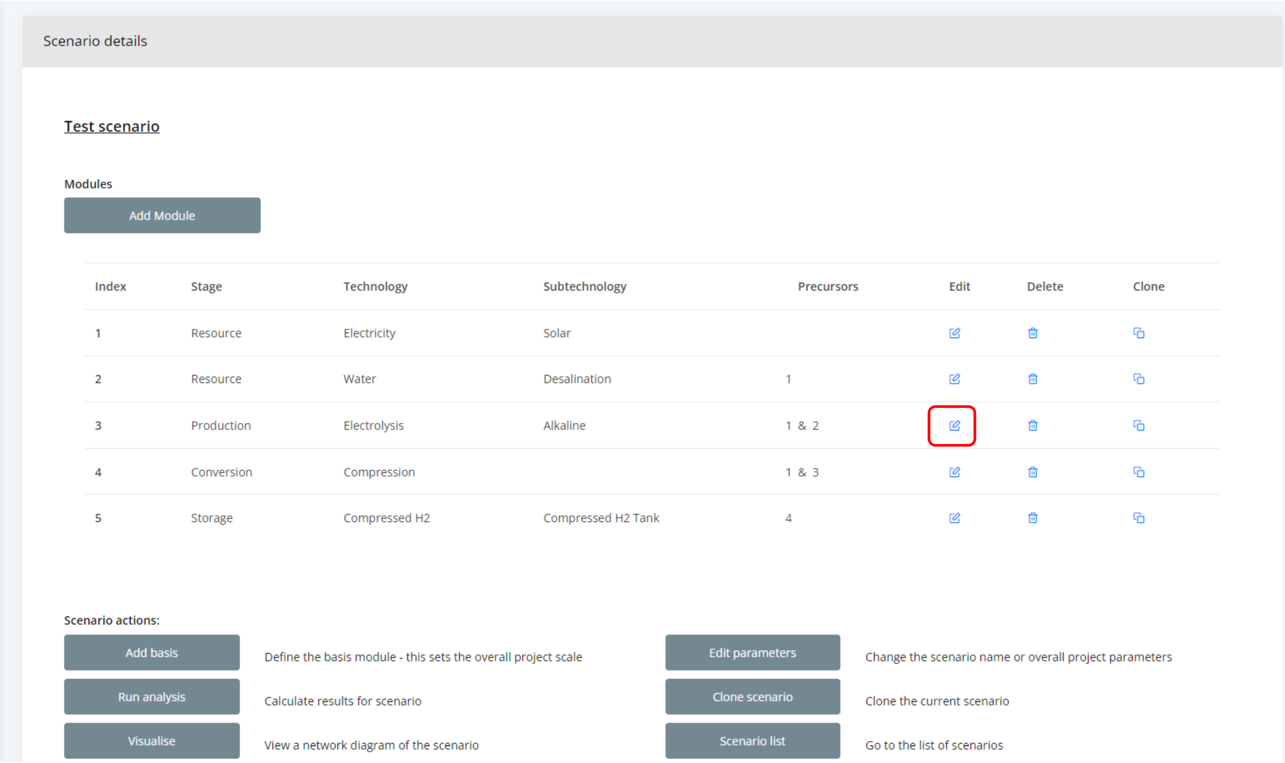
If you wish to change specific parameters, both the scenario and modules can be updated. To edit scenario parameters (including name), click "Edit parameters":



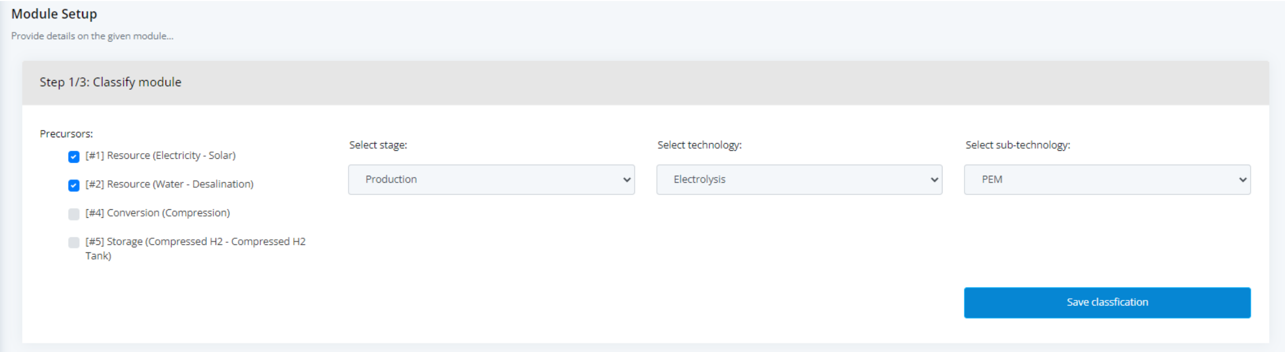
This will bring up the form similar to scenario creation (with name and parameters) – edit these to change such values for the scenario.

3.2 Edit module parameters

To edit parameters of a specific module, click the "edit" link button for that module – e.g. to modify the electrolyser, we would click on the link in row three.

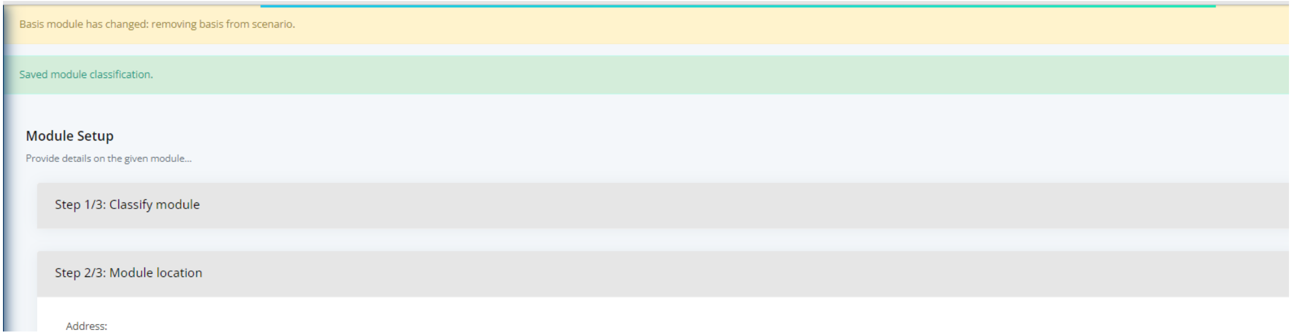


The module classification, location and parameters can all be changed. Here, the electrolyser will be changed to a PEM (instead of an alkaline).



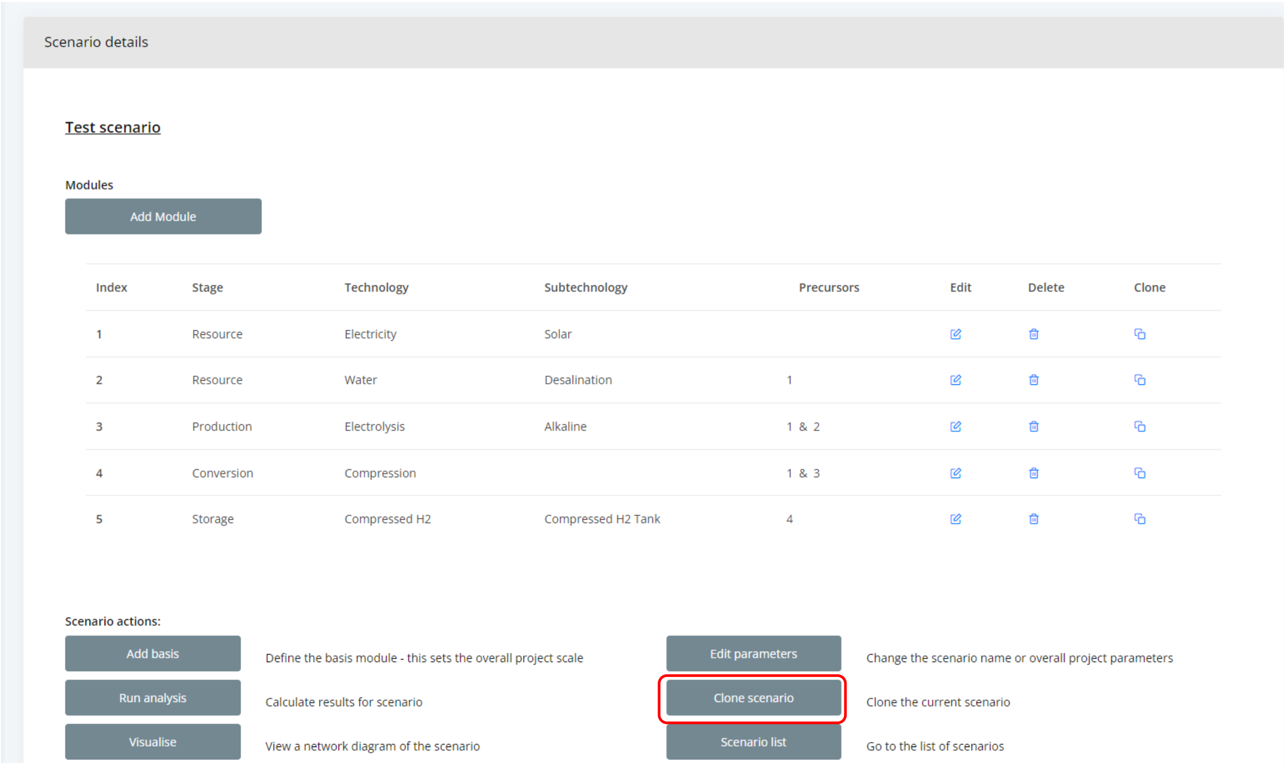
Note that in this case – we have changed the technology of the "basis module" – thus the basis will need to be removed from the scenario and need to be re-added – the app tells you this (top message in below screenshot).

Also note that if you change the module classification – this may allowable precursor links – you may need to modify other modules accordingly.

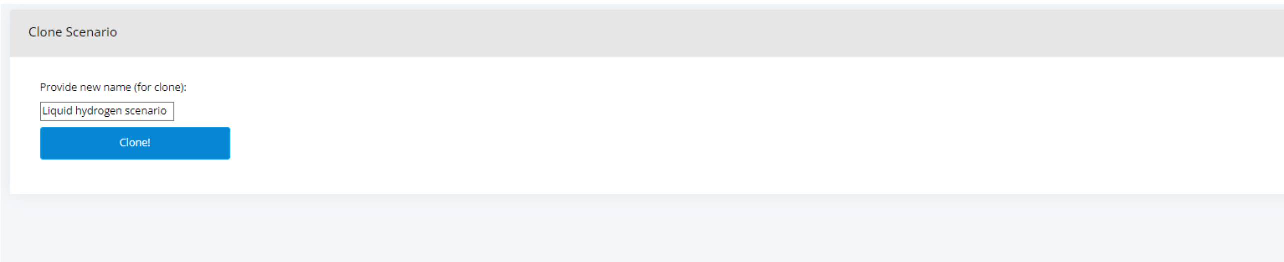


3.3 *Cloning scenarios*

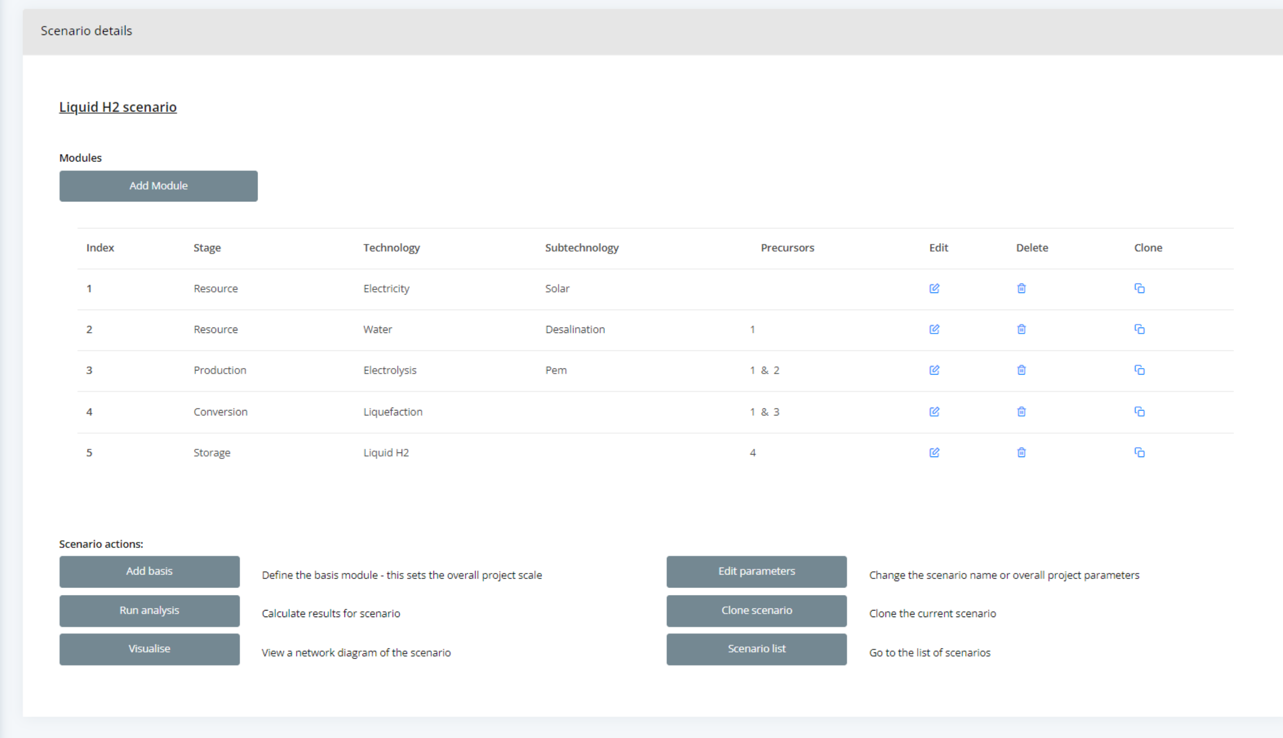
A scenario can be "cloned" to produce a replica. This is very useful for scenario comparisons. For example, imagine we want to compare the above scenario to a similar one which uses liquid hydrogen storage instead of compressed hydrogen. Start by clicking "Clone scenario":



Now provide a name for the new scenario & then click clone:



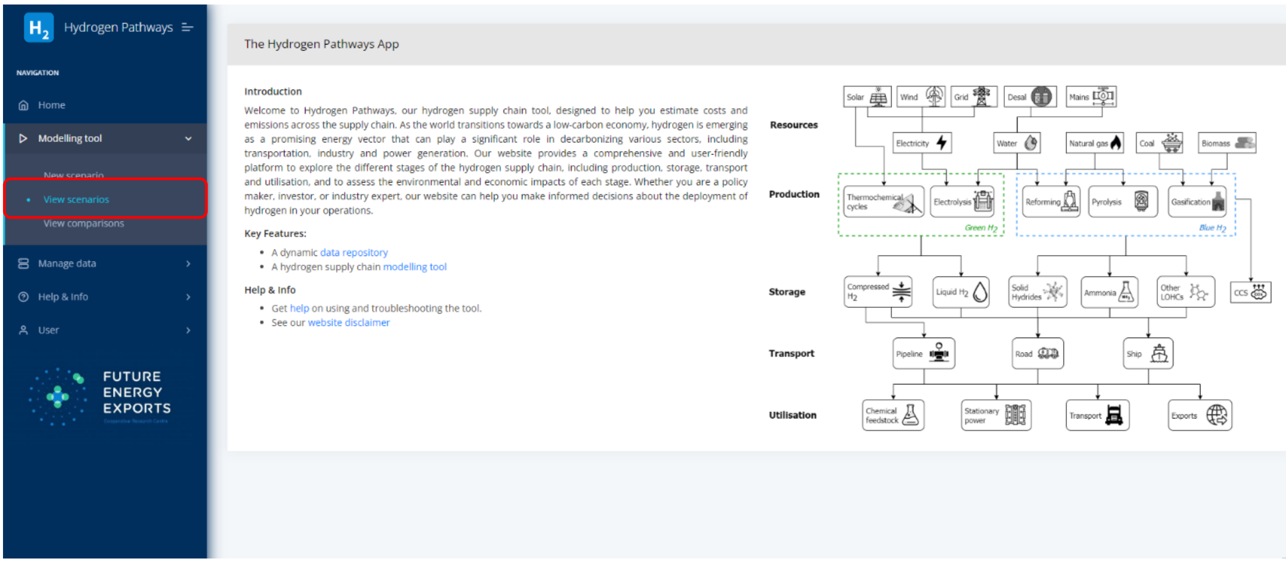
This produces a clone of the previous scenario. You can now edit individual modules (e.g. conversion and storage modules) to create alternative pathways:



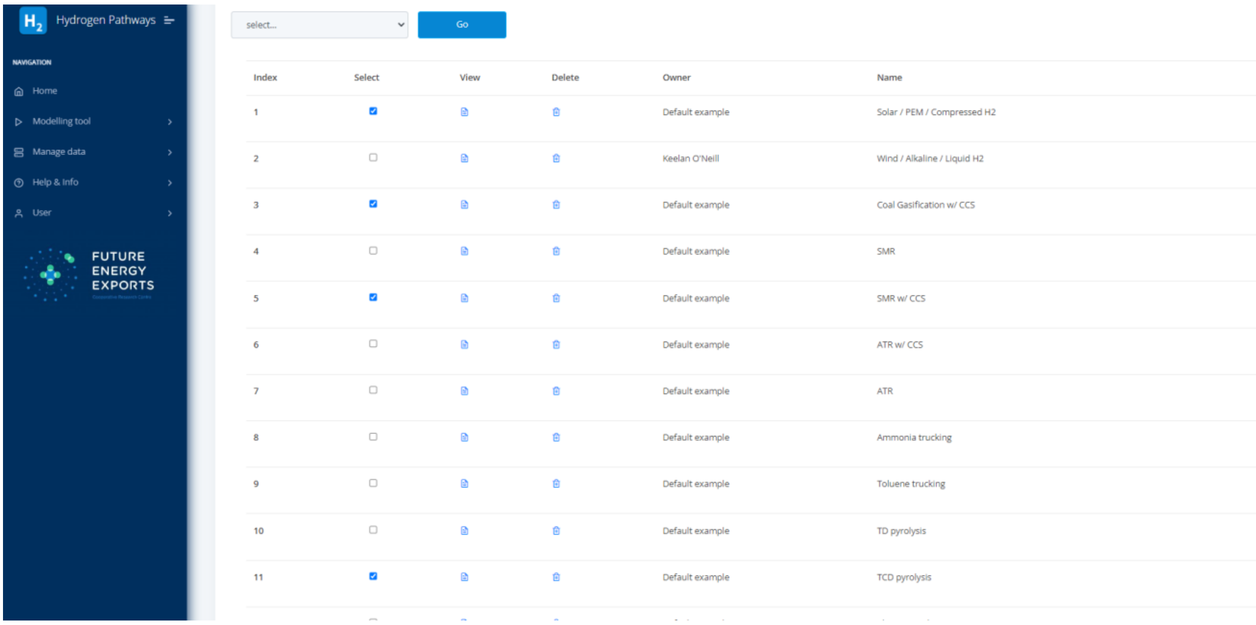
Index	Stage	Technology	Subtechnology	Precursors	Edit	Delete	Clone
1	Resource	Electricity	Solar				
2	Resource	Water	Desalination	1			
3	Production	Electrolysis	Pem	1 & 2			
4	Conversion	Liquefaction		1 & 3			
5	Storage	Liquid H2		4			

4. Comparing multiple scenarios

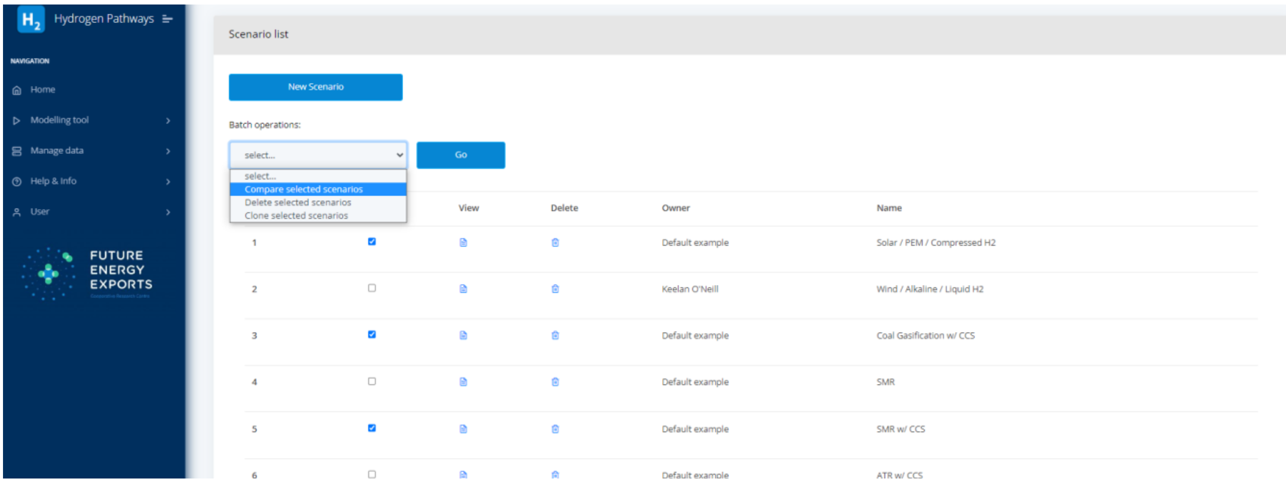
A scenario comparison can be created from the "view scenarios" screen:



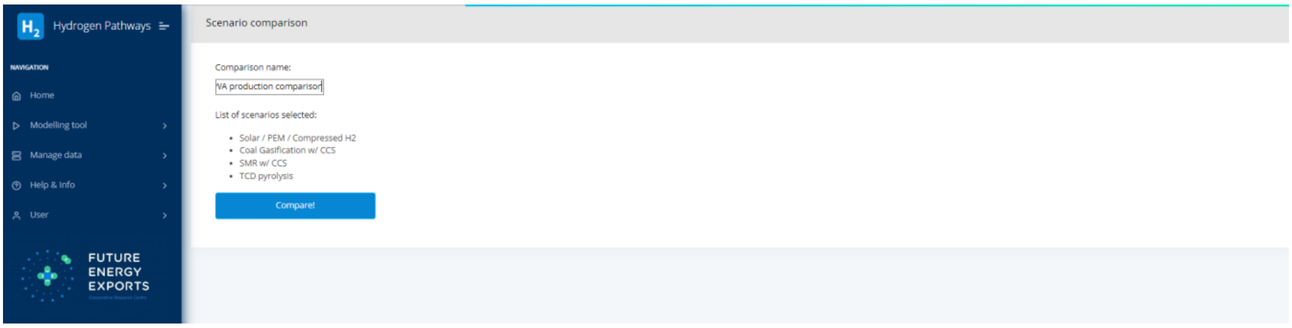
Select the scenarios you wish to compare (by checking the box in the select column), e.g. here scenarios #1, 3, 5 and 11 have been selected.



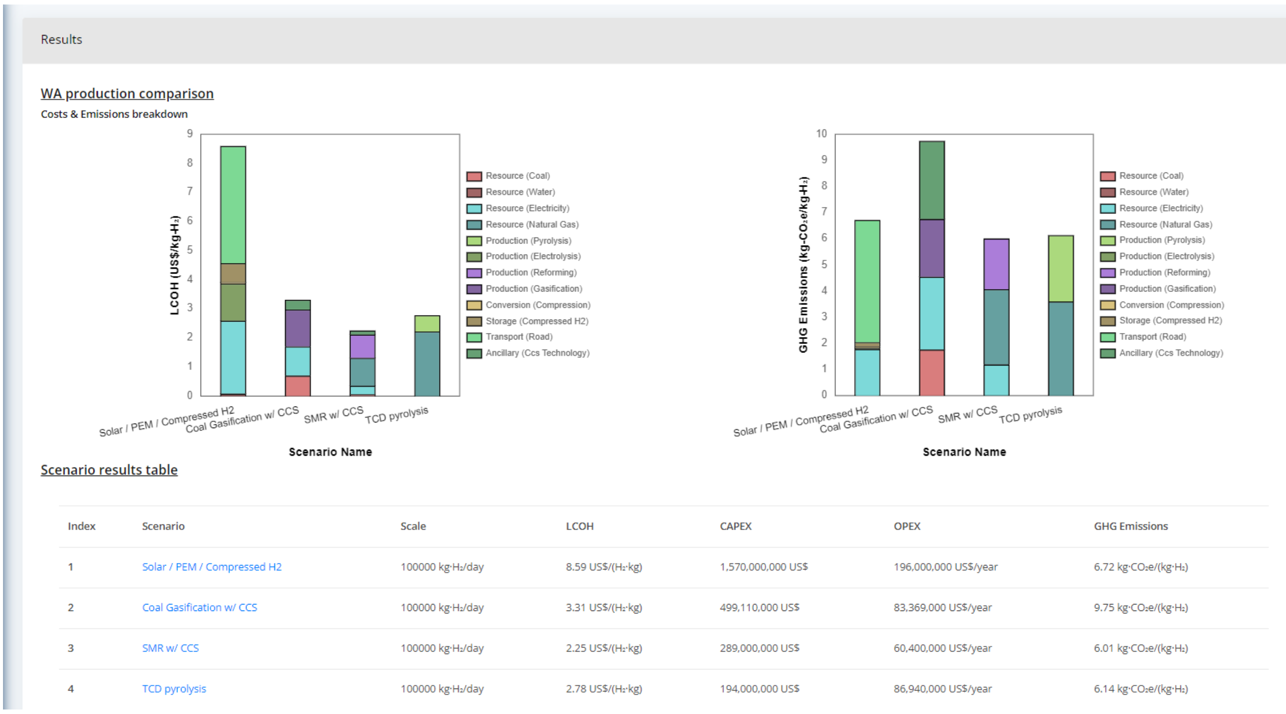
From the dropdown (above the table), click on "Compare selected scenarios", then click "Go"



Create a name for the comparison, then click compare:



Give the following a little bit of time (~1 min) – this is calculating results for all scenarios. The next screen will then pull up a comparison of LCOH & GHG emissions across each of the selected scenarios. Note that modules have been clustered according to technology type (see module classifications in Appendix A) – so similar subtechnologies (e.g. Solar, Wind & grid are all subtechs of electricity) will be clustered together.



Index	Scenario	Scale	LCOH	CAPEX	OPEX	GHG Emissions
1	Solar / PEM / Compressed H2	100000 kg-H₂/day	8.59 US$/(H₂-kg)	1,570,000,000 US$	196,000,000 US$/year	6.72 kg-CO₂e/(kg-H₂)
2	Coal Gasification w/ CCS	100000 kg-H₂/day	3.31 US$/(H₂-kg)	499,110,000 US$	83,369,000 US$/year	9.75 kg-CO₂e/(kg-H₂)
3	SMR w/ CCS	100000 kg-H₂/day	2.25 US$/(H₂-kg)	289,000,000 US$	60,400,000 US$/year	6.01 kg-CO₂e/(kg-H₂)
4	TCD pyrolysis	100000 kg-H₂/day	2.78 US$/(H₂-kg)	194,000,000 US$	86,940,000 US$/year	6.14 kg-CO₂e/(kg-H₂)

Appendix A. Module classification options

The following details the categorisation options of different module technology options. Modules are classified according to "stage", "technology" and (maybe) "subtechnology". The stage is the position within the supply chain. The current development of the supply chain tool incorporates eight stages which are summarised in **Table 1** including a description and example technologies.

Table 1 Classification of stages within the hydrogen supply chain. Acronyms in example technologies: steam methane reforming (SMR) and Carbon capture and storage (CCS).

Stage	**Description**	**Example technology**
Resource	Any feedstock or input required for hydrogen production.	Electricity, water
Production	A process which generates hydrogen.	Electrolysis, SMR
Conversion	A process which transforms hydrogen from a produced state into a state suitable for transport.	Liquefaction, Ammonia generation
Storage	Intermediate storage of hydrogen in converted state (in some form of tank/vessel).	Liquid H_2, Ammonia
Transport	Movement of hydrogen (in converted state) between two locations.	Pipeline, Truck, Ship
Release	The transformation of hydrogen from a converted state back to a usable state (opposite of conversion).	Regasification, Dehydrogenation
Utilisation	The application or use of hydrogen.	Chemical feedstock, power generation
Ancillary	Supporting or alternate technologies attached to the supply chain.	CCS

The main bulleted list (below) is leveled as follows:

- Stage
    - Technology
        - Subtechnology

The following bulleted list breaks down the stages into possible technology options. Please note not all technologies have a subtechnology (e.g. natural gas or coal).

- Resource
    - Electricity
        - Solar
        - Wind
        - Grid
    - Water

        - Desalination
        - Mains
    - Natural gas
    - Coal
- Production
    - Electrolysis
        - PEM (Polymer electrolyte membrane)
        - Alkaline
        - SOE (Solid oxide electrolyser)
    - Reforming
        - SMR
        - SMR w/ carbon capture
        - ATR
        - ATR w/ carbon capture
    - Pyrolysis
        - Thermal decomposition (natural gas fired)
        - Thermocatalytic decomposition (natural gas fired)
        - Plasma pyrolysis
    - Gasification
        - Coal gasification
        - Coal gasification w/ carbon capture
- Conversion
    - Compression
    - Liquefaction
    - Ammonia hydrogenation
    - Methanol hydrogenation
    - LOHC hydrogenation
        - Toluene hydrogenation
        - N-Ethyl Carbazole hydrogenation
        - Dibenzyltoluene hydrogenation
- Storage
    - Compressed H2
    - Liquid H2
    - Ammonia
    - Methanol
    - LOHC
        - Toluene/Methylcyclohexane
        - N-Ethyl Carbazole/Perhydro-N-Ethyl Carbazole
        - Dibenzyltoluene / Perhydro-Dibenzyltoluene
- Transport
    - Pipeline
        - Hydrogen pipeline
    - Road
        - Compressed H2 trucking
        - Liquid H2 trucking
        - Ammonia trucking
        - Methanol trucking
        - LOHC trucking
    - Shipping
        - Liquid H2 shipping

        - Ammonia shipping
        - Methanol shipping
        - LOHC shipping
- Release
    - Expansion
    - Regasification
    - Ammonia dehydrogenation
    - Methanol dehydrogenation
    - LOHC dehydrogenation
        - Methylcyclohexane dehydrogenation
        - Perhydro-N-Ethyl Carbazole dehydrogenation
        - Perhydro-Dibenzyltoluene dehydrogenation
- Utilisation
    - Feedstock
        - Steel
    - Power generation
        - Fuel cells
        - Gas turbine
- Ancillaries
    - CCS technologies
        - CO_2 compression
        - CO_2 pipeline
        - CO_2 storage