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Hydrogen Financial Analysis Scenario Tool (H2FAST): Spreadsheet Tool User's Manual

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List of Acronyms

CHP	combined heat and power
CSD	compression, storage, and dispensing
DSCR	debt service coverage ratio
EBITD	earnings before interest, taxes, and depreciation
EV	battery-electric vehicle
FCEV	fuel cell electric vehicle
H2	hydrogen
H2FAST	Hydrogen Financial Analysis Scenario Tool
IRR	internal rate of return
IRS	Internal Revenue Service
ITC	investment tax credit
LCFS	low-carbon fuel standard
MACRS	Modified Accelerated Cost Recovery System
mmBTU	one million British Thermal Units
NPV	net present value
NREL	National Renewable Energy Laboratory
PP&E	plant, property, and equipment
PTC	production tax credit
SERA	Scenario Evaluation, Regionalization, and Analysis
SMR	steam methane reforming

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1 Introduction

The Hydrogen Financial Analysis Scenario Tool (H2FAST) provides a quick and convenient in-depth financial analysis for hydrogen refueling stations. It is meant to facilitate investments in hydrogen stations and improve policy-design decisions to support early station and fuel cell electric vehicle (FCEV) market development. Intended users include policy and government decision makers, station operators, equity investors, strategic investors, and lenders. H2FAST's capabilities also enable various analyses beyond the examination of hydrogen stations (see Section 4).

This manual describes how to use the spreadsheet version of H2FAST, which is one of three H2FAST formats developed by the National Renewable Energy Laboratory (NREL). All formats are based on the same financial computations, conform to Generally Accepted Accounting Principles (GAAP), and are compatible with analysis for International Financial Reporting Standards (IFRS) (FASAB 2014, Investopedia 2014). However, each format provides a different level of complexity and user interactivity.

The web tool is the simplest to use and allows users to quickly vary approximately 20 input values. The results are basic financial performance parameters such as investor cash flow, internal rate of return, and the break-even sale price of hydrogen. The web tool is available at https://www.nrel.gov/hydrogen/h2fast/.

The next most complex format is the interactive Microsoft Excel spreadsheet, which can be downloaded at https://www.nrel.gov/hydrogen/h2fast/. As this manual illustrates, the H2FAST spreadsheet offers basic and advanced user interface modes for modeling up to 300 stations. It provides users with detailed annual finance projections in the form of income statements, cash flow statements, and balance sheets; graphical presentation of financial performance parameters for numerous common metrics; life-cycle cost breakdown for each analysis scenario; and common ratio analysis results such as debt/equity position, return on equity, and debt service coverage ratio. It also enables risk analysis based on user-defined distributions of input values.

Finally, the most complex and customizable format is part of SERA—NREL's Scenario Evaluation, Regionalization, and Analysis Model—and will be available at https://developer.nrel.gov/. This format is designed for expert users. It accepts user-defined input files and is ideal for examining large numbers of scenarios quickly, for example, to evaluate regional and national deployment financial scenarios.

2 Getting Started

The spreadsheet version of H2FAST can be accessed by visiting https://www.nrel.gov/hydrogen/h2fast/ and clicking the "Spreadsheet Version" button. After the Excel file is downloaded to a computer (free of charge), users must enable macros when the file is opened. To revert to the default settings and values, the model can simply be downloaded again. This tool is designed for use with Microsoft Excel 2010 and newer Excel versions on a PC platform; full functionality is not guaranteed with the use of older Excel versions or an Apple computer.

The spreadsheet opens on the Interface worksheet (Figure 1). This is the primary worksheet for inputting values and viewing results. Four other worksheets are accessible by clicking the tabs at the bottom of the screen. The Description worksheet provides basic information about the tool. The Report Tables worksheet shows detailed technical and financial outputs in tabular form. The Overrides worksheet enables customized inputs for various parameters.

Active cells in each worksheet are color coded: yellow for user inputs, blue for calculated values, and green for key results. Although equations in the blue cells can be modified, only expert users should attempt this, because it can cause the model to malfunction or produce inaccurate results. The green cells should never be modified.

For many of the cells, descriptive information pops up when the cell is clicked. In addition, information cells (denoted with an "i" and/or a red triangle in the upper right corner) can be clicked for more information.

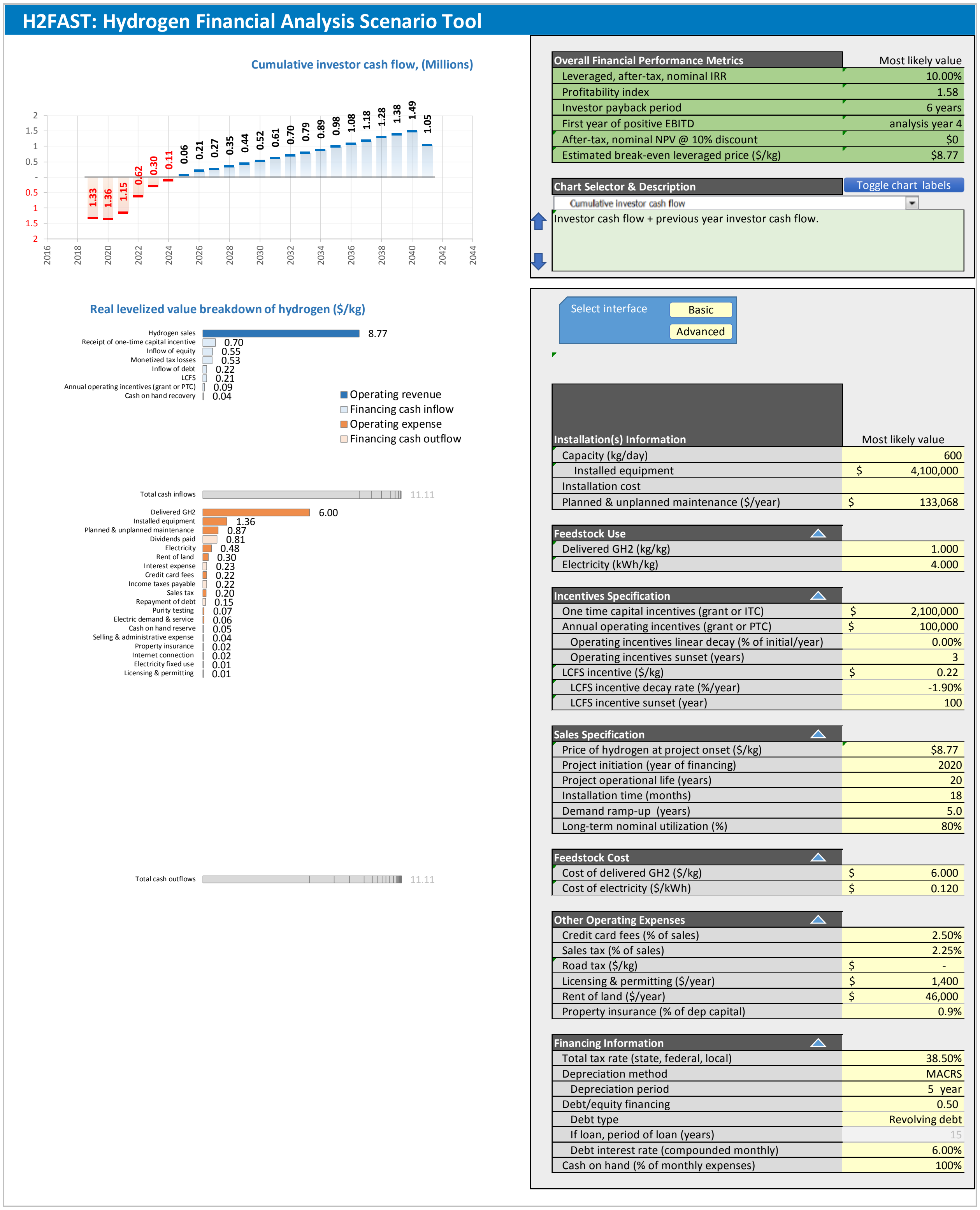
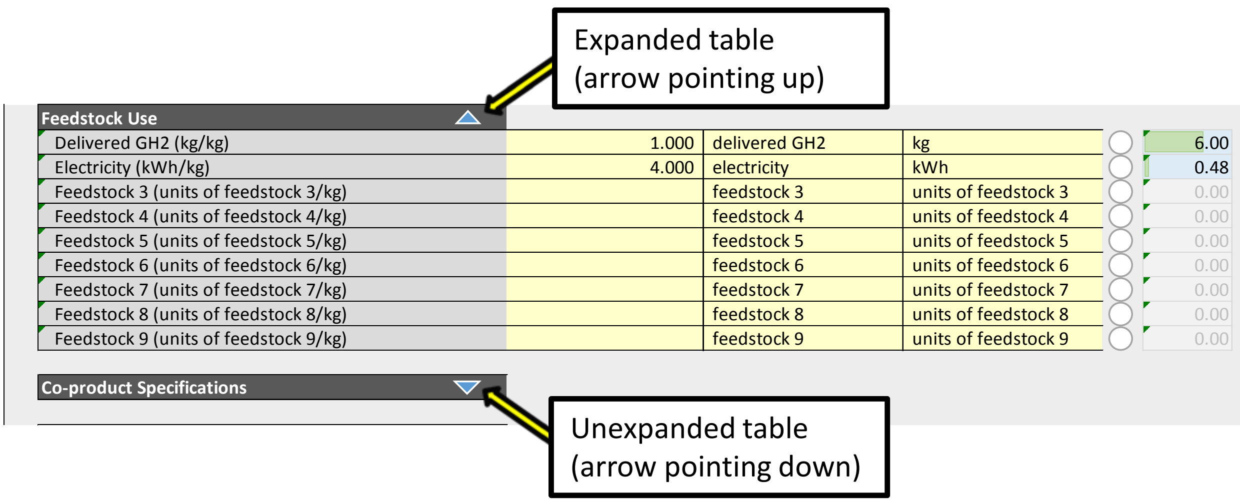


Figure 1. Interface worksheet, basic mode

2.1 Inputs

Users input information within the Interface worksheet. Clicking the "Basic" or "Advanced" button above the Installation(s) Information table selects the interface type. Basic is the default and enables a relatively small number of input fields. In this mode, the default values can simply be accepted, or new values can be entered into the yellow cells.

The advanced mode enables additional input fields, and it gives the option of analyzing up to 300 installations. For analyzing only one installation, the default values can simply be accepted, or new values can be entered into the yellow cells for all sections under the Installation(s) Information table. Clicking the down-arrows expands each input section (Figure 2). Default labels, units, and values are provided for some fields, but these can be overwritten, and/or customized entries can be created using the numerous fields available for that purpose.[1] For example, in Figure 2, the default feedstock types (delivered gaseous hydrogen and electricity) and units (kg and kWh) could be retained or changed. In addition, custom feedstock types and units could be entered by overwriting the fields such as "feedstock 3" and "units of feedstock 3." In any case, it is important that the default numbers are replaced with installation-specific values. The default values are meant to approximate a feasible station scenario in California, but they do not represent actual or predicted values that would be applicable to a broader set of hydrogen stations or locations.



Feedstock Use				
Delivered GH2 (kg/kg)	1.000	delivered GH2	kg	6.00
Electricity (kWh/kg)	4.000	electricity	kWh	0.48
Feedstock 3 (units of feedstock 3/kg)		feedstock 3	units of feedstock 3	0.00
Feedstock 4 (units of feedstock 4/kg)		feedstock 4	units of feedstock 4	0.00
Feedstock 5 (units of feedstock 5/kg)		feedstock 5	units of feedstock 5	0.00
Feedstock 6 (units of feedstock 6/kg)		feedstock 6	units of feedstock 6	0.00
Feedstock 7 (units of feedstock 7/kg)		feedstock 7	units of feedstock 7	0.00
Feedstock 8 (units of feedstock 8/kg)		feedstock 8	units of feedstock 8	0.00
Feedstock 9 (units of feedstock 9/kg)		feedstock 9	units of feedstock 9	0.00

Co-product Specifications

Figure 2. Example expanded and unexpanded sections under the Installation(s) Information table

For analyzing multiple installations, one or more circles (under the heading "Multiple scenarios?") can be clicked next to an input value that will be different for different installations. This turns the cell to the left of the circle blue, making it a calculation cell that should not be modified directly—its value can be changed via the Multi-Scenario Inputs table, which appears immediately to the right of the Installation(s) Information table when the circle is clicked. In the Multi-Scenario Inputs table, the number of scenarios to model can be set (from 1 to 300), and then inputs can be entered for all relevant fields. In the example shown in Figure 3, clicking the circles next to the "One time capital incentives (grant or ITC)" and "Annual operating incentives

[1] The customized feedstock fields are useful for analyzing H2A cases (see https://www.hydrogen.energy.gov/h2a_analysis.html).

(grant or PTC)" input fields has brought up the Multi-Scenario Inputs table, where the user has selected scenarios to model, named two installations, and entered incentive values for the "With incentives" scenario. The incentive values for the selected scenario (highlighted in yellow) appear in the corresponding incentives fields in the Installation(s) Information table. Values in any input field in the Installation(s) Information table for which the circle is not clicked are applied to all installations defined in the Multi-Scenario Inputs table.

H2FAST does not assume a particular station configuration, refueling pressure, or state of technological maturity. The tool is intended to be flexible so that users can input station cost assumptions for a wide variety of systems. H2FAST is not a cost-estimation tool. Guidance on appropriate values for station costs (e.g., capital equipment costs) is available in Melaina and Penev (2013) as well as in Argonne National Laboratory's Hydrogen Refueling Station Analysis Model (HRSAM) (ANL 2015) and the U.S. Department of Energy's Hydrogen Analysis (H2A) forecourt production case studies (DOE 2015). The U.S. Energy Information Administration's *Annual Energy Outlook* is a useful source for forecasts of electricity and natural gas prices (EIA 2017).[2]

Among the input fields, those within the Take or Pay Contract Specification table are a relatively new addition to H2FAST (Figure 4). Take-or-pay contracts are a way to support the economics of early-stage hydrogen stations (Investopedia 2016). Modeled stations will receive the value entered for "Price of unsold hydrogen ($/kg)" for each kilogram of hydrogen they do not sell. The remaining three fields can constrain this support by reducing the unsold hydrogen price annually, limiting the duration of the take-or-pay contract, and setting a station utilization rate above which unsold hydrogen would not be covered under the contract.[3] Appendix A has descriptions of all inputs and default values.

[2] Additional information on hydrogen station network planning can be found within web resources provided by the California Fuel Cell Partnership (https://cafcp.org/), the H2USA public-private partnership (http://h2usa.org/), and the California Energy Commission's Alternative and Renewable Fuel and Vehicle Technology Program (www.energy.ca.gov/drive/projects). Relevant near-term hydrogen station finance and incentive analyses have been conducted by Energy Independence Now (www.einow.org/publications/). The Alternative Fuels Data Center's Station Locator (www.afdc.energy.gov/locator/stations/) shows current hydrogen station locations in the United States, and Ludwig Bolkow Systemtechnik GmbH (www.netinform.net/h2/H2Stations/) maintains a map of worldwide hydrogen stations.

[3] Entering a negative number in the price decay field makes the take-or-pay hydrogen price escalate over time.

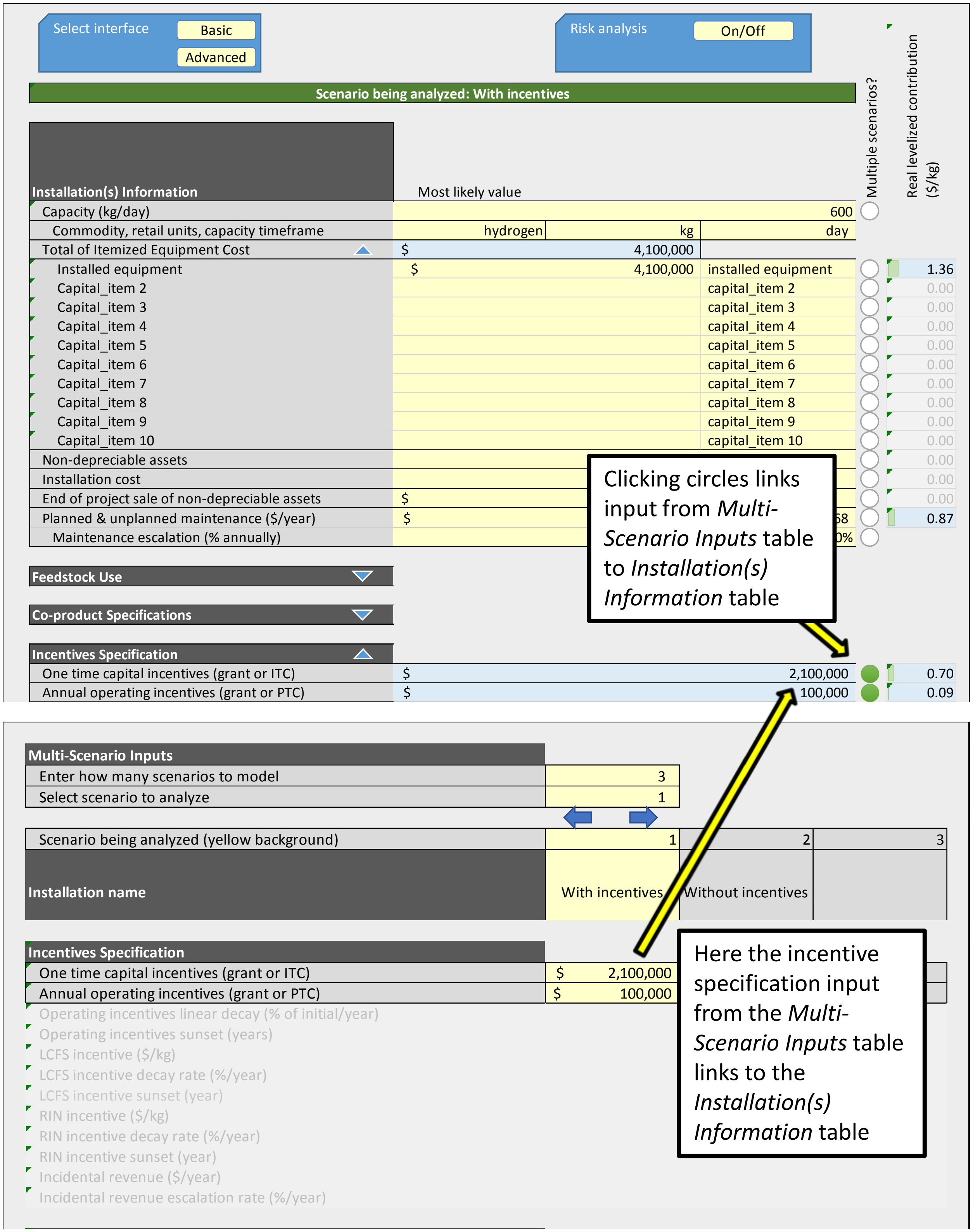


Figure 3. Example of the linkage of values between the Installation(s) Information table (top) and Multi-Scenario Inputs table (bottom)

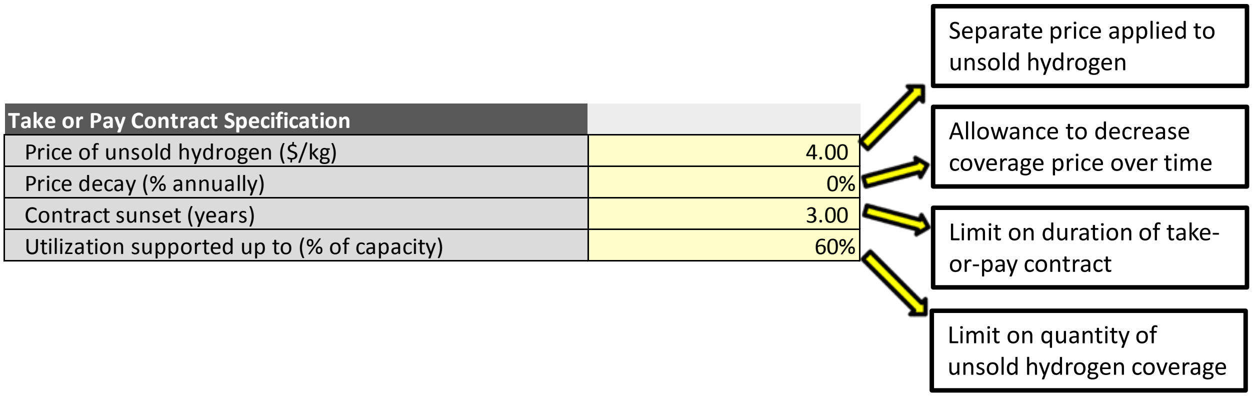


Figure 4. Explanation of fields in Take or Pay Contract Specification input table

Once values have been entered or defaults accepted for all relevant cells in the Installation(s) Information and Multi-Scenario Inputs tables, the results are calculated automatically as described in the following section.

2.2 Results

Results can be viewed for each installation by clicking the blue arrows at the top of the Multi-Scenario Inputs table. The selected installation is highlighted in yellow; for example, in Figure 3 above, the "With incentives" installation is selected. For the installation selected, results are presented in five areas in the Interface worksheet. The Overall Financial Performance Metrics table at the top shows values for leveraged, after-tax, nominal IRR (internal rate of return); profitability index; investor payback period; first year of positive EBITD (earnings before interest, taxes, and depreciation); after-tax, nominal NPV (net present value) at the selected discount rate; and estimated break-even leveraged price (Figure 5). Clicking on each metric title shows a definition of the metric (Appendix B has descriptions of all outputs).

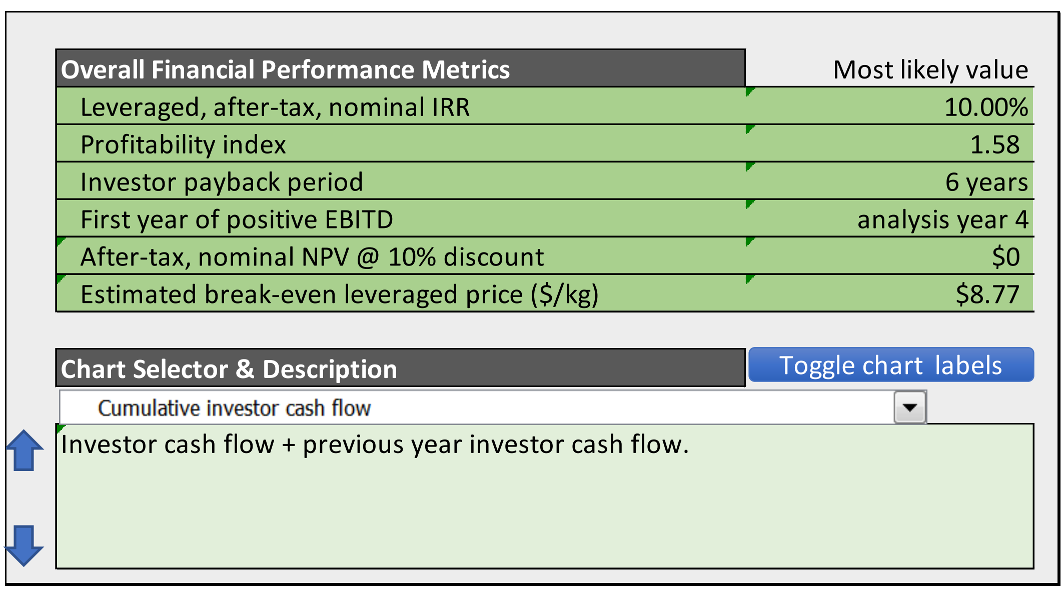


Figure 5. Interface worksheet, Overall Financial Performance Metrics table

The IRR is the discount rate at which a project's NPV is equal to zero. The IRR calculations can exhibit complex behavior (Miller 2008). In simple cases where investor cash flow is negative in the first year and positive in each subsequent year, the IRR can have only one value. However, if investor cash flow switches between positive and negative more than once during the project period, multiple solutions for the IRR will exist. H2FAST uses Excel's native IRR calculation. In cases with multiple IRR solutions, it typically displays the smallest positive solution. In contrast, the profitability index—the present value of future equity investor cash flows divided by the initial equity investment—is a robust financial performance metric that always returns a single, valid result.

NPV and break-even price are linked to the value entered for "Leveraged after-tax nominal discount rate" in the Financing Information table (using the advanced interface). The NPV is calculated using that discount rate. The break-even price is the price at which an installation would need to sell a commodity to receive an IRR equal to the discount rate specified. If the actual price (e.g., "Price of hydrogen at project onset ($/kg)" in the Sales Specification table) is set exactly equal to the break-even price, the IRR received will equal the discount rate entered, and the NPV will be zero (Figure 6). The values can be matched exactly using an Excel calculation: typing an equal sign in the cell next to "Price of hydrogen at project onset ($/kg)," selecting the cell next to "Estimated break-even leveraged price ($/kg)," and then pressing "Enter" on the keyboard.

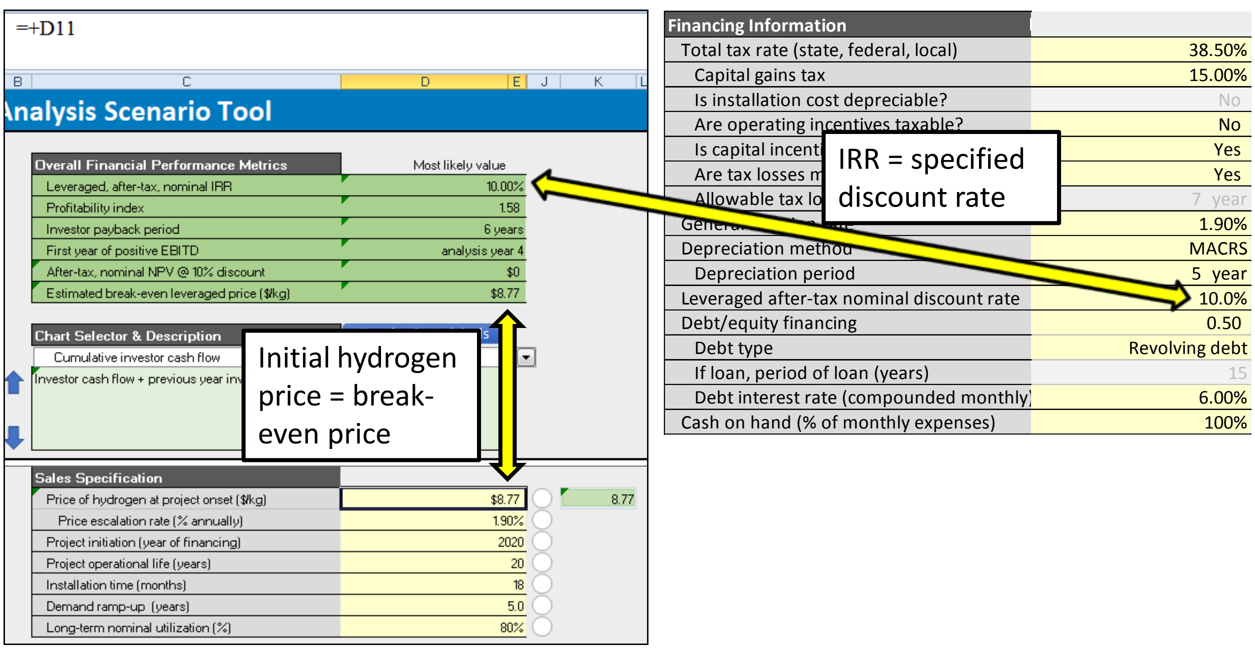


Figure 6. Specifying project IRR by setting the initial hydrogen price equal to the break-even hydrogen price

The break-even leveraged price of hydrogen per kilogram often will be substantially higher than a typical gasoline price per gallon, even though the amount of energy in a kilogram of hydrogen is approximately equal to the energy in a gallon of gasoline. However, because an FCEV is about twice as efficient as a similar conventional gasoline vehicle, an owner can drive twice as far on a kilogram of hydrogen than on a gallon of gasoline. Therefore, if the hydrogen price is $10 per kilogram, the cost to the owner would be equivalent to a gasoline price of about $5 per gallon on a cost-per-mile-driven basis.

When multiple installations are analyzed, the basic financial results for all stations will be displayed in the Overall Financial Performance Metrics Scenario History table. In the example shown in Figure 7, the results for two installations are shown, and the results for the "Without incentives" installation are highlighted. After any values are changed in the model, each station must be highlighted using the blue arrows in the Multi-Scenario Inputs table to "refresh" the results in the Overall Financial Performance Metrics Scenario History table so they reflect the changes. This table is particularly useful for supply chain analysis (see Section 4.2).

Overall Financial Performance Metrics Scenario History		
Leveraged, after-tax, nominal IRR	10%	10%
Profitability index	1.58	2.12
Investor payback period	6 years	10 years
First year of positive EBITD	analysis year 4	analysis year 4
After-tax, nominal NPV @ 10% discount	$ -	$ -
Estimated break-even leveraged price ($/kg)	$8.77	$11.57

Multi-Scenario Inputs		
Enter how many scenarios to model	2	
Select scenario to analyze	2	
Scenario being analyzed (yellow background)	1	2
Installation name	With incentives	Without incentives

Figure 7. Overall Financial Performance Metrics Scenario History table (top), with results for the "Without incentives" installation highlighted via the Multi-Scenario Inputs table (bottom)

Various results also can be displayed within the Interface worksheet's chart field. Selecting a chart from the drop-down menu under Chart Selector & Description displays the selected chart (Figure 8). The text field below the menu describes the active chart. Clicking the blue up and down arrows to the right of the text field scrolls through the various charts. The "Toggle chart labels" button turns the chart labels on and off.

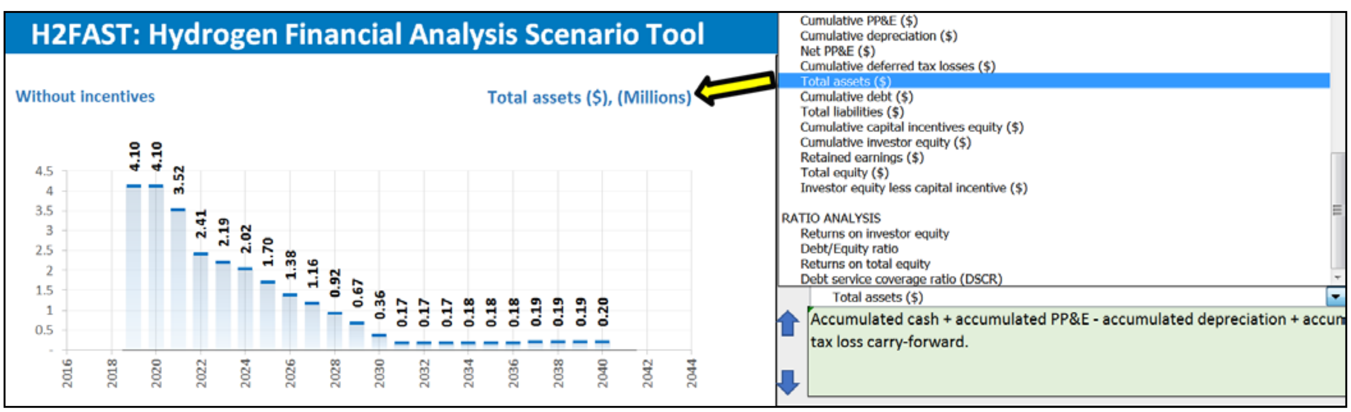


Figure 8. Interface worksheet, Chart Selector & Description, showing chart options

Below the rotating chart area is another chart with bars and values representing levelized (dollars per kilogram of hydrogen or other commodity produced) cash inflows and outflows for the selected installation (Figure 9). Below that chart is the final results output within the Interface worksheet, the cost of goods sold chart. The example in Figure 10 highlights the effects of accelerated capital depreciation (5-year MACRS) on equipment costs. It also shows costs dipping below the hydrogen price after year 5 of the project.

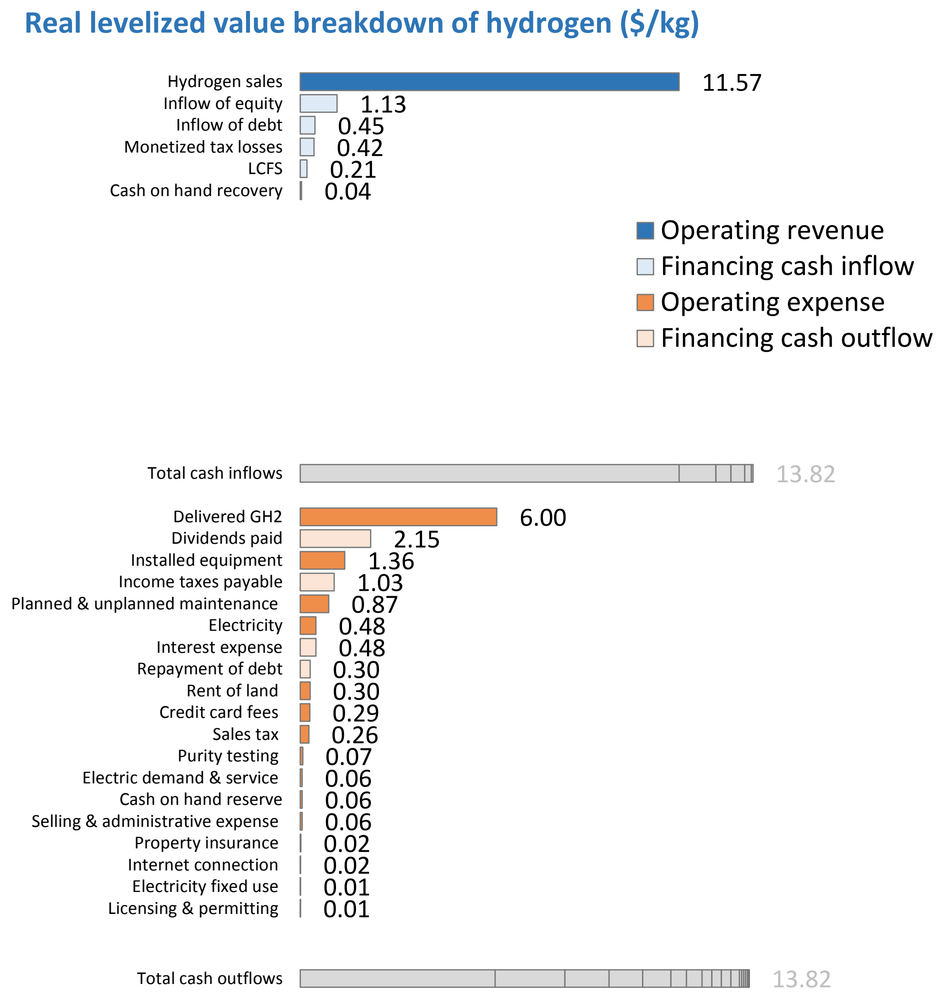


Figure 9. Interface worksheet, levelized value breakdown results

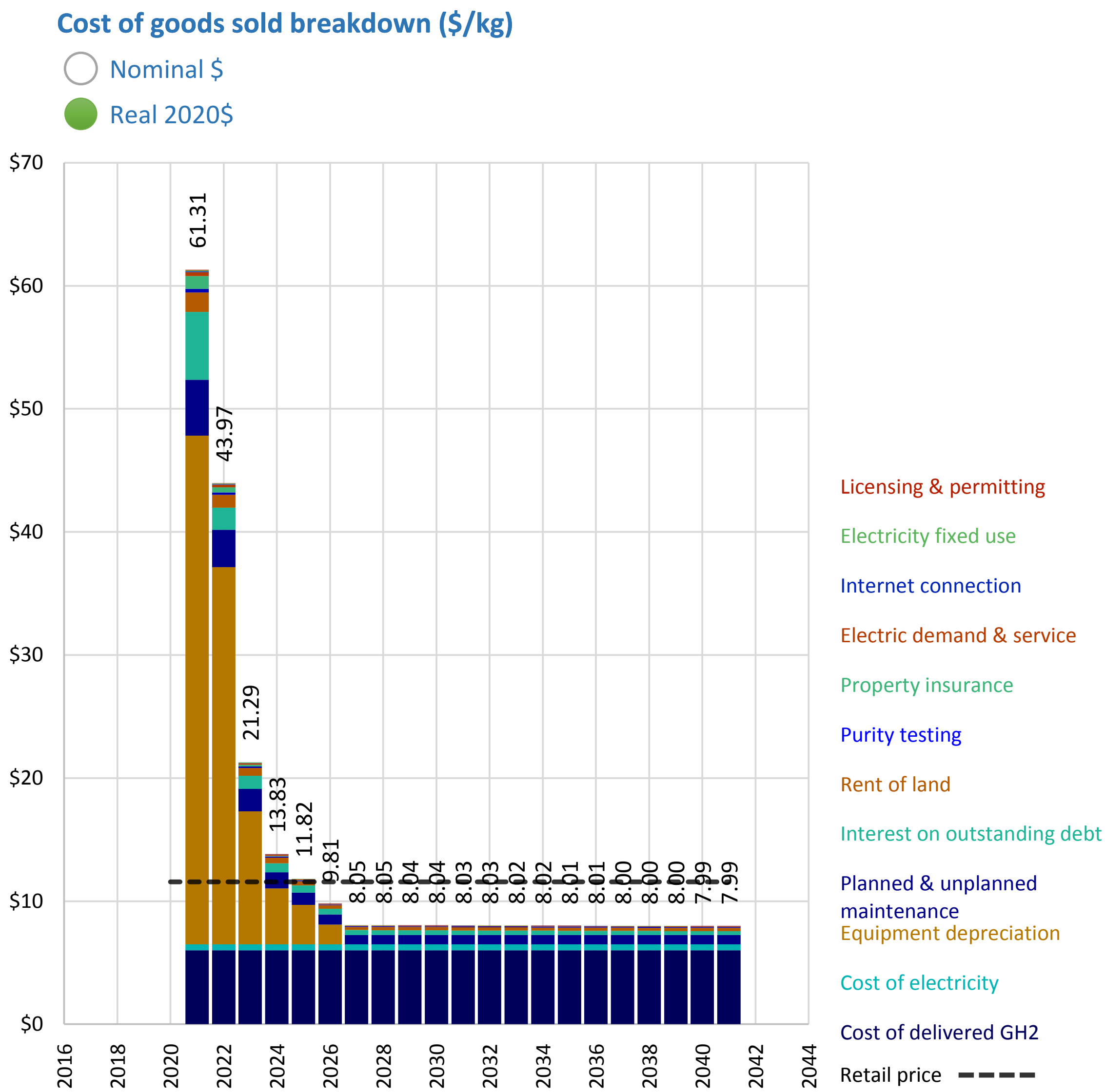


Figure 10. Interface worksheet, cost of goods sold results

Tabular results for each year of the project's life are available within the Report Tables worksheet (Figure 11). These results include annual projections for the income statement, cash flow statement, balance sheets, key prices and parameters, and financial ratios.

	B	C	D	E	F	G	H	I	
150		CASH FLOW STATEMENT							
151		Net Income	$ -	$ (50,430)	$ (458,680)	$ (917,302)	$ (480,724)	$ (179,798)	$
152									
153		Adjustments to reconcile net income to net cash							
154		Depreciation	$ -	$ -	$ 615,000	$ 1,394,000	$ 836,400	$ 501,840	$
155		Net Cash	$ -	$ (50,430)	$ 156,320	$ 476,698	$ 355,676	$ 322,042	$
156									
157		Cash Flows From Investing Activities							
158		Capital expenditure for Installed equipment	$ (4,100,000)	$ -	$ -	$ -	$ -	$ -	$
170		Net Cash Provided by (Used in) Investing Activities	$ (4,100,000)	$ -	$ -	$ -	$ -	$ -	$
171									
172		Cash Flows From Financing Activities							
173		Incurrence of debt	$ 1,366,667	$ -	$ -	$ -	$ -	$ -	$
174		Repayment of debt	$ -	$ -	$ -	$ -	$ -	$ -	$
175		Inflow of equity	$ 2,733,333	$ 54,633	$ -	$ -	$ -	$ -	$
176		Dividends paid	$ -	$ -	$ (159,623)	$ (474,760)	$ (315,868)	$ (288,404)	$
178		Net Cash Used in Financing Activities	$ 4,100,000	$ 54,633	$ (159,623)	$ (474,760)	$ (315,868)	$ (288,404)	$
179									
180		Net Change of Cash and Cash Equivalents	$ -	$ 4,203	$ (3,304)	$ 1,939	$ 39,807	$ 33,638	$
181									
182		BALANCE SHEET							
183		Assets							
184		Cumulative cash	$ -	$ 4,203	$ 899	$ 2,837	$ 42,645	$ 76,283	$
185		Cumulative PP&E	$ 4,100,000	$ 4,100,000	$ 4,100,000	$ 4,100,000	$ 4,100,000	$ 4,100,000	$

Description | Interface | Report Tables | Overrides

Figure 11. Report Tables worksheet showing tabular results

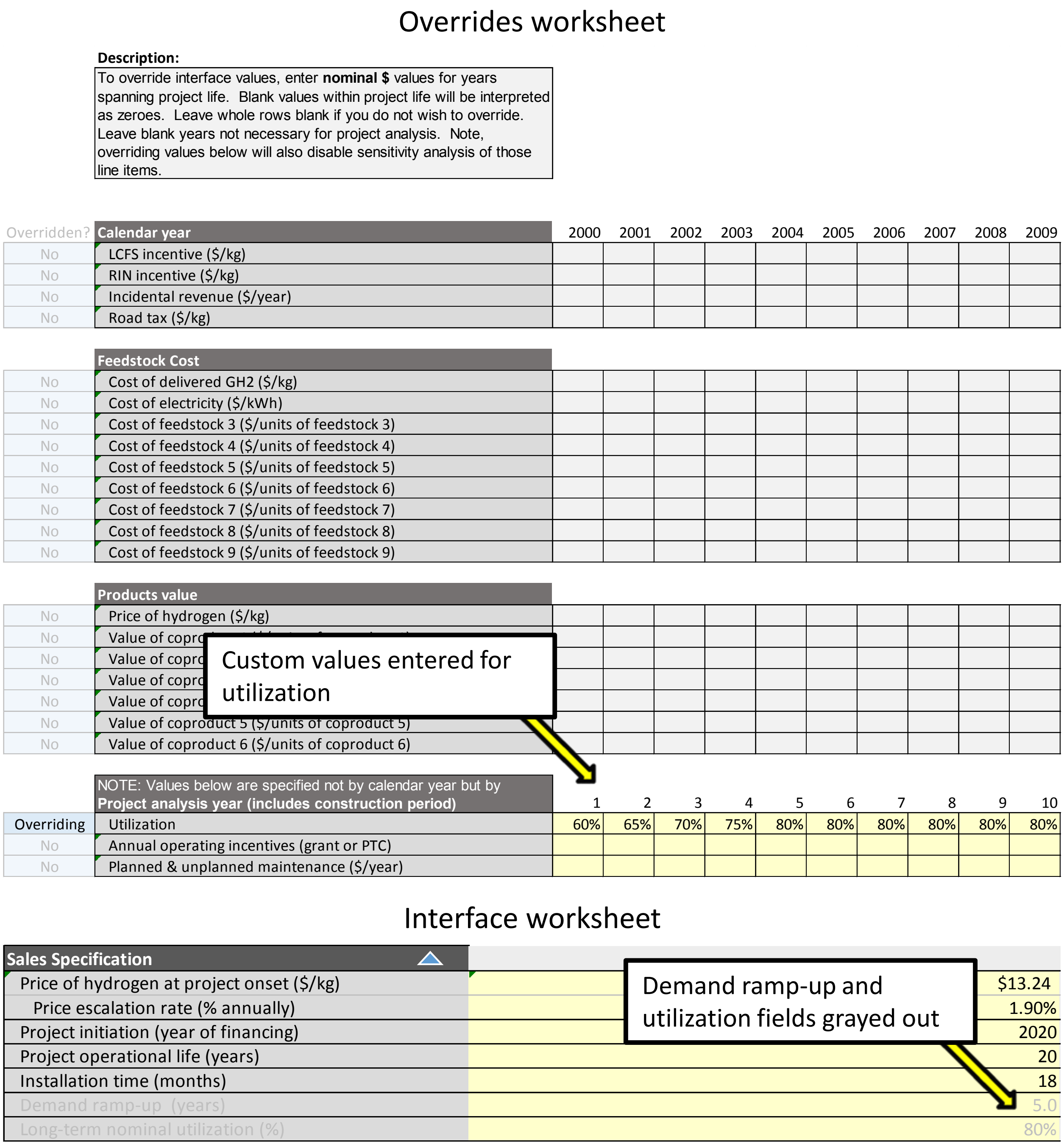
3 Advanced Functions

Several advanced functions within H2FAST enable further customization of the analysis: overrides, risk analysis, and built-in Excel analytic tools. These are described below.

3.1 Overrides

The Overrides worksheet is used to create customized inputs. Various H2FAST inputs have a single value applied to each year in the project period. For example, under Sales Specification, a “Long-term nominal utilization (%)” of 80% would apply 80% utilization to every year after demand has ramped up fully. Other inputs couple an initial value with an escalation rate to produce a set of values over time. For example, under Feedstock Cost, a “Cost of delivered GH2 ($/kg)”of $8.00 and an “Escalation rate of cost (% annually)” of 1.90% would yield a delivered hydrogen cost of $8/kg in the first year, $8.15/kg ($8/kg × 101.9%) in the second year, and so forth.

A time series of inputs can be customized by entering values in the corresponding rows within the Overrides worksheet. Figure 12 shows a customized series of utilization inputs for 10 years of a project’s life. For overridden items, cells for all years of the analysis period (highlighted in yellow) must be populated with values, and populating cells beyond the highlighted years enables analysis of sensitivities to project length, installation time, or year of commissioning. Here the values entered within the Overrides worksheet replace the values for demand ramp-up and long-term utilization in the Interface worksheet, which are now grayed out, as shown in Figure 12. Deleting all values from the Overrides worksheet removes the override and returns the model to using the inputs from the Interface worksheet. Any monetary values input in the Overrides worksheet should be entered in nominal dollars. For example, the U.S. Energy Information Administration’s *Annual Energy Outlook* might be used to develop custom values for electricity price in nominal dollars.


Overrides worksheet

Description:
To override interface values, enter **nominal $** values for years spanning project life. Blank values within project life will be interpreted as zeroes. Leave whole rows blank if you do not wish to override. Leave blank years not necessary for project analysis. Note, overriding values below will also disable sensitivity analysis of those line items.

Overridden?	Calendar year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
No	LCFS incentive ($/kg)										
No	RIN incentive ($/kg)										
No	Incidental revenue ($/year)										
No	Road tax ($/kg)										
	Feedstock Cost										
No	Cost of delivered GH2 ($/kg)										
No	Cost of electricity ($/kWh)										
No	Cost of feedstock 3 ($/units of feedstock 3)										
No	Cost of feedstock 4 ($/units of feedstock 4)										
No	Cost of feedstock 5 ($/units of feedstock 5)										
No	Cost of feedstock 6 ($/units of feedstock 6)										
No	Cost of feedstock 7 ($/units of feedstock 7)										
No	Cost of feedstock 8 ($/units of feedstock 8)										
No	Cost of feedstock 9 ($/units of feedstock 9)										
	Products value										
No	Price of hydrogen ($/kg)										
No	Value of copro										
No	Value of copro										
No	Value of copro										
No	Value of copro										
No	Value of coproduct 5 ($/units of coproduct 5)										
No	Value of coproduct 6 ($/units of coproduct 6)										

	NOTE: Values below are specified not by calendar year but by **Project analysis year (includes construction period)**	1	2	3	4	5	6	7	8	9	10
Overriding	Utilization	60%	65%	70%	75%	80%	80%	80%	80%	80%	80%
No	Annual operating incentives (grant or PTC)										
No	Planned & unplanned maintenance ($/year)										

Interface worksheet

Sales Specification	
Price of hydrogen at project onset ($/kg)	$13.24
Price escalation rate (% annually)	1.90%
Project initiation (year of financing)	2020
Project operational life (years)	20
Installation time (months)	18
Demand ramp-up (years)	5.0
Long-term nominal utilization (%)	80%

Figure 12. Using Overrides worksheet to input custom utilization values

3.2 Risk Analysis

Risk analysis accounts for the effects of uncertain input parameters on the financial performance of modeled installations. This capability is accessed by activating the advanced user interface and then clicking the "On/Off" button in the "Risk analysis field."[4] Clicking this button reveals three fields for most input parameters: a most likely value, a "% less" value, and a "% more" value (Figure 13). The % less and more values are calculated with respect to the most likely

[4] Note that overriding values, as described in Section 3.1, will disable risk analysis for the overridden items.

value; for example, if the most likely value is $100,000, then entering -20% in the % less field assigns a value of $80,000 to that field. These three values define a triangular distribution used for Monte Carlo analysis. As the default setting, all three values are the same for each parameter, and the uncertainty values are grayed out. When an uncertainty value is changed, it turns black and becomes active for subsequent analyses. The % less value must be less than or equal to zero, and the % more value must be greater than or equal to zero. Once the uncertainty distributions are defined for one or more input parameters, clicking the "Evaluate uncertainty (1,000 runs)" button in the "Risk analysis" field initiates the analysis. H2FAST takes 1,000 random samples from each of the defined input distributions to calculate probability distributions for input parameters and financial results. The analysis usually takes a few minutes to run. The elapsed time and percentage of the analysis complete are displayed at the bottom left of the screen.

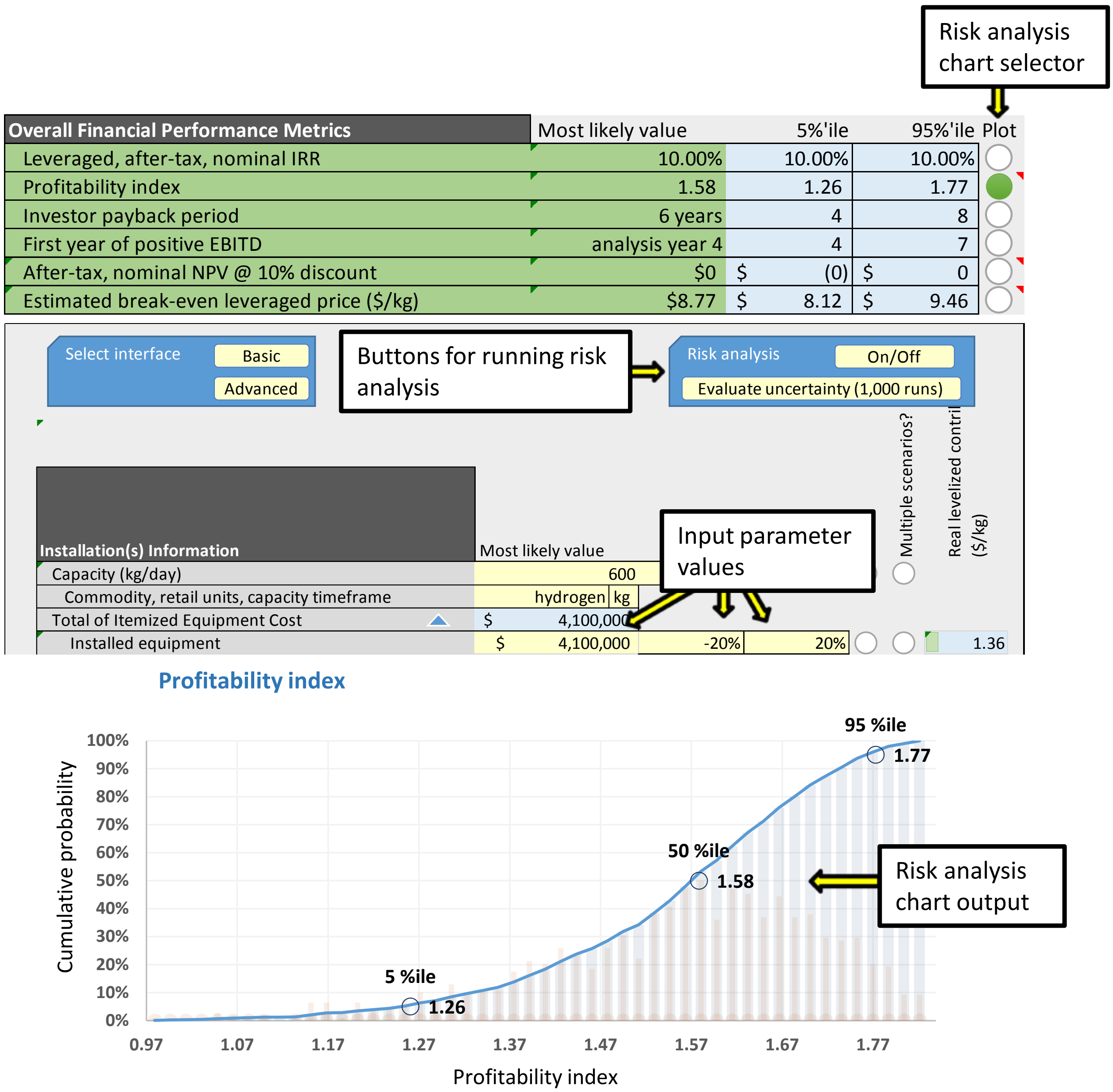


Figure 13. H2FAST risk analysis functions

Once the analysis is 100% complete, the updated results are shown in the Overall Financial Performance Metrics table, which provides most likely, 5th percentile, and 95th percentile values for each metric. The probability distributions for each of these metrics can be plotted by clicking the adjacent circle under the heading "Plot." The resulting risk analysis chart appears below the cost of goods sold chart. In a similar fashion, the probability distributions for the relevant input parameters can be plotted. As the risk analysis is being used, a message on the risk analysis chart might appear stating, "Inputs have changed. Rerun model before examining statistical results." This message appears when the risk analysis function is first activated and when input values are changed. If this message is present, the risk analysis must be run again—by clicking the "Evaluate uncertainty (1,000 runs)" button—to produce valid results.

Additional analyses can be viewed for three of the financial performance metrics: profitability index, after-tax nominal NPV, and estimated break-even leveraged price. Clicking the plot circle adjacent to one of these metrics and then scrolling down below the financial performance and risk analysis charts reveals tornado and waterfall charts. The tornado chart plots the sensitivity of the selected metric to the user-defined variations in input parameters; if more than 10 input distributions are defined, the tornado chart plots the 10 that have the most impact on the metric. Figure 14 is an example tornado chart, showing the sensitivity of profitability index to initial hydrogen price, cost of delivered liquid hydrogen, and station capacity. At a hydrogen price of $10/kg, the profitability index is -5.70. At $14/kg it is 6.56, and at $16/kg it is 12.69. The sensitivity to the other parameters can be read in a similar manner.

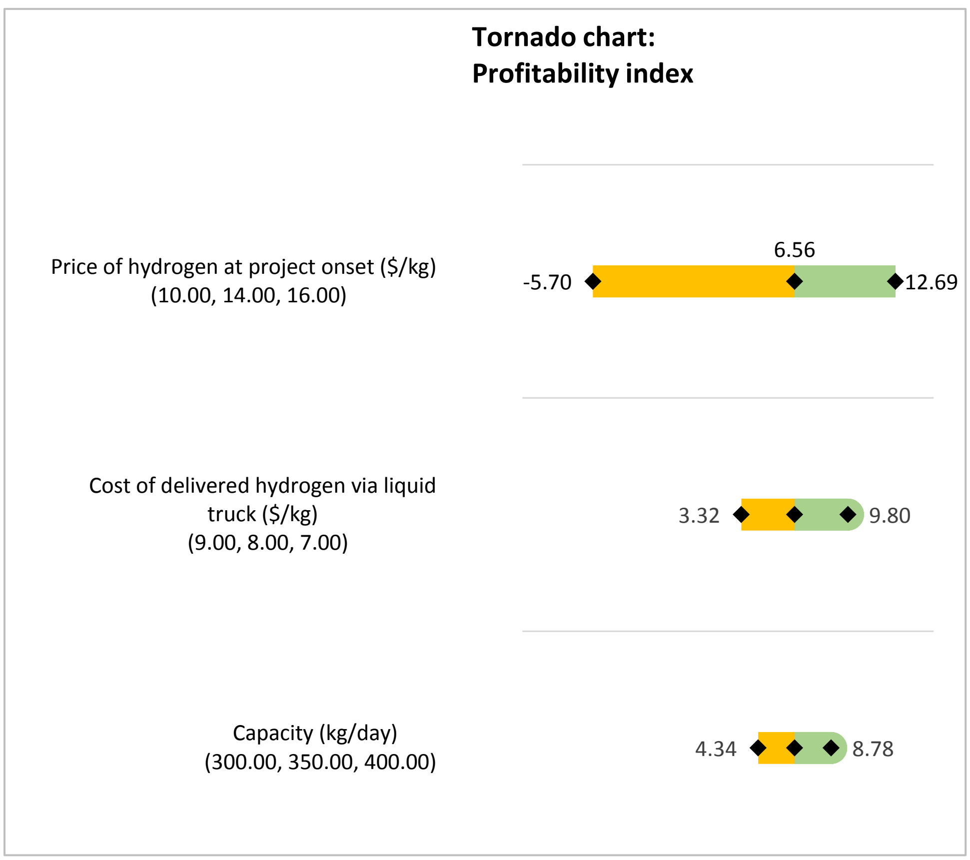


Figure 14. Tornado chart showing sensitivity of profitability index to three input parameters

The waterfall chart plots the cumulative effects on the selected metric of the variations in user-defined input parameters; if more than 10 input distributions are defined, the waterfall chart plots the 10 that have the most impact on the metric. Only variations that improve financial performance are shown. Figure 15 is an example waterfall chart, showing the cumulative effects on break-even hydrogen price of changes in delivered liquid hydrogen cost and station capacity. Reducing the delivered hydrogen cost from $8/kg to $7/kg reduces the break-even hydrogen price by $1.06/kg. Increasing station capacity from 350 kg/day to 400 kg/day reduces the break-even price by an additional $0.43/kg—for a final break-even price of $10.92/kg.

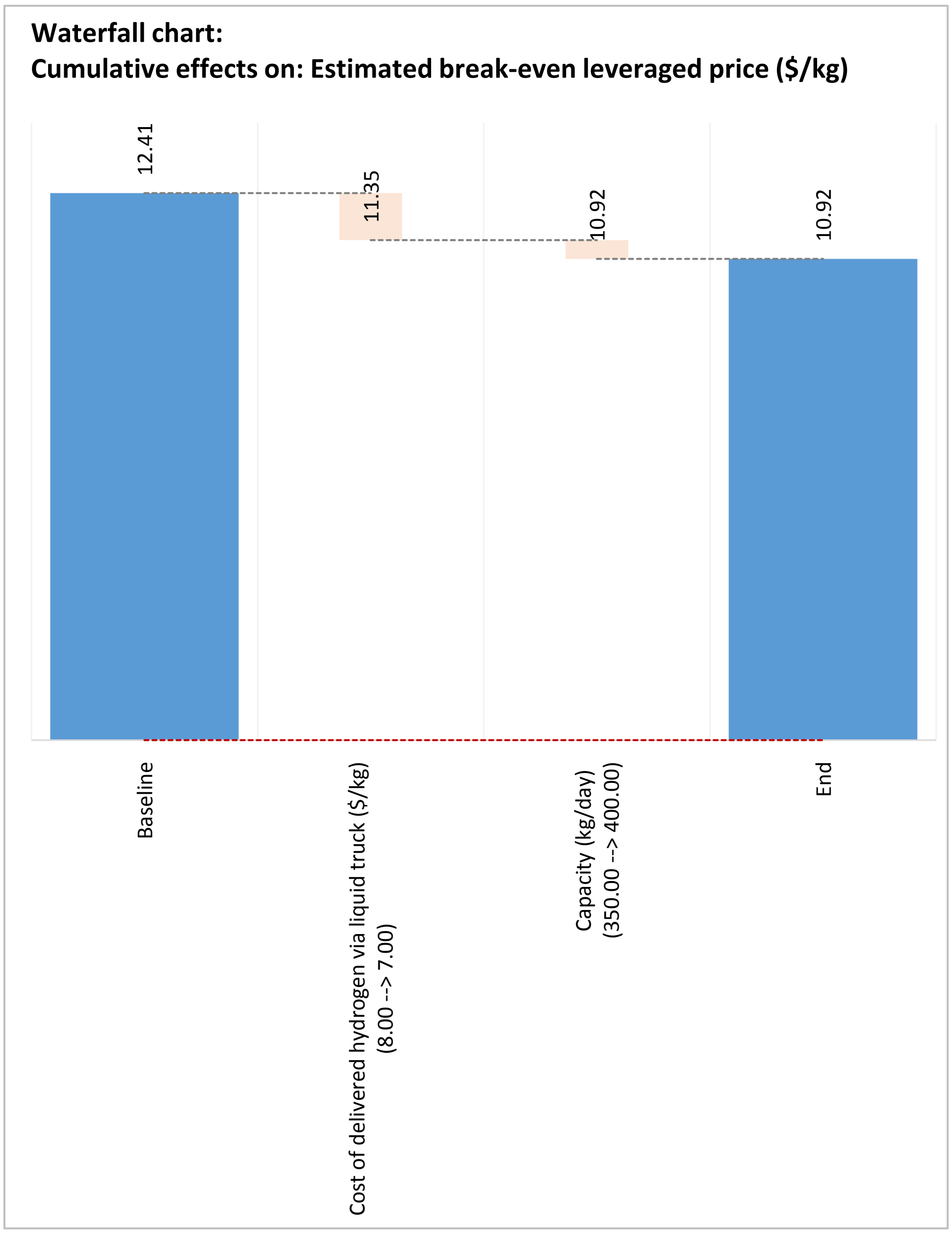


Figure 15. Waterfall chart showing the cumulative effects of input parameter variations on break-even hydrogen price

3.3 Built-in Excel Analytic Tools

Excel's built-in analytic tools, including Goal Seek and Solver, can be used to solve for conditional inputs. For example, assuming a simulated station with the financial performance metrics shown in Figure 16, the size of the one-time capital incentive required to achieve an IRR of 10% and a break-even hydrogen price of $10/kg can be determined. First, the discount rate is set to 10% in the Financing Information table (as Figure 16 shows, the discount rate is already set at 10% in this example). Next, in the Sales Specification table, the "Price of hydrogen at project onset ($/kg)" is set to $10. Then the following steps are completed.

Overall Financial Performance Metrics	Most likely value
Leveraged, after-tax, nominal IRR	1.62%
Profitability index	0.98
Investor payback period	15 years
First year of positive EBITD	analysis year 4
After-tax, nominal NPV @ 10% discount	($1,233,723)
Estimated break-even leveraged price ($/kg)	$11.79

Figure 16. Initial station financial metrics for Goal Seek example

1) In the Excel menu bar, the Data menu is selected, "What-if Analysis" is clicked, and then "Goal Seek" is selected (Figure 17).

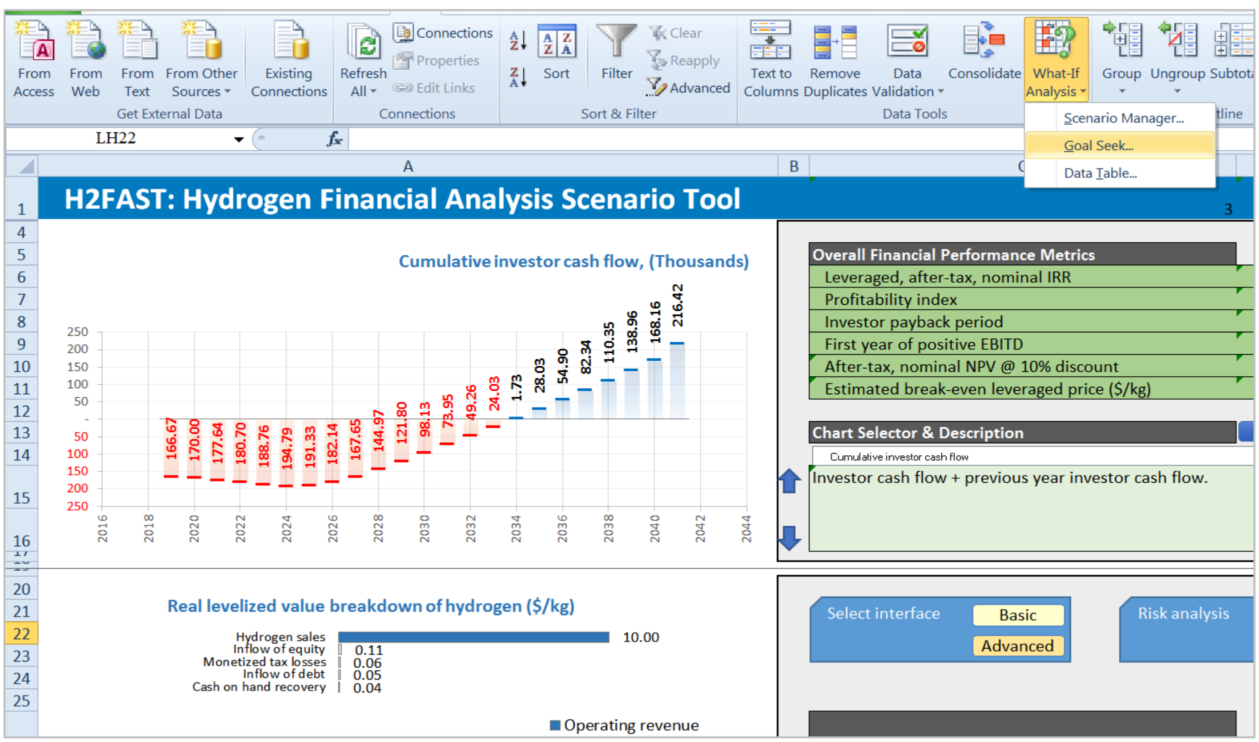


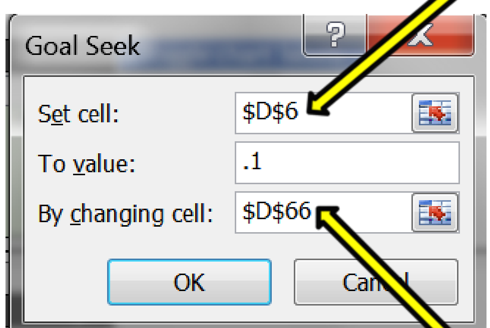
Figure 17. Activating the Goal Seek function in Excel

2) Within the Goal Seek window, the icon next to the "Set cell" field is clicked, the cell next to "Leveraged, after-tax, nominal IRR" within the Overall Financial Performance Metrics table is selected, and then the icon is clicked again to return to the Goal Seek window.

3) The value 0.1 is entered in the "To value" field within the Goal Seek window.

4) Within the Goal Seek window, the icon next to the "By changing cell" field is clicked, the cell next to "One time capital incentives (grant or ITC)" within the Incentives Specification table is selected, and then the icon is clicked again to return to the Goal Seek window. Figure 18 illustrates steps 2–4.

Overall Financial Performance Metrics	Most likely value
Leveraged, after-tax, nominal IRR	1.62%
Profitability index	0.98
Investor payback period	15 years
First year of positive EBITD	analysis year 4
After-tax, nominal NPV @ 10% discount	($1,233,723)
Estimated break-even leveraged price ($/kg)	$11.79



Incentives Specification		
One time capital incentives (grant or ITC)	$	-
Annual operating incentives (grant or PTC)	$	-
Operating incentives linear decay (% of initial/year)		0.00%
Operating incentives sunset (years)		-
LCFS incentive ($/kg)	$	-
LCFS incentive decay rate (%/year)		-1.90%
LCFS incentive sunset (year)		100

Figure 18. Choosing values for the Goal Seek function

5) Clicking "OK" within the Goal Seek window initiates the calculations. When the calculations are complete, each cell will contain the new values resulting in an IRR of about 10% and a

break-even hydrogen price of about \$10/kg. In this case, a one-time capital incentive of \$1,500,524 is required, as shown in Figure 19.

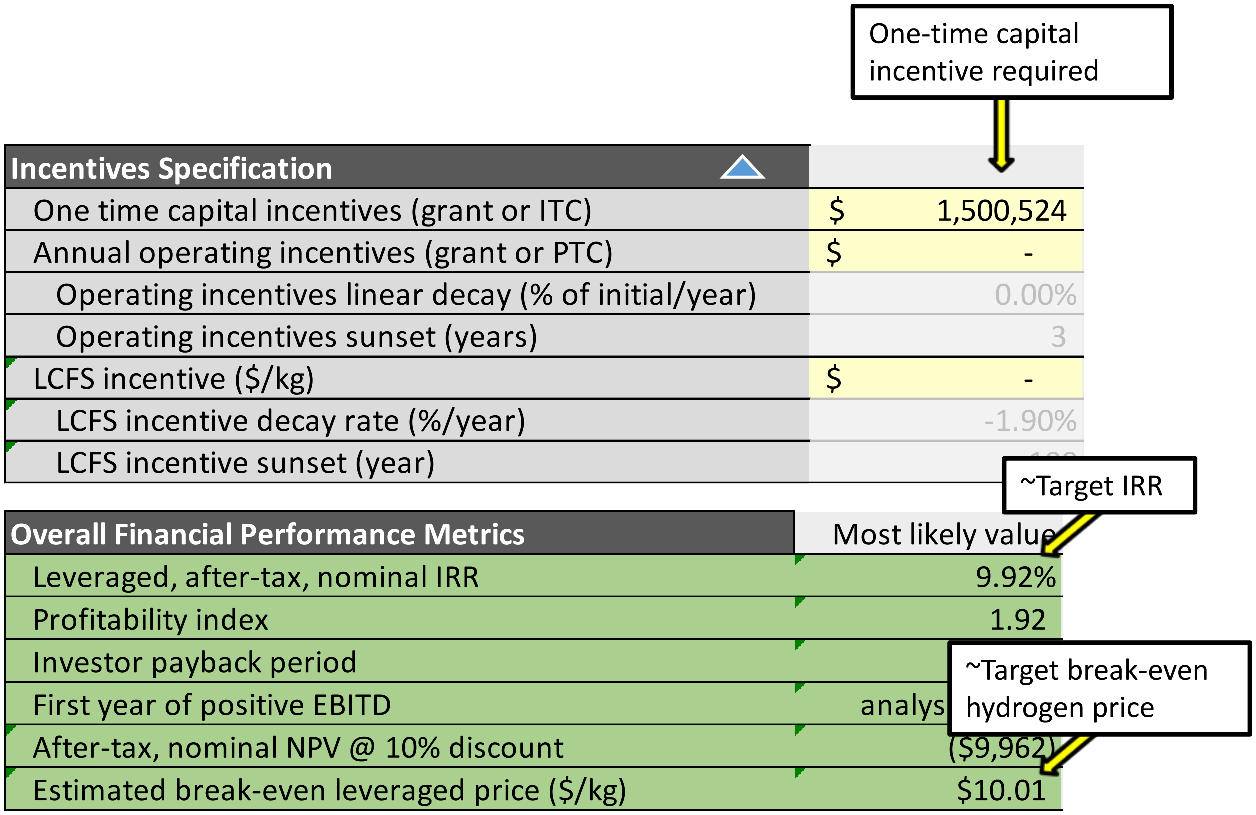


Figure 19. Results of Goal Seek analysis

Excel's Solver is similar to Goal Seek, but it can be used to vary multiple H2FAST parameters simultaneously and can place limits on how much each parameter is varied. Figure 20 shows how to access the Solver function within Excel's Data menu.[5] Figure 21 shows the Solver dialog box open within the Interface worksheet, along with an example analysis. Here the goal is to achieve a break-even hydrogen price of \$7/kg as defined in the "Set Objective" and "To" fields within the dialog box. The Solver is set to vary three cells—for installed equipment, installation, and maintenance costs—to achieve this goal. In addition, three constraints have been added by clicking the "Add" button and using the constraint dialog box: the equipment cost must be \$1 million or more, the installation cost must be \$100,000 or more, and the maintenance cost must be \$20,000 or more. When the "Solve" button is clicked, the Solver performs iterative calculations to achieve a \$7/kg hydrogen break-even price by varying the three selected parameters within the defined constraints.

[5] Before the "Solver" button becomes visible as shown in the figure, the function might need to be loaded into Excel by accessing the File menu, clicking the "Options" button, clicking "Add-Ins," selecting "Excel Add-Ins" from the drop-down menu, clicking the "Go" button, and then selecting the Solver add-in.

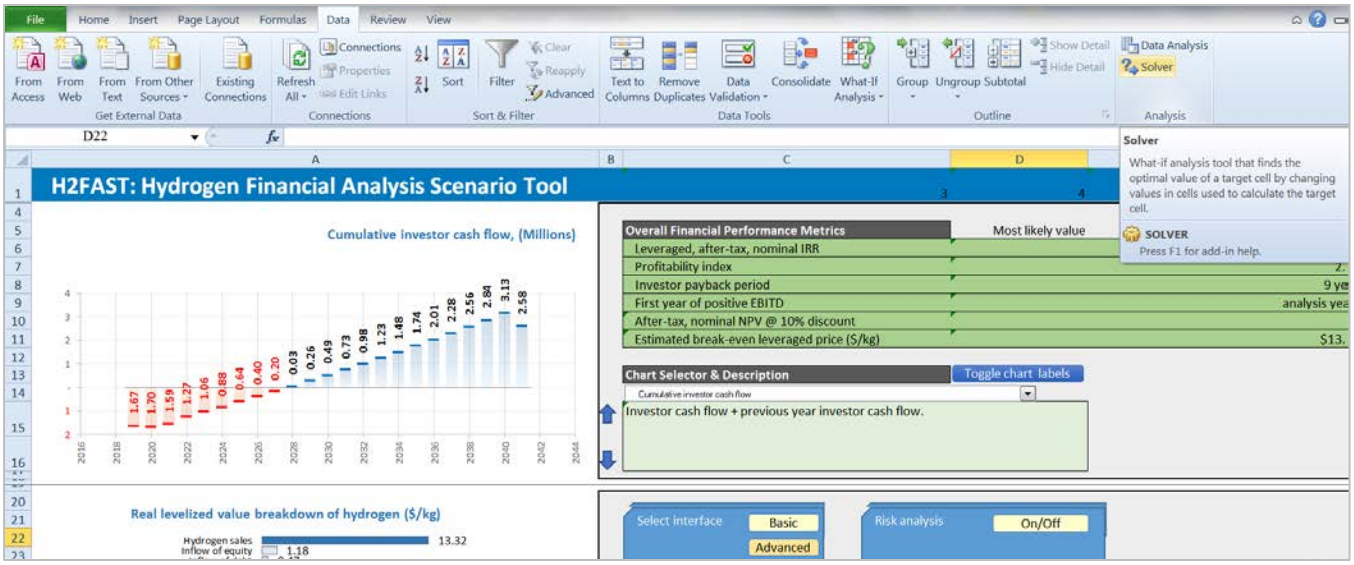


Figure 20. Activating the Solver function in Excel

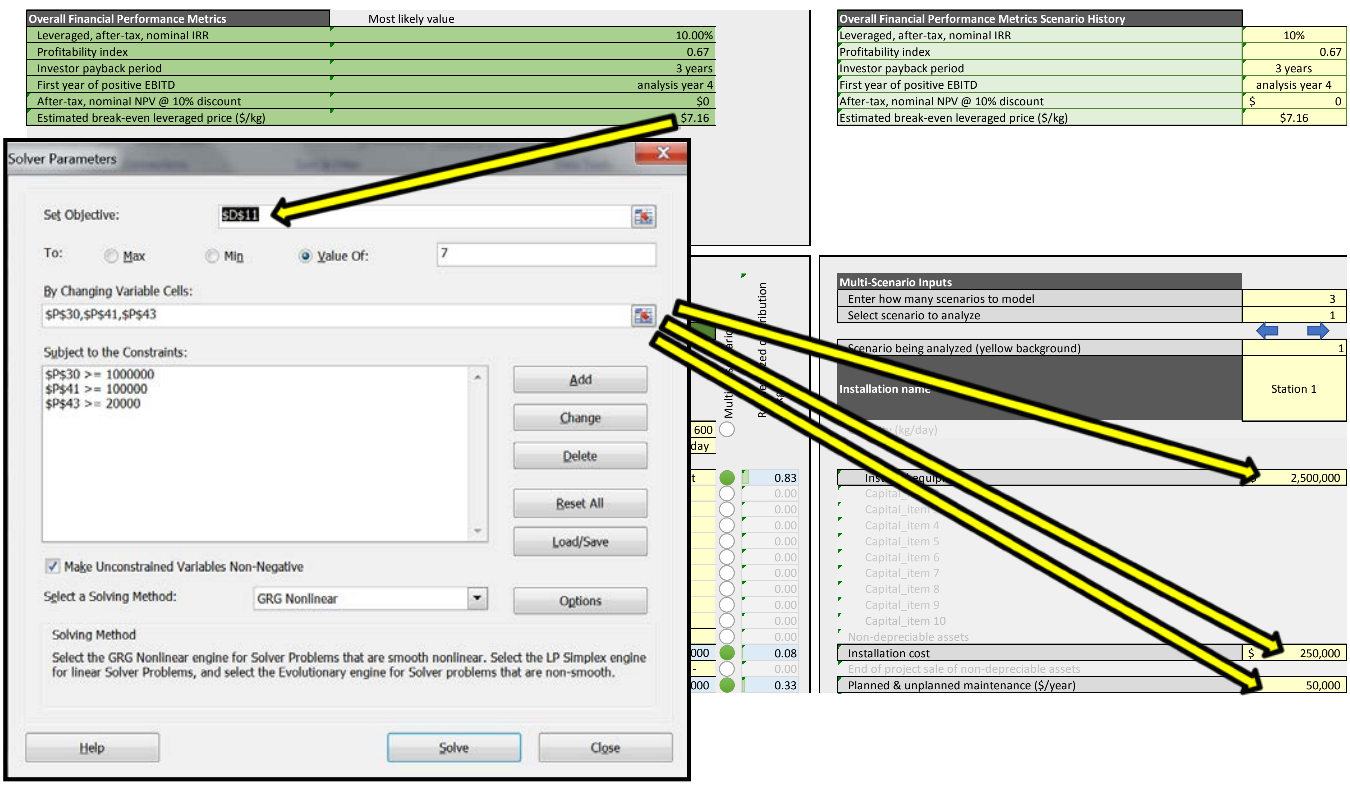


Figure 21. Example of using the Solver for H2FAST analysis

Figure 22 shows the results of the Solver analysis. It has achieved a hydrogen break-even price of $7/kg by reducing the equipment cost by about $180,000, reducing the installation cost by about $3,000, and reducing the maintenance cost by about $1,000/year.

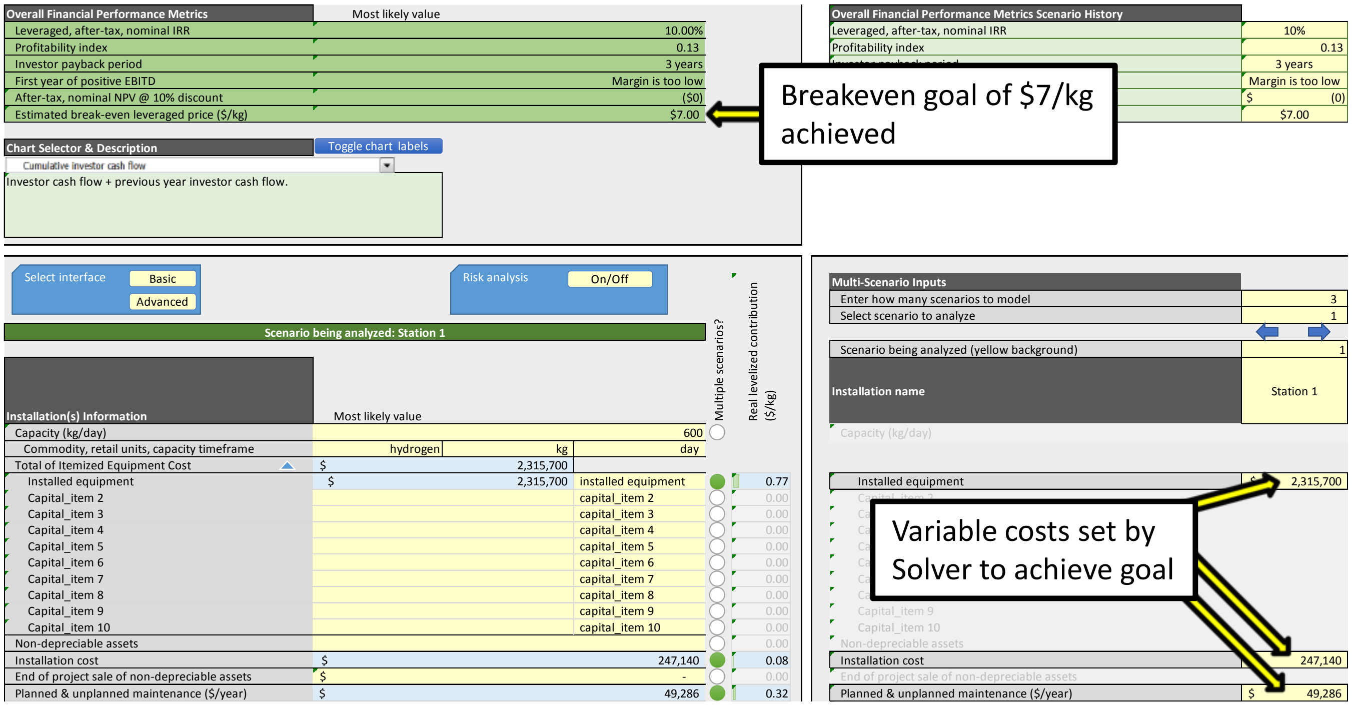


Figure 22. Solver-generated solution of example H2FAST analysis

4 Case Studies

This section provides examples of the diverse types of analyses that can be performed using H2FAST. The possibilities include comparing the economics of different vehicle fleets, performing supply chain analysis, and analyzing combined heat and power (CHP) systems.

4.1 Fleet Comparison

This case study compares the economics of two 500-vehicle fleets: one consisting of hydrogen-powered FCEVs and the other of battery-electric vehicles (EVs). Note this analysis is for illustrative purposes only—it does not represent an actual comparison of the two vehicle technologies and their costs.

Both fleets drive a total of 30,000 miles/day, and the commodity of interest is miles driven, as entered in the Installation(s) Information table (Figure 23). Figure 24 shows the distinct inputs for the FCEV and EV fleets, as entered in the Multi-Scenario Inputs table.

Installation(s) Information	Most likely value		
Capacity (miles/day)			30,000
Commodity, retail units, capacity timeframe	miles driven	miles	day

Figure 23. Capacity in miles per day for both fleets, Installation(s) Information table

Installation name	500 FCEVs fleet	500 EV fleet	
Capacity (mile/day)			
Total of Itemized Equipment Cost			
Fueling infrastructure	$ 3,000,000	$ 1,000,000	
Cars	$ 20,000,000	$ 25,000,000	
Capital_item 3			
Capital_item 4			
Capital_item 5			
Capital_item 6			
Capital_item 7			
Capital_item 8			
Capital_item 9			
Capital_item 10			
Non-depreciable assets			
Installation cost			
End of project sale of non-depreciable assets			
Planned & unplanned maintenance ($/year)	$ 1,075,000	$ 1,275,000	
Maintenance escalation (% annually)			
Feedstock Use			
Delivered GH2 (kg/mile)	0.017		
Electricity (kWh/mile)	0.067	0.360	

Figure 24. Key inputs for FCEV and EV fleets, Multi-Scenario Inputs table

The two fleets differ in terms of equipment and maintenance costs as well as feedstock use. As shown in the highlighted column of Figure 24, the hydrogen fueling infrastructure costs $3 million, and the FCEVs cost $20 million, for a total equipment cost of $23 million. The FCEV fleet's maintenance cost is $1.075 million/year. Its feedstock use is 0.017 kg of hydrogen and 0.067 kWh of electricity per mile. As shown in the non-highlighted column of Figure 24, the electric fueling infrastructure costs $1 million, and the EVs cost $25 million, for a total equipment cost of $26 million. The EV fleet's maintenance cost is $1.275 million/year. Its feedstock use is 0.360 kWh of electricity per mile.

Under these hypothetical assumptions, the FCEV fleet has a break-even price of $0.45/mile, and the EV fleet has a break-even price of $0.41/mile—thus the EV fleet is more economically competitive. The real levelized value breakdowns show the drivers of this break-even price difference for the FCEV fleet (Figure 25) and EV fleet (Figure 26). As shown in blue, both fleets receive similar low-carbon fuel standard (LCFS) and debt inflows, whereas the EV fleet has higher inflows from equity and monetized tax losses because of higher equipment costs; the net difference among inflows is $0.03/mile higher for the EV fleet. As shown in orange, the FCEV fleet's lower financing outflows compared with the EV fleet's—resulting from its lower equipment costs—are offset by the FCEV fleet's higher operating expenses, which are primarily due to hydrogen fuel costs; the net difference among outflows is $0.01/mile lower for the EV fleet. The sum of the net differences between inflows and outflows results in the $0.04/mile lower break-even price for the EV fleet.

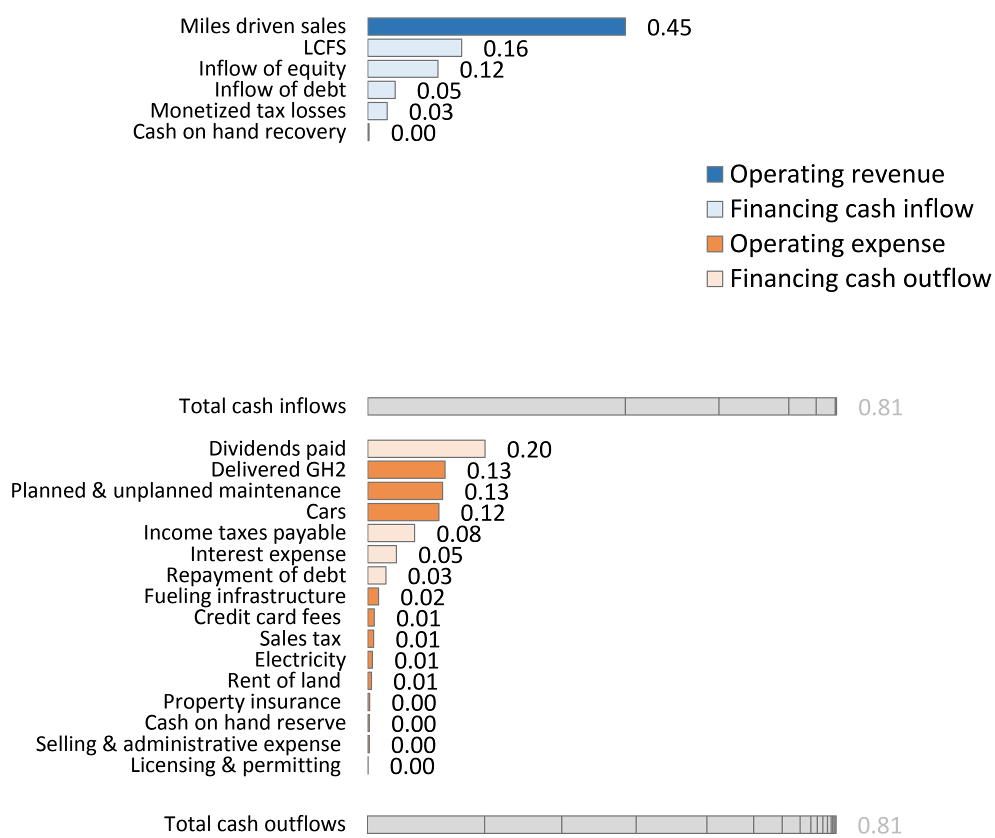


Figure 25. Real levelized value breakdown of miles driven ($/mile) for FCEV fleet

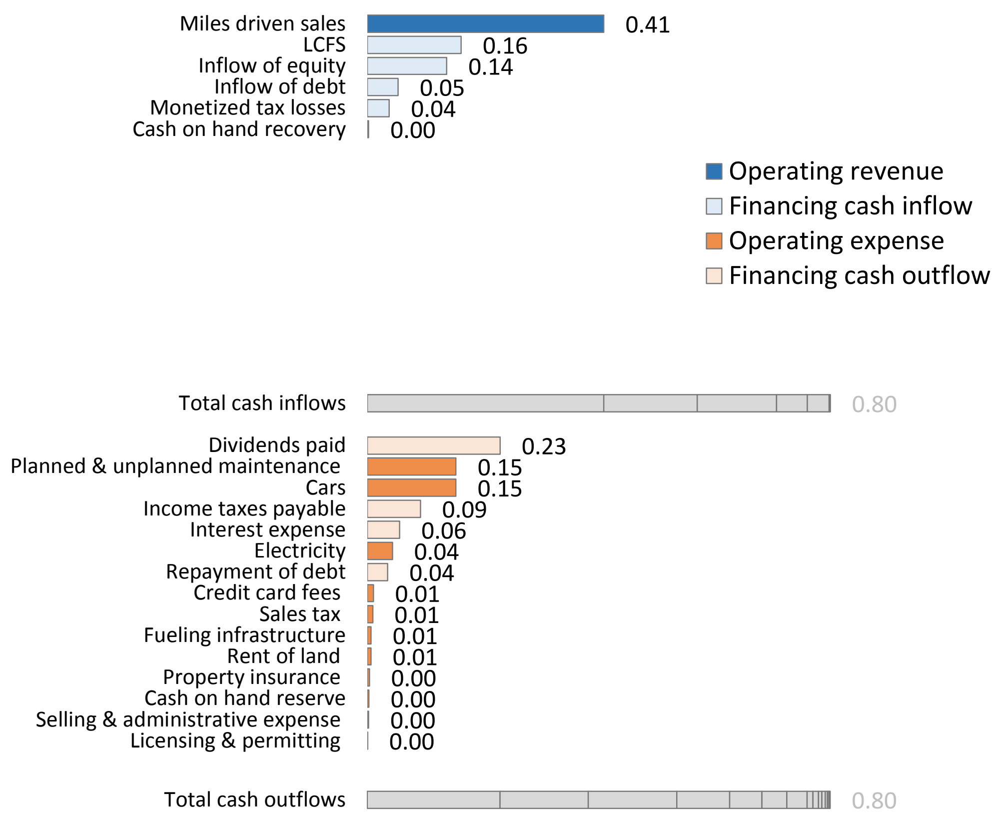


Figure 26. Real levelized value breakdown of miles driven ($/mile) for EV fleet

4.2 Supply Chain Analysis

This case study shows how H2FAST's ability to analyze multiple installations can be used to perform supply chain analysis. Specifically, it analyzes a hypothetical basic supply chain consisting of hydrogen production via steam methane reforming (SMR), pipeline transportation of the hydrogen to a refueling station, and compression, storage, and dispensing (CSD) at the station. Note this analysis is for illustrative purposes only—it does not represent an actual evaluation of a hydrogen supply chain and its costs.

Figure 27 shows the key inputs for each step in the supply chain. Each cell is filled with a static value except for the cost of hydrogen for the pipeline and CSD. The cost of hydrogen to the pipeline is determined by the price of hydrogen produced in the first, SMR step of the supply chain. These values are linked by typing the equal sign (=) in the pipeline's "Cost of hydrogen ($/kg)" cell and then clicking the "Estimated break-even leveraged price ($/kg)" cell corresponding to the SMR step in the Overall Financial Performance Metrics Scenario History table. Similarly, the cost of hydrogen to the CSD is determined by the price of transported hydrogen resulting from the first two—SMR plus pipeline—steps. These costs are linked by typing the equal sign in the CSD's "Cost of hydrogen ($/kg)" cell and then clicking the "Estimated break-even leveraged price ($/kg)" cell corresponding to the pipeline step in the Overall Financial Performance Metrics Scenario History table. Figure 28 shows the links between these price and cost values.

Multi-Scenario Inputs			
Enter how many scenarios to model	3		
Select scenario to analyze	1		
Scenario being analyzed (yellow background)	1	2	3
Installation name	Steam methane reformer	Pipeline, 1 mile per station	CSD
Capacity (kg/day)	379,387	2,000	2,000
Total of Itemized Equipment Cost			
Process Plant Equipment	$ 108,538,142		
Balance of Plant and Offsites	$ 43,364,725		
SCR NOx Control on Stack	$ 644,348		
Pipeline		$ 400,000	
Forecourt CSD			$ 8,000,000
Capital_item 6			
Capital_item 7			
Capital_item 8			
Capital_item 9			
Capital_item 10			
Non-depreciable assets			
Installation cost	$ 64,550,649	$ 400,000	$ 2,000,000
End of project sale of non-depreciable assets			
Planned & unplanned maintenance ($/year)	$ 7,627,361	$ 2,000	$ 200,000
Maintenance escalation (% annually)			
Feedstock Use			
Natural gas (kg/kg)	0.156		
Electricity (kWh/kg)	0.569		4.000
Hydrogen (kg/kg)		1.000	1.000
Feedstock 4 (units of feedstock 4/kg)			
Feedstock 5 (units of feedstock 5/kg)			
Feedstock 6 (units of feedstock 6/kg)			
Feedstock 7 (units of feedstock 7/kg)			
Feedstock 8 (units of feedstock 8/kg)			
Feedstock 9 (units of feedstock 9/kg)			
Co-product Specifications			
Incentives Specification			
Sales Specification			
Price of hydrogen at project onset ($/kg)			
Price escalation rate (% annually)			
Project initiation (year of financing)			
Project operational life (years)	40	60	20
Installation time (months)			
Demand ramp-up (years)	2	5	5
Long-term nominal utilization (%)	80.00%	80.00%	80.00%
Feedstock Cost			
Cost of natural gas ($/kg)		$ 1.593	$ 1.800
Escalation rate of cost (% annually)			
Cost of electricity ($/kWh)	$ 0.060		$ 0.120
Escalation rate of cost (% annually)			
Cost of hydrogen ($/kg)		$ 1.59	$ 1.80

Figure 27. Key inputs for supply chain analysis, Multi-Scenario Inputs table

Overall Financial Performance Metrics Scenario History			
Leveraged, after-tax, nominal IRR	10%	10%	10%
Profitability index	3.58	6.42	2.16
Investor payback period	11 years	13 years	10 years
First year of positive EBITD	analysis year 2	analysis year 2	analysis year 3
After-tax, nominal NPV @ 10% discount	$ -	$ -	$ -
Estimated break-even leveraged price ($/kg)	$1.59	$1.80	$5.74

Feedstock Cost			
Cost of natural gas ($/kg)		1.593	1.800
Escalation rate of cost (% annually)			
Cost of electricity ($/kWh)	$ 0.060		$ 0.120
Escalation rate of cost (% annually)			
Cost of hydrogen ($/kg)		$ 1.59	$ 1.80

Figure 28. Link between break-even hydrogen prices for SMR ($1.59/kg) and SMR + pipeline ($1.80/kg) in the Overall Financial Performance Metrics Scenario History table (top) and hydrogen costs for pipeline ($1.59/kg) and CSD ($1.80/kg) in the Multi-Scenario Inputs table (bottom)

The results of this analysis show the margin associated with the latter two steps in the modeled supply chain. The pipeline buys hydrogen at a price of $1.59/kg and sells it at $1.80/kg, for a margin of $0.21/kg. The CSD buys hydrogen at $1.80/kg and sells it at $5.74/kg, for a margin of $3.94/kg.

4.3 Combined Heat and Power Analysis

H2FAST's ability to account for co-products enables it to analyze CHP systems. This case study analyzes the cost and benefit of waste heat recovery in a hypothetical system that consumes natural gas and produces electricity. It compares an installation without heat recovery to a CHP installation with heat recovery. Note this analysis is for illustrative purposes only—it does not represent an actual evaluation of CHP technology and its costs.

Figure 29 shows the key inputs shared between the installations. Figure 30 shows the CHP system's cost for heat-recovery equipment as well as the heat the system produces per unit of electricity production.

Select interface | Basic | Advanced

Risk analysis | On/Off

Scenario being analyzed: CHP with heat recovery

Installation(s) Information	Most likely value			Multiple scenarios?	Real levelized contribution ($/kWh)
Capacity (kWh/hour)			1,400		
Commodity, retail units, capacity timeframe	electricity	kWh	hour		
Total of Itemized Equipment Cost	$	7,100,000			
Installed equipment	$	5,600,000	installed equipment		0.03
Heat recovery	$	1,500,000	Heat recovery		0.01
Capital_item 3			capital_item 3		0.00
Capital_item 4			capital_item 4		0.00
Capital_item 5			capital_item 5		0.00
Capital_item 6			capital_item 6		0.00
Capital_item 7			capital_item 7		0.00
Capital_item 8			capital_item 8		0.00
Capital_item 9			capital_item 9		0.00
Capital_item 10			capital_item 10		0.00
Non-depreciable assets					0.00
Installation cost	$		700,000		0.00
End of project sale of non-depreciable assets	$		-		0.00
Planned & unplanned maintenance ($/year)	$		280,000		0.03
Maintenance escalation (% annually)			1.90%		

Feedstock Use					
Natural gas (mmBTU/kWh)	0.007	natural gas	mmBTU		0.04
Electricity (kWh/kWh)		electricity	kWh		0.00
Feedstock 3 (units of feedstock 3/kWh)		feedstock 3	units of feedstock 3		0.00
Feedstock 4 (units of feedstock 4/kWh)		feedstock 4	units of feedstock 4		0.00
Feedstock 5 (units of feedstock 5/kWh)		feedstock 5	units of feedstock 5		0.00
Feedstock 6 (units of feedstock 6/kWh)		feedstock 6	units of feedstock 6		0.00
Feedstock 7 (units of feedstock 7/kWh)		feedstock 7	units of feedstock 7		0.00
Feedstock 8 (units of feedstock 8/kWh)		feedstock 8	units of feedstock 8		0.00
Feedstock 9 (units of feedstock 9/kWh)		feedstock 9	units of feedstock 9		0.00

Co-product Specifications					
Waste heat (mmBTU/kWh)	0.001	waste heat	mmBTU		0.00

Figure 29. Key inputs shared by installations with and without waste heat recovery, Installation(s) Information table

Scenario being analyzed (yellow background)	1	2
Installation name	CHP with heat recovery	CHP without heat recovery
Capacity (kWh/hour)		
Installed equipment		
Heat recovery	$ 1,500,000	
Capital_item 3		
Capital_item 4		
Capital_item 5		
Capital_item 6		
Capital_item 7		
Capital_item 8		
Capital_item 9		
Capital_item 10		
Non-depreciable assets		
Installation cost		
End of project sale of non-depreciable assets		
Planned & unplanned maintenance ($/year)		
Maintenance escalation (% annually)		
Feedstock Use		
Natural gas (mmBTU/kWh)		
Electricity (kWh/kWh)		
Feedstock 3 (units of feedstock 3/kWh)		
Feedstock 4 (units of feedstock 4/kWh)		
Feedstock 5 (units of feedstock 5/kWh)		
Feedstock 6 (units of feedstock 6/kWh)		
Feedstock 7 (units of feedstock 7/kWh)		
Feedstock 8 (units of feedstock 8/kWh)		
Feedstock 9 (units of feedstock 9/kWh)		
Co-product Specifications		
Waste heat (mmBTU/kWh)	0.001	

Figure 30. Key inputs for CHP system, Multi-Scenario Inputs table

Based on these inputs, the system without heat recovery breaks even at an electricity price of $0.17/kWh, whereas the CHP system breaks even at an electricity price of $0.18/kWh. Figure 31 and Figure 32 show the levelized value breakdown for both systems. Waste heat sales add $0.01 per kWh of electricity production to the CHP system's revenue (Figure 31, top) over the non-CHP system's revenue (Figure 32, top). However, the CHP system also requires the extra $0.01/kWh of electricity revenue to make up for its higher expenses/financing outflows (Figure 31, bottom) compared with the non-CHP system's expenses/financing outflows (Figure 32, bottom). As a result, the CHP system's heat recovery is not justified by the economics in this example.

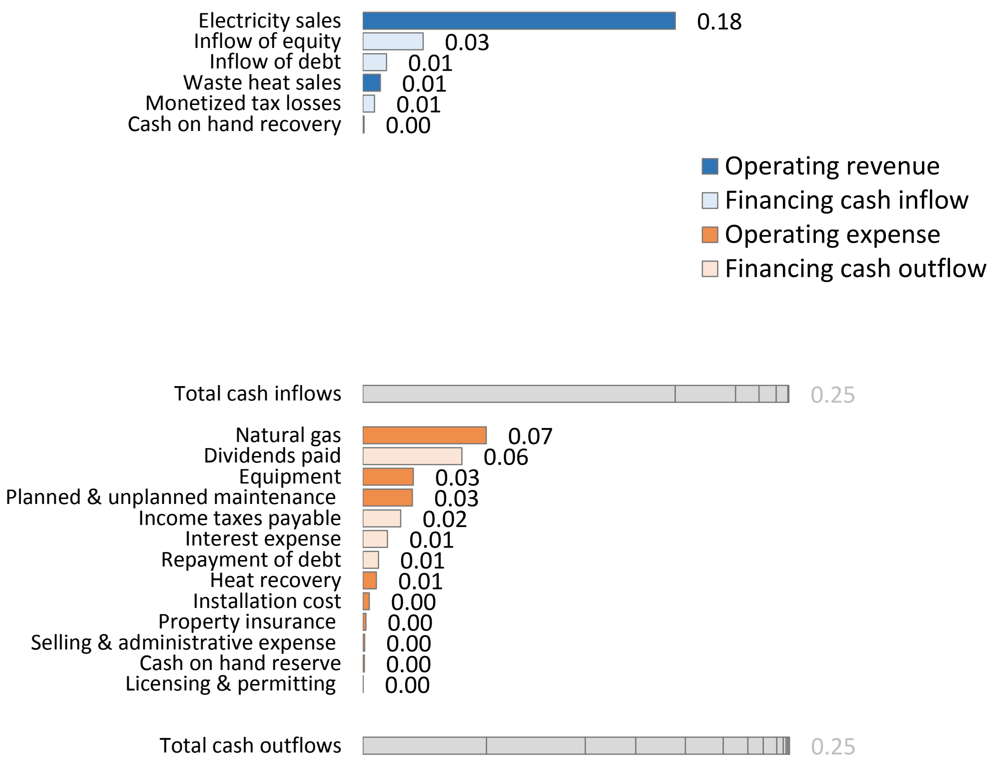


Figure 31. Real levelized value breakdown of electricity ($/kWh) for CHP system

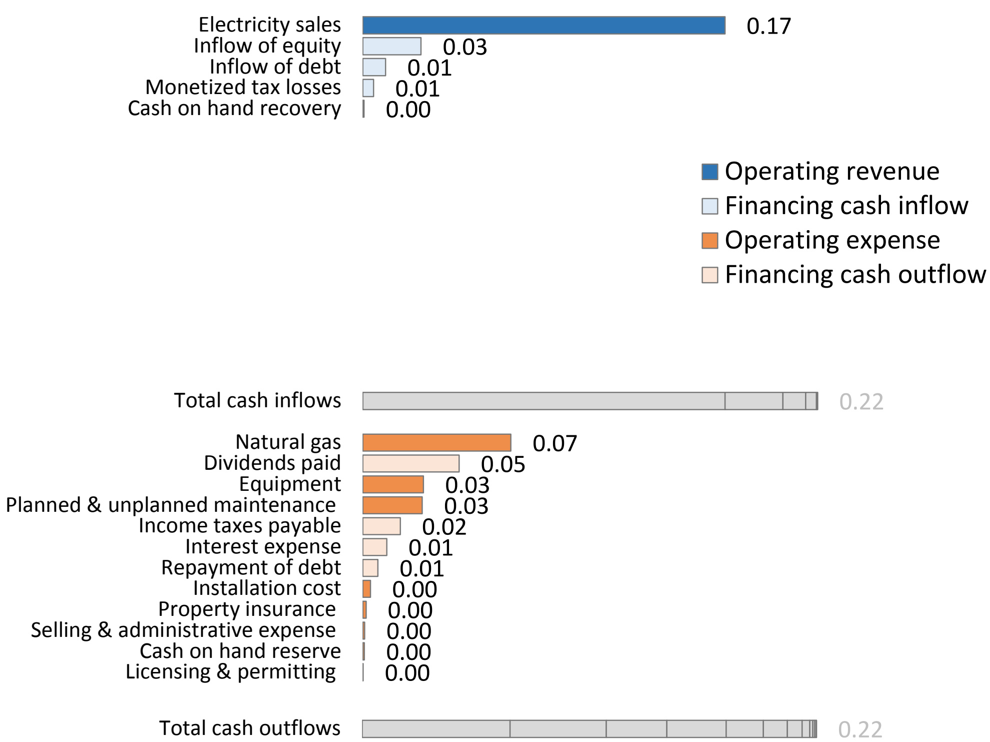


Figure 32. Real levelized value breakdown of electricity ($/kWh) for system without heat recovery

5 Technical Support

If you have questions or comments about the spreadsheet version of H2FAST, please contact:

Michael Penev
Phone: 303-275-3880
Email: Michael.Penev@nrel.gov

References

ANL (Argonne National Laboratory). 2015. "H2A Refueling Station Analysis Model (HRSAM) Version 1.0." Accessed March 25, 2015. https://www.hydrogen.energy.gov/h2a_delivery.html.

DOE (U.S. Department of Energy). 2015. "DOE H2A Analysis: Production Case Studies." Accessed March 25, 2015. https://www.hydrogen.energy.gov/h2a_prod_studies.html.

EIA (U.S. Energy Information Administration). 2017. "Annual Energy Outlook 2017." Accessed July 3, 2017. https://www.eia.gov/forecasts/aeo/.

FASAB (Federal Accounting Standards Advisory Board). 2014. *FASAB Handbook of Federal Accounting Standards and Other Pronouncements, as Amended*. Washington, DC: Federal Accounting Standards Advisory Board.

Investopedia. 2014. "Accounting (Fundamental Analysis) Terms." Accessed December 2014. http://www.investopedia.com/categories/accounting.asp.

Investopedia. 2016. "Take or Pay." Accessed September 2016: http://www.investopedia.com/terms/t/takeorpay.asp.

Melaina, M. and M. Penev. 2013. *Hydrogen Station Cost Estimates: Comparing Hydrogen Station Cost Calculator Results with other Recent Estimates*. NREL/TP-5400-56412. Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gov/docs/fy13osti/56412.pdf.

Miller, H. 2008. "Engineering Economics - EIT Review: Cash Flow Evaluation." Golden, CO: Colorado School of Mines. http://inside.mines.edu/~knelson/Lecture%20Cash%20Flow%20Evaluation%20New.ppt.

Appendix A: Model Inputs and Default Values

Installation Information[a]		
Input	**Default Value**	**Description**
Select interface	Basic	Advanced mode allows access to detailed model assumptions.
Enter number of installations to model	3	Input information for up to 300 installations.
Capacity (kg/day)	600	This value defines average daily dispensing capacity. The station is still capable of adequately refueling cars during peak demand days.
Equipment capital cost	$4.1 million	Cost of equipment only (not including engineering cost, permitting, and installation). Note: model assumes that salvage value equals decommissioning costs.
Non-depreciable assets (e.g., land)	—	Cost of assets, such as land, that are not subject to depreciation.
Installation cost	—	This cost should include costs associated with installation, such as engineering, permitting, and lot and utility upgrades.
End of project sale of non-depreciable assets	—	Net recovered value at end of life (salvage value – demolition expense), in nominal dollars. This should include non-depreciable fixed assets such as land.
Planned & unplanned maintenance ($/year)	$133,068	Levelized annual maintenance expenses for planned and unplanned equipment servicing and overhauls. Expenses are assumed to be non-depreciable.
Maintenance escalation (% annually)	1.9%	Each year expenses may escalate due to higher cost of technician labor or material expenses.

[a] These values are entered in the Installation(s) Information and Multi-Scenario Inputs tables.

Co-Product Specifications and Feedstock Use[a]		
Input	**Default Value**	**Description**
Delivered GH2 (kg/kg)	1.000	Yearly average amount of delivered hydrogen as gas per kilogram of hydrogen sold.
Electricity (kWh/kg)	4.000	Yearly average amount of electricity used per kilogram of hydrogen sold.
User defined feedstock (units/unit)	—	Yearly average amount of user-defined feedstock used per number of retail units sold.
User defined co-product (units/unit)	—	Yearly average co-product generated per yearly average product sold.

[a] These values are entered in the Co-Product Specifications and Feedstock Use tables.

Incentives Specifications		
Input	**Default Value**	**Description**
One time capital incentives (grant or ITC)	$2.1 million	Incentive is provided at the beginning of the project (accounted on Dec. 31, the year before construction begins). The credit can be a grant or an investment tax credit (ITC).
Annual operating incentives (grant or PTC)	$100,000	Production-based incentives commence the month of station commissioning. This can be a grant or a production tax credit (PTC). If PTC, specify as non-taxable (row 157).
Operating incentives linear decay (% of initial/year)	0%	Annual operating incentives may be reduced each year. This input allows this revenue stream to be ramped down to zero by a fixed annual percentage.
Operating incentives sunset (years)	3	Number of years in which operating incentives are available. This input can simulate early termination of incentives before an annual ramp-down is complete.
LCFS incentive ($/kg)	$0.22	Incentive issued per retail unit sold. Example: low-carbon fuel standard (LCFS) credit.
LCFS incentive decay rate (%/year)	-1.9%	Annual incentive decay rate per year as % of the initial quantity. Note: escalation can be specified by entering a negative number.
LCFS incentive sunset (years)	100	Number of years in which incentive is available. This input can simulate early termination of incentive before an annual ramp-down is complete.
RIN incentive ($/kg)	—	Incentive issued per retail unit sold. Example: Renewable Identification Number (RIN) credit.
RIN incentive decay rate (%/year)	20%	Annual incentive decay rate per year as % of the initial quantity. Note: escalation can be specified by entering a negative number.
RIN incentive sunset (year)	20	Number of years in which incentives are available. This input can simulate early termination of incentives before an annual ramp-down is complete.
Incidental revenue	—	Station revenue enhancements derived from hydrogen. Value should be expressed as (marginal revenue − marginal expenses).
Incidental revenue escalation rate (%/year)	1.9%	Rate of annual escalation for incidental revenue.

Sales Specification		
Input	**Default Value**	**Description**
Price of hydrogen at project onset ($/kg)	8.77	This is the total cost to the end customer and includes all transaction costs such as credit card fees and sales taxes. Specified price is for the beginning of the project.
Price escalation rate (% annually)	1.9%	Rate of annual escalation.
Project initiation (year of financing)	2020	Year in which the project starts (Jan. 1). Note: financial reporting occurs Dec. 31, and investments into the project will be reported as of Dec. 31 of the prior year.
Project operational life (years)	20	Operating life of the project. Enter a value between 5 and 60. Note: project operational life plus installation time must be less than 100 years.
Installation time (months)	18	Months between investment in a station and its first sale.
Demand ramp-up (years)	5.0	Number of years to achieve long-term average utilization. This value imposes a straight-line ramp-up in station utilization.
Long-term nominal utilization (%)	80%	Infrastructure requires reserve capacity for network robustness to nearby station outage and abnormal traffic events. 70% is advised.

Feedstock Cost and Co-Product Value[a]		
Input	**Default Value**	**Description**
Cost of delivered GH2 ($/kg)	6.00	Stations using delivered hydrogen are charged for delivered gas. Price is defined at the start of the project (not at start of operation).
Escalation rate of cost (% annually)	1.9%	Rate of annual escalation.
Cost of electricity ($/kWh)	$0.120	Blended electricity price.
Escalation rate of cost (% annually)	1.9%	Rate of annual escalation.
Cost of user defined feedstock ($/unit)	—	Blended user-defined feedstock price.
Escalation rate of cost (% annually)	1.9%	Rate of annual escalation.
Value of user-defined co-product ($/unit)	—	Value of user-defined co-product.
Escalation rate of value (% annually)	1.9%	Rate of annual escalation.

[a] These values are entered in the Feedstock Cost and Co-Product Value tables.

Take or Pay Contract Specification		
Input	**Default Value**	**Description**
Price of unsold hydrogen ($/kg)	—	Price paid for unused capacity up to supported level. Price point at the year of start of sales. Note: price is in nominal dollars.
Price decay (% annually)	10%	Annual decay rate of take-or-pay contract price. Note: decay is based on first-year total cost.
Contract sunset (years)	20	Years of consideration for take-or-pay contract.
Utilization supported up to (% of capacity)	85%	Ceiling of equipment utilization covered under take-or-pay contract.

Other Operating Expenses		
Input	**Default Value**	**Description**
Credit card fees (% of sales)	2.50%	This is a flow-through expense for credit card fees.
Sales tax (% of sales)	2.25%	This is a flow-through expense for sales taxes.
Road tax ($/kg)	—	This is a flow-through expense for road taxes.
Road tax escalation rate (%/year)	1.9%	Rate of annual escalation.
Staffing labor hours (h/year-station)	—	This value allows allocation for any on-site labor attributed to dispensing. As stations are typically fully automatic, this value is usually zero.
Labor rate ($/h)	40	Fully burdened rate of labor. Note that this is for on-site labor, if any, and should not factor in labor rates for maintenance and station hydrogen restocking.
Labor escalation rate (% annually)	1.9%	Rate of annual escalation.
Licensing & permitting ($/year-station)	1,400	All licensing and permitting expenses. Do not include licensing and permitting during station installation (those are accounted for in the installation expense).
Licensing & permitting escalation rate (%/year)	1.9%	Rate of annual escalation.
Rent of land ($/station-year)	46,000	Rent is paid annually for the footprint of any hydrogen equipment. Rent expenses prior to operation should be rolled into installation cost.
Rent escalation (% annually)	1.9%	Rate of annual escalation.
Property insurance (% of dep capital)	0.9%	Annual expense as percentage of the depreciated equipment value. Insurance covering installation should be rolled into installation costs.
Selling & administrative expense (% of sales)	0.5%	Use this value to assign any overhead expenses, such as administrative and management costs, as a percentage of the sales revenue stream.
Purity testing ($/year)	$8,100	Fixed operating expense in $/year.
Purity testing escalation (% annually)	5%	Rate of annual escalation.
Internet connection ($/year)	$2,300	Fixed operating expense in $/year.
Internet connection escalation (% annually)	1.9%	Rate of annual escalation.
Electricity fixed use ($/year)	$2,100	Fixed operating expense in $/year.
Electricity fixed use escalation (% annually)	1.9%	Rate of annual escalation.
Electric demand & service ($/year)	$8,900	Fixed operating expense in $/year.
Electric demand & service escalation (% annually)	1.9%	Rate of annual escalation.
User-defined charges	—	Fixed operating expense in $/year.
User-defined charges escalation (% annually)	1.9%	Rate of annual escalation.

Financing Information		
Input	**Default Value**	**Description**
Total tax rate (state, federal, local)	38.50%	Specify the total tax rate, which may include federal, state, county, and city taxes.
Capital gains tax	15%	Specify the total tax rate, which may include federal, state, county, and city taxes.
Is installation cost depreciable?	No	Specify whether costs associated with construction and permitting are depreciable.
Are operating incentives taxable?	No	Specify whether operating incentives are treated as income (taxable) or whether they are tax exempt.
Is capital incentive depreciable?	Yes	Specify whether incentives received for capital are taxable or tax exempt.
Are tax losses monetized (tax equity application)	Yes	Can tax losses be monetized by offsetting coupled business tax liabilities?
Allowable tax loss carry-forward	7 years	IRS allows carry-forward of tax losses usually for 7 years. Note: this is not used if tax losses are monetized (tax equity application).
General inflation rate	1.90%	This value specifies a general inflation rate and is used in calculation of levelized costs.
Depreciation method	MACRS	Specify depreciation method: Modified Accelerated Cost Recovery System (MACRS) or linear.
Depreciation period	5 years	Value should be less than or equal to the project life. If MACRS is used, it should also be one of the allowed schedules (use drop down).
Leveraged after-tax nominal discount rate	10.0%	Specify a discount rate for reporting of net present value. Note that this rate should include consideration of inflation.
Debt/equity financing	0.5	This factor guides the initial financing capital structure (ratio of debt financing to equity financing).
Debt type	Revolving debt	Specify the type of debt financing (loan or revolving debt). In case of revolving debt, a fixed amount of debt is issued.
If loan, period of loan (years)	15	Enter repayment period for loan (if loan debt is used). This value should not exceed the equipment life.
Debt interest rate (compounded monthly)	6.00%	Enter interest rate on debt—used for both loan and revolving debt calculations.
Cash on hand (% of monthly expenses)	100%	This is cash retained by the business for purposes of liquidity and includes operating expenses, taxes, and interest.

Car Specifications (used for some plots)		
Input	**Default Value**	**Description**
Car annual driving (miles/year)	12,000	Average annual vehicle miles traveled. Entry used for specifying number of cars and refuelings supported by retail location.
Car fuel efficiency (miles/gge)	60	Average vehicle fuel efficiency. Entry used for specifying number of cars and refuelings supported by retail location.
Fueling / charging quantity (gge/visit)	4	Average vehicle fueling quantity per visit. Entry used for specifying number of cars and refuelings supported by retail location.

Appendix B: Model Outputs

Global Scenario Outputs

Overall Financial Performance Metrics	
Output	**Description**
Leveraged, after-tax, nominal IRR	Rate of return based on investor cash flow (investments and withdrawals).
Profitability index	(Present value of future equity investor cash flows)/(initial equity investment)
Investor payback period	Number of years before cumulative investor cash flow first becomes greater than zero.
First year of positive EBITD	First year in which earnings before interest, tax, and depreciation are greater than zero.
After-tax, nominal NPV	Net present value of investor net cash flow (investments and withdrawals).
Estimated break-even leveraged price ($/kg)	Price of hydrogen that would yield specified leveraged, after-tax, nominal IRR.

User-Selectable Graphs

Overall Metrics	
Output	**Description**
Cumulative investor cash flow	Investor cash flow + previous year investor cash flow.
Investor cash flow	Investor withdrawals − investor contributions.
Monetized tax losses	Tax loss credits could be applied when majority equity holder has tax liabilities in excess of any credits.
Gross margin	(Total revenue − cost of goods sold) / total revenue.
Cost of goods sold ($/year)	Total operating expenses + depreciation + interest − selling and administrative.
Cost of goods sold ($/kg)	Cost of goods sold / annual hydrogen sales (kg).
Average utilization (%)	Annual dispensed hydrogen / design annual capability. Note: design capacity hinges on no excessive customer wait times during peak demand during the year.
Hydrogen sales (kg/day)	Total annual sales / 365.
Capacity covered by take or pay contract (kg/day)	Daily average hydrogen capacity qualifying for take-or-pay contract payments.
Sales price of hydrogen ($/kg)	Price of hydrogen to the end customers ($/kg).
Value of user-defined co-product ($/unit)	Price of user-defined co-product to the end customers ($/unit).
Cost of delivered GH2 ($/kg)	Amount paid for supply of delivered GH2 to installation ($/kg).
Cost of electricity ($/kWh)	Amount paid for supply of electricity to installation ($/kWh).
Cost of user-defined feedstock ($/unit)	Amount paid for supply of user-defined feedstock to installation ($/unit).
Number of cars supported by infrastructure	Number of cars supported by stated demand assuming average vehicle use of 12,000 miles/year and fuel economy of 60 miles/gge.

Average number of fuelings per day	Average number of vehicle fuelings per day assuming fueling/charging quantity (gge/visit) = 4.

Income Statement Values	
Output	**Description**
Hydrogen sales ($/year)	Annual revenue derived from sales of hydrogen. Does not include revenue from incentives.
User-defined co-product sales ($/year)	Annual revenue from user-defined co-product.
LCFS ($/year)	Annual revenue from LCFS.
RIN ($/year)	Annual revenue from RIN.
Take or pay revenue ($/year)	Revenue from take or pay contract
Annual operating incentives (grant or PTC) ($/year)	Annual revenue derived from production incentives (nominal $).
Incidental revenue ($/year)	Other station revenue enhancements from presence of hydrogen. This value should be expressed as (marginal revenue − marginal expenses).
Credit card fees ($/year)	Reduction in total revenue based on credit card fees (flow-through expense).
Sales tax ($/year)	Reduction in total revenue based on sales tax expense (flow-through expense).
Road tax ($/year)	Reduction in total revenue based on road tax expense (flow-through expense).
Total revenue	Sales revenue + incentive revenue − credit card fees − sales tax − road tax (annual basis).
Cost of delivered GH2 ($/year)	Annual expense for use of delivered GH2.
Cost of electricity ($/year)	Annual expense for electricity use.
Cost of user-defined feedstock ($/year)	Annual expense for use of user-defined feedstock.
Total feedstock & utilities cost ($/year)	Annual expense for all feedstock and utilities use. Note: this does not include fixed operating expenses.
Labor ($/year)	Annual labor expense.
Planned & unplanned maintenance ($/year)	Annual expenses for maintenance.
Rent of land ($/year)	Annual expense attribution for equipment real estate rent.
Property insurance ($/year)	Annual insurance expense associated with value of equipment. Note: insurance is proportional to the depreciated equipment value.
Licensing & permitting ($/year)	Annual expenses associated with licensing and permitting.
Selling & administrative ($/year)	Annual expenses associated with selling and administrative activities (management overhead).
Purity testing ($/year)	Annual expenses associated with purity testing.
Internet connection ($/year)	Annual expenses associated with internet connection.
User-defined charges ($/year)	Annual expenses associated with user-defined charges.
Total operating expenses ($/year)	Annual total operating expenses. Does not include depreciation, taxes, and interest.
EBITD ($/year)	Total annual revenue − total operating expenses. Earnings before interest, taxes, and depreciation (EBITD).
Interest on outstanding debt ($/year)	Annual interest on outstanding debt. Note: in case of loan debt, interest is accrued monthly.
Equipment depreciation ($/year)	Depreciation expense for equipment, calculated based on quarter of equipment commissioning. Note: this is a tax-accounting metric and not a cash expenditure.

Income Statement Values	
Output	**Description**
Taxable income ($/year)	Income subject to taxation, before consideration of tax loss carry-forward.
Remaining available deferred carry-forward tax losses ($/year)	Tax loss carry-forward remaining after annual taxes payable calculations.
Income taxes payable ($/year)	Taxes payable for the year.
Income before extraordinary items ($/year)	Income after interest, ordinary income taxes.
Sale of non-depreciable assets ($/year)	Sale of non-depreciable fixed assets such as land.
Net capital gains or loss ($/year)	Sale of non-depreciable fixed assets less cost basis.
Capital gains taxes payable ($/year)	Capital gains taxes payable on sale of non-depreciable assets gains.
Net income ($/year)	Revenues − operating expenses − interest expense − taxes payable − depreciation expense.

Cash Flow Statement Values	
Output	**Description**
Net annual operating cash flow	Net income + dividends.
Capital expenditure for equipment	Cash flow for initial equipment purchases.
Capital expenditure for user-defined item	Cash flow for initial purchase of user-defined capital item.
Expenditure for non-depreciable fixed assets	Expenditure for the purchase of non-depreciable fixed assets such as land.
Capital expenditures for equipment installation	Cash flow for initial installation, permitting, and commissioning expenses.
Total capital expenditure	Total cash flow for initial equipment and installation expenses.
Incurrence of debt	Cash flow associated with acquisition of debt financing.
Repayment of debt	Cash flow associated with repayment of debt. Note: in the case of revolving debt, repayment is done in full at the end of the analysis period.
Inflow of equity	Cash flow associated with equity investment.
Dividends paid	Cash flow to equity investors (dividends or owner withdrawals).
One-time capital incentive	Cash flow from receipt of capital incentive and/or grants.
Net cash for financing activities	Incurrence of debt − repayment of debt + inflow of equity − dividends paid + receipt of capital incentives.
Net change of cash	Annual change in cash position.

Balance Sheet Values	
Output	**Description**
Cumulative cash	Previous year cash position + current year net cash.
Cumulative PP&E	Total undepreciated plant, property, and equipment (PP&E).
Cumulative depreciation	Accumulated depreciation: previous year depreciation expense + current year depreciation expense.
Net PP&E	Depreciated value of plant, property, and equipment (PP&E): cumulative PP&E − cumulative depreciation.
Cumulative deferred tax losses	Tax loss carry-forward usable to offset future year tax liabilities.
Total assets	Accumulated cash + accumulated PP&E − accumulated depreciation + accumulated tax loss carry-forward.
Cumulative debt	Outstanding debt.
Total liabilities	Outstanding debt. Note: accounting is performed on annual basis (assumes accounts payable = accounts receivable, and maintains cash on hand for liquidity).
Cumulative capital incentives equity	Accumulated equity from one-time receipt of capital incentives.
Cumulative investor equity	Accumulated equity from investor contributions.
Retained earnings	Previous year retained earnings + current year net income − current year paid dividends.
Total equity	Accumulated equity from capital incentives + accumulated equity from investor contributions + retained earnings + accumulated tax loss carry-forward. Note: value can be negative in highly leveraged scenarios.
Investor equity less capital incentive	Total equity − capital incentive.

Ratio Analysis	
Output	**Description**
Returns on investor equity	Net income / investor equity. Note: investor equity = total equity − capital incentive.
Debt/equity ratio	Total debt / total equity.
Returns on total equity	Net income / total equity. Note: total equity = investor equity + capital incentive.
Debt service coverage ratio (DSCR)	EBITD / interest. EBITD: earnings before interest, taxes, and depreciation.

Appendix C: Quick Facts about Hydrogen Refueling

Photo by Chris Ainscough, NREL 19512

Hydrogen	
Sources of hydrogen	Conversion of natural gas via steam methane reforming is the primary means of producing hydrogen today. Onsite production by electrolysis is also used for smaller demands. Future systems may include gasification of biomass, large-scale electrolysis using wind, or direct conversion using solar, coal, or nuclear resources.
Energy equivalence	The energy in 1 kilogram of hydrogen is approximately equivalent to the energy in 1 gallon of gasoline.
Cost per kilogram of hydrogen	Because a fuel cell electric vehicle is about twice as efficient as a similar conventional gasoline vehicle, an owner can drive twice as far on a kilogram of hydrogen than on a gallon of gasoline. Therefore, if the hydrogen price is \$10/kg, the cost to the owner would be equivalent to about \$5/gal gasoline on a cost-per-mile-driven basis.
Fuel Cell Vehicles	
Onboard hydrogen storage methods	Compressed hydrogen at 5,000–10,000 psi (near term); other options include liquid hydrogen and hydrogen stored on or in other materials
Projected range per full fuel tank	300+ miles
Hydrogen required for 300-mile range	~ 5–6 kilograms
Hydrogen Stations	
Public stations open	40
Private stations open	24
States with most stations	California (43), Hawaii (4), Ohio (3), Connecticut (2)

Data sources: Alternative Fuels Data Center (www.afdc.energy.gov/fuels/hydrogen.html), FuelEconomy.gov (www.fueleconomy.gov). Station statistics are as of October 11, 2017.