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The #H2IQ Hour

Today's Topic:

Demonstrations of *H2A-Lite*
and *H2FAST* Models

This presentation is part of the monthly H2IQ hour to highlight hydrogen and fuel cell research, development, and demonstration (RD&D) activities including projects funded by U.S. Department of Energy's Hydrogen and Fuel Cell Technologies Office (HFTO) within the Office of Energy Efficiency and Renewable Energy (EERE).

This webinar is being recorded and will be available on the [H2IQ webinar archives](#).

Technical Issues:

- If you experience technical issues, **please check your audio settings under the “Audio” tab.**
- If you continue experiencing issues, direct message the host, Cassie Osvatics

Questions?

There will be a Q&A session at the end of the presentation.

To submit a question, please type it into the **Q&A box on the right-hand side of your screen next to the chat box/Chat**

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The #H2IQ Hour Q&A

Please type your
questions into
the **Q&A Box**

Q&A ×

All (0)

Select a question and then type your answer here, There's a 256-character limit.

Send

Send Privately...



H2A-Lite & H2FAST Model Summary and Demonstration

Michael (Misho) Penev
NREL
November 3, 2022

Webinar Outline



H2A-Lite

Model purpose & framework

Layout & walkthrough

Model demonstration



H2FAST

Model purpose & framework

Layout & walkthrough

Model demonstration

H2A-Lite Model Purpose

Provide high level articulation of hydrogen production technologies with focus on **convenience** and high impact parameters.

How:

- reduce inputs to **key standard parameters**
- **pre-populated technologies** calibrated from H2A
- one-place for **multiple technologies**
- **results rich** and visual articulation
- rigorous financial and **incentive analysis**
- **fast** model operation
- includes embedded **sensitivity** and **risk** analysis
- simple embedded **walkthrough + documentation**

Target audience:

- business professionals / investors
- policy makers
- newer hydrogen analysts
- large scale modelling (e.g. SERA, ReEDS, NEMS)

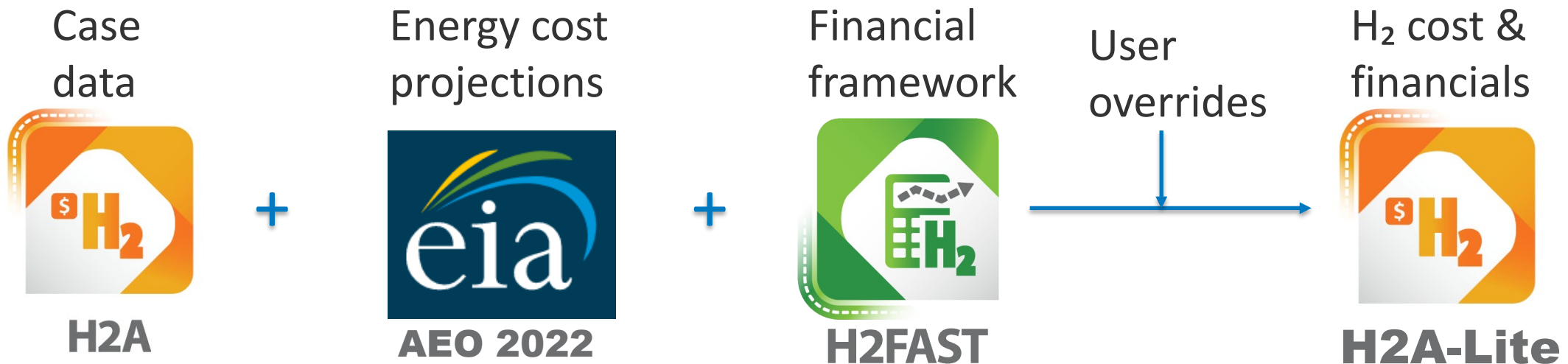


H2A-Lite
n2A

H2A-Lite Model Framework

Based on Hydrogen Financial Analysis Scenario Tool (H2-FAST)

- Uses Generally Accepted Accounting Principles (GAAP) financial analysis
- Also compatible with International Financial Reporting Standards (IFRS)
- Articulates standard financial reports for duration of analysis
 - Income statements
 - Cash flow statements
 - Balance sheets



Comparison H2A vs. H2A-Lite

Aspect	H2A	H2A-Lite
Model use	Detailed, for R&D and target setting	Technology macro view
User experience requirement	Expert	Novice to Expert
# of input parameters	~100	~30
Number of production files	20	1
Number of tabs	19	5
Risk analysis	Simple	Rigorous
Financial analysis	Disc. cash flow	GAAP*
Documentation	Supplemental PDF	Self documented
Incentives analysis	Basic, income	Rigorous, income, tax credits
Clarity of parameter for other models	Complex	Concise

*GAAP: Generally Accepted Accounting Principles, US-standard accounting and finance methodology NREL | 8

Included Case Studies

- Central PEM: current & future
 - grid, wind, solar
- Central SOEC: current & future
 - natural gas & nuclear heat
- Central biomass: current & future
- Central SMR: current *
- Central ATR+CCS: current *
- Central coal+CCS: current *
- Distributed PEM: current & future
- Distributed SMR: current & future
- User-defined

* Case studies for fossil fuels include assumptions in [2022 NETL Report](#)

Model Differences

	H2A	→	H2A-Lite
Dollar basis*:	2016\$	→	2020\$
Energy & feedstock basis:	AEO Ref. 2017	→	AEO Ref. 2022
Biomass cost:	Billion-ton study	→	AEO biomass for power generation
Renewable electricity cost:	N/A	→	NREL Annual technology baseline 2022
Refurbishments schedule:	Discrete	→	Annualized
Production incentive:	Income-basis	→	Income or tax credit
Capital expenditure:	Scheduled	→	Lump sum + construction period

* Modeling being adapted to allow for user-defined dollar year

Webinar Outline



H2A-Lite

Model purpose & framework

Layout & walkthrough

Model demonstration



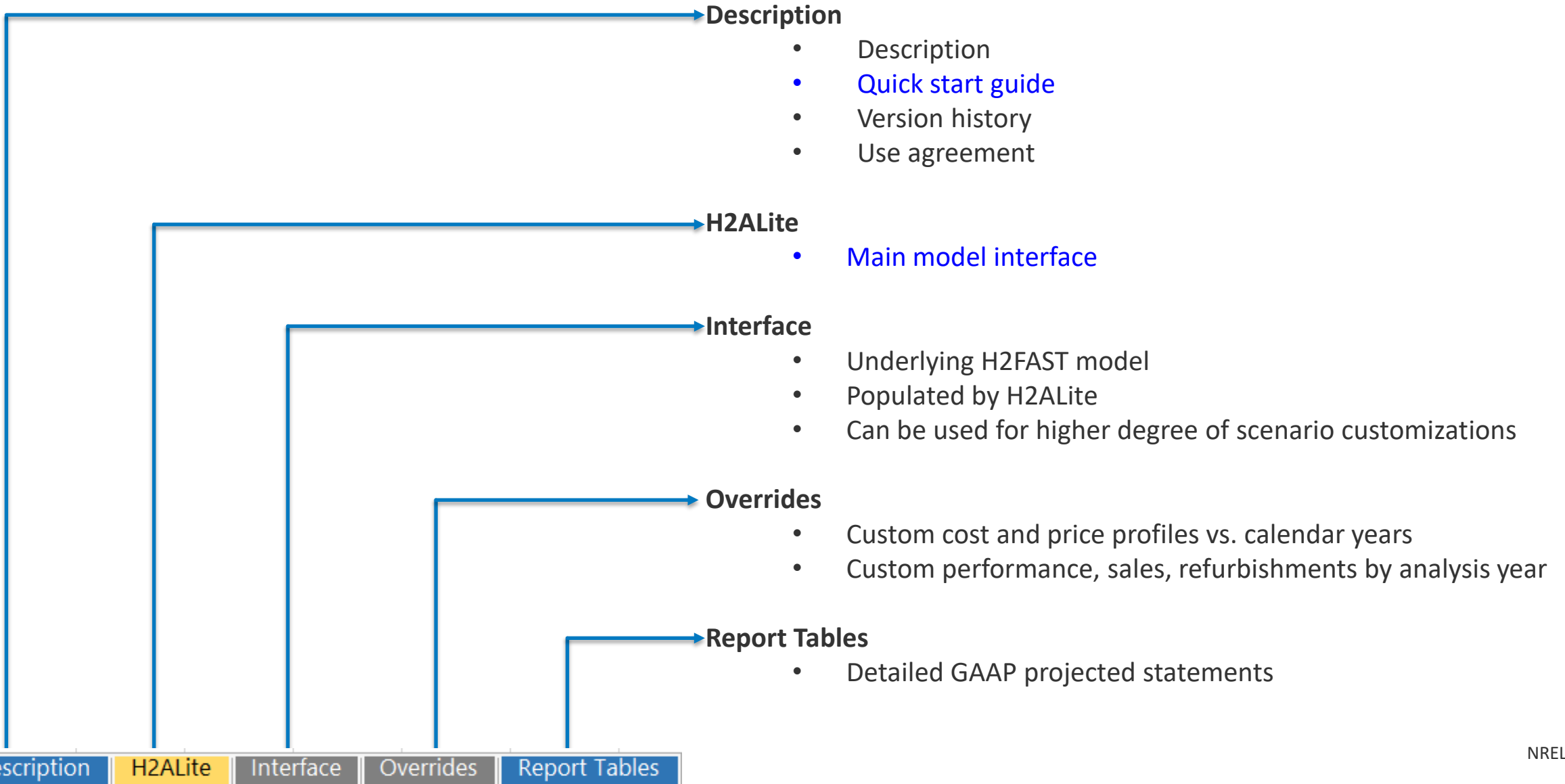
H2FAST

Model purpose & framework

Layout & walkthrough

Model demonstration

Model Tab Descriptions



Model Layout: H2ALite tab

H2A-Lite: Hydrogen Analysis - Lite

Real levelized cost → 4.45 [2020\$/kg H₂]

Select H₂ production technology pathway →

Biomass
 Coal+CCS
 Grid PEM
 Solar PEM
 Wind PEM
 SOFC
 NG SMR
 NG ATR+CCS
 User Defined

Central Grid Electrolysis (PEM)

Description: The modeled system is a standalone grid powered PEM electrolyzer system with a total hydrogen production capacity of 50,000 kg/day. The production system is based on a generic system using input from several key industry collaborators (KIC) with commercial experience in PEM electrolysis and brief system and subsystem techno-economic models, the electrolyzer units use process water, passed through deionizing beds, and grid electricity for electrolysis

1

Hydrogen Analysis - Lite

Real levelized cost → 4.45 [2020\$/kg H₂]

Modeled system is a standalone grid powered PEM electrolyzer system with a total hydrogen production capacity of 50,000 kg/day. The production system is based on a generic system using input from several key industry collaborators (KIC) with commercial experience in PEM electrolysis and brief system and subsystem techno-economic models, the electrolyzer units use process water, passed through deionizing beds, and grid electricity for electrolysis

2

Analysis inputs

Specify production nameplate capacity [kg/d] 56,500

Desired startup year 2015

Valid capacity range: 1,695 to 56,500 [kg/d]

Technology estimation

Total installed capital cost [2020\$]	\$ 86,495,734
Fixed OpEx w/o replacements [2020\$/year]	\$ 4,305,059
Variable OpEx [2020\$/kg H ₂]	\$ 0.024
System life [years]	40
Utilization [%]	97%

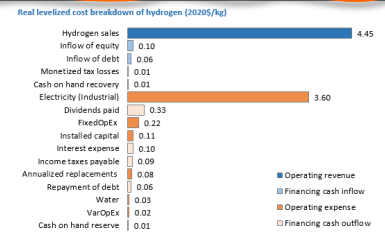
Normalized CapEx

1,531	[\$/kg-day]
662	[\$/kW]

Production rate 54,805 [kg/d]

Refurbishments & replacements

Annualized replacement costs [2020\$/year]	1,545,228
Replacements interval [years]	
Replacements (% of installed CapEx)	



Energy & feedstock use

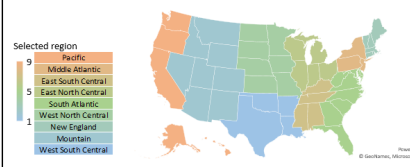
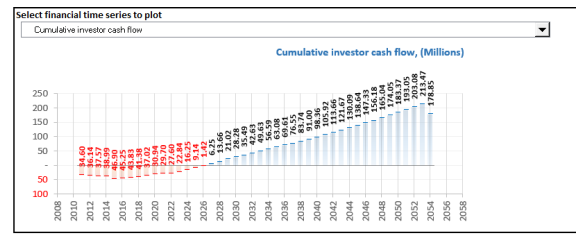
Usage per kg H ₂	H2A default	User override
Electricity (Commercial)	0.000 [kWh]	
Electricity (Industrial)	55.500 [kWh]	
Electricity (On-shore wind)	0.000 [kWh]	
Natural Gas (Commercial)	0.000 [mmBTU]	
Natural Gas (Industrial)	0.000 [mmBTU]	
Biomass	0.000 [t/ton]	
Coal	0.000 [mmBTU]	
Oil	0.000 [gal]	
Water Total	3.780 [gal]	

Select regional prices → (AEO 2022 Ref)

US Average	User override
0.115	[\$/kWh]
0.075	[\$/kWh]
0.048	[\$/kWh]
0.034	[\$/kWh]
8.28	[\$/mmBTU]
4.11	[\$/mmBTU]
52.6	[\$/t/ton]
2.33	[\$/mmBTU]
2.94	[\$/gal]
0.0033	[\$/gal]

Energy & feedstock impact on production

Input Power [kW HHV]	Input Energy [kWh HHV/kg]	Efficiency [BHV]
130,656	55.5000	71.2%



Coproducts

H ₂ O sequestration	0%
Steam co-product sales	0.000 [mmBTU/kg H ₂]

Financials specification

Real return on equity	8%
Debt/equity	1.50
Interest rate	3.7%
Depreciation type	MACRS
MACRS depreciation period	20 [years]
Total income tax rate	25.74%
Cash on hand	1.0 [month of OpEx]

Financial incentives

Per-kilogram incentives	0.00
Per-kilogram incentive mechanism	Tax credit
Per-kilogram incentive sunset	10 [years]
Per-kilogram annual reduction %	0.00
Capital incentive or investment tax credit	0.0%

Tornado chart spread of parameters ±1% ±10% of baseline

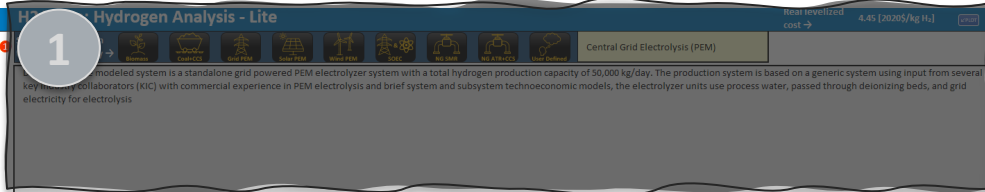
Please update tornado!

Electricity (Industrial) cost [\$/kWh] (0.68, 0.76, 0.83)	4.07	4.35	4.83
Electricity (Industrial) use [kWh/kg] (50.0, 55.5, 61.1)	4.07		4.83
Utilization [%] (100%, 97%, 87%)	4.43		4.52
Return on equity (7%, 8%, 9%)	4.41		4.50
Capacity [kg/d] (62,140, 56,500, 50,850)	4.45		4.53
CapEx [\$] (77,846,161, 86,495,734, 95,145,308)	4.42		4.48
Fixed OpEx [\$/yr] (3,874,553, 4,305,059, 4,735,565)	4.43		4.47
System life [yr] (44, 40, 36)	4.44		4.47
Interest rate [%] (3.33%, 3.70%, 4.07%)	4.44		4.46
Debt/equity (1.65, 1.50, 1.35)	4.44		4.46

1 Technology Selection & Description

1. Click on icon for technology of interest
2. Description of technology will update
3. Technology parameters will populate below
4. Price in upper-right corner will display cost of H₂

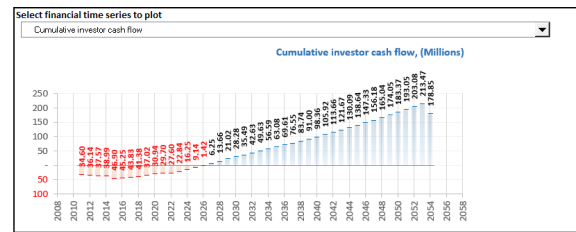
Model Layout: H2ALite tab



2	Nameplate capacity [kg/d]	H2A default & estimates	Enter user overrides in yellow cells	Valid capacity range:
	56,500	56,500		1,695 to 56,500 [kg/d]
	2015			2015

Technology estimation		Normalized CapEx	
Total installed capital cost [2020\$]	\$ 86,495,734	1,531	[\$/kg-day]
Fixed OpEx w/o replacements [2020\$/year]	\$ 4,305,059	662	[\$/kW]
Variable OpEx [2020\$/kg H ₂]	\$ 0.024		
System life [years]	40	Production rate	
Utilization [%]	97%	56,805	[kg/d]

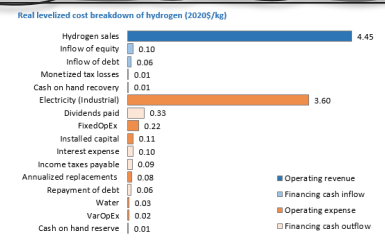
Energy & feedstock use		Usage per kg H ₂	
Electricity (Commercial)	0.000	[kWh]	
Electricity (Industrial)	55.500	[kWh]	
Electricity (On-shore wind)	0.000	[kWh]	
Natural Gas (Commercial)	0.000	[mmBTU]	
Natural Gas (Industrial)	0.000	[mmBTU]	
Biomass	0.000	[s, ton]	
Coal	0.000	[mmBTU]	
Water	3.780	[gall]	
Water Total	3.780	[gall]	



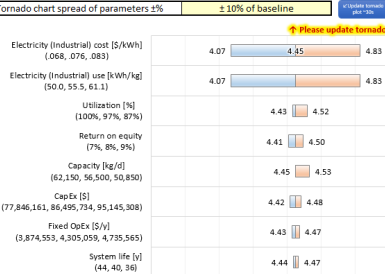
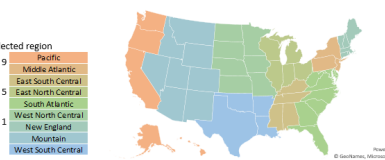
Coproducts		H2A default	User override
HCO sequestration		0%	
Steam co-product sales		0.000	[mmBTU/kg H ₂]

Financials specification		H2A default	User override
Real return on equity		8%	
Debt/equity		1.50	
Interest rate		3.7%	
Depreciation type		MACRS	
MACRS depreciation period		20	[years]
Total income tax rate		25.74%	
Cash on hand		1.0	[month of OpEx]

Financial incentives		H2A default	User override
Per-kilogram incentives		0.00	[\$/kg H ₂]
Per-kilogram incentive mechanism		Tax credit	
Per-kilogram incentive sunset		10	[years]
Per-kilogram annual reduction %		0.00	[%/year]
Capital incentive or investment tax credit		0.0%	[% of CapEx]



Select regional prices → (AEO 2022 Ref)		US Average	Energy & feedstock impact on total cost	Input Power	Input Energy	Efficiency
H2A default	User override	User override	[\$/kg H ₂]	[kW HHV]	[kWh HHV/kg]	[HHV]
0.115			\$ 3.59791	130.656	55.5000	71.2%

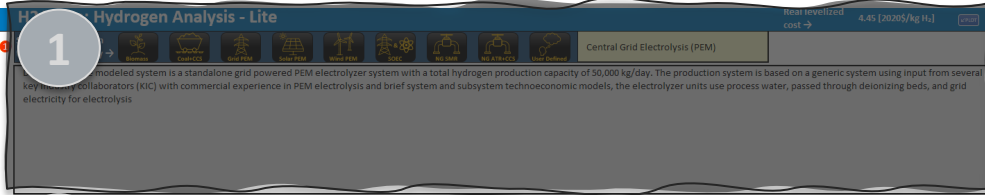


2	Analysis inputs	H2A default & estimates	3 Enter user overrides in yellow cells	Valid capacity range: 1,695 to 56,500 [kg/d]
	Specify production nameplate capacity [kg/d]	56,500	2015	
	Desired startup year			

2 Nameplate Capacity & Tech Year

- In blue: values from H2A default case.
- In yellow: user override values.
 - user overrides must be blank for defaults to take precedence
- Startup year must be populated
 - Select 2015 for startup year to represent "Current" H2A case information
 - Select 2040 for startup year to represent "Future" H2A case information

Model Layout: H2ALite tab



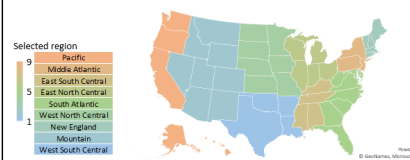
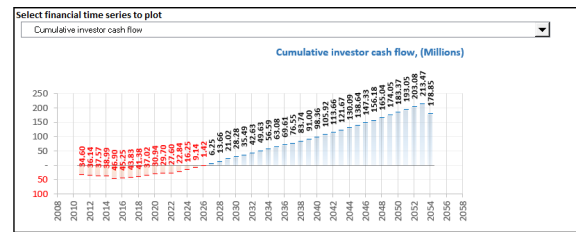
1

2

3

Technology estimation		Normalized CapEx	
Total installed capital cost [2020\$]	\$ 86,495,734	1,531	[\$/kg-day]
Fixed OpEx w/o replacements [2020\$/year]	\$ 4,305,059	662	[\$/kW]
Variable OpEx [2020\$/kg H ₂]	\$ 0.024		
System life [years]	40		
Utilization [%]	97%		
		Production rate	
		54,805	[kg/d]

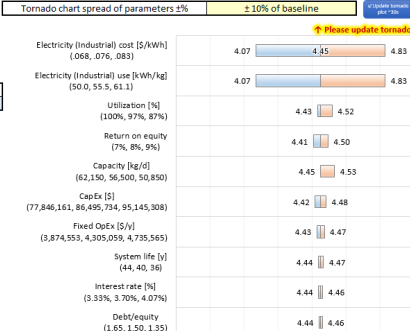
Energy & feedstock use		Usage per kg H ₂		Select regional prices → (AEO 2022 Ref)		US Average		Energy & feedstock prices →		Input Power		Input Energy		Efficiency	
		H2A default	User override	H2A default	User override					[kW HHV]	[kWh HHV/kg]			[BHV]	
Electricity (Commercial)	0.000	[kWh]		0.115	[\$/kWh]										
Electricity (Industrial)	55.500	[kWh]		0.075	[\$/kWh]					130.656	55.5000				
Electricity (On-shore wind)	0.000	[kWh]		0.048	[\$/kWh]							0			
Natural Gas (Commercial)	0.000	[mmBTU]		0.034	[\$/kWh]							0			
Natural Gas (Industrial)	0.000	[mmBTU]		8.28	[\$/mmBTU]										
Biomass	0.000	[\$/ton]		4.11	[\$/mmBTU]										
Coal	0.000	[mmBTU]		52.6	[\$/ton]										
Water	0.000	[gall]		2.33	[\$/mmBTU]										
Water Total	3.780	[gall]		2.94	[\$/gall]										
				0.0033	[\$/gall]										
				Total:	\$ 3.62										



Coproducts		H2A default		User override	
CO ₂ sequestration			0%		
Steam co-product sales		0.000	[mmBTU/kg H ₂]		

Financials specification		Debt %, equity %	
Real return on equity	8%		
Debt/equity	1.50	D=60%, E=40%	
Interest rate	3.7%		
Depreciation type	MACRS		
MACRS depreciation period	20 [years]		
Total income tax rate	25.74%		
Cash on hand	1.0 [month of OpEx]		

Financial incentives		Per-kilogram incentives	
Per-kilogram incentives	0.00	[\$/kg H ₂]	
Per-kilogram incentive mechanism	Tax credit		
Per-kilogram incentive sunset	10 [years]		
Per-kilogram annual reduction %	0.00	[%/year]	
Capital incentive or investment tax credit	0.0%	[% of CapEx]	



Technology estimation		Normalized CapEx	
Total installed capital cost [2020\$]	\$ 86,495,734	1,531	[\$/kg-day]
Fixed OpEx w/o replacements [2020\$/year]	\$ 4,305,059	662	[\$/kW]
Variable OpEx [2020\$/kg H ₂]	\$ 0.024		
System life [years]	40		
Utilization [%]	97%		
		Production rate	
		54,805	[kg/d]

- ### 3 Technology CapEx, OpEx, Life, Utilization
- Parameters in blue will reflect H2A values based on specified nameplate capacity and technology year.
 - Normalized CapEx is available to the right to inform underlying metrics such as \$/kW for electrolyzers.
 - Use yellow cells to provide overrides of any of the above parameters.
 - Model results will update as any input values are altered

Model Layout: H2ALite tab

Hydrogen Analysis - Lite

Central Grid Electrolyzer (PEM)

Real levelized cost → 4.45 [2020\$/kg H₂]

Modeled system is a standalone grid powered PEM electrolyzer system with a total hydrogen production capacity of 50,000 kg/day. The production system is based on input from several key technology collaborators (KIC) with commercial experience in PEM electrolysis and brief system and subsystem techno-economic models, the electrolyzer units use process water, passed through deionizing beds, and grid electricity for electrolysis.

1. H2A values for refurbishments and replacements are annualized.

2. User can override annualized value or explicit replacement intervals and % of CapEx spent in each refurbishment event.

3. Click "↓Plot" macro to show capital expenditure schedule with any specified refurbishments.

4. Refurbishments & Replacements

Parameter	Value
Annualized replacement costs [2020\$/year]	1,545,228
Replacements interval (years)	
Replacements (% of installed CapEx)	

Real levelized cost breakdown of hydrogen (2020\$/kg)

Category	Value
Hydrogen sales	4.45
Inflow of equity	0.10
Inflow of debt	0.06
Monetized tax losses	0.01
Cash on hand recovery	0.01
Electricity (Industrial)	3.60
Dividends paid	0.33
Fixed OpEx	0.22
Installed capital	0.11
Interest expense	0.10
Income taxes payable	0.09
Annualized replacements	0.08
Repayment of debt	0.06
Water	0.03
VarOpEx	0.02
Cash on hand reserve	0.01

Energy & feedstock use

Usage per kg H ₂	H2A default	User override
Electricity (Commercial)	0.000 [kWh]	
Electricity (Industrial)	55.500 [kWh]	
Electricity (Solar)	0.000 [kWh]	
Electricity (On-shore wind)	0.000 [kWh]	
Natural Gas (Commercial)	0.000 [mmBTU]	
Natural Gas (Industrial)	0.000 [mmBTU]	
Biomass	0.000 [s.ton]	
Coal	0.000 [mmBTU]	
Oil	0.000 [gal]	
Water Total	3.780 [gal]	

Select regional prices → (AEO 2022 Ref)

Energy & feedstock impact on cost	US Average	User override
H2A default	0.115 [\$/kWh]	
Electricity (Industrial)	0.075 [\$/kWh]	
Electricity (Solar)	0.048 [\$/kWh]	
Electricity (On-shore wind)	0.034 [\$/kWh]	
Natural Gas (Commercial)	8.28 [\$/mmBTU]	
Natural Gas (Industrial)	4.11 [\$/mmBTU]	
Biomass	52.6 [\$/s.ton]	
Coal	2.33 [\$/mmBTU]	
Oil	2.94 [\$/gal]	
Water	0.0033 [\$/gal]	
Total	\$ 3.62	

Input Power

Input Power	Input Energy	Efficiency
[kW HHV]	[kWh HHV/kg]	[BHV]
130,656	55,500	71.2%

Select financial time series to plot

Cumulative investor cash flow

Cumulative investor cash flow, (Millions)

2008 2010 2012 2014 2016 2018 2020 2022 2024 2026 2028 2030 2032 2034 2036 2038 2040 2042 2044 2046 2048 2050 2052 2054 2056 2058

100 150 200 250

18.14 18.07 18.00 17.93 17.86 17.79 17.72 17.65 17.58 17.51 17.44 17.37 17.30 17.23 17.16 17.09 17.02 16.95 16.88 16.81 16.74 16.67 16.60 16.53 16.46 16.39 16.32 16.25 16.18 16.11 16.04 15.97 15.90 15.83 15.76 15.69 15.62 15.55 15.48 15.41 15.34 15.27 15.20 15.13 15.06 14.99 14.92 14.85 14.78 14.71 14.64 14.57 14.50 14.43 14.36 14.29 14.22 14.15 14.08 14.01 13.94 13.87 13.80 13.73 13.66 13.59 13.52 13.45 13.38 13.31 13.24 13.17 13.10 13.03 12.96 12.89 12.82 12.75 12.68 12.61 12.54 12.47 12.40 12.33 12.26 12.19 12.12 12.05 11.98 11.91 11.84 11.77 11.70 11.63 11.56 11.49 11.42 11.35 11.28 11.21 11.14 11.07 11.00 10.93 10.86 10.79 10.72 10.65 10.58 10.51 10.44 10.37 10.30 10.23 10.16 10.09 10.02 9.95 9.88 9.81 9.74 9.67 9.60 9.53 9.46 9.39 9.32 9.25 9.18 9.11 9.04 8.97 8.90 8.83 8.76 8.69 8.62 8.55 8.48 8.41 8.34 8.27 8.20 8.13 8.06 7.99 7.92 7.85 7.78 7.71 7.64 7.57 7.50 7.43 7.36 7.29 7.22 7.15 7.08 7.01 6.94 6.87 6.80 6.73 6.66 6.59 6.52 6.45 6.38 6.31 6.24 6.17 6.10 6.03 5.96 5.89 5.82 5.75 5.68 5.61 5.54 5.47 5.40 5.33 5.26 5.19 5.12 5.05 4.98 4.91 4.84 4.77 4.70 4.63 4.56 4.49 4.42 4.35 4.28 4.21 4.14 4.07 4.00 3.93 3.86 3.79 3.72 3.65 3.58 3.51 3.44 3.37 3.30 3.23 3.16 3.09 3.02 2.95 2.88 2.81 2.74 2.67 2.60 2.53 2.46 2.39 2.32 2.25 2.18 2.11 2.04 1.97 1.90 1.83 1.76 1.69 1.62 1.55 1.48 1.41 1.34 1.27 1.20 1.13 1.06 0.99 0.92 0.85 0.78 0.71 0.64 0.57 0.50 0.43 0.36 0.29 0.22 0.15 0.08 0.01

Selected region

9 Pacific
5 Middle Atlantic
5 East South Central
5 East North Central
5 South Atlantic
1 West North Central
1 New England
1 Mountain
1 West South Central

Tornado chart spread of parameters ±1% ±10% of baseline

Please update tornado!

Parameter	Value
Electricity (Industrial) cost [\$/kWh] (0.68, 0.76, 0.83)	4.07 4.35 4.83
Electricity (Industrial) use [kWh/kg] (50.0, 55.5, 61.1)	4.07 4.35 4.83
Utilization [%] (100%, 97%, 87%)	4.43 4.52
Return on equity (7%, 8%, 9%)	4.41 4.50
Capacity [kg/d] (62,150, 56,500, 50,850)	4.45 4.53
CapEx (\$) (77,846,161, 86,495,734, 95,145,308)	4.42 4.48
Fixed OpEx [\$/h] (3,874,553, 4,305,059, 4,735,565)	4.43 4.47
System life [yr] (44, 40, 36)	4.44 4.47
Interest rate [%] (3.33%, 3.70%, 4.07%)	4.44 4.46
Debt/equity (1.65, 1.50, 1.35)	4.44 4.46

Coproducts

Coproducts	H2A default	User override
CO ₂ sequestration	0%	
Steam co-product sales	0.000 [mmBTU/kg H ₂]	

Financials specification

Financials specification	Value
Real return on equity	8%
Debt/equity	1.50
Interest rate	3.7%
Depreciation type	MACRS
MACRS depreciation period	20 [years]
Total income tax rate	25.74%
Cash on hand	1.0 [month of OpEx]

Debt %, equity %
D=60%, E=40%

Financial incentives

Financial incentives	Value
Per-kilogram incentives	0.00 [\$/kg H ₂]
Per-kilogram incentive mechanism	Tax credit
Per-kilogram incentive sunset	10 [years]
Per-kilogram annual reduction %	0.00 [%/year]
Capital incentive or investment tax credit	0.0% [% of CapEx]

Refurbishments & replacements	
Annualized replacement costs [2020\$/year]	1,545,228
Replacements interval (years)	
Replacements (% of installed CapEx)	

↓PLOT

4 Refurbishments & Replacements

- H2A values for refurbishments and replacements are annualized.
- User can override annualized value or explicit replacement intervals and % of CapEx spent in each refurbishment event.
- Click "↓Plot" macro to show capital expenditure schedule with any specified refurbishments.

Note: both replacement interval and % of CapEx must be provided for values to take hold.

Model Layout: H2ALite tab

1 Hydrogen Analysis - Lite

Central Grid Electrolysis (PEM)

Real levelized cost → 4.45 [2020\$/kg H₂]

The modeled system is a standalone grid powered PEM electrolyzer system with a total hydrogen production capacity of 50,000 kg/day. The production system is based on a generic system using input from several key technology collaborators (KIC) with commercial experience in PEM electrolysis and brief system and subsystem techno-economic models, the electrolyzer units use process water, passed through deionizing beds, and grid electricity for electrolysis.

2 H2A default & estimates

Enter user overrides in yellow cells

Valid capacity range: 1,695 to 56,500 [kg/d]

Hydrogen nameplate capacity [kg/d]: 56,500

Year: 2015

3 Financials

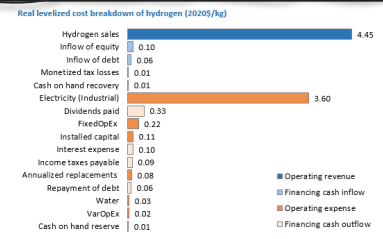
Normalized CapEx: 1,531 [\$/kg-day]

Normalized OpEx: 662 [\$/kW]

Production rate: 54,805 [kg/d]

4 Replacements

Replacement costs [2020\$/year]: 1,545,228



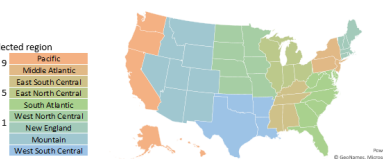
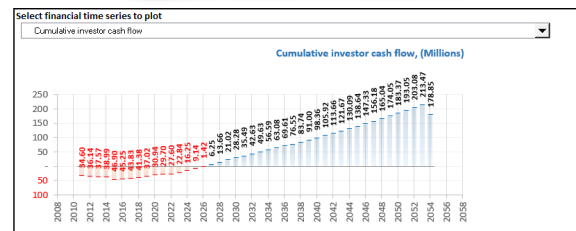
5 Energy & feedstock use

	H2A default	User override
Electricity (Commercial)	0.000 [kWh]	
Electricity (Industrial)	55.500 [kWh]	
Electricity (Solar)	0.000 [kWh]	
Electricity (On-shore wind)	0.000 [kWh]	
Natural Gas (Commercial)	0.000 [mmBTU]	
Natural Gas (Industrial)	0.000 [mmBTU]	
Biomass	0.000 [s.ton]	
Coal	0.000 [mmBTU]	
Diesel	0.000 [gal]	
Water Total	3.780 [gal]	

Select regional prices → AEO 2022 Ref

Energy & feedstock impact on production [\$/kg H ₂]	US Average	User override
H2A default	0.115 [\$/kWh]	
Electricity (Industrial)	0.075 [\$/kWh]	
Electricity (Solar)	0.048 [\$/kWh]	
Electricity (On-shore wind)	0.034 [\$/kWh]	
Natural Gas (Commercial)	8.28 [\$/mmBTU]	
Natural Gas (Industrial)	4.11 [\$/mmBTU]	
Biomass	52.6 [\$/s.ton]	
Coal	2.33 [\$/mmBTU]	
Diesel	2.94 [\$/gal]	
Water	0.0033 [\$/gal]	
Total	\$ 3.62	

Input Power [kW HHV]	Input Energy [kWh HHV/kg]	Efficiency [BHV]
130,656	55,500	71.2%



Coproducts

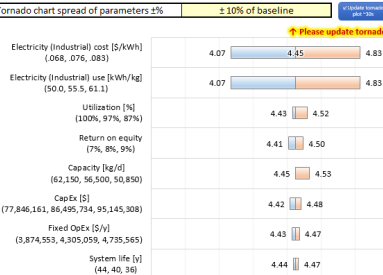
	H2A default	User override
H ₂ O sequestration	0%	
Steam co-product sales	0.000 [mmBTU/kg H ₂]	

Financials specification

	H2A default	User override
Real return on equity	8%	
Debt/equity	1.50	
Interest rate	3.7%	
Depreciation type	MACRS	
MACRS depreciation period	20 [years]	
Total income tax rate	25.74%	
Cash on hand	1.0 [month of OpEx]	

Financial incentives

	H2A default	User override
Per-kilogram incentives	0.00 [\$/kg H ₂]	
Per-kilogram incentive mechanism	Tax credit	
Per-kilogram incentive sunset	10 [years]	
Per-kilogram annual reduction %	0.00 [%/year]	
Capital incentive or investment tax credit	0.0% [% of CapEx]	



Energy & feedstock use	Usage per kg H ₂	
	H2A default	User override
Electricity (Commercial)	0.000 [kWh]	
Electricity (Industrial)	55.500 [kWh]	
Electricity (Solar)	0.000 [kWh]	
Electricity (On-shore wind)	0.000 [kWh]	
Natural Gas (Commercial)	0.000 [mmBTU]	
Natural Gas (Industrial)	0.000 [mmBTU]	
Biomass	0.000 [s.ton]	
Coal	0.000 [mmBTU]	
Diesel	0.000 [gal]	
Water Total	3.780 [gal]	

5 Energy & Water Use Rates

- In blue: values from H2A default case.
- In yellow: user override values.

Note: entries with grayed out H2A values can also receive overrides.

Model Layout: H2ALite tab

1 Hydrogen Analysis - Lite

2 H2A default & estimates

3 Capital cost [2020\$]

4 Replacement costs [2020\$/year]

5 Energy & feedstock use

6 Select regional prices

Real leveled cost breakdown of hydrogen (2020\$/kg)

Cumulative investor cash flow

Selected region

Tornado chart spread of parameters ±1%

±10% of baseline

↑ Please update tornado!

Co-products

Financials specification

Financial incentives

Energy & feedstock use

Electricity (Commercial)
Electricity (Industrial)
Electricity (Solar)
Electricity (On-shore wind)
Natural Gas (Commercial)
Natural Gas (Industrial)
Biomass
Coal
Diesel
Water Total

4 Select regional prices (AEO 2022 Ref)

US Average	User override	MAP	PLOT	Energy & feedstock impact on price [\$/kg H ₂]
H2A default				
0.115 [\$/kWh]				\$ -
0.075 [\$/kWh]				\$ 3.59731
0.048 [\$/kWh]				\$ -
0.034 [\$/kWh]				\$ -
8.28 [\$/mmBTU]				\$ -
4.11 [\$/mmBTU]				\$ -
52.6 [\$/s.ton]				\$ -
2.33 [\$/mmBTU]				\$ -
2.94 [\$/gal]				\$ -
0.0033 [\$/gal]				\$ 0.03
Total:				\$ 3.62

- 6** Energy & Water Costs
1. Select region for price projections.
 2. In blue: regional values in startup year
 3. Use yellow cells if overriding a price is desired. (Note: model will use override as a constant value on real 2020\$ basis)
 4. Use "Plot" macro to show time series for feed cost.
 5. Use "Map" macro to display regionalized prices in startup year.
 6. Panel on right shows H₂ price contribution

Model Layout: H2ALite tab

Hydrogen Analysis - Lite

Central Grid Electrolyzer (PEM)

Real levelized cost → 4.45 [2020\$/kg H₂]

Modeled system is a standalone grid powered PEM electrolyzer system with a total hydrogen production capacity of 50,000 kg/day. The production system is based on a generic system using input from several key technology collaborators (KIC) with commercial experience in PEM electrolysis and brief system and subsystem techno-economic models, the electrolyzer units use process water, passed through deionizing beds, and grid electricity for electrolysis

1. Nameplate capacity [kg/d]: 55,500

2. H2A default & estimates: 55,500

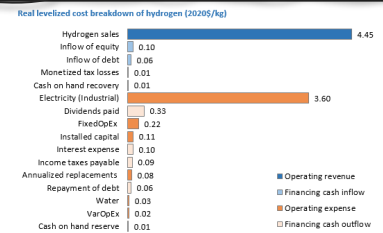
3. Enter user overrides in yellow cells

4. Valid capacity range: 1,095 to 56,500 [kg/d]

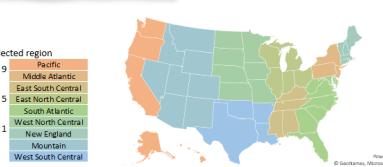
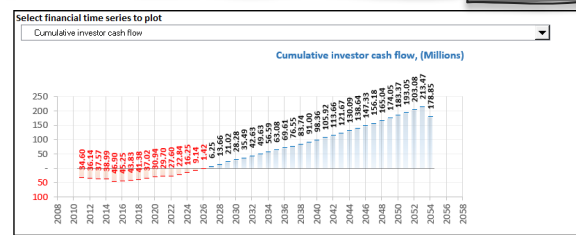
5. Normalized CapEx: 662 [\$/kW]

6. Production rate: 54,805 [kg/d]

7. US Average: 3.62 [\$/kg H₂]



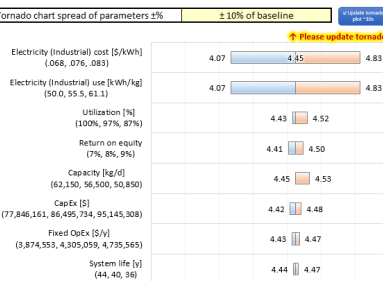
Input Power	Input Energy	Efficiency
[kW HHV]	[kWh HHV/kg]	[HHV]
130,656	55,500	71.2%



Coproducts	H2A default	User override
H ₂ O sequestration	0%	
Steam co-product sales	0.000 [mmBTU/kg H ₂]	

Financials specification	Value	Unit
Real return on equity	8%	
Debt/equity	1.50	
Interest rate	3.7%	
Depreciation type	MACRS	
MACRS depreciation period	20	[years]
Total income tax rate	25.74%	
Cash on hand	1.0	[month of OpEx]

Financial incentives	Value	Unit
Per-kilogram incentives	0.00	[\$/kg H ₂]
Per-kilogram incentive mechanism	Tax credit	
Per-kilogram incentive sunset	10	[years]
Per-kilogram annual reduction %	0.00	[%/year]
Capital incentive or investment tax credit	0.0%	[% of CapEx]



Financials specification		
Real return on equity	8%	
Debt/equity	1.50	
Interest rate	3.7%	
Depreciation type	MACRS	
MACRS depreciation period	20	[years]
Total income tax rate	25.74%	
Cash on hand	1.0	[month of OpEx]

Debt %, equity %
D=60%, E=40%

↑ PLOT

7 Financials Specification

- H2A default values are provided in blue
- In yellow are user overrides

Model Layout: H2ALite tab

Hydrogen Analysis - Lite

Central Grid Electrolyzer (PEM)

Real levelized cost → 4.45 (2020\$/kg H₂)

Modeled system is a standalone grid powered PEM electrolyzer system with a total hydrogen production capacity of 50,000 kg/day. The production system is based on a generic system using input from several key industry collaborators (KIC) with commercial experience in PEM electrolysis and brief system and subsystem techno-economic models, the electrolyzer units use process water, passed through deionizing beds, and grid electricity for electrolysis.

1. Nameplate capacity [kg/d]: 56,500

2. H2A default & estimates: 56,500

3. Enter user overrides in yellow cells

4. Valid capacity range: 1,695 to 56,500 (kg/d)

5. Real levelized cost breakdown of hydrogen (2020\$/kg)

6. US Average

7. Select financial time series to plot

8. Financial Incentives Specifications

9. Tornado chart spread of parameters ±1%

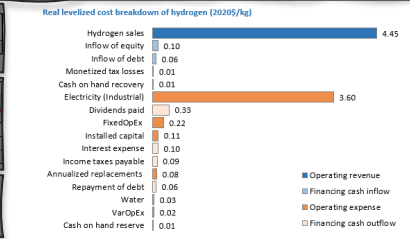
RESET H2ALite Sheet

Financial incentives		
Per-kilogram incentives	0.00	[\$/kg H ₂]
Per-kilogram incentive mechanism	Tax credit	
Per-kilogram incentive sunset	10	[years]
Per-kilogram annual reduction %	0.00	[%/year]
Capital incentive or investment tax credit	0.0%	[% of CapEx]

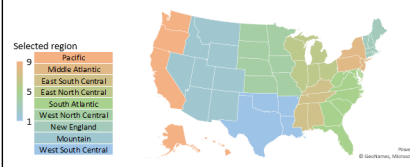
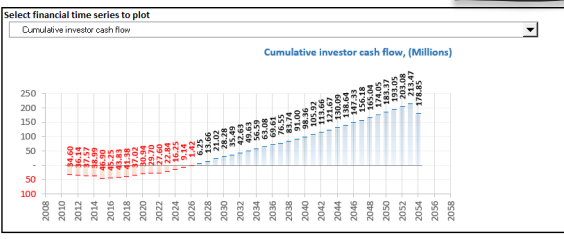
↑ PLOT

8 Financial Incentives Specifications

- By default, incentives are not factored into H2A cases.
- Per-kg incentives can be modeled as:
 - ordinary income: resulting in ~1:1 reduction in price
 - tax credit: higher price reduction relative to ordinary income mechanics as incentive bypasses taxation

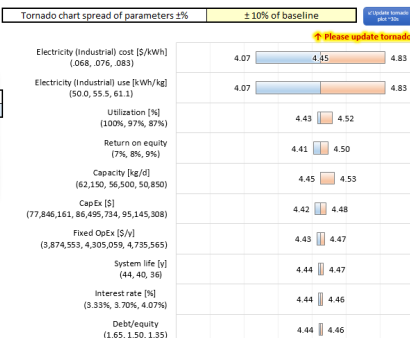


Input Power	Input Energy	Efficiency
[kW HHV]	[kWh HHV/kg]	[HHV]
130,656	55,500	71.2%



Coproducts	H2A default	User override
H ₂ O sequestration	0%	
Steam co-product sales	0.000	(mmBTU/kg H ₂)

Financials specification	H2A default	User override
Return on equity	8%	Debt %, equity %
Debt %	1.50	D=60%, E=40%
CapEx	2.7%	
MACRS	20	
Depreciation period	20	[years]
Corporate tax rate	25.74%	
Cash on hand	1.0	[month of OpEx]



Model Layout: H2ALite tab

Hydrogen Analysis - Lite

Central Grid Electrolyzer (PEM)

Modeled system is a standalone grid powered PEM electrolyzer system with a total hydrogen production capacity of 50,000 kg/day. The production system is based on a generic system using input from several key industry collaborators (KIC) with commercial experience in PEM electrolysis and brief system and subsystem techno-economic models, the electrolyzer units use process water, passed through deionizing beds, and grid electricity for electrolysis.

1 Real levelized cost breakdown of hydrogen (2020\$/kg)

2 Nameplate capacity [kg/d]

3 Initial cost [2020\$]

4 Replacements [2020\$/year]

5 H2A default & estimates

6 Selection of energy & feedstock use

7 Financials specification

8 Incentives

9 Input Energy & Efficiency

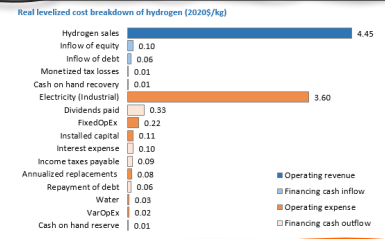
Energy & feedstock use

- Electricity (Commercial)
- Electricity (Industrial)
- Electricity (Solar)
- Electricity (On-shore wind)
- Natural Gas (Commercial)
- Natural Gas (Industrial)
- Biomass
- Coal
- Diesel
- Water Total

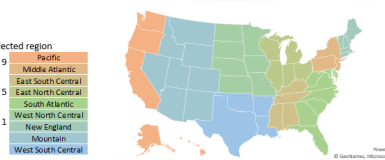
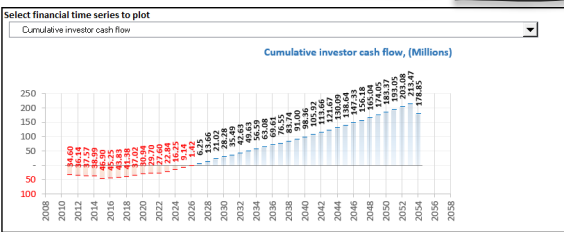
Input Power	Input Energy	Efficiency
[kW HHV]	[kWh HHV/kg]	[HHV]
-	-	-
130,656	55.5000	-
-	0	0
-	0	0
-	-	-
-	-	-
-	-	-
-	-	-
-	-	-
130,656	55.5	71.2%

9 Power & Efficiency Values

- No user input required in this section
- Tip: electrolysis power rating result here can be used to set electrolyzer installed CapEx to desired \$/kW target. E.g. CapEx in section **3**: = \$500 * 130,565 kW will result in electrolyzer CapEx of \$500/kW
- Clicking **“Switch to LHV”** macro button will toggle analysis between lower heating value and higher heating value basis.



Input Energy	Efficiency
[kWh HHV/kg]	[HHV]
130,656	55.5
	71.2%



Tornado chart spread of parameters ±1% ±10% of baseline

Parameter	Value
Electricity (Industrial) cost [\$/kWh] (0.68, 0.76, 0.83)	4.07
Electricity (Industrial) use [kWh/kg] (50.0, 55.5, 61.1)	4.07
Utilization [%] (100%, 97%, 87%)	4.43
Return on equity (7%, 8%, 9%)	4.41
Capacity [kg/d] (62,150, 56,500, 50,850)	4.45
CapEx [\$] (77,846,161, 86,495,734, 95,145,308)	4.42
Fixed OpEx [\$/h] (3,874,553, 4,305,059, 4,735,565)	4.43
System life [y] (44, 40, 36)	4.44
Interest rate [%] (3.33%, 3.70%, 4.07%)	4.44
Debt/equity (1.65, 1.50, 1.35)	4.44

Model Layout: H2ALite tab

Hydrogen Analysis - Lite

Central Grid Electrolyzer (PEM)

Modeled system is a standalone grid powered PEM electrolyzer system with a total hydrogen production capacity of 50,000 kg/day. The production system is based on a generic system using input from several key technology collaborators (KIC) with commercial experience in PEM electrolysis and brief system and subsystem techno-economic models, the electrolyzer units use process water, passed through deionizing beds, and grid electricity for electrolysis

1. Model Overview

2. Nameplate capacity [kg/d]: 56,500

3. Total cost [2020\$]: \$ 86,495,734

4. Annualized replacements [2020\$/year]: \$ 4,305,059

5. Replacements: 1,545,228

6. Selection of input energy sources

7. Financials specification

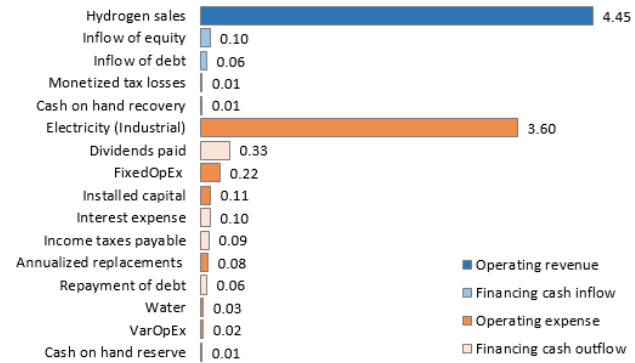
8. Incentives

9. Input Energy

10. Levelized cost breakdown of hydrogen (2020\$/kg)

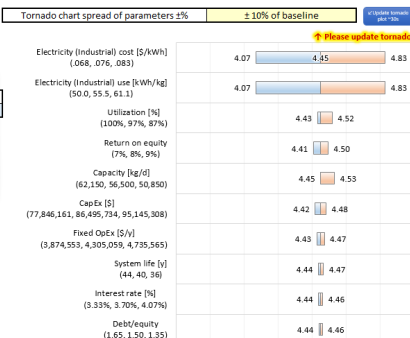
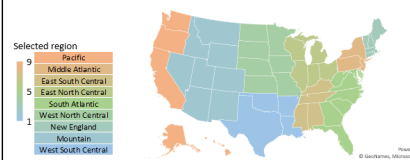
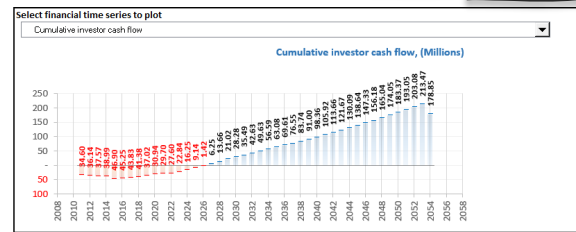
Levelized cost: 4.45 [2020\$/kg H₂]

Real levelized cost of hydrogen (2020\$/kg)



10 Levelized Cost Breakdown

- Displays levelized cash flows per kg H₂
- Sorts financing & operating cash flows by total contribution



Model Layout: H2ALite tab

Hydrogen Analysis - Lite

Central Grid Electrolyzer (PEM)

Modeled system is a standalone grid powered PEM electrolyzer system with a total hydrogen production capacity of 50,000 kg/day. The production system is based on a generic system using input from several key stakeholders (KIC) with commercial experience in PEM electrolysis and brief system and subsystem techno-economic models, the electrolyzer units use process water, passed through deionizing beds, and grid electricity for electrolysis

1 [Navigation icons]

2 [Nameplate capacity [kg/d], H2A default & estimates, Enter user overrides in yellow cells]

3 [Financials: Initial cost [2020\$], Replacements [2020\$/year], etc.]

4 [Replacements: Replacement costs [2020\$/year], Interval (years), etc.]

5 [Energy Use: H2A default, User override]

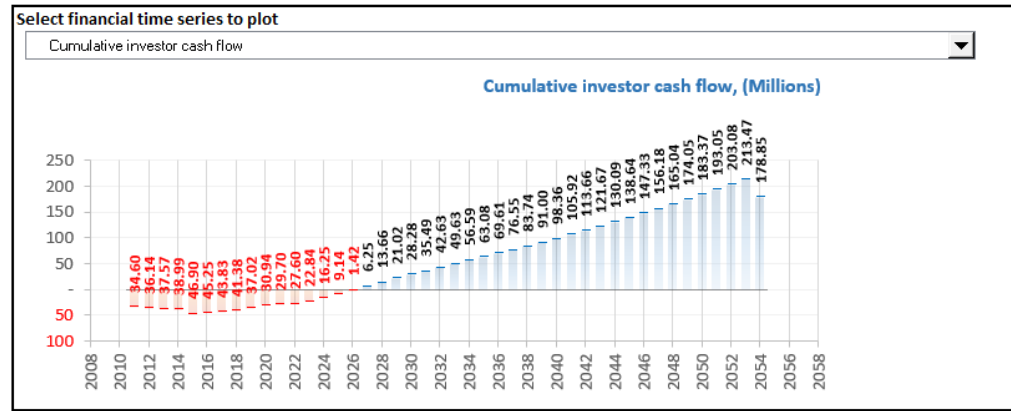
6 [Selected regional: US Average, Energy & feedstock impact on]

7 [Input Energy: kWh HHV/kg, Efficiency]

8 [Financials: Return on equity, Debt % equity, etc.]

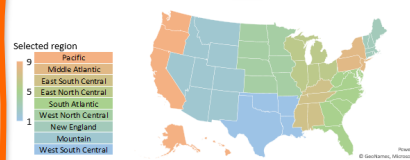
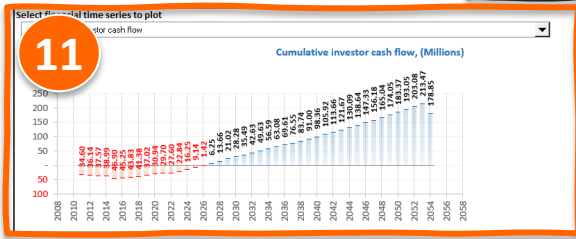
9 [Financials: Debt/equity, Interest rate, etc.]

10 [Breakdown of Hydrogen (2020\$/kg): Hydrogen sales, W of equity, etc.]



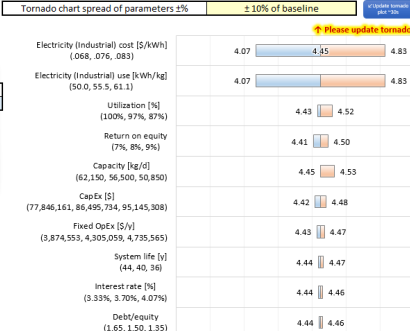
11 Time Series Charts

- Chart can be updated via drop-down menu on top to any analysis parameter
- Chart can also be updated by using "Plot" macro buttons in the H2ALite tab



7 [Financials: Return on equity, Debt % equity, etc.]

8 [Financials: Debt/equity, Interest rate, etc.]



Model Layout: H2ALite tab

1 Hydrogen Analysis - Lite

2 H2A default & estimates

3 Capital cost (2020\$)

4 Replacements

5 H2A default

6 Selection

7 Financials specification

8 Incentives

9 Input Energy

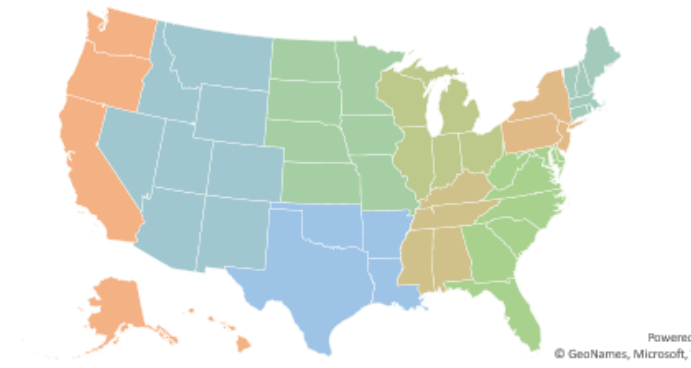
10 Breakdown of hydrogen (2020\$/kg)

11 Cumulative investor cash flow (Millions)

12 Regionalization Map

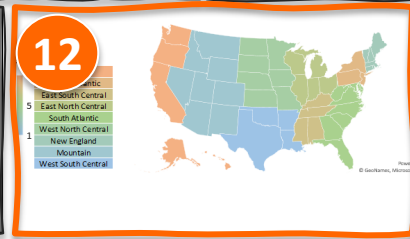
Selected region

- 9 Pacific
- Middle Atlantic
- East South Central
- 5 East North Central
- South Atlantic
- 1 West North Central
- New England
- Mountain
- West South Central



12 Regionalization Map

- Displays Census Regions used by AEO for informing regional price forecasts
- Chart can be updated by using “map” macro buttons in the H2ALite tab



Tornado chart spread of parameters ±1% ±10% of baseline

Parameter	Value
Electricity (Industrial) cost [\$/kWh] (0.68, 0.76, 0.83)	4.07
Electricity (Industrial) use [kWh/kg] (50.0, 55.5, 61.1)	4.07
Utilization [%] (100%, 97%, 87%)	4.43
Return on equity (7%, 8%, 9%)	4.41
Capacity [kg/d] (62,140, 56,500, 50,850)	4.45
CapEx (\$) (77,846,161, 86,495,734, 95,145,308)	4.42
Fixed OpEx [\$/h] (3,874,553, 4,305,059, 4,735,565)	4.43
System life [y] (44, 40, 36)	4.44
Interest rate [%] (3.33%, 3.70%, 4.07%)	4.44
Debt/equity (1.65, 1.50, 1.35)	4.44

Model Layout: H2ALite tab

Hydrogen Analysis - Lite

1. Model description: A standalone grid powered PEM electrolyzer system with a total hydrogen production capacity of 50,000 kg/day. The production system is based on a generic system using input from several key technology collaborators (KIC) with commercial experience in PEM electrolysis and brief system and subsystem techno-economic models, the electrolyzer units use process water, passed through deionizing beds, and grid electricity for electrolysis.

2. Nameplate capacity [kg/d]: 55,500

3. Capital cost [2020\$]: \$ 86,495,734

4. Replacements [2020\$/year]: \$ 4,305,059

5. Electricity use [kWh/kg H₂]: 55,500

6. Selection of regional electricity prices

7. Return on equity: 8%

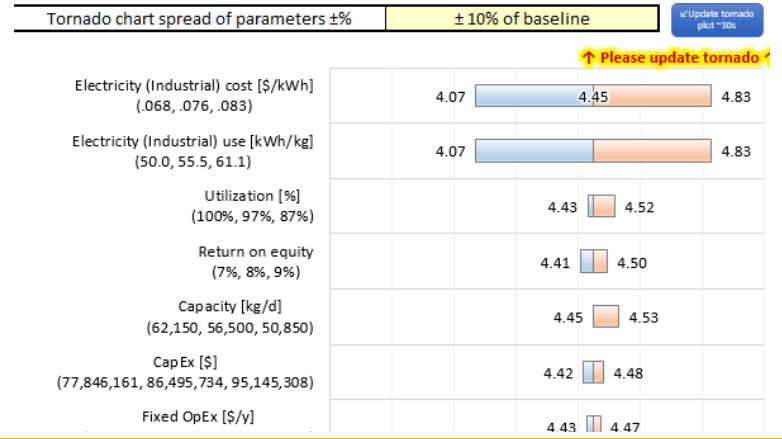
8. Incentives: Tax credit, Incentive mechanism, Incentive sunset, Annual reduction %, Incentive or investment tax credit

9. Input Energy: 130,656 kWh HHV/kg

10. Breakdown of hydrogen production costs

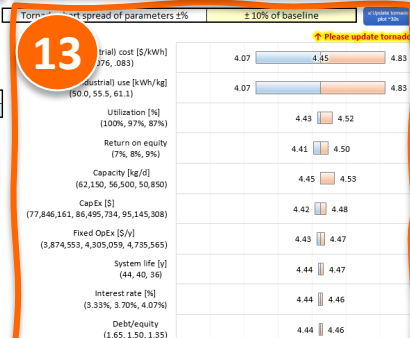
11. Cumulative investor cash flow (Millions) from 2008 to 2035

12. Regional selection map of the United States



13 Tornado Chart

1. Provides single-parameter sensitivity for all input variables
2. Spread can be specified (default is 10%)
3. Click "Update tornado plot" macro button to refresh cases



Webinar Outline



H2A-Lite

Model purpose & framework
Case studies & benchmarking

Model demonstration



H2FAST

Model purpose & framework
Layout & walkthrough
Model demonstration

Webinar Outline



H2A-Lite

Model purpose & framework
Layout & walkthrough
Model demonstration



H2FAST

Model purpose & framework
Layout & walkthrough
Model demonstration

Model Purpose

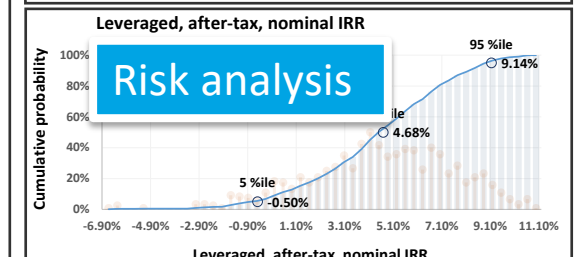
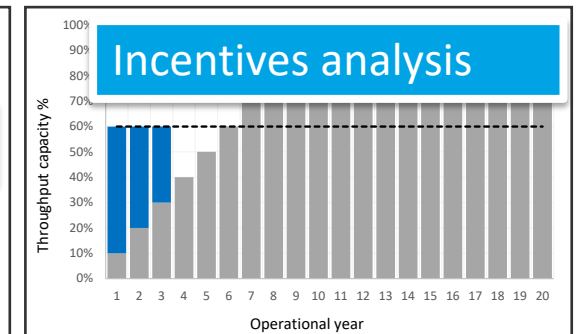
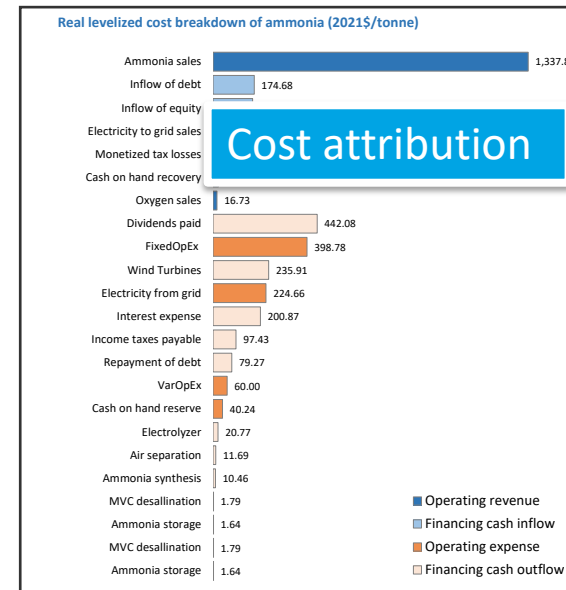
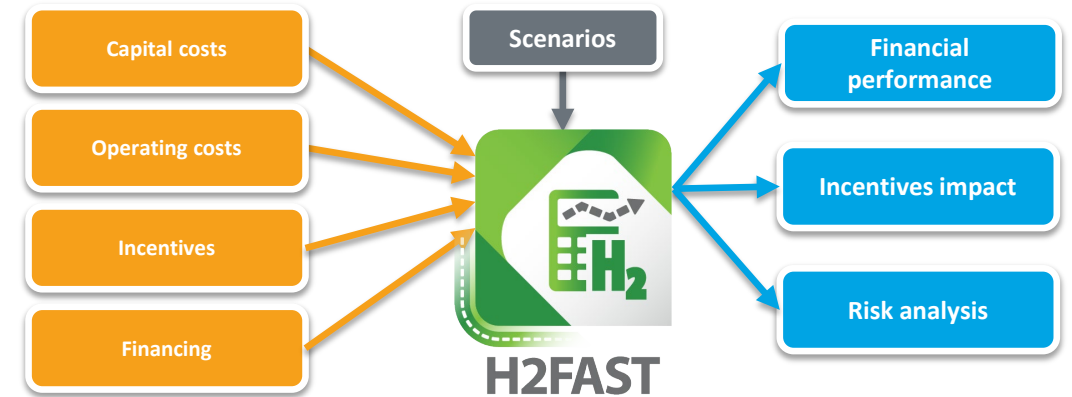
Provide flexible rigorous financial analysis for wide variety of hydrogen and non-hydrogen production and service systems.

Accommodate diverse systems and services. (example past applications)

- Retail hydrogen sales
- Hydrogen production (electrolytic, fossil, biomass, others)
- Hydrogen delivery & distribution
- Ammonia production
- Methane pyrolysis
- EV charging
- Seasonal energy storage
- Fleet operations
- Combined heat and power (CHP fuel cells)

Model users

- System operators
- Government & policy makers
- Equity and debt investors
- Strategic investors (gas suppliers, utilities, car OEMs)
- Equipment manufacturers
- Academic institutions & national laboratories



Model Framework

Model computation framework: Generally Accepted Accounting Principles (GAAP)*

- ✓ **Income statement** projections (revenues, expenses, taxes)
- ✓ **Cash flow statement** projections (cash on hand, capital expenditures, financing transactions)
- ✓ **Balance sheet** projections (assets, liabilities, equity)**

Price taker & price-setting modes

- **Price taker:** user specifies a market price of commodity. Model computes financial performance.



- **Price-setting mode:** user specifies target financial performance. Model computes required price.



* Model can perform analysis compatible with International Financial Reporting Standards (IFRS)

** Model returns all project cash generated in excess of reserve requirements as “dividends” and does not speculate on treatment of any retained earnings. Users can perform their own attribution of retained earnings (e.g. dividends to share holders, reinvestment, reserves for bond repayments)

Webinar Outline



H2A-Lite

Model purpose & framework
Layout & walkthrough
Model demonstration



H2FAST

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Layout & walkthrough
Model demonstration

Model Tabs Descriptions



Description

- Description
- Version history
- Use agreement
- Contact info

Interface

- User inputs, scenarios, risk analysis, graphical outputs

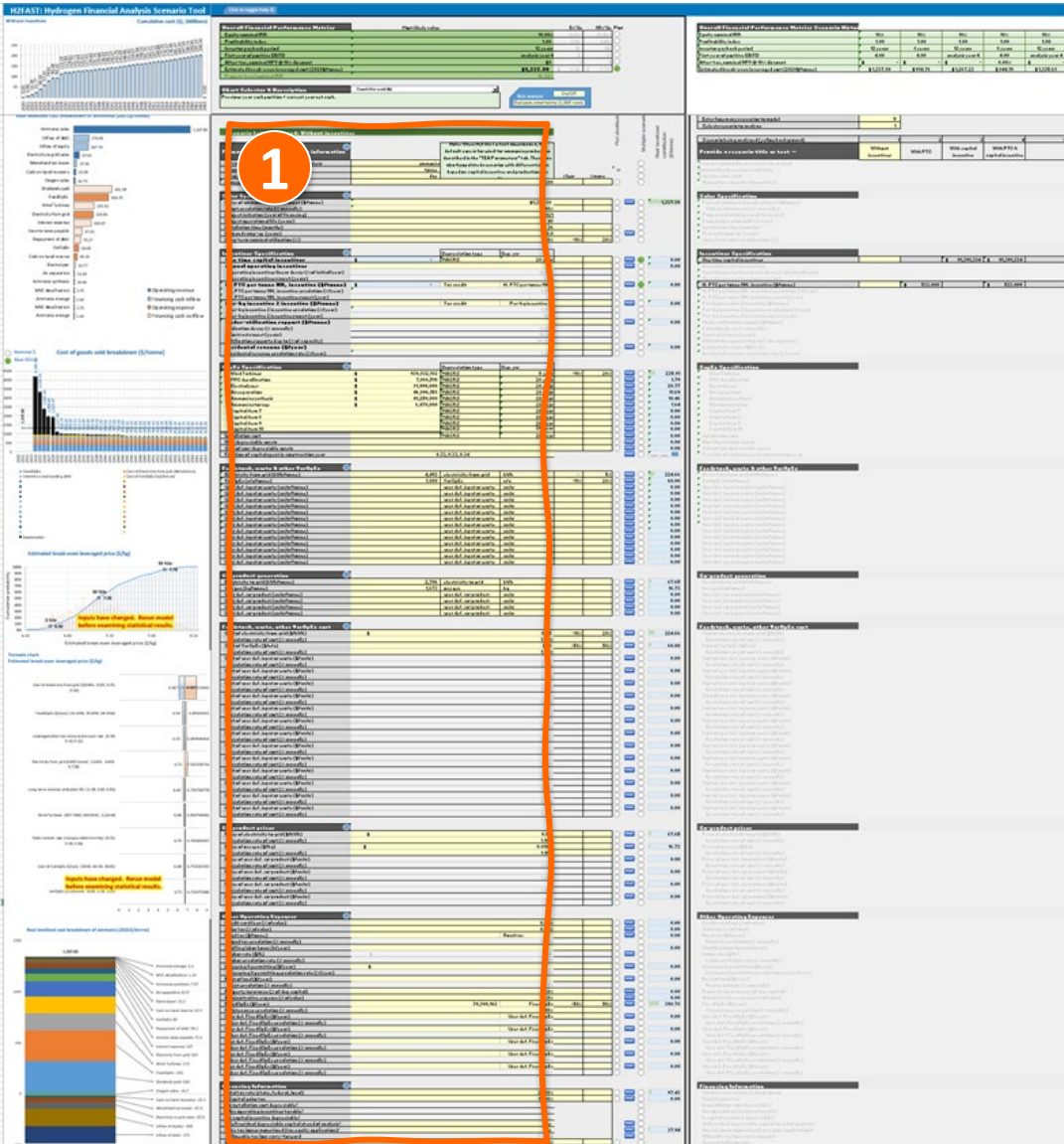
Overrides

- Custom cost and price profiles vs. calendar years
- Custom performance, sales, refurbishments by analysis year

Report Tables

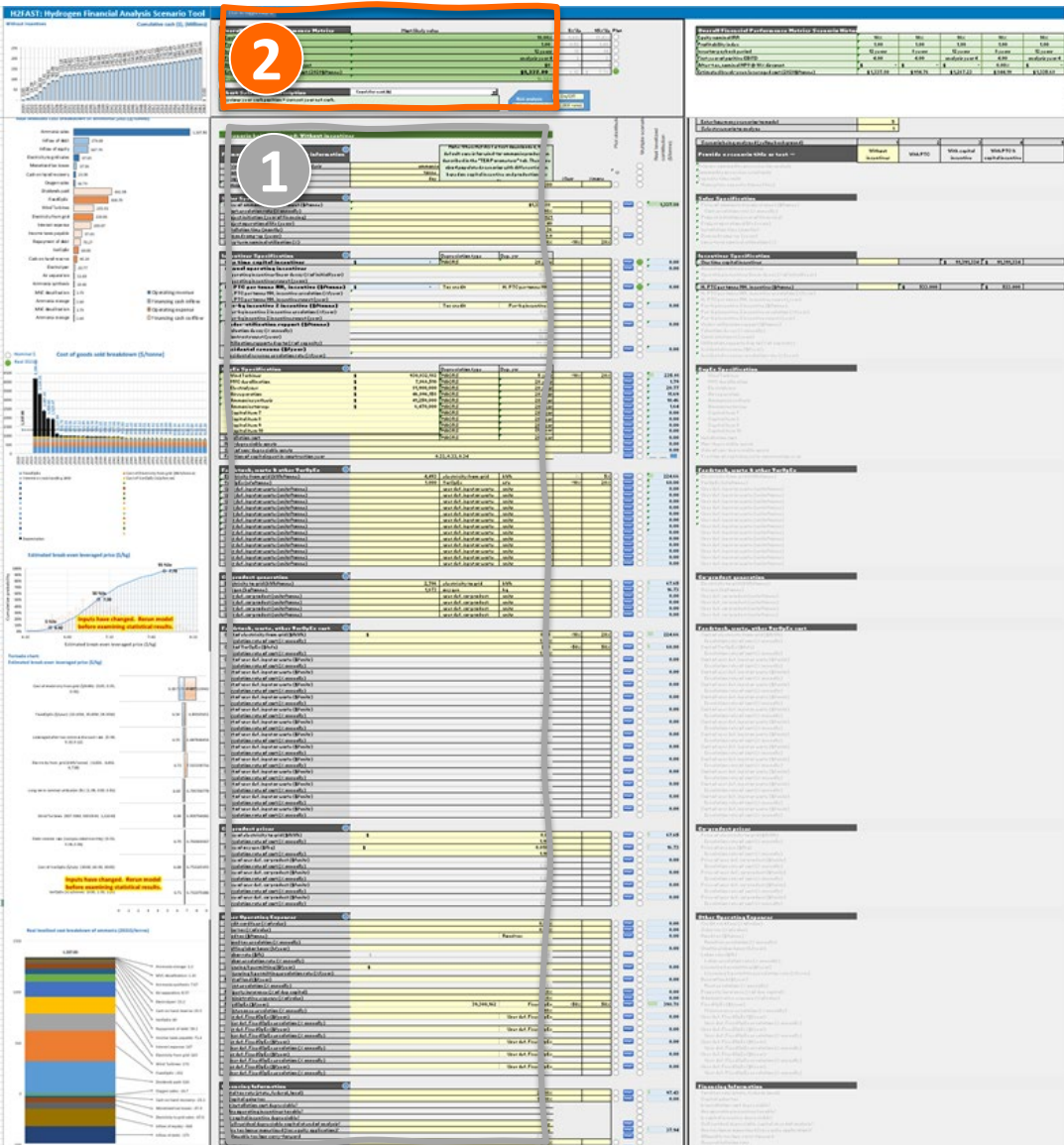
- Detailed GAAP projected statements

Interface Tab Organization



1. Inputs for currently analyzed scenario
 1. Specify primary commodity
 2. Sales specifications (price, system life, utilization)
 3. Incentives specifications
 4. CapEx specifications
 5. Feedstock, waste streams, other VarOpEx **quantities**
 6. Co-products generation **quantities**
 7. Feedstock, waste streams, VarOpEx **cost** profiles
 8. Co-products **price** profiles
 9. Other operating expenses
 10. Financing information (capital structure, taxation, liquidity)

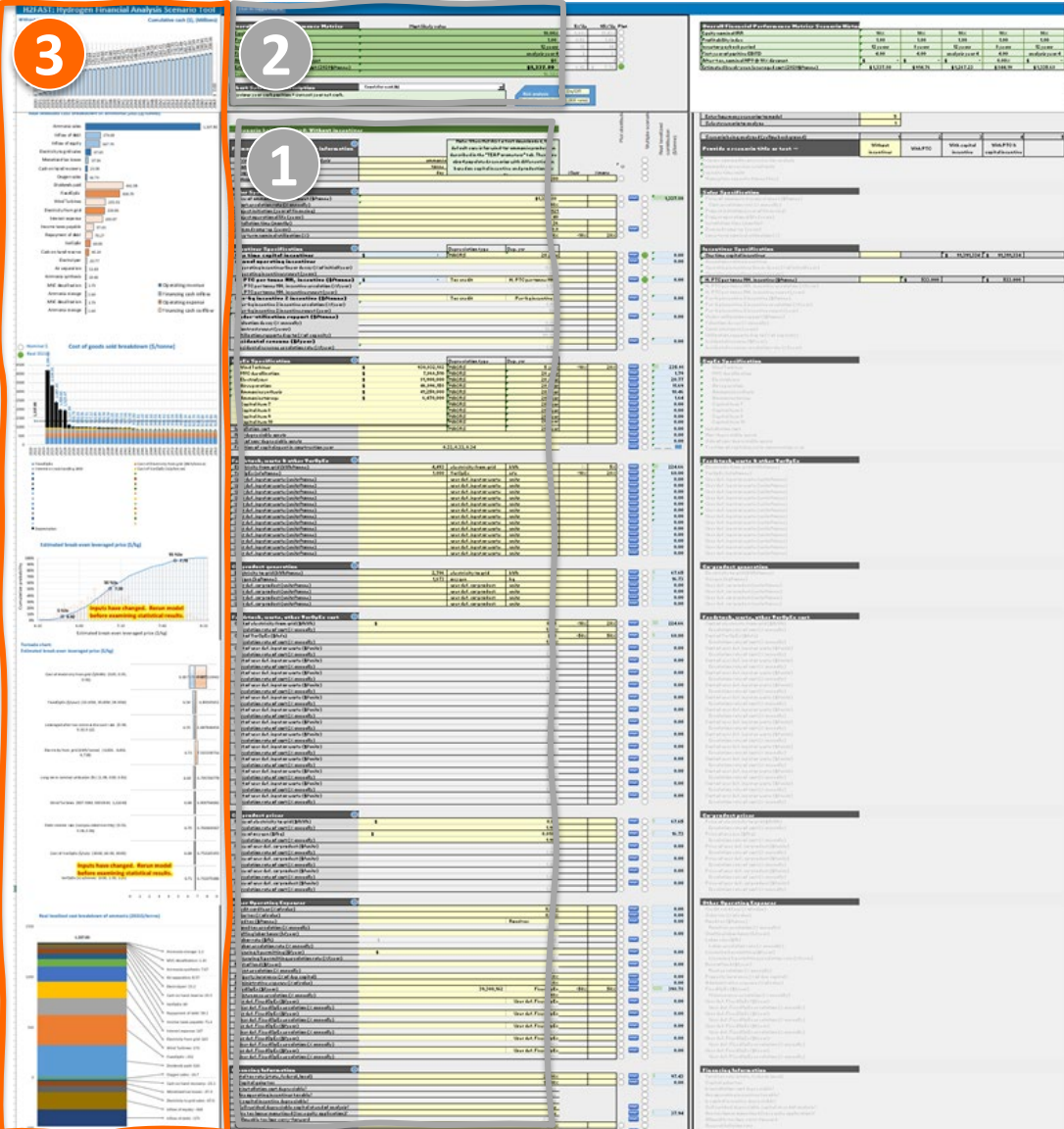
Interface Tab Organization



2 Overall financial metrics for currently analyzed scenario

1. Equity nominal IRR
 1. Note: IRR functions can have multiple results if equity cash flow is complex.
2. Profitability index
3. Investor payback
4. First year of positive earnings before interest taxes and depreciation (EBITD)
5. After-tax nominal NPV
6. Price to achieve targeted IRR
7. Project nominal level-IRR

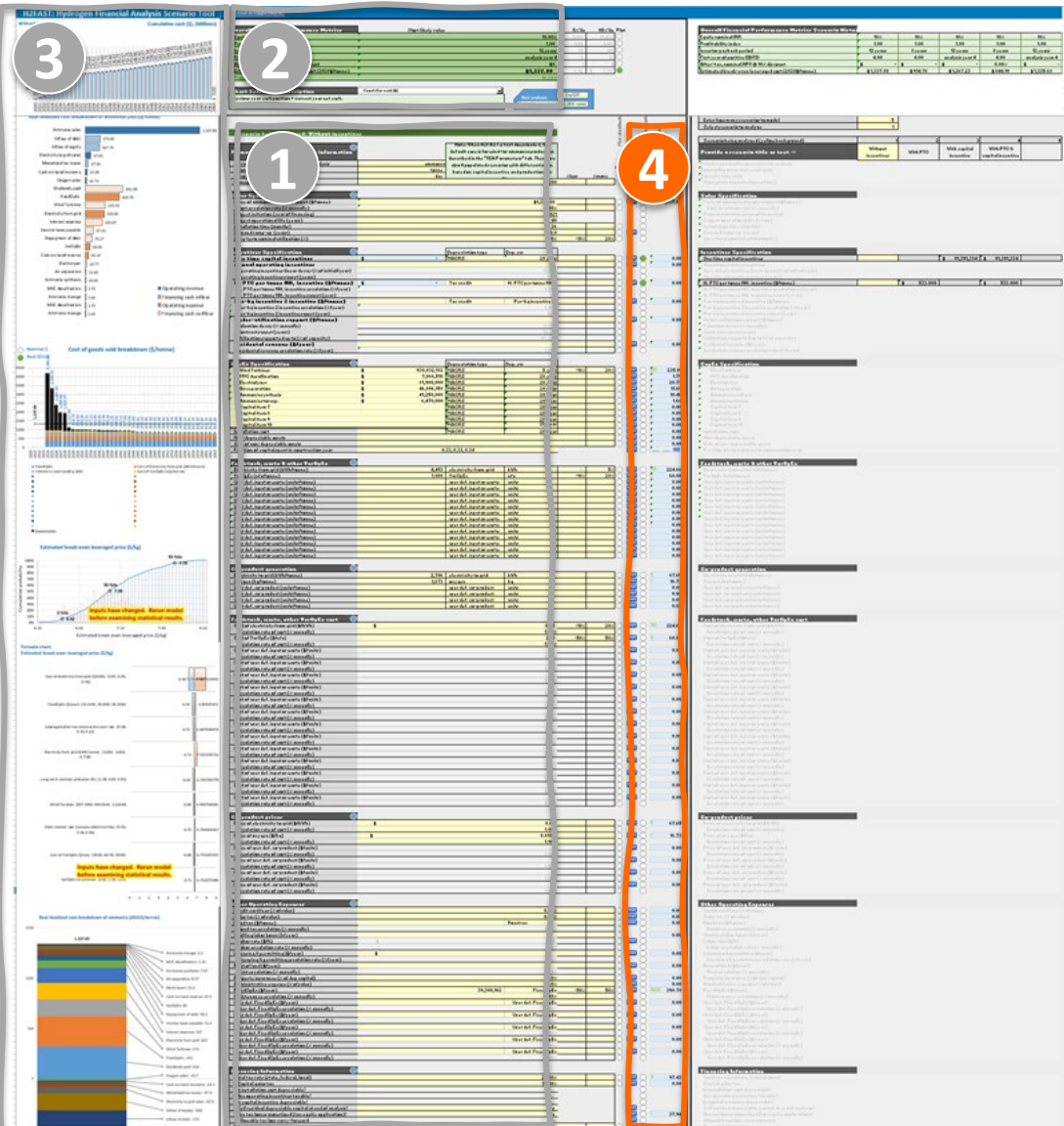
Interface Tab Organization



3 Visualizations

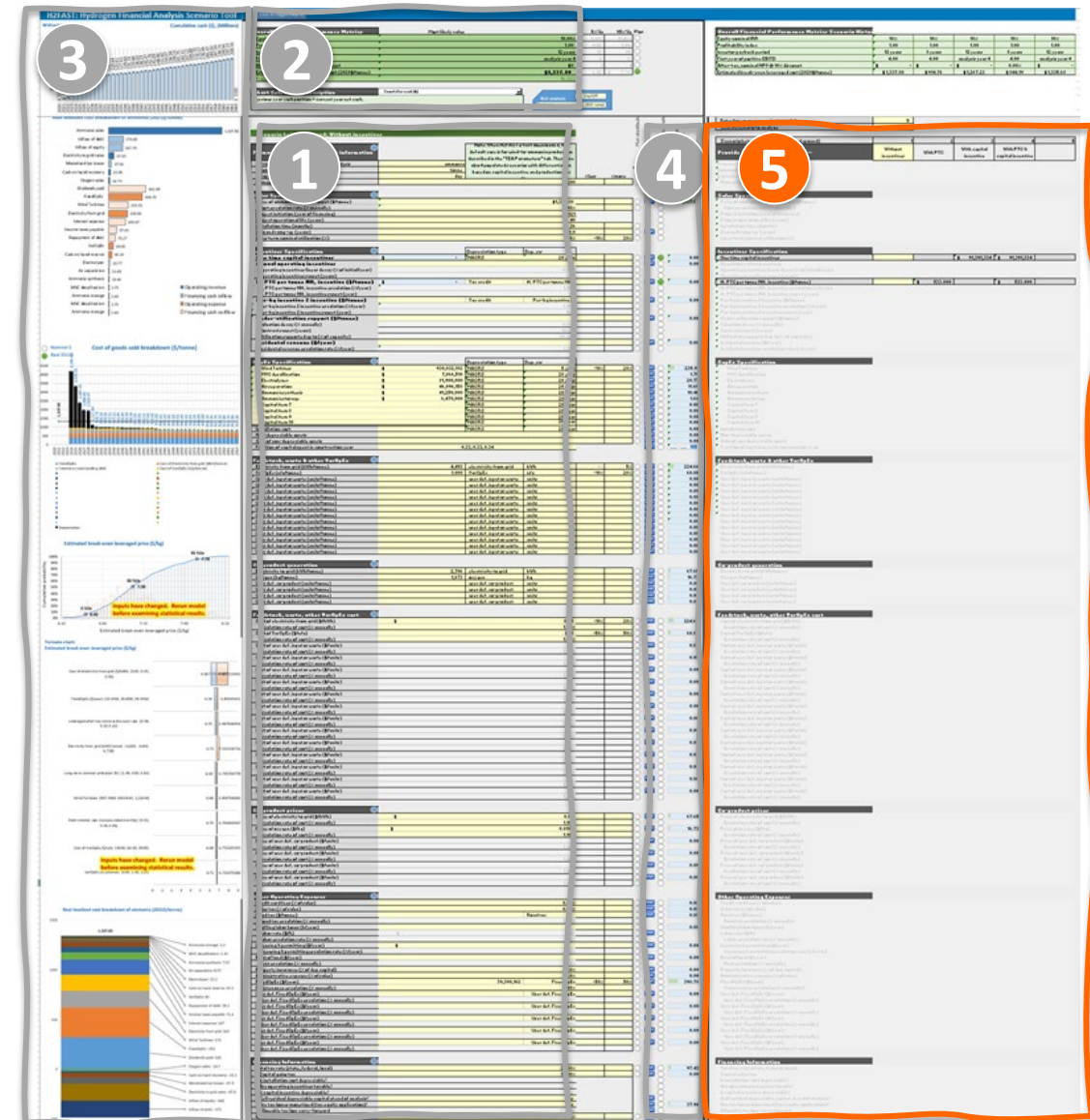
1. Time series of all financial parameters. User can switch among parameters to plot via drop down menu or by clicking “Plot” buttons next to input parameters.
2. Cash flows normalized to primary commodity (operating and financing cash flows)
3. Cost of goods sold (operating costs & depreciation vs. time)
4. Statistical distribution of specified input or output parameter
5. Sensitivity to single-parameter uncertainty spread (tornado chart)
6. Normalized costs to primary commodity. (cost stack-chart)

Interface Tab Organization



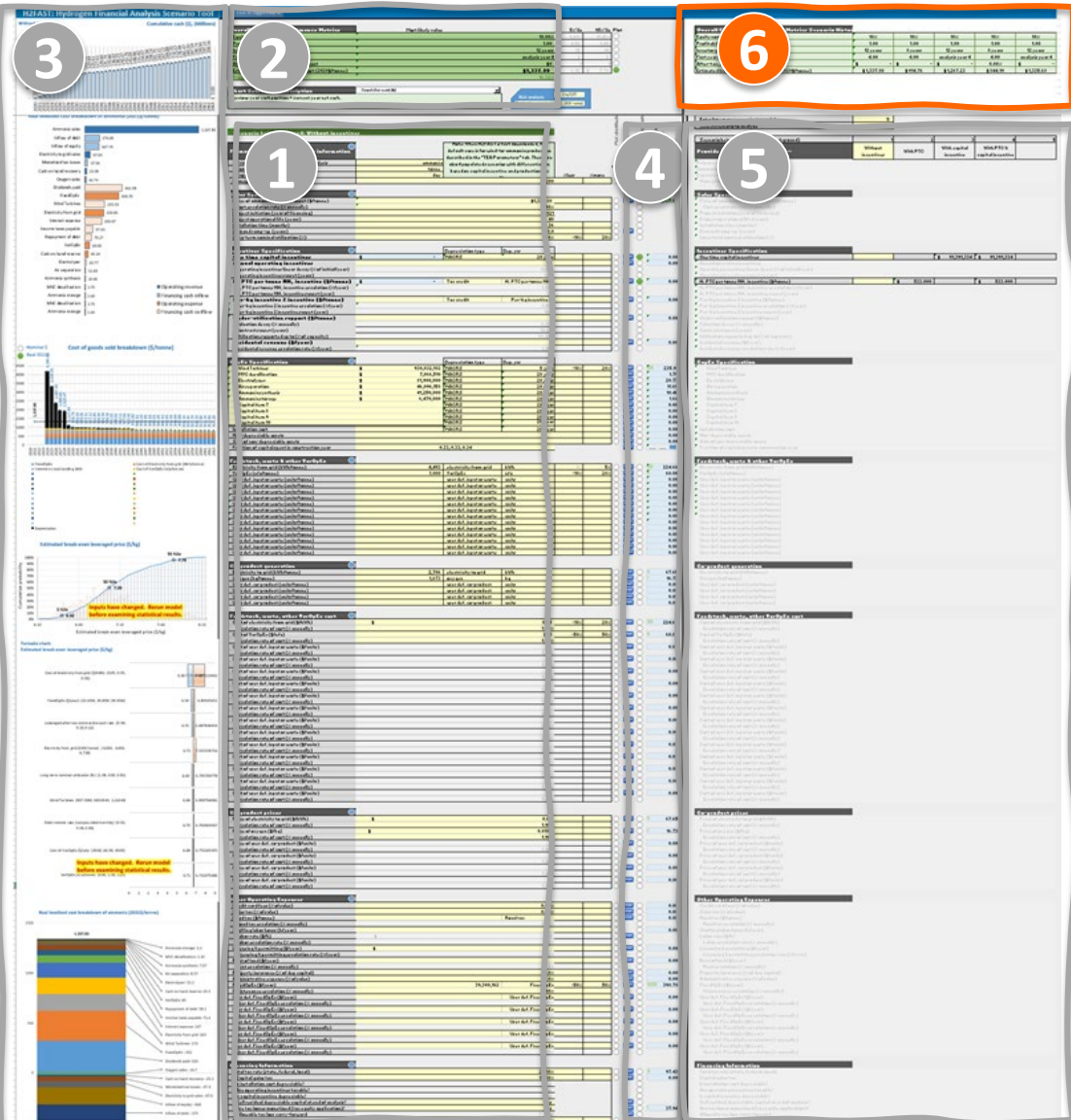
- 4 Scenario differentiation selectors**
Specify which parameters will be different among modeled scenarios. E.g.
To model fueling stations of different nameplate capacities:
 1. select nameplate capacity as a scenario differentiator (click button to highlight it as)
 2. similarly, select capital cost and any other items that would change with nameplate capacity.

Interface Tab Organization



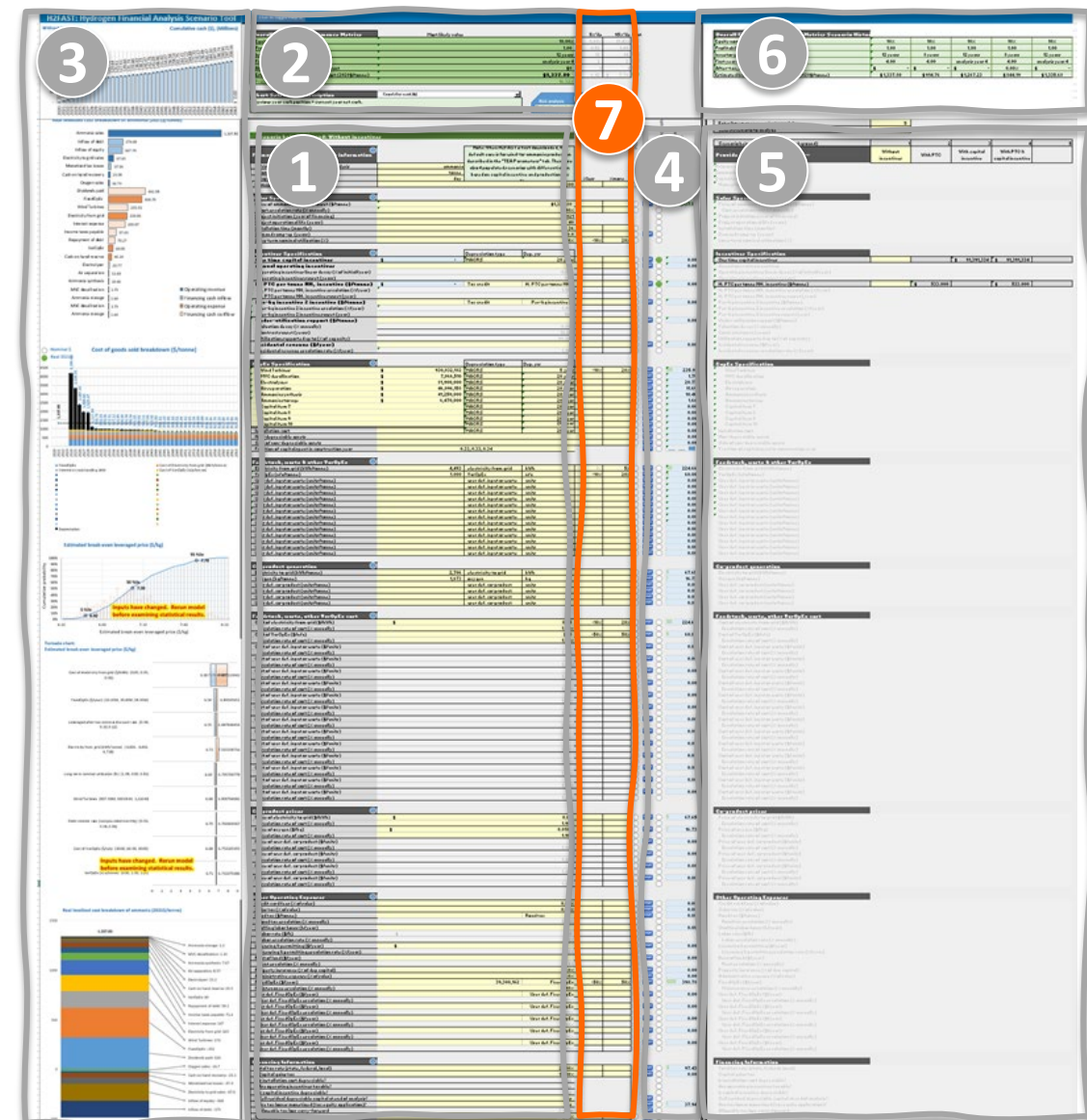
- 5 Scenario differentiation parameters**
 1. Select how many scenarios you would like to model
 2. Arrows (← →) let user chose scenario to analyze. Highlights scenarios in yellow.
 3. Name each scenario (e.g. large station, small station)
 4. Enter values for parameters that will be differentiators. (lines with selected differentiators will be highlighted)

Interface Tab Organization



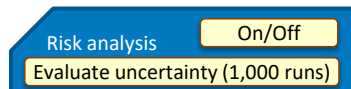
- 6** Recorded overall financial metric per scenario
- 1. Financial metrics will be stored here for each scenario.
- 2. Recording occurs when scenario selector is moved from one scenario to another using the selector arrows (← →).
- 3. Remember to refresh scenarios as needed by selecting each scenario.

Interface Tab Organization



7 Risk parameter analysis

1. Activate this section by clicking the “Risk analysis On/Off” macro button.



2. Enter ranges for all parameters that are significantly uncertain. E.g. -20%, +50% CapEx. This will result in a triangular distribution with most likely value of specified CapEx.
3. Clicking “Evaluate uncertainty (1,000 runs)” macro will perform a Monte Carlo analysis. Progress of run is displayed on Excel’s status bar (lower left corner of window)
4. After completion of runs
 1. User can select plot of any input or result distribution
 2. Tornado chart will be updated for any items selected in the results (section 2)

Overrides Tab Organization

- Use this section to provide analysis-year overrides. E.g.:
 - Capacity factor vs. year of operation
 - Feedstock consumption rate (e.g. to simulate efficiency degradation if desired)
 - CapEx expenditure for refurbishments (% of up-front capital investments)

The screenshot displays a spreadsheet interface with a grid of input fields. The columns represent years from 2000 to 2069. The rows are organized into several sections, each with a header row and multiple data rows. The sections include:

- Calendar year**: Rows for parameters like 'Electricity incentive (\$/MWh)', 'Feedstock cost (\$/tonne)', and 'Capacity factor (%)'.
- Feedstock, waste, other V&D/E cost**: Rows for 'Electricity (\$/MWh)', 'Feedstock (\$/tonne)', and 'Waste (\$/tonne)'.
- Price of electricity**: Rows for 'Electricity (\$/MWh)', 'Co-product (\$/unit)', and 'Waste (\$/tonne)'.
- Capacity factor**: Rows for 'Capacity factor (%)', 'Electricity (\$/MWh)', and 'Co-product (\$/unit)'.
- Feedstock**: Rows for 'Feedstock (\$/tonne)', 'Waste (\$/tonne)', and 'Electricity (\$/MWh)'.
- Capacity**: Rows for 'Capacity (MW)', 'Electricity (\$/MWh)', and 'Co-product (\$/unit)'.
- Annual operating incentives**: Rows for 'Annual operating incentives (\$/MWh)', 'Electricity (\$/MWh)', and 'Co-product (\$/unit)'.
- Refurbishment and upgrade costs of initial capital**: Rows for 'Refurbishment costs (\$/MWh)', 'Electricity (\$/MWh)', and 'Co-product (\$/unit)'.

A blue text box with the text "Inputs based on analysis year" is overlaid on the grid, highlighting the columns from year 1 to 69. The grid cells are mostly empty, indicating that the values are to be entered by the user.

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Funding for H2A-Lite and H2FAST is provided by the U.S. Department of Energy's Hydrogen and Fuel Cell Technologies Office (HFTO)

www.nrel.gov



H2A-Lite

<https://www.nrel.gov/hydrogen/h2a-lite.html>



H2FAST

<https://www.nrel.gov/hydrogen/h2fast.html>



Please direct any additional questions to h2fast@nrel.gov