February 19, 2025

Demo for Hydrogen in R&D GREET®

3:00-4:00 p.m. CT

Instructors

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Outline Steps for Hydrogen Scenarios

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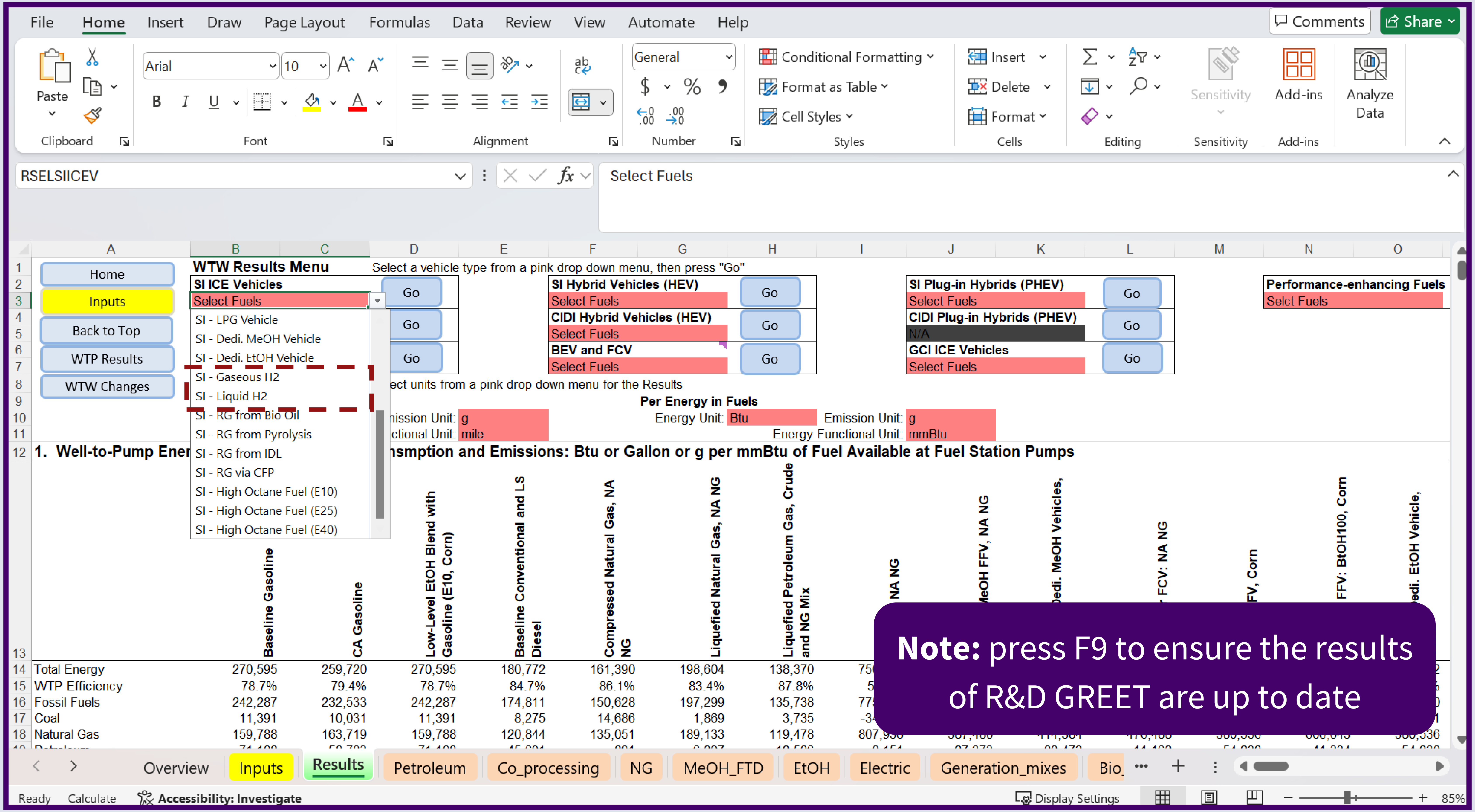
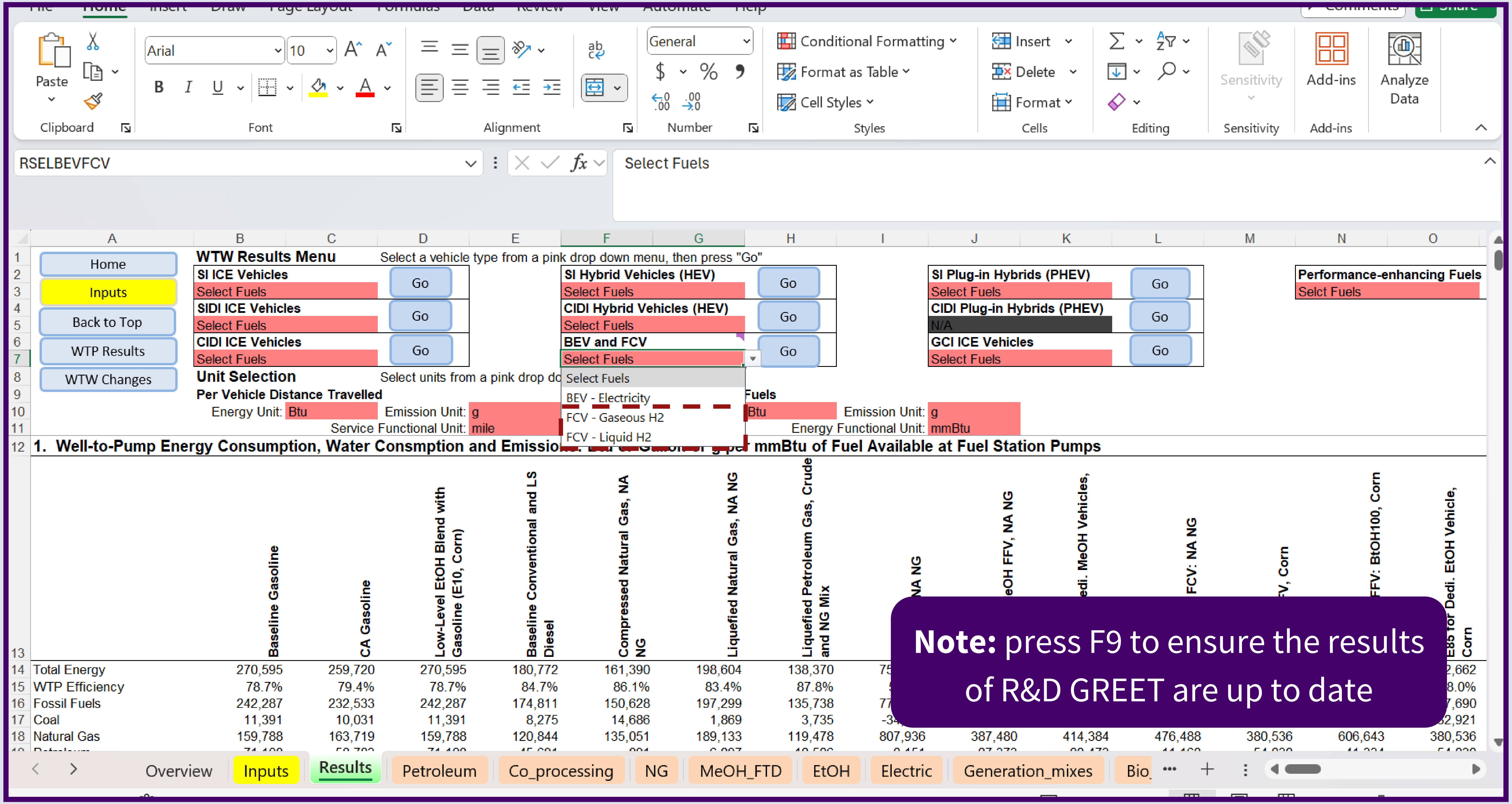
Main Outputs for SI-ICE LDVs and FCV LDVs



Note: press F9 to ensure the results of R&D GREET are up to date



Note: press F9 to ensure the results of R&D GREET are up to date

Hydrogen Overview

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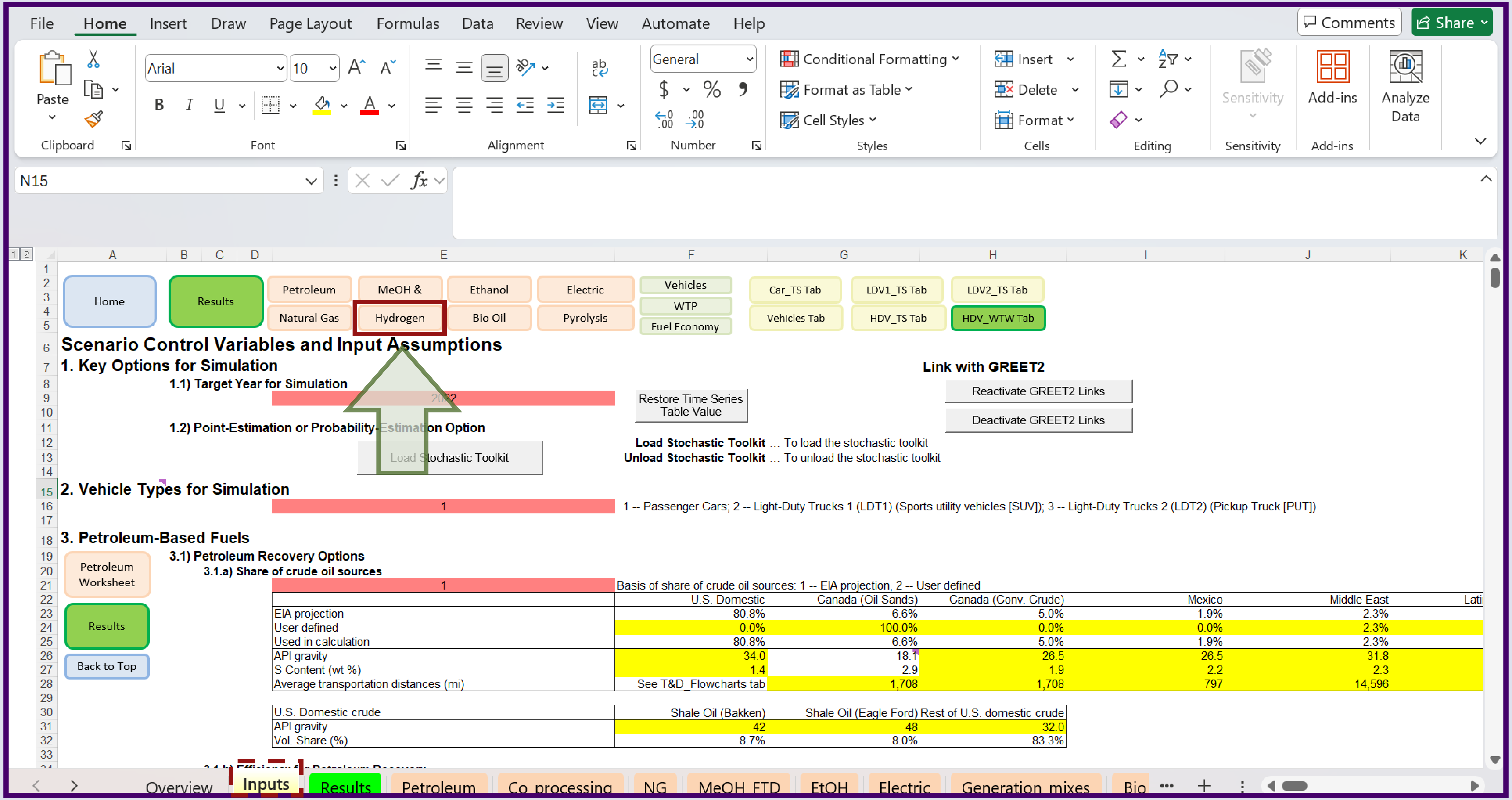
General Settings to Alter a Hydrogen Pathway



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LDV1_TS Tab
HDV_TS Tab
LDV2_TS Tab
HDV_WTW Tab
Scenario Control Variables and Input Assumptions
1. Key Options for Simulation
1.1) Target Year for Simulation
2022
Restore Time Series Table Value
Link with GREET2
Reactivate GREET2 Links
Deactivate GREET2 Links
1.2) Point-Estimation or Probability-Estimation Option
Load Stochastic Toolkit
Load Stochastic Toolkit ... To load the stochastic toolkit
Unload Stochastic Toolkit ... To unload the stochastic toolkit
2. Vehicle Types for Simulation
1
1 -- Passenger Cars; 2 -- Light-Duty Trucks 1 (LDT1) (Sports utility vehicles [SUV]); 3 -- Light-Duty Trucks 2 (LDT2) (Pickup Truck [PUT])
3. Petroleum-Based Fuels
Petroleum Worksheet
Results
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3.1) Petroleum Recovery Options
3.1.a) Share of crude oil sources
1
Basis of share of crude oil sources: 1 -- EIA projection, 2 -- User defined
U.S. Domestic | Canada (Oil Sands) | Canada (Conv. Crude) | Mexico | Middle East
EIA projection | 80.8% | 6.6% | 5.0% | 1.9% | 2.3%
User defined | 0.0% | 100.0% | 0.0% | 0.0% | 2.3%
Used in calculation | 80.8% | 6.6% | 5.0% | 1.9% | 2.3%
API gravity | 34.0 | 18.1 | 26.5 | 26.5 | 31.8
S Content (wt %) | 1.4 | 2.9 | 1.9 | 2.2 | 2.3
Average transportation distances (mi) | See T&D_Flowcharts tab | 1,708 | 1,708 | 797 | 14,596
U.S. Domestic crude | Shale Oil (Bakken) | Shale Oil (Eagle Ford) | Rest of U.S. domestic crude
API gravity | 42 | 48 | 32.0
Vol. Share (%) | 8.7% | 8.0% | 83.3%
Overview
Inputs
Results
Petroleum
Co_processing
NG
MeOH_FTD
EtOH
Electric
Generation_mixes
Bio

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Y220

6. Hydrogen Production

Hydrogen Worksheet

Results

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6.1) Basis of H2 Production Assumptions from Different Technology Pathways

1	1 -- GREET Default, 2 -- User defined

6.1.a) Scenarios for H2A Model Cases

2	1 -- Current, 2 -- Future

6.2) Share of H2 Production by Location

	Gaseous H2	Liquid H2
Central Plants	100.0%	100.0%
Refueling Stations	0.0%	0.0%

6.3) Share of H2 Feedstock Sources in Central Plants

	Gaseous H2	Liquid H2
NG	100.0%	100.0%
PEM Electrolysis	0.0%	0.0%
Nuclear (LWR) High Temperature Electrolysis with SOEC	0.0%	0.0%
Nuclear (Thermo-Chemical Cracking of Water)	0.0%	0.0%
High Temperature Electrolysis (Nuclear HTGR or NG)	0.0%	0.0%
Coal	0.0%	0.0%
Biomass	0.0%	0.0%
Integrated fermentation	0.0%	0.0%
Coke Oven Gas	0.0%	0.0%
Byproduction from chlorine plants	0.0%	0.0%
By-product from NGL steam cracker plants	0.0%	0.0%
Pet Coke	0.0%	0.0%
RNG SMR	0.0%	
NG Autothermal Reforming	0.0%	
RNG Autothermal Reforming	0.0%	
Methane Pyrolysis (Using NG)	0.0%	
Methane Pyrolysis (Using RNG)	0.0%	

Overview | Inputs | Results | Petroleum | Co_processing | NG | MeOH_FTD | EtOH | Electric | Generation_mixes | Bio

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6.5) NG Feedstock Options for H2 Production via SMR

	Gaseous H2	Liquid H2
Central Plants	1	1
Distributed Production at Refueling Stations	1	1

Note:
1 -- North American NG, 4 -- Renewable Natural Gas

6.6) CO2 Sequestration Options for Central Plant H2 Production

	Gaseous H2	Liquid H2
NG-Based SMR H2 Plants	1	1
Coal-Based H2 Plants	2	2
Biomass-Based H2 Plants	1	1
Pet Coke-to-H2 Plant	1	
ATR H2 Plants	2	2

Note:
1 -- Without CO2 sequestration
2 -- With CO2 sequestration

6.7) Selection of H2 Plant Design Types

	NG/RNG	Coal	Biomass	Petcoke
Central Plant G.H2	1	0	0	0
Refueling Station G.H2	0			
Central Plant L.H2	1	0	0	
Refueling Station L.H2	0			

6.8) Selection of Method for Estimating Credits of Co-Products for NG Based Fuel Pathways (Co-products are defined in Section 6.7)

	NG/RNG	Coal	Biomass	Petcoke
Central Plant G.H2	1	1	1	1
Refueling Station G.H2	1			
Central Plant L.H2	1	1	1	
Refueling Station L.H2	1			

6.9) Electric Generation Source for H2 Production via PEM Electrolysis

Gaseous H2	Liquid H2
1	1

1 -- Solar, 2 -- Wind, 3 -- Hydro, 4 --Nuclear (LWR), 5-- Mix for transportation use (see 10.2.a)

Overview | Inputs | Results | Petroleum | Co_processing | NG | MeOH_FTD | EtOH | Electric | Generation_mixes | Bio

6.10) Electric Generation Source for H2 Production via Electrolysis at Refueling Stations

Gaseous H2	Liquid H2
1	1

1 -- Solar, 2 -- Wind, 3 -- Hydro, 4 --Nuclear (LWR), 5-- Mix for transportation use (see 10.2.a)

6.11) Shares of Willow, Poplar, Switchgrass, Corn Stover, Forest Residue, and Miscanthus for H2 production in central plants

	Willow	Poplar	Switchgrass	Corn Stover
Gaseous H2	0.0%	100.0%	0.0%	0.0%
Liquid H2	0.0%	100.0%	0.0%	0.0%

6.12) Simulation Options of Treating H2 produced from Coke Oven Gas (COG)

Gaseous H2	Liquid H2
3	3

1 -- Scenario 1: COG is treated as a co-product
2 -- Scenario 2: COG is treated as a byproduct
3 -- Scenario 3: Supplemental NG and electricity use to makeup for BTU withdrawal from separated H2

6.13) Selection of Electricity Generation Mix for H2 liquifaction in Central Plants

H2 Plant Type	Electricity Mix	
NG-Based Plant	2	1 -- NGCC; 2 -- Mix for stationary use (see 10.2.a)
Solar Energy-Based Plant	2	1 -- Solar; 2 -- Mix for stationary use (see 10.2.a)
Nuclear Plant (HTGR water cracking)	1	1 -- Nuclear; 2 -- Mix for stationary use (see 10.2.a)
Coal-Based Plant	2	1 -- Coal IGCC; 2 -- Mix for stationary use (see 10.2.a)
Biomass-Based Plant	2	1 -- Biomass IGCC; 2 -- Mix for stationary use (see 10.2.a)
COG-Based Plant	2	1 -- Coal IGCC; 2 -- Mix for stationary use (see 10.2.a)

6.14) Electricity Source for High Temperature Electrolysis with SOEC

Gaseous H2	Liquid H2
6	6

1 -- Oil Power Plants, 2 -- NG Power Plants, 3 -- Coal Power Plants, 4 -- Nuclear Power Plants
5 -- Other Renewable Power Plants, 6 -- Mix for transportation use (see 10.2.a), 7 -- NGCC Turbine

6.15) Integrated Fermentation Plant Type

1

1 -- w/ H2 Recovery, 2 -- w/ Energy Recovery

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13. GREET Default Key Assumptions for Well-to-Pump Activities

13.18) Hydrogen Production Effeicincies

13.18.a) Central Plant H2 Production Efficiencies

	E	I	J	K
1100		Source		User D
1101		Gaseous H2	H2 Production for L.H2	Gaseous H2
1102	NA NG feedstock	NETL Model		
1103	Without steam or electricity export	71.8%	71.8%	71.8%
1104	With steam or electricity export (excluding energy in co-products)	71.8%	71.8%	71.8%
1105	With steam or electricity export: net steam export credit: Btu of steam per mmBtu of H2 produced	0	213,343	213,343
1106	With steam or electricity export: net electricity export credit: kWh per mmBtu of H2 produced			14.01
1107	Feedstock share	69.3%	69.3%	69.3%
1108	NG share	99.1%	99.1%	99.1%
1109	Electricity share	0.9%	0.9%	0.9%
1110	NNA NG feedstock			
1111	Without steam or electricity export	72.1%	72.1%	72.1%
1112	With steam or electricity export (excluding energy in co-products)			
1113	With steam or electricity export: net steam export credit: Btu of steam per mmBtu of H2 produced			
1114	With steam or electricity export: net electricity export credit: kWh per mmBtu of H2 produced			0.00
1115	NNA FG feedstock			
1116	Without steam or electricity export	72.1%	72.1%	72.1%
1117	With steam or electricity export (excluding energy in co-products)			
1118	With steam or electricity export: net steam export credit: Btu of steam per mmBtu of H2 produced			
1119	With steam or electricity export: net electricity export credit: kWh per mmBtu of H2 produced			0.00
1120	Coal feedstock	NETL Model		
1121	Gasification in central plants: without steam or electricity co-generation	58.9%	58.9%	58.9%
1122	Gasification in central plants: without steam or electricity co-generation (CCS)	58.4%	58.4%	58.4%
1123	Synthesis process for H2 production in central plants: without steam or electricity co-generation			100.0%
1124	Gasification for H2 production in central plants: with steam or electricity co-generation (without accounting Btu in steam or electricity)	44.3%	44.3%	56.9%
1125	Synthesis process for H2 production in central plants, with steam or electricity co-generation (without accounting Btu in steam or electricity)			100.0%
1126	Net Steam export credit: Btu of steam per mmBtu of H2 produced			0
1127	Net electricity export credit: kWh per mmBtu of H2 produced	0.00	0.00	0.00
1128	Biomass feedstock			

Inputs | Results | Petroleum | Co_processing | NG | MeOH_FTD | EtOH | Electric | Generation_mixes | Bio_electricity

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Y220

	L
926	
1098	
1099	
1100	efined
1101	H2 Production for L.H2
1102	
1103	71.8%
1104	71.8%
1105	213,343
1106	14.01
1107	69.3%
1108	99.1%
1109	0.9%
1110	
1111	72.1%
1112	
1113	
1114	0.00
1115	
1116	72.1%
1117	
1118	
1119	0.00
1120	
1121	58.9%
1122	58.4%
1123	100.0%
1124	56.9%
1125	100.0%
1126	0
1127	0.00
1128	

SMR and SMR-CCS Parameters	NETL Model			
	current w/o ccs	current w/ccs	future w/o ccs	future w/ccs
Efficiency	71.8%	65.7%	71.8%	65.7%
Feedstock share	69.3%	66.9%	69.3%	66.9%
NG share	99.08%	91.5%	99.1%	91.5%
Electricity share	0.9%	8.5%	0.9%	8.5%

SMR for Industries Parameters	
Conditions	current w/o ccs
Efficiency	71.8%
Feedstock share	69.3%
NG share	99.1%
Electricity share	0.9%
Steam Export, Btu	213,343

ATR Parameters	wCCS	Units
Efficiency	66.0%	
Feedstock Share	100%	
Electricity	106,596	Btu/mmBtu
Intermediate Fuel	95,562	Btu/mmBtu
Capture Rate	94.5%	

Methane Pyrolysis Parameters	Components	Value	Units (per mmBtu H2)
Inputs	NG	1.733	mmBtu
	Electricity	1.120	mmBtu
	Miscellaneous	0.257	mmBtu
	Water	26.243	gal
Outputs	Steam	274,877	Btu
	Carbon Black	0.0336	ton
	Coke	0.0011	ton
Efficiency	H2 output basis	35.04%	

Coal Gasification Parameters	Fuel share	
	Coal Share	Electricity Share
w/o CCS	97.7%	2.3%
CCS	95.7%	4.3%

	Biomass Gasification	Efficiency	Biomass		NG Share	Electricity Share
			Feedstock	Fuel		

Overview | Inputs | Results | Petroleum | Co_processing | NG | MeOH_FTD | EtOH | Electric | Generation_mixes | Bio

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Further Explore Hydrogen Scenarios

Hydrogen tabs in R&D GREET 1

Primary
Hydrogen

Some Secondary
Ag_Inputs
Petroleum
EtOH
MeOH
E-fuels
Algae
PUP Conversion
Plastics

Inputs
Results
Fuel_Prod_TS
Fuel_Specs
Electricity
Car_TS
Vehicles
Tractor WTW
Rail PTW
EF
T&D
T&D Flowcharts

Hydrogen tabs in R&D GREET 2

Primary

Silicon

Rare Earth

Steel

Nickel

Some Secondary

TEC_Results

MHDV_TEC_Results

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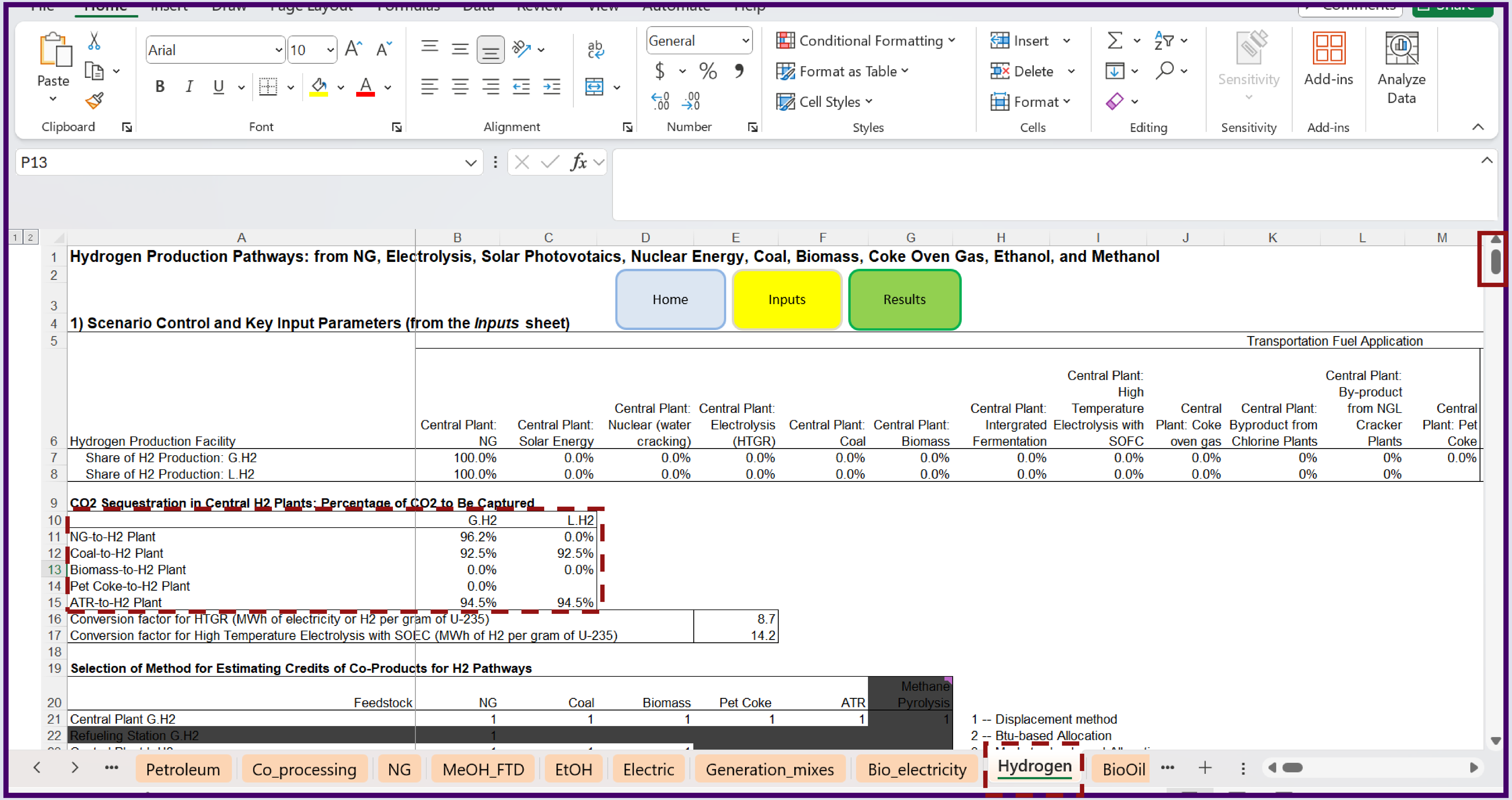

Hydrogen Production Pathways: from NG, Electrolysis, Solar Photovotaics, Nuclear Energy, Coal, Biomass, Coke Oven Gas, Ethanol, and Methanol

Home | Inputs | Results

1) Scenario Control and Key Input Parameters (from the *Inputs* sheet)

Transportation Fuel Application

Hydrogen Production Facility	Central Plant: NG	Central Plant: Solar Energy	Central Plant: Nuclear (water cracking)	Central Plant: Electrolysis (HTGR)	Central Plant: Coal	Central Plant: Biomass	Central Plant: Intergrated Fermentation	Central Plant: High Temperature Electrolysis with SOFC	Central Plant: Coke oven gas	Central Plant: Byproduct from Chlorine Plants	Central Plant: By-product from NGL Cracker Plants	Central Plant: Pet Coke
Share of H2 Production: G.H2	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%	0%	0.0%
Share of H2 Production: L.H2	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%	0%	

CO2 Sequestration in Central H2 Plants: Percentage of CO2 to Be Captured

	G.H2	L.H2
NG-to-H2 Plant	96.2%	0.0%
Coal-to-H2 Plant	92.5%	92.5%
Biomass-to-H2 Plant	0.0%	0.0%
Pet Coke-to-H2 Plant	0.0%	
ATR-to-H2 Plant	94.5%	94.5%

Conversion factor for HTGR (MWh of electricity or H2 per gram of U-235)	8.7
Conversion factor for High Temperature Electrolysis with SOEC (MWh of H2 per gram of U-235)	14.2

Selection of Method for Estimating Credits of Co-Products for H2 Pathways

Feedstock	NG	Coal	Biomass	Pet Coke	ATR	Methane Pyrolysis
Central Plant G.H2	1	1	1	1	1	1
Refueling Station G.H2	1					

1 -- Displacement method
2 -- Btu-based Allocation

S3

	A	B	C	D	E
61	**Selection of Electricity Generation Mix for H2 production pathways**				
62	1	1--U.S. Mix, 2--ASCC Mix, 3--FRCC Mix, 4--HICC Mix, 5--MRO Mix, 6--NPCC Mix, 7--RFC Mix, 8--SERC Mix, 9--SPP Mix, 10--TRE Mix, 11--WECC Mix, 12--CA Mix, 13--User Defined Mix			
63					
64	**Share for NGCC wCCS technology (Only for User Defined Mix selection)**			0.0%	0.0%
65					
66	**Selection of Electricity Generation Mix for H2 liquifaction in Central Plants**				
67	**H2 Plant Type**				
68	NG-Based Plant	2	1 -- NGCC; 2 -- Mix for stationary use (see 10.2.a in the Inputs tab)		
69	Solar Energy-Based Plant	2	1 -- Solar; 2 -- Mix for stationary use (see 10.2.a in the Inputs tab)		
70	Nuclear Plant (LWR/HTGR water cracking)	1	1 -- Nuclear; 2 -- Mix for stationary use (see 10.2.a in the Inputs tab)		
71	Coal-Based Plant	2	1 -- Coal IGCC; 2 -- Mix for stationary use (see 10.2.a in the Inputs tab)		
72	Biomass-Based Plant	2	1 -- Biomass IGCC; 2 -- Mix for stationary use (see 10.2.a in the Inputs tab)		
73	COG-Based Plant	2	1 -- Coal IGCC; 2 -- Mix for stationary use (see 10.2.a in the Inputs tab)		
74					
75	**G.H2 Production: Non-Combustion Emissions**				
76		g/mmBtu of H2 output	g/mmBtu of NG inptus		
77	VOC	0.965	0.693		
78	CO	1.261	0.906		
79	NOx	1.645	1.182		
80	PM10	1.207	0.867		
81	PM 2.5	1.164	0.836		
82	SOx	0.027	0.019		
83					
84	**Yeast and Enzyme Use in Intergrated Fermentation**				
85		Gaseous H2	Liquid H2		
86	Ammonia (kg/ mmbtu H2)	0.894	0.894		
87	NaOH (kg/ mmbtu H2)	3.414	3.414		
88	H2SO4 (kg/ mmbtu H2)	1.821	1.821		
89	Glucose (kg/ mmbtu H2)	2.945	2.945		

Bio_electricity | Hydrogen | BioOil | Algae | Macroalgae | Waste | RNG | Pyrolysis_IDL | IBR | E_fuel | Fuel_Prod_TS

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S3

	A	B	C	D	E
93	**Electrolysis Pathways**				
94	Share of co-product O2 exported	100%			
95	O2 Byproduct (ton/mmBtu H2)	0.077			
96	0	0--No co-product credit, 1--With O2 co-product credit			
97					
98	**Biogenic CH4 in RNG (g/mmBtu)**	390			
99					
100	**ATR Pathways: By Product**				
101	Share of by-product N2 exported	100%			
102	N2 Byproduct (ton/mmBtu H2)	0.142			
103	0	N2 Byproduct option (0: No by-product credit, 1:			
104					
105	**1.1) H2 production from chloralkali process**				
106	H2 handling method		3	1 -- H2 diverted from vented emissions (carrying no energy/emissions burdens)	
107				2 -- H2 divered from internal combustion (NG substituing H2)	
108				3 -- H2 as co-products allocated by mass	
109				4 -- H2 as coproducts allocated by market value	
110					

Row	A	B	C	D
111		Cl2	NaOH	H2
112	Co-products (kg/kg H2)	35.1	39.6	1
113	Market Values ($/kg)	0.255	0.441	1
114	Mass share	46.3%	52.4%	1.3%
115	Market value share	32.6%	63.7%	3.6%
116				

	A	B	C	D	E	F	G	H
117	**Energy use before allocation**							
118			Diaphragm		Membrane		Capacity Weighted	
119	Capacity Share		55%		45%			
120	Water consumption (gal/kg H2)		21.4		21.4		21.4	
121	Energy use (mmBtu/kg H2)		Electricity	Heat (as NG use)	Electricity	Heat (as NG use)	Electricity	Heat (as NG use)

Bio_electricity | Hydrogen | BioOil | Algae | Macroalgae | Waste | RNG | Pyrolysis_IDL | IBR | E_fuel | Fuel_Prod_TS

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4) Summary of Energy Consumption, Water Consumption, and Emissions: Btu or Gallons or Grams per mmBtu of H2 Throughput at Each Stage

4.1) Energy Use, Water Consumption, and Total Emissions

Row		Central Plants: NG to Gaseous Hydrogen		Central Plants: PEM electrolysis to Gaseous Hydrogen via Solar		Central Plants: Nuclear Energy to Gaseous Hydrogen (Thermo-Chemical Cracking of Water)		Central Plants: Electrolysis (HTGR) to Gaseous Hydrogen		Central Plants: Coal to Gaseous Hydrogen with CCS		Central Plants: Biomass to Gaseous Hydrogen	
324		Feedstock	Fuel	Feedstock	Fuel	Feedstock	Fuel	Feedstock	Fuel	Feedstock	Fuel	Feedstock	Fuel
325	Loss factor		0.961		1.000		1.000		1.000		1.000		1.000
326	Total energy	112,046	373,715	1,750,297	226,234	1,009,396	226,234	1,209,143	168,148	20,047	983,539	38,325	1,554,825
327	Fossil fuels	111,403	330,332	0	184,686	7,822	184,686	9,370	94,489	19,144	927,837	37,895	308,872
328	Coal	923	62,176	0	59,546	1,821	59,546	2,181	23,761	1,926	761,366	615	68,699
329	Natural gas	110,020	235,078	0	92,213	4,066	92,213	4,871	38,810	3,418	123,540	10,236	174,563
330	Petroleum	460	33,078	0	32,927	1,935	32,927	2,318	31,918	13,800	42,931	27,043	65,610
331	Water consumption	3.457	54.691	87.055	16.796	163.219	16.796	188.383	14.307	3.863	79.680	1.537	51.426
332	VOC	11.107	4.866	0.000	1.798	0.100	1.798	0.120	0.972	7.322	9.990	1.747	4.794
333	CO	35.006	12.957	0.000	10.873	0.490	10.873	0.587	7.942	1.754	18.735	7.552	23.578
334	NOx	41.190	15.953	0.000	12.729	0.818	12.729	0.979	7.535	4.847	18.863	10.995	34.148
335	PM10	0.406	3.172	0.000	1.480	0.086	1.480	0.103	0.727	8.507	7.684	0.789	2.805
336	PM2.5	0.384	2.393	0.000	0.772	0.052	0.772	0.063	0.347	1.184	1.810	0.688	1.898
337	SOx	11.211	9.495	0.000	7.401	0.471	7.401	0.564	3.041	6.799	27.179	1.172	26.823
338	BC	0.077	0.150	0.000	0.044	0.010	0.044	0.013	0.021	0.035	0.080	0.386	0.545
339	OC	0.162	0.482	0.000	0.208	0.013	0.208	0.016	0.089	0.071	0.321	0.134	0.483
340	CH4	210.790	62.082	0.000	27.165	1.156	27.165	1.385	12.777	147.657	135.939	4.225	46.586
341	N2O	1.417	0.594	0.000	0.237	0.045	0.237	0.054	0.103	0.030	0.332	2.956	3.923
342	CO2	6,624	82,223	0	14,052	563	14,052	675	7,210	1,490	30,116	3,133	22,831
343	CO2 (w/ C in VOC & CO)	6,714	82,259	0	14,075	564	14,075	676	7,225	1,516	30,177	3,150	22,883
344	GHGs	13,382	84,271	0	14,949	611	14,949	732	7,634	5,924	34,319	4,083	25,342

4.2) Urban Emissions: Grams per mmBtu of H2 Throughput at Each Stage

Row													
346	Loss factor												
347	VOC	0.594	0.720	0.000	0.314	0.008	0.314	0.010	0.258	0.041	0.372	0.082	0.456

Bio_electricity | Hydrogen | BioOil | Algae | Macroalgae | Waste | RNG | Pyrolysis_IDL | IBR | E_fuel | Fuel_Prod_TS

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	A	B	C	D	E	F	G	H	I	J	K	L	M
387	**WTG: Energy Consumption, Water Consumption, and Emissions of Hydrogen Pathways for H2 Module**												
388		**Units**	**Central: NG SMR**	**Central: Low Temperature Electrolysis PEM using Solar**	**Central: Coal Gasification with CCS**	**Central: Biomass Gasification**	**Central: High Temperature Electrolysis with SOEC using Nuclear LWR**	**Central: By-product H2 from Chlorine Plants**	**Central: By-product H2 from NGL Steam Cracker Plants**	**Distributed: NG SMR**	**Distributed: Low Temperature Electrolysis PEM using Solar**	**Central: RNG SMR**	**Distributed: RNG SMR**
389	Total energy	Btu/mmBtu	551,766	1,750,297	777,351	1,366,916	1,342,922	201,833	1,142,460	634,975	1,760,678	-1,201,714	-991,276
390	Fossil fuels	Btu/mmBtu	549,140	0	762,295	162,082	13,116	162,529	1,135,234	599,813	0	180,330	294,251
391	Coal	Btu/mmBtu	3,763	0	703,746	9,768	2,992	56,335	10,358	50,400	0	54,955	99,227
392	Natural gas	Btu/mmBtu	544,661	0	34,745	92,586	6,797	101,429	1,124,121	547,268	0	123,645	191,912
393	Petroleum	Btu/mmBtu	716	0	23,804	59,727	3,326	4,765	754	2,144	0	1,730	3,112
394	Water consumption	gal/mmBtu	42.141	87.055	66.746	36.167	191.238	17.885	6.020	39.927	87.420	51.711	49.054
395	VOC	g/mmBtu	17.386	0.000	15.513	4.742	0.170	1.542	13.866	17.607	0.000	-25.025	-22.844
396	CO	g/mmBtu	50.998	0.000	9.617	20.257	0.833	5.835	57.994	56.970	0.000	-24.428	-14.971
397	NOx	g/mmBtu	63.517	0.000	10.982	32.414	1.379	9.864	55.864	70.833	0.000	23.712	32.868
398	PM10	g/mmBtu	3.126	0.000	14.712	2.113	0.144	1.313	3.820	3.164	0.000	-3.430	-3.089
399	PM2.5	g/mmBtu	3.028	0.000	2.223	1.814	0.088	0.763	3.712	2.638	0.000	-3.980	-4.046
400	SOx	g/mmBtu	15.934	0.000	26.578	20.594	0.785	7.281	12.685	20.951	0.000	6.828	12.265
401	BC	g/mmBtu	0.356	0.000	0.071	0.887	0.018	0.048	0.614	0.195	0.000	-6.508	-6.352
402	OC	g/mmBtu	0.874	0.000	0.183	0.409	0.022	0.215	1.569	0.537	0.000	0.491	0.172
403	CH4	g/mmBtu	294.075	0.000	256.431	23.646	1.935	26.228	215.650	335.106	0.000	680.982	704.135
404	N2O	g/mmBtu	2.297	0.000	0.124	6.642	0.078	0.250	1.854	2.287	0.000	0.893	0.949
405	CO2	g/mmBtu	92,139	0	17,555	11,912	942	12,064	67,799	96,980	0	13,194	21,779
406	CO2 (w/ C in VOC & CO)	g/mmBtu	92,273	0	17,618	11,958	944	12,078	67,933	97,124	0	13,078	21,684
407	GHGs	gCO2e/mmBtu	101,664	0	25,294	14,476	1,023	12,928	74,866	107,735	0	31,877	41,177
408	VOC: Urban	g/mmBtu	1.305	0.000	0.099	0.224	0.014	0.107	2.387	1.799	0.000	-15.523	-14.252

Petroleum | Co_processing | NG | MeOH_FTD | EtOH | Electric | Generation_mixes | Bio_electricity | Hydrogen | BioOil

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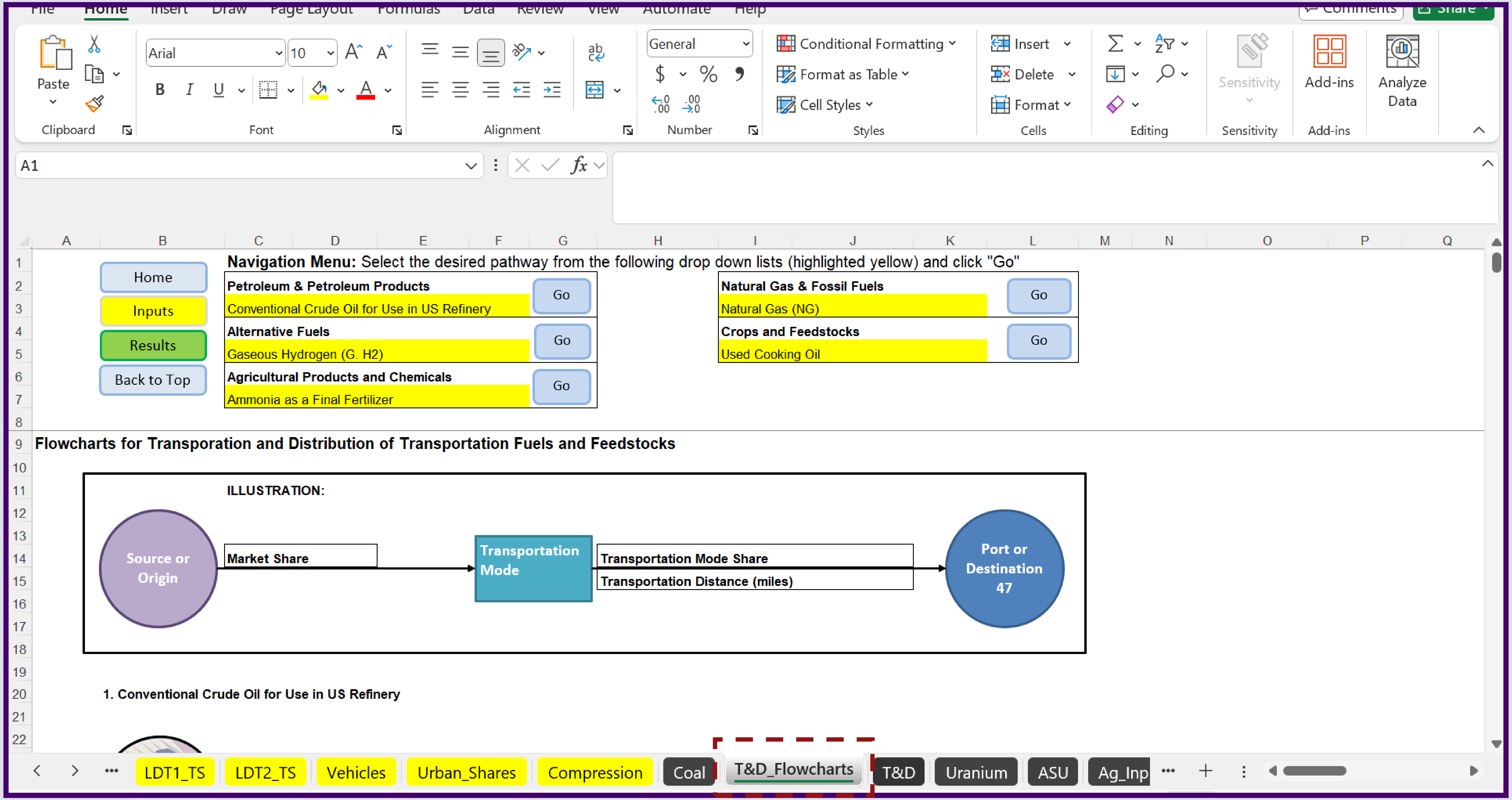

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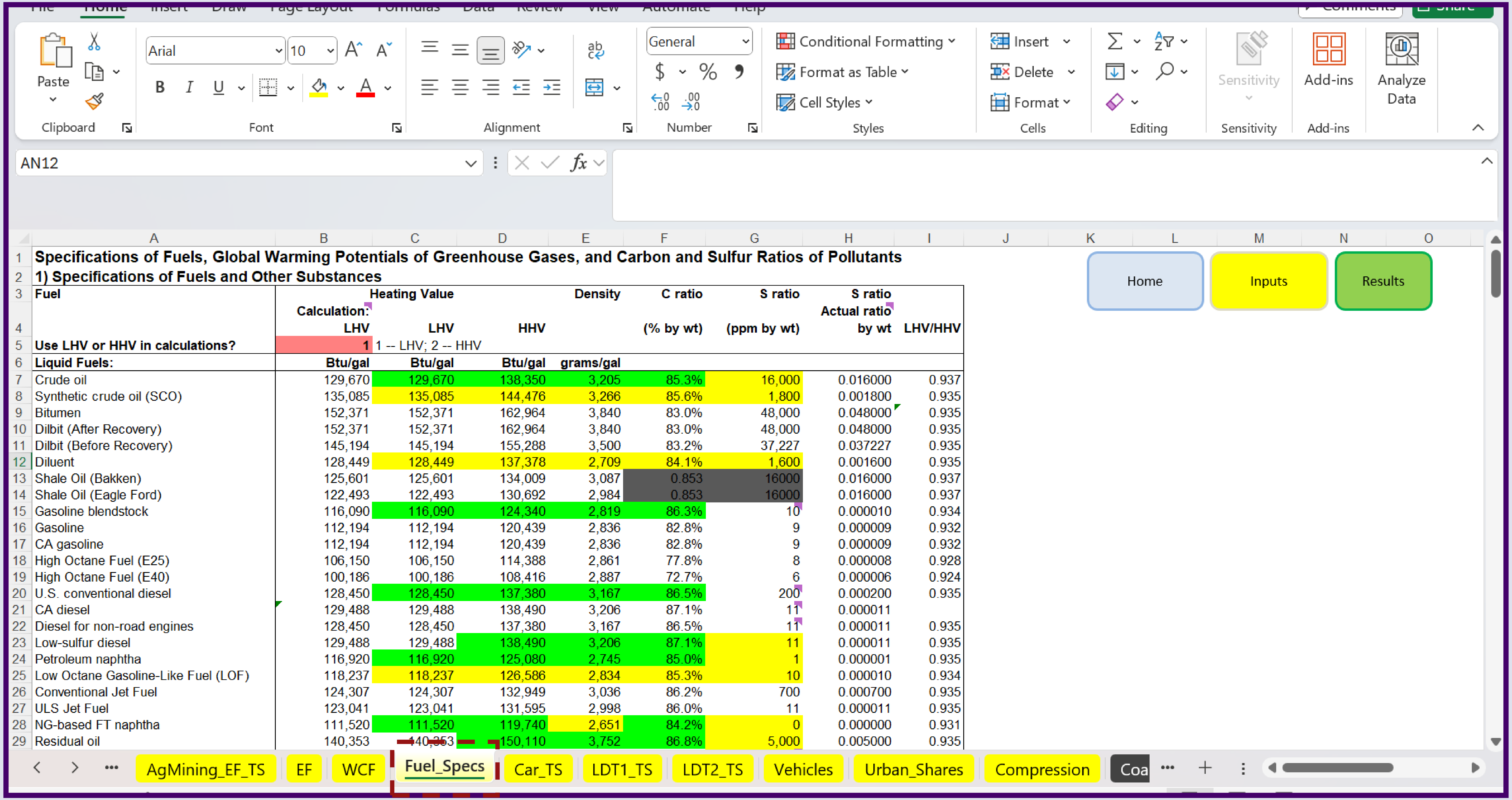

Specifications of Fuels, Global Warming Potentials of Greenhouse Gases, and Carbon and Sulfur Ratios of Pollutants

1) Specifications of Fuels and Other Substances

Fuel	Heating Value Calculation: LHV	Heating Value LHV	Heating Value HHV	Density	C ratio (% by wt)	S ratio (ppm by wt)	S ratio Actual ratio by wt	LHV/HHV
Use LHV or HHV in calculations?	1	1 -- LHV; 2 -- HHV						
Liquid Fuels:	Btu/gal	Btu/gal	Btu/gal	grams/gal				
Crude oil	129,670	129,670	138,350	3,205	85.3%	16,000	0.016000	0.937
Synthetic crude oil (SCO)	135,085	135,085	144,476	3,266	85.6%	1,800	0.001800	0.935
Bitumen	152,371	152,371	162,964	3,840	83.0%	48,000	0.048000	0.935
Dilbit (After Recovery)	152,371	152,371	162,964	3,840	83.0%	48,000	0.048000	0.935
Dilbit (Before Recovery)	145,194	145,194	155,288	3,500	83.2%	37,227	0.037227	0.935
Diluent	128,449	128,449	137,378	2,709	84.1%	1,600	0.001600	0.935
Shale Oil (Bakken)	125,601	125,601	134,009	3,087	0.853	16000	0.016000	0.937
Shale Oil (Eagle Ford)	122,493	122,493	130,692	2,984	0.853	16000	0.016000	0.937
Gasoline blendstock	116,090	116,090	124,340	2,819	86.3%	10	0.000010	0.934
Gasoline	112,194	112,194	120,439	2,836	82.8%	9	0.000009	0.932
CA gasoline	112,194	112,194	120,439	2,836	82.8%	9	0.000009	0.932
High Octane Fuel (E25)	106,150	106,150	114,388	2,861	77.8%	8	0.000008	0.928
High Octane Fuel (E40)	100,186	100,186	108,416	2,887	72.7%	6	0.000006	0.924
U.S. conventional diesel	128,450	128,450	137,380	3,167	86.5%	200	0.000200	0.935
CA diesel	129,488	129,488	138,490	3,206	87.1%	11	0.000011	
Diesel for non-road engines	128,450	128,450	137,380	3,167	86.5%	11	0.000011	0.935
Low-sulfur diesel	129,488	129,488	138,490	3,206	87.1%	11	0.000011	0.935
Petroleum naphtha	116,920	116,920	125,080	2,745	85.0%	1	0.000001	0.935
Low Octane Gasoline-Like Fuel (LOF)	118,237	118,237	126,586	2,834	85.3%	10	0.000010	0.934
Conventional Jet Fuel	124,307	124,307	132,949	3,036	86.2%	700	0.000700	0.935
ULS Jet Fuel	123,041	123,041	131,595	2,998	86.0%	11	0.000011	0.935
NG-based FT naphtha	111,520	111,520	119,740	2,651	84.2%	0	0.000000	0.931
Residual oil	140,353	140,353	150,110	3,752	86.8%	5,000	0.005000	0.935

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Hydrogen Scenarios

G. H_2 SMR

Determine the WTG GHG Emissions of Gaseous H_2 Produced from Steam Methane Reforming (SMR) with 95% Carbon Capture and Sequestration (CCS) and Steam Export of 0.15 mmBtu/mmBtu H_2

6.5) NG Feedstock Options for H2 Production via SMR

	Gaseous H2	Liquid H2
Central Plants	1	1
Distributed Production at Refueling Stations	1	1

Note:
1 -- North American NG, 4 -- Renewable Natural Gas

6.6) CO2 Sequestration Options for Central Plant H2 Production

	Gaseous H2	Liquid H2
NG-Based SMR H2 Plants	1	1
Coal-Based H2 Plants	2	2
Biomass-Based H2 Plants	1	1
Pet Coke-to-H2 Plant	1	
ATR H2 Plants	2	2

Note:
1 -- Without CO2 sequestration
2 -- With CO2 sequestration

6.7) Selection of H2 Plant Design Types

	NG/RNG	Coal	Biomass	Petcoke
Central Plant G.H2	1	0	0	0
Refueling Station G.H2	0			
Central Plant L.H2	1	0	0	
Refueling Station L.H2	0			

6.8) Selection of Method for Estimating Credits of Co-Products for NG Based Fuel Pathways (Co-products are defined in Section 6.7)

	NG/RNG	Coal	Biomass	Petcoke
Central Plant G.H2	1	1	1	1
Refueling Station G.H2	1			
Central Plant L.H2	1	1	1	
Refueling Station L.H2	1			

6.9) Electric Generation Source for H2 Production via PEM Electrolysis

Gaseous H2	Liquid H2
1	1

1 -- Solar, …

Overview | Inputs | Results | Petroleum | Co_processing | NG | MeOH_FTD | EtOH | Electric | Generation_mixes | Bio

Note: CCS is disabled by default

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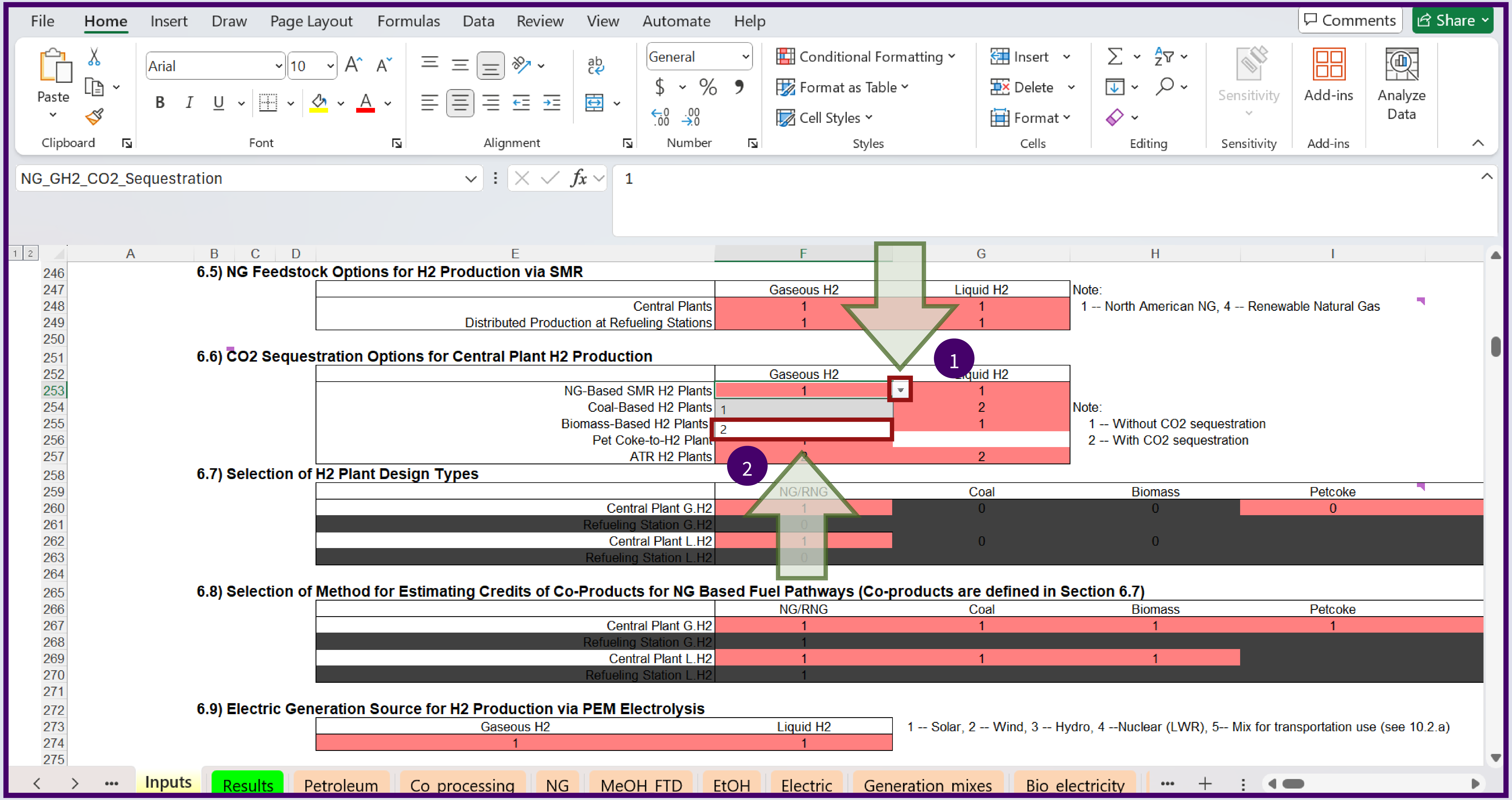

NG_GH2_CO2_Sequestration
1
6.5) NG Feedstock Options for H2 Production via SMR
Gaseous H2
Liquid H2
Central Plants 1 1
Distributed Production at Refueling Stations 1 1
Note:
1 -- North American NG, 4 -- Renewable Natural Gas
6.6) CO2 Sequestration Options for Central Plant H2 Production
Gaseous H2
Liquid H2
NG-Based SMR H2 Plants 1 1
Coal-Based H2 Plants 1 2
Biomass-Based H2 Plants 2 1
Pet Coke-to-H2 Plant
ATR H2 Plants 2
Note:
1 -- Without CO2 sequestration
2 -- With CO2 sequestration
1
2
6.7) Selection of H2 Plant Design Types
NG/RNG
Coal
Biomass
Petcoke
Central Plant G.H2 1 0 0 0
Refueling Station G.H2 0
Central Plant L.H2 1 0 0
Refueling Station L.H2 0
6.8) Selection of Method for Estimating Credits of Co-Products for NG Based Fuel Pathways (Co-products are defined in Section 6.7)
NG/RNG
Coal
Biomass
Petcoke
Central Plant G.H2 1 1 1 1
Refueling Station G.H2 1
Central Plant L.H2 1 1 1
Refueling Station L.H2 1
6.9) Electric Generation Source for H2 Production via PEM Electrolysis
Gaseous H2
Liquid H2
1 1
1 -- Solar, 2 -- Wind, 3 -- Hydro, 4 --Nuclear (LWR), 5-- Mix for transportation use (see 10.2.a)
Inputs
Results
Petroleum
Co_processing
NG
MeOH_FTD
EtOH
Electric
Generation_mixes
Bio_electricity

Z1109

13. GREET Default Key Assumptions for Well-to-Pump Activities

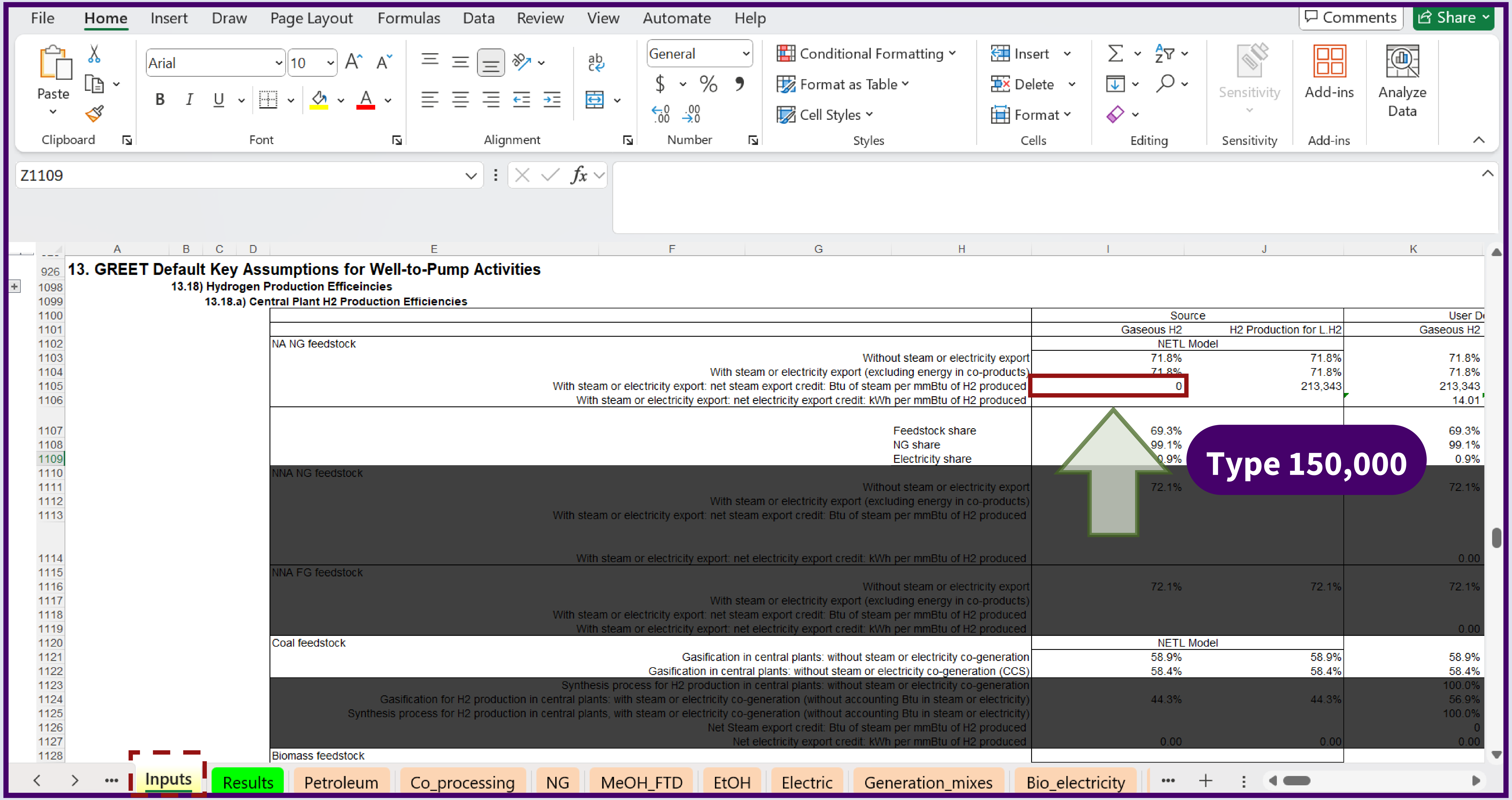
13.18) Hydrogen Production Effeicincies

13.18.a) Central Plant H2 Production Efficiencies

Row		Source: Gaseous H2	Source: H2 Production for L.H2	User D…: Gaseous H2
1102	NA NG feedstock	NETL Model		
1103	Without steam or electricity export	71.8%	71.8%	71.8%
1104	With steam or electricity export (excluding energy in co-products)	71.8%	71.8%	71.8%
1105	With steam or electricity export: net steam export credit: Btu of steam per mmBtu of H2 produced	0	213,343	213,343
1106	With steam or electricity export: net electricity export credit: kWh per mmBtu of H2 produced			14.01
1107	Feedstock share	69.3%	69.3%	69.3%
1108	NG share	99.1%	99.1%	99.1%
1109	Electricity share	0.9%	0.9%	0.9%
1110	NNA NG feedstock			
1111	Without steam or electricity export	72.1%	72.1%	72.1%
1112	With steam or electricity export (excluding energy in co-products)			
1113	With steam or electricity export: net steam export credit: Btu of steam per mmBtu of H2 produced			
1114	With steam or electricity export: net electricity export credit: kWh per mmBtu of H2 produced			0.00
1115	NNA FG feedstock			
1116	Without steam or electricity export	72.1%	72.1%	72.1%
1117	With steam or electricity export (excluding energy in co-products)			
1118	With steam or electricity export: net steam export credit: Btu of steam per mmBtu of H2 produced			
1119	With steam or electricity export: net electricity export credit: kWh per mmBtu of H2 produced			0.00
1120	Coal feedstock	NETL Model		
1121	Gasification in central plants: without steam or electricity co-generation			8.9%
1122	Gasification in central plants: without steam or electricity co-generation (CCS)			4%
1123	Synthesis process for H2 production in central plants: without steam or electricity co-generation			0%
1124	Gasification for H2 production in central plants: with steam or electricity co-generation (without accounting Btu in steam or electricity)			9%
1125	Synthesis process for H2 production in central plants, with steam or electricity co-generation (without accounting Btu in steam or electricity)			0%
1126	Net Steam export credit: Btu of steam per mmBtu of H2 produced			0
1127	Net electricity export credit: kWh per mmBtu of H2 produced			0.00
1128	Biomass feedstock			

Inputs | Results | Petroleum | Co_processing | NG | MeOH_FTD | EtOH | Electric | Generation_mixes | Bio_electricity

Note: steam export is 0 mmBtu by default



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Percentage of Carbon Sequestered by Default in Central NG-to-H_2 Plants

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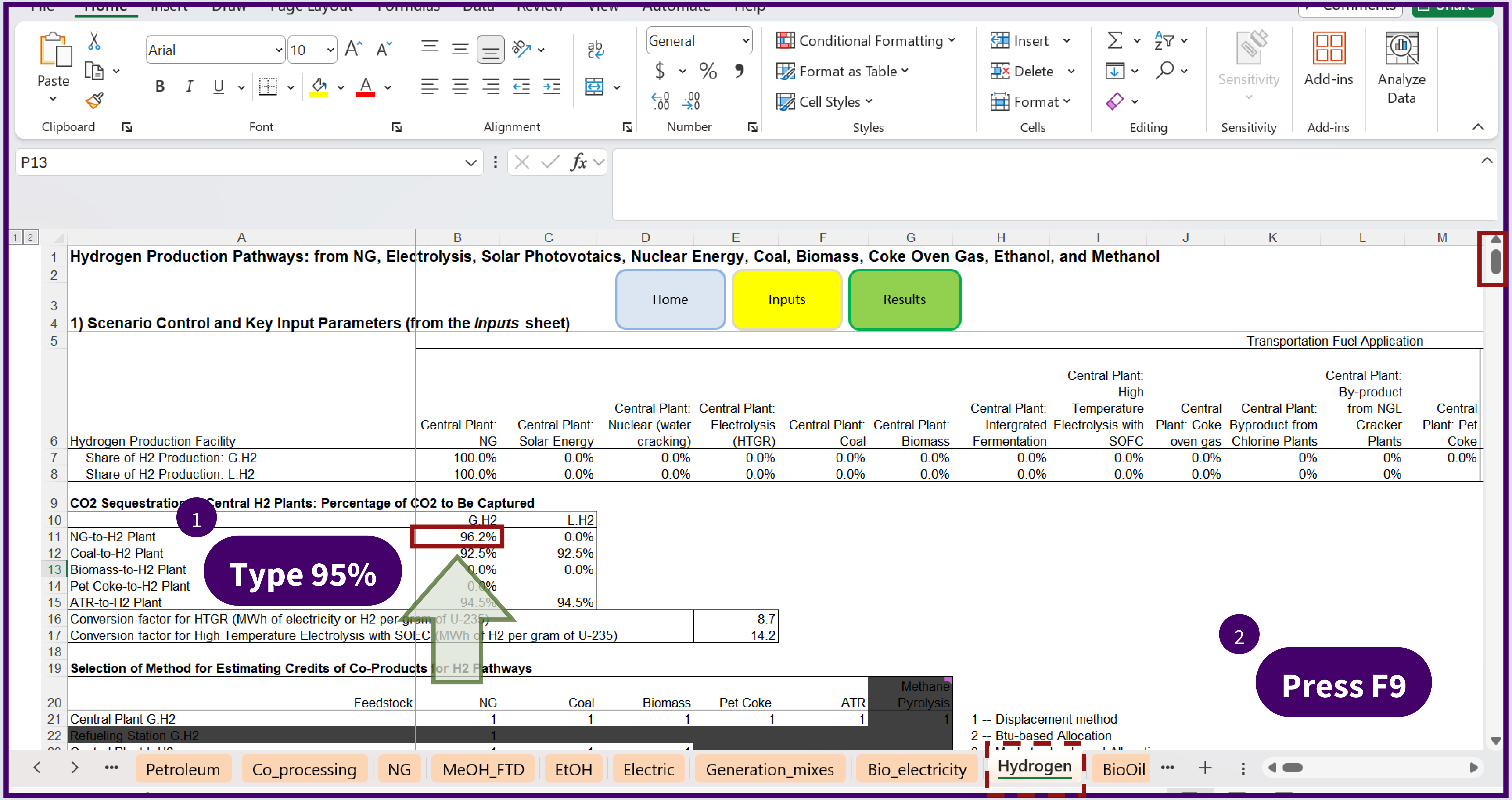

P13
Hydrogen Production Pathways: from NG, Electrolysis, Solar Photovotaics, Nuclear Energy, Coal, Biomass, Coke Oven Gas, Ethanol, and Methanol
Home
Inputs
Results
1) Scenario Control and Key Input Parameters (from the Inputs sheet)
Transportation Fuel Application
Hydrogen Production Facility
Central Plant: NG
Central Plant: Solar Energy
Central Plant: Nuclear (water cracking)
Central Plant: Electrolysis (HTGR)
Central Plant: Coal
Central Plant: Biomass
Central Plant: Intergrated Fermentation
Central Plant: High Temperature Electrolysis with SOFC
Central Plant: Coke oven gas
Central Plant: Byproduct from Chlorine Plants
Central Plant: By-product from NGL Cracker Plants
Central Plant: Pet Coke
Share of H2 Production: G.H2 100.0% 0.0% 0.0% 0.0% 0.0% 0.0% 0.0% 0.0% 0.0% 0% 0% 0.0%
Share of H2 Production: L.H2 100.0% 0.0% 0.0% 0.0% 0.0% 0.0% 0.0% 0.0% 0.0% 0% 0%
CO2 Sequestration Central H2 Plants: Percentage of CO2 to Be Captured
G.H2 L.H2
NG-to-H2 Plant 96.2% 0.0%
Coal-to-H2 Plant 92.5% 92.5%
Biomass-to-H2 Plant 0.0% 0.0%
Pet Coke-to-H2 Plant 0.0%
ATR-to-H2 Plant 94.5% 94.5%
Conversion factor for HTGR (MWh of electricity or H2 per gram of U-235) 8.7
Conversion factor for High Temperature Electrolysis with SOEC (MWh of H2 per gram of U-235) 14.2
Selection of Method for Estimating Credits of Co-Products for H2 Pathways
Feedstock NG Coal Biomass Pet Coke ATR Methane Pyrolysis
Central Plant G.H2 1 1 1 1 1 1
Refueling Station G.H2 1
1 -- Displacement method
2 -- Btu-based Allocation
1
Type 95%
2
Press F9
Petroleum
Co_processing
NG
MeOH_FTD
EtOH
Electric
Generation_mixes
Bio_electricity
Hydrogen
BioOil

Well-to-Gate (WTG) GHG Emissions

WTG: Energy Consumption, Water Consumption, and Emissions of Hydrogen Pathways for H2 Module

Row		Units	Central: NG SMR with CCS	Central: Low Temperature Electrolysis PEM using Solar	Central: Coal Gasification with CCS	Central: Biomass Gasification	Central: High Temperature Electrolysis with SOEC using Nuclear LWR	Central: By-product H2 from Chlorine Plants	Central: By-product H2 from NGL Steam Cracker Plants	Distributed: NG SMR	Distributed: Low Temperature Electrolysis PEM using Solar	Central: RNG SMR with CCS	Distributed: RNG SMR
389	Total energy	Btu/mmBtu	524,891	1,750,297	777,351	1,366,916	1,342,922	201,833	1,142,460	634,975	1,760,678	-1,403,370	-991,276
390	Fossil fuels	Btu/mmBtu	504,226	0	762,295	162,082	13,116	162,529	1,135,234	599,813	0	48,529	294,251
391	Coal	Btu/mmBtu	29,620	0	703,746	9,768	2,992	56,335	10,358	50,400	0	84,062	99,227
392	Natural gas	Btu/mmBtu	473,126	0	34,745	92,586	6,797	101,429	1,124,121	547,268	0	-38,091	191,912
393	Petroleum	Btu/mmBtu	1,480	0	23,804	59,727	3,326	4,765	754	2,144	0	2,558	3,112
394	Water consumption	gal/mmBtu	68.452	87.055	66.746	36.167	191.238	17.885	6.020	39.927	87.420	78.629	49.054
395	VOC	g/mmBtu	16.544	0.000	15.513	4.742	0.170	1.542	13.866	17.524	0.000	-28.559	-22.927
396	CO	g/mmBtu	45.629	0.000	9.617	20.257	0.833	5.835	57.994	56.862	0.000	-34.584	-15.079
397	NOx	g/mmBtu	57.015	0.000	10.982	32.414	1.379	9.864	55.864	70.693	0.000	14.683	32.727
398	PM10	g/mmBtu	3.165	0.000	14.712	2.113	0.144	1.313	3.820	3.060	0.000	-3.807	-3.193
399	PM2.5	[illegible]	[illegible]	[illegible]	2.223	1.814	0.088	0.763	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
400	SOx	[illegible]	[illegible]	[illegible]	26.578	20.594	0.785	7.281	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
401	BC	[illegible]	[illegible]	[illegible]	0.071	0.887	0.018	0.048	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
402	OC	[illegible]	[illegible]	[illegible]	0.183	0.409	0.022	0.215	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
403	CH4	[illegible]	[illegible]	[illegible]	256.431	23.646	1.935	26.228	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
404	N2O	[illegible]	[illegible]	[illegible]	0.124	6.642	0.078	0.250	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
405	CO2	[illegible]	[illegible]	[illegible]	17,555	11,912	942	12,064	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
406	CO2 (w/ C in VOC & CO)	g/mmBtu	7,350	0	17,618	11,958	944	12,078	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
407	GHGs	gCO2e/mmBtu	16,386	0	25,294	14,476	1,023	12,928	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
408	VOC: Urban	g/mmBtu	1.202	0.000	0.099	0.224	0.014	0.107	2.387	1.741	0.000	-16.695	-14.310

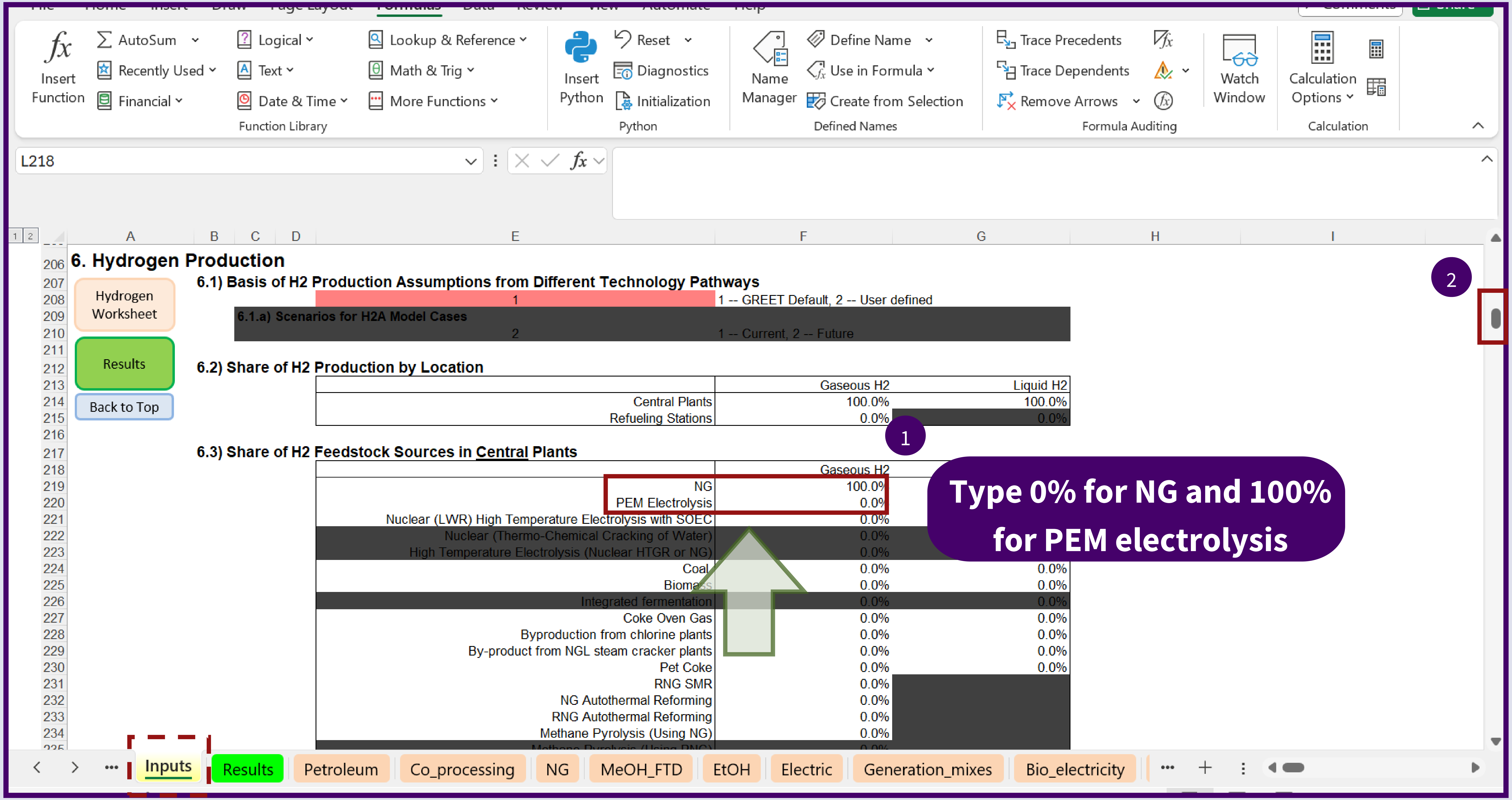
Petroleum | Co_processing | NG | MeOH_FTD | EtOH | Electric | Generation_mixes | Bio_electricity | Hydrogen | BioOil

WTG GHG emissions
16,386 g CO_2e/mmBtu

Gaseous hydrogen from SMR with CCS and steam export

G. H_2 PEM Electrolysis

Determine the WTG GHG Emissions of Gaseous H_2 Produced from PEM Electrolysis Using the U.S. Average Electricity Grid Mix While Exporting all Oxygen Produced



Insert Function
AutoSum
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Math & Trig
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Name Manager
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Trace Precedents
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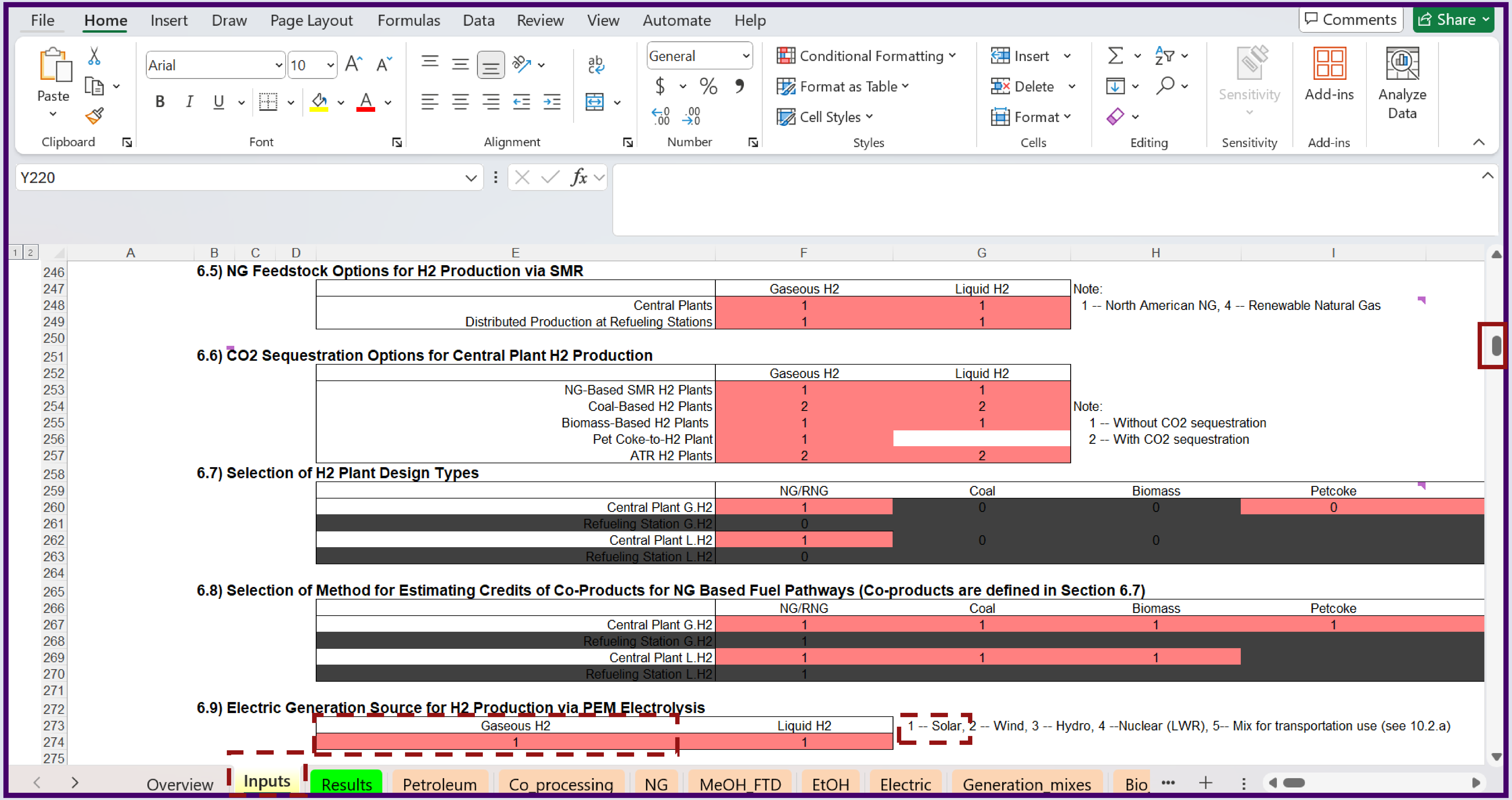
1 -- Current, 2 -- Future
6.2) Share of H2 Production by Location
Gaseous H2
Liquid H2
Central Plants 100.0% 100.0%
Refueling Stations 0.0% 0.0%
6.3) Share of H2 Feedstock Sources in Central Plants
Gaseous H2
NG 100.0%
PEM Electrolysis 0.0%
Nuclear (LWR) High Temperature Electrolysis with SOEC 0.0%
Nuclear (Thermo-Chemical Cracking of Water) 0.0%
High Temperature Electrolysis (Nuclear HTGR or NG) 0.0%
Coal 0.0% 0.0%
Biomass 0.0% 0.0%
Integrated fermentation 0.0% 0.0%
Coke Oven Gas 0.0% 0.0%
Byproduction from chlorine plants 0.0% 0.0%
By-product from NGL steam cracker plants 0.0% 0.0%
Pet Coke 0.0% 0.0%
RNG SMR 0.0%
NG Autothermal Reforming 0.0%
RNG Autothermal Reforming 0.0%
Methane Pyrolysis (Using NG) 0.0%
1
2
Type 0% for NG and 100% for PEM electrolysis
Inputs
Results
Petroleum
Co_processing
NG
MeOH_FTD
EtOH
Electric
Generation_mixes
Bio_electricity

Default Electricity Source for Hydrogen Production via PEM Electrolysis



6.5) NG Feedstock Options for H2 Production via SMR

	Gaseous H2	Liquid H2
Central Plants	1	1
Distributed Production at Refueling Stations	1	1

Note:
1 -- North American NG, 4 -- Renewable Natural Gas

6.6) CO2 Sequestration Options for Central Plant H2 Production

	Gaseous H2	Liquid H2
NG-Based SMR H2 Plants	1	1
Coal-Based H2 Plants	2	2
Biomass-Based H2 Plants	1	1
Pet Coke-to-H2 Plant	1	
ATR H2 Plants	2	2

Note:
1 -- Without CO2 sequestration
2 -- With CO2 sequestration

6.7) Selection of H2 Plant Design Types

	NG/RNG	Coal	Biomass	Petcoke
Central Plant G.H2	1	0	0	0
Refueling Station G.H2	0			
Central Plant L.H2	1	0	0	
Refueling Station L.H2	0			

6.8) Selection of Method for Estimating Credits of Co-Products for NG Based Fuel Pathways (Co-products are defined in Section 6.7)

	NG/RNG	Coal	Biomass	Petcoke
Central Plant G.H2	1	1	1	1
Refueling Station G.H2	1			
Central Plant L.H2	1	1	1	
Refueling Station L.H2	1			

6.9) Electric Generation Source for H2 Production via PEM Electrolysis

Gaseous H2	Liquid H2
1	1

1 -- Solar, 2 -- Wind, 3 -- Hydro, 4 --Nuclear (LWR), 5-- Mix for transportation use (see 10.2.a)

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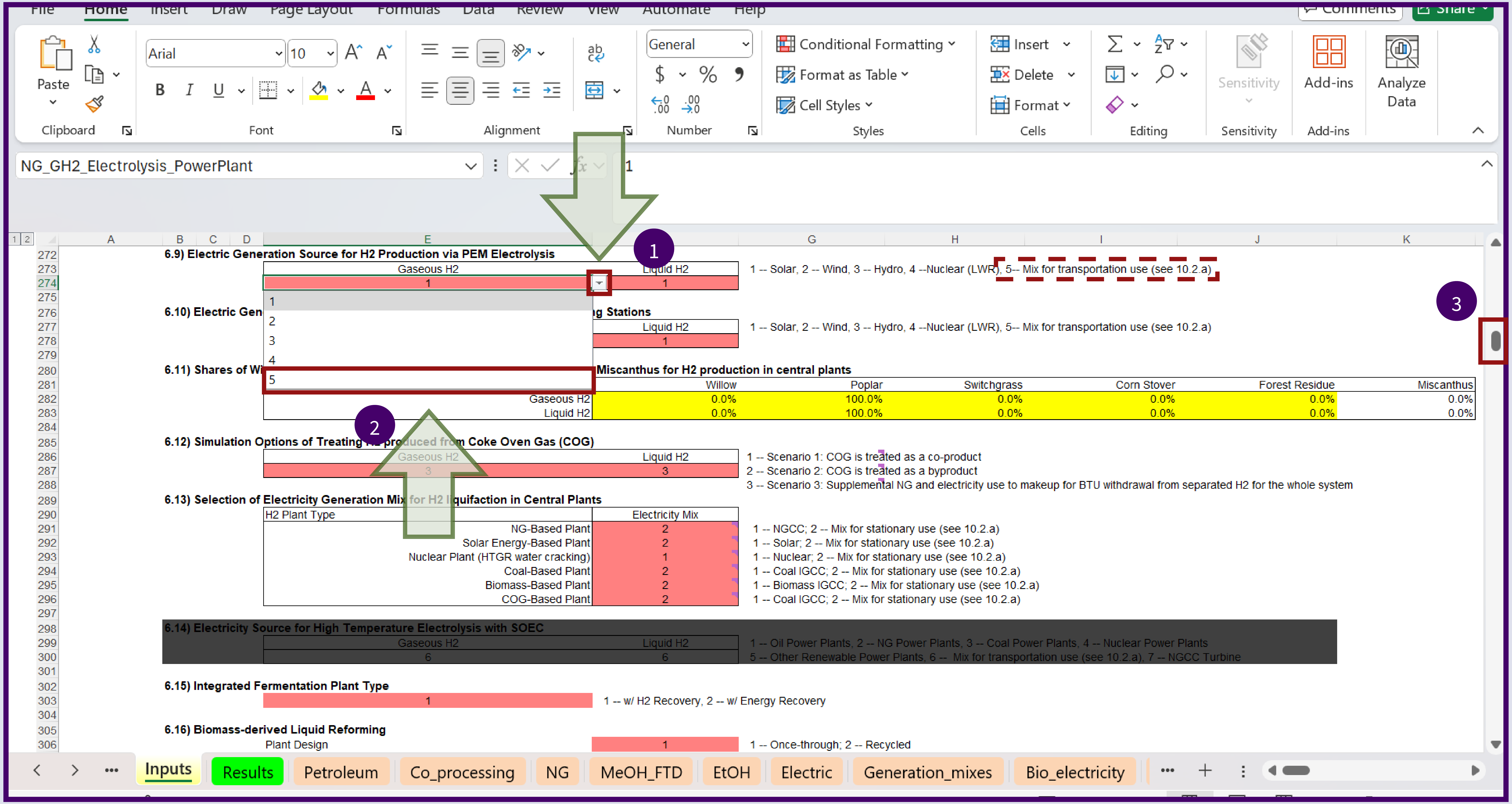

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10. Electric Generation

Electric Worksheet | Results | Back to Top

10.1) GREET-Calculated or User-Inputted Emission Factors for Power Plants

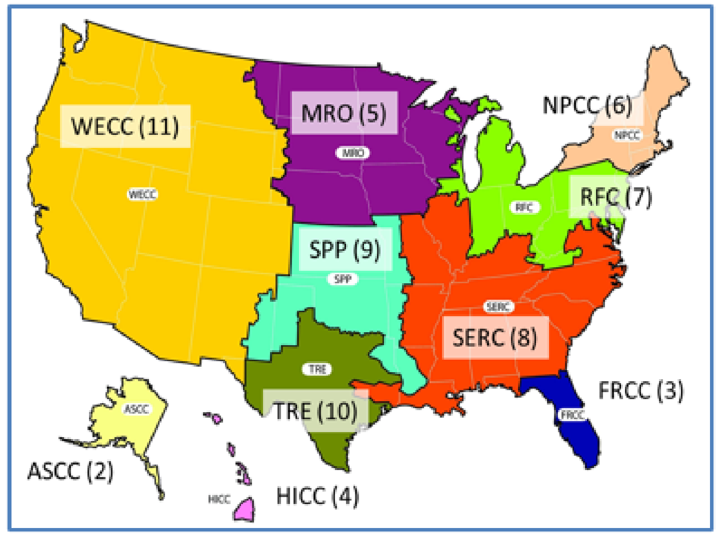
2

1 -- GREET-calculated emissions factors via emission factors in EF Sheet
2 -- Emission factors based on EPA and EIA database in g/kWh

10.2) Electricity Generation Mix

10.2.a) Selection of Electricity Generation Mix for Transportation Use

Mix for transportation use	1
Mix for stationary use	1



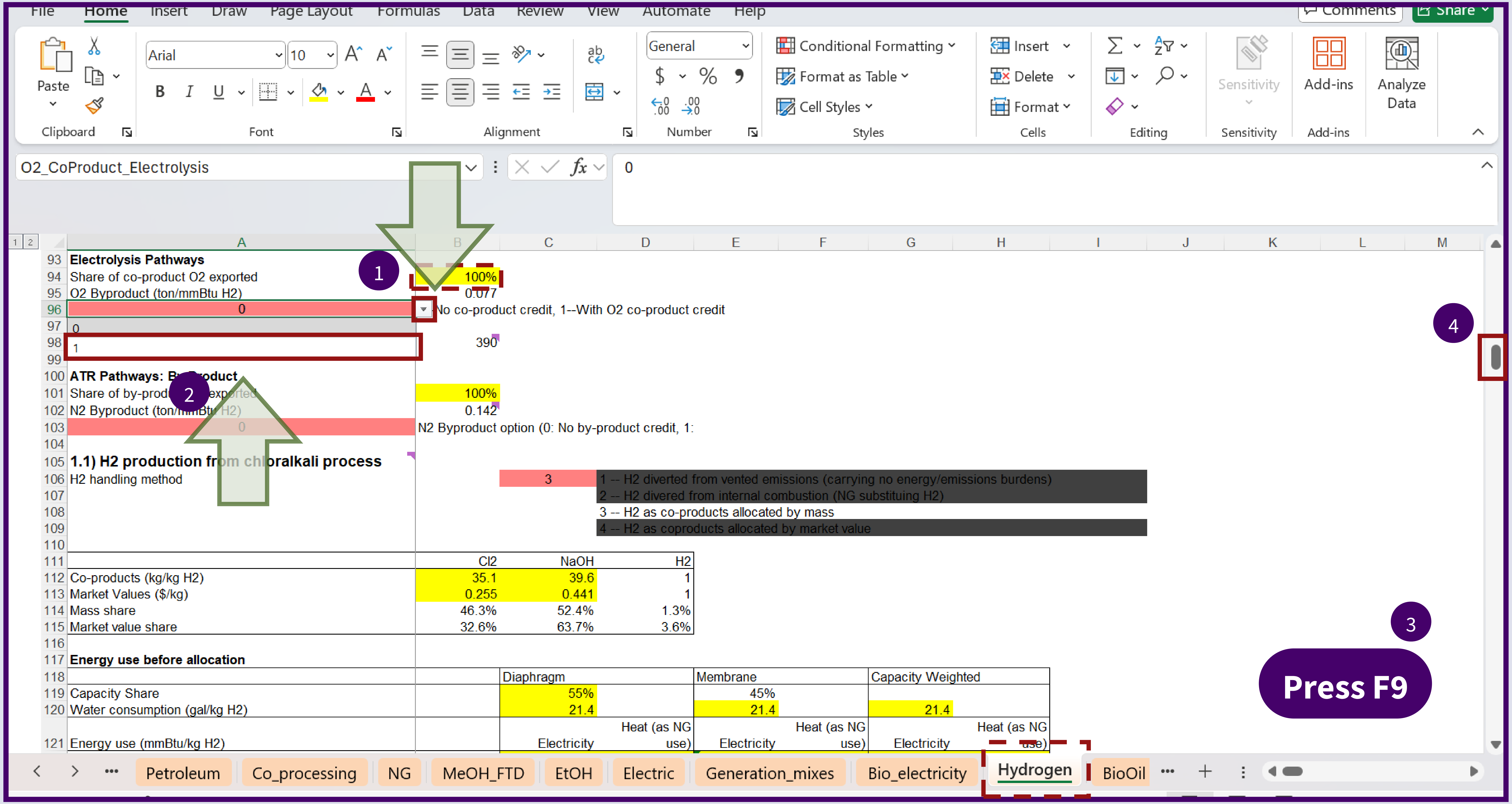
(U.S. EPA)

1 U.S. Mix
2 ASCC Mix
3 FRCC Mix
4 HICC Mix
5 MISO (former MRO) Mix
6 NPCC Mix
7 PJM (former RFC) Mix
8 SERC Mix
9 SPP Mix
10 TRE Mix
11 WECC Mix
12 CA Mix
13 User Defined Mix
14 NG Power Plants (transportation only)
15 Coal Power Plants (transportation only)
16 Nuclear Power Plants (transportation only)
17 Hydro Power Plants (transportation only)
18 NGCC Turbine (transportation only)
19 Geothermal (transportation only)

10.2.b) Electric Generation Mixes: Data Table for Use in GREET (From Annual Energy Outlook 2023)

	U.S. Mix		ASCC Mix		FRCC Mix	
	Transportation	Stationary	Transportation	Stationary	Transportation	Stationary
Residual oil	0.3%	0.3%	13.7%	13.7%	0.2%	0.2%
Natural gas	38.5%	38.5%	46.7%	46.7%	71.3%	71.3%
Coal	20.6%	20.6%	11.4%	11.4%	10.4%	10.4%
Nuclear power	18.9%	18.9%	0.0%	0.0%	12.5%	12.5%
Biomass	0.3%	0.3%	0.6%	0.6%	0.2%	0.2%
Others	21.5%	21.5%	27.6%	27.6%	5.5%	5.5%

10.2.c) Electric Generation Mixes for GREET Simulations



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Well-to-Gate (WTG) GHG Emissions

D389 =D326

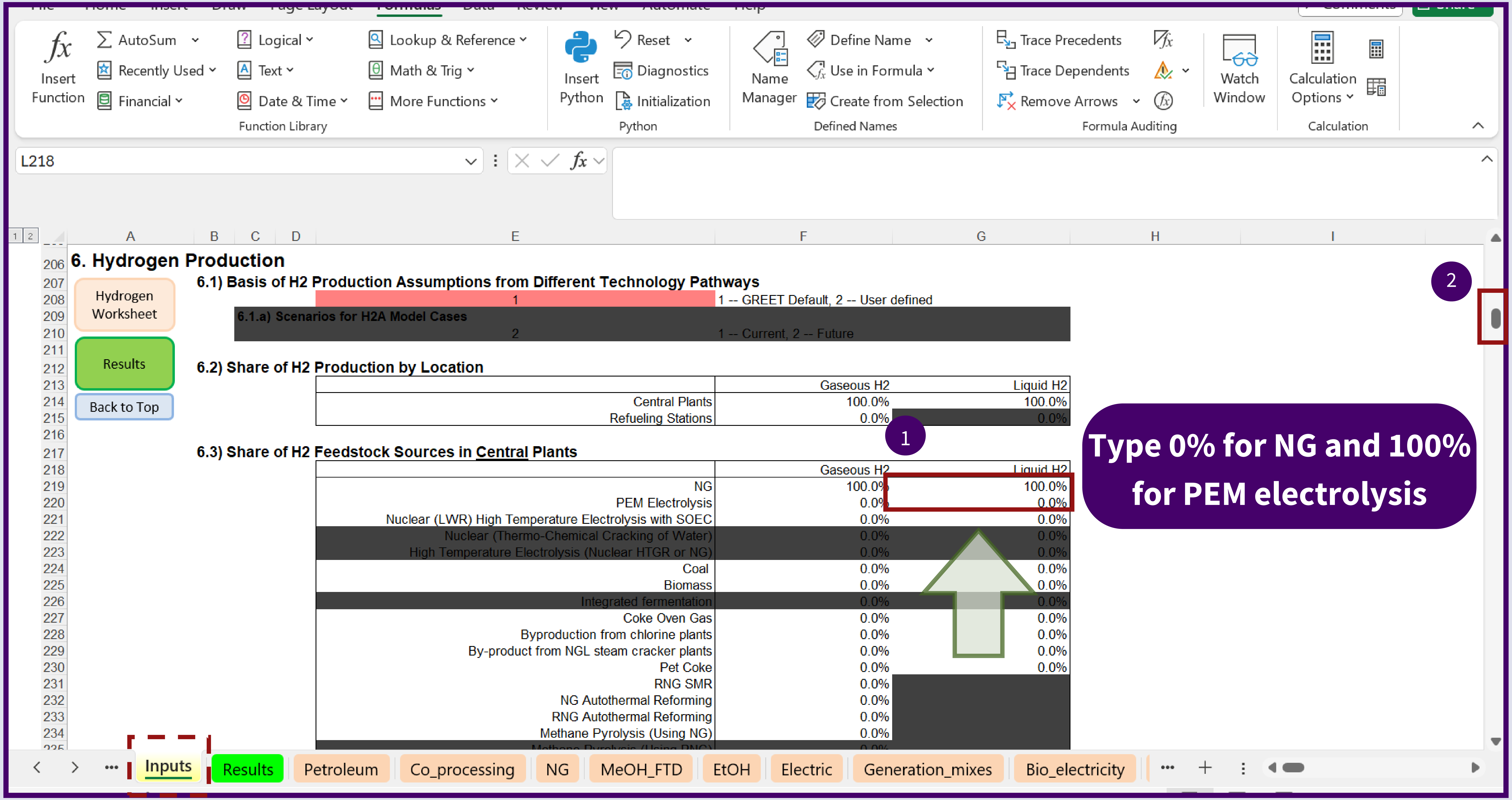
387	WTG: Energy Consumption, Water Consumption, and Emissions of Hydrogen Pathways for H2 Module												
388		Units	Central: NG SMR	Central: Low Temperature Electrolysis PEM using Mix for transportation use	Central: Coal Gasification with CCS	Central: Biomass Gasification	Central: High Temperature Electrolysis with SOEC using Nuclear LWR	Central: By-product H2 from Chlorine Plants	Central: By-product H2 from NGL Steam Cracker Plants	Distributed: NG SMR	Distributed: Low Temperature Electrolysis PEM using Solar	Central: RNG SMR	Distributed: RNG SMR
389	Total energy	Btu/mmBtu	551,766	3,344,108	777,351	1,366,916	1,311,114	201,833	1,142,460	634,975	1,728,869	-1,201,714	-991,276
390	Fossil fuels	Btu/mmBtu	549,140	2,620,299	762,295	162,082	-11,808	162,529	1,135,234	599,813	-24,924	180,330	294,251
391	Coal	Btu/mmBtu	3,763	1,037,475	703,746	9,768	-6,876	56,335	10,358	50,400	-9,868	54,955	99,227
392	Natural gas	Btu/mmBtu	544,661	1,550,468	34,745	92,586	-7,951	101,429	1,124,121	547,268	-14,748	123,645	191,912
393	Petroleum	Btu/mmBtu	716	32,356	23,804	59,727	3,019	4,765	754	2,144	-308	1,730	3,112
394	Water consumption	gal/mmBtu	42.141	307.227	66.746	36.167	188.558	17.885	6.020	39.927	84.741	51.711	49.054
395	VOC	g/mmBtu	17.386	24.046	15.513	4.742	-0.059	1.542	13.866	17.607	-0.229	-25.025	-22.844
396	CO	g/mmBtu	50.998	85.526	9.617	20.257	0.020	5.835	57.994	56.970	-0.814	-24.428	-14.971
397	NOx	g/mmBtu	63.517	151.480	10.982	32.414	-0.062	9.864	55.864	70.833	-1.441	23.712	32.868
398	PM10	g/mmBtu	3.126	21.920	14.712	2.113	-0.064	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
399	PM2.5	g/mmBtu	3.028	12.381	2.223	1.814	-0.030	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
400	SOx	g/mmBtu	[illegible]	[illegible]	[illegible]	20.594	-0.421	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
401	BC	g/mmBtu	[illegible]	[illegible]	[illegible]	0.887	0.012	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
402	OC	g/mmBtu	[illegible]	[illegible]	[illegible]	0.409	-0.010	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
403	CH4	g/mmBtu	[illegible]	[illegible]	[illegible]	23.646	-2.039	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
404	N2O	g/mmBtu	[illegible]	[illegible]	[illegible]	6.642	0.041	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
405	CO2	g/mmBtu	[illegible]	[illegible]	[illegible]	11,912	-948	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
406	CO2 (w/ C in VOC & CO)	g/mmBtu	92,273	198,928	17,618	11,958	-948	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
407	GHGs	gCO2e/mmBtu	101,664	212,462	25,294	14,476	-998	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
408	VOC: Urban	g/mmBtu	1.305	1.625	0.099	0.224	-0.001	0.107	2.387	1.799	-0.015	-15.523	-14.252

WTG GHG emissions
212,462 g CO_2e/mmBtu

Gaseous hydrogen from PEM electrolysis exporting all oxygen produced

Nuclear-Powered PEM

Determine the WTP GHG Emissions of Liquified H_2 Produced from PEM Electrolysis Using Nuclear Energy Transported 200 miles via Tube Truck



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AutoSum
Recently Used
Financial
Logical
Text
Date & Time
Lookup & Reference
Math & Trig
More Functions
Function Library
Insert Python
Reset
Diagnostics
Initialization
Python
Name Manager
Define Name
Use in Formula
Create from Selection
Defined Names
Trace Precedents
Trace Dependents
Remove Arrows
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Byproduction from chlorine plants 0.0% 0.0%
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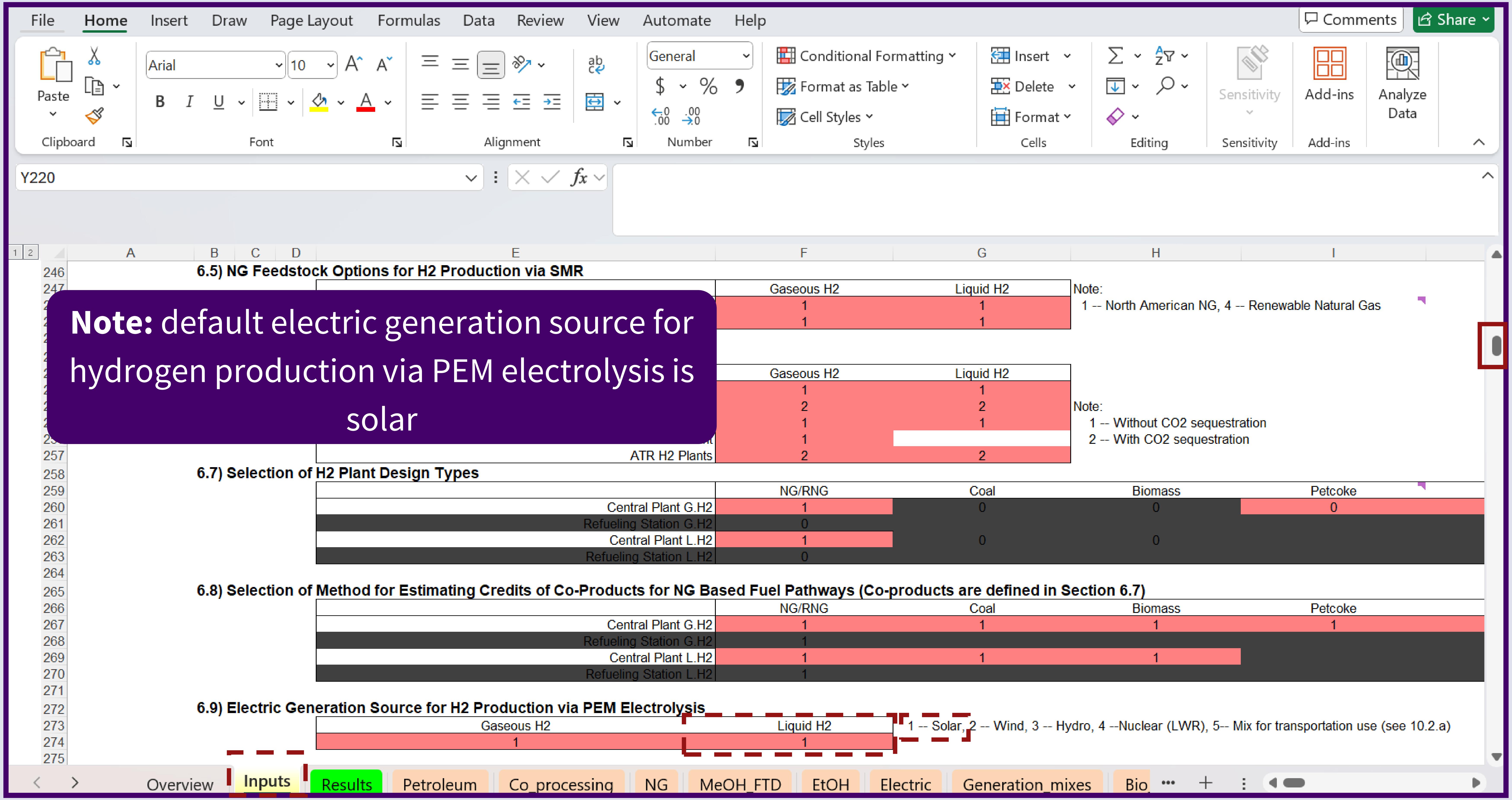
RNG SMR 0.0%
NG Autothermal Reforming 0.0%
RNG Autothermal Reforming 0.0%
Methane Pyrolysis (Using NG) 0.0%
1
2
Type 0% for NG and 100% for PEM electrolysis
Inputs
Results
Petroleum
Co_processing
NG
MeOH_FTD
EtOH
Electric
Generation_mixes
Bio_electricity

Note: default electric generation source for hydrogen production via PEM electrolysis is solar



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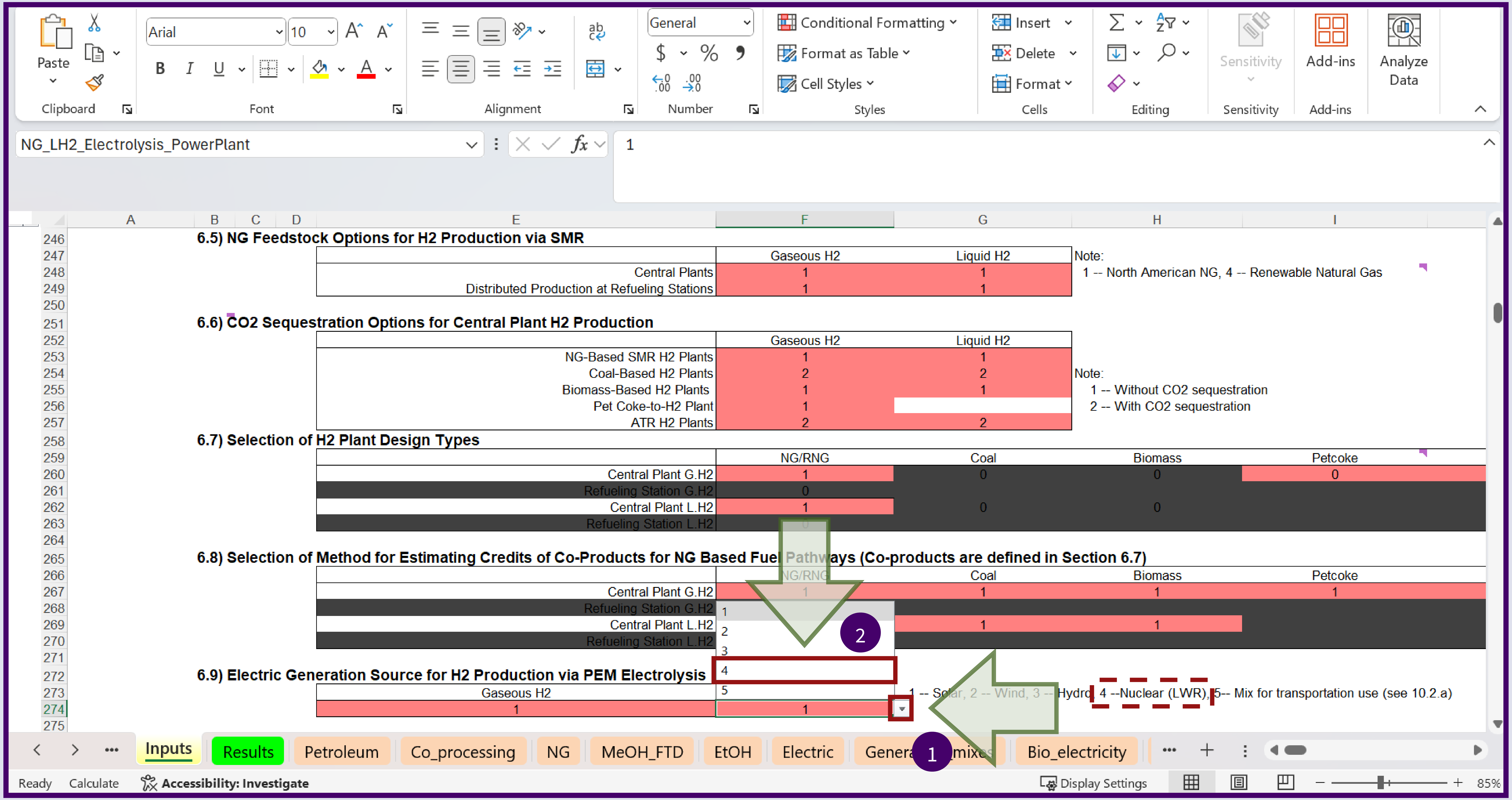

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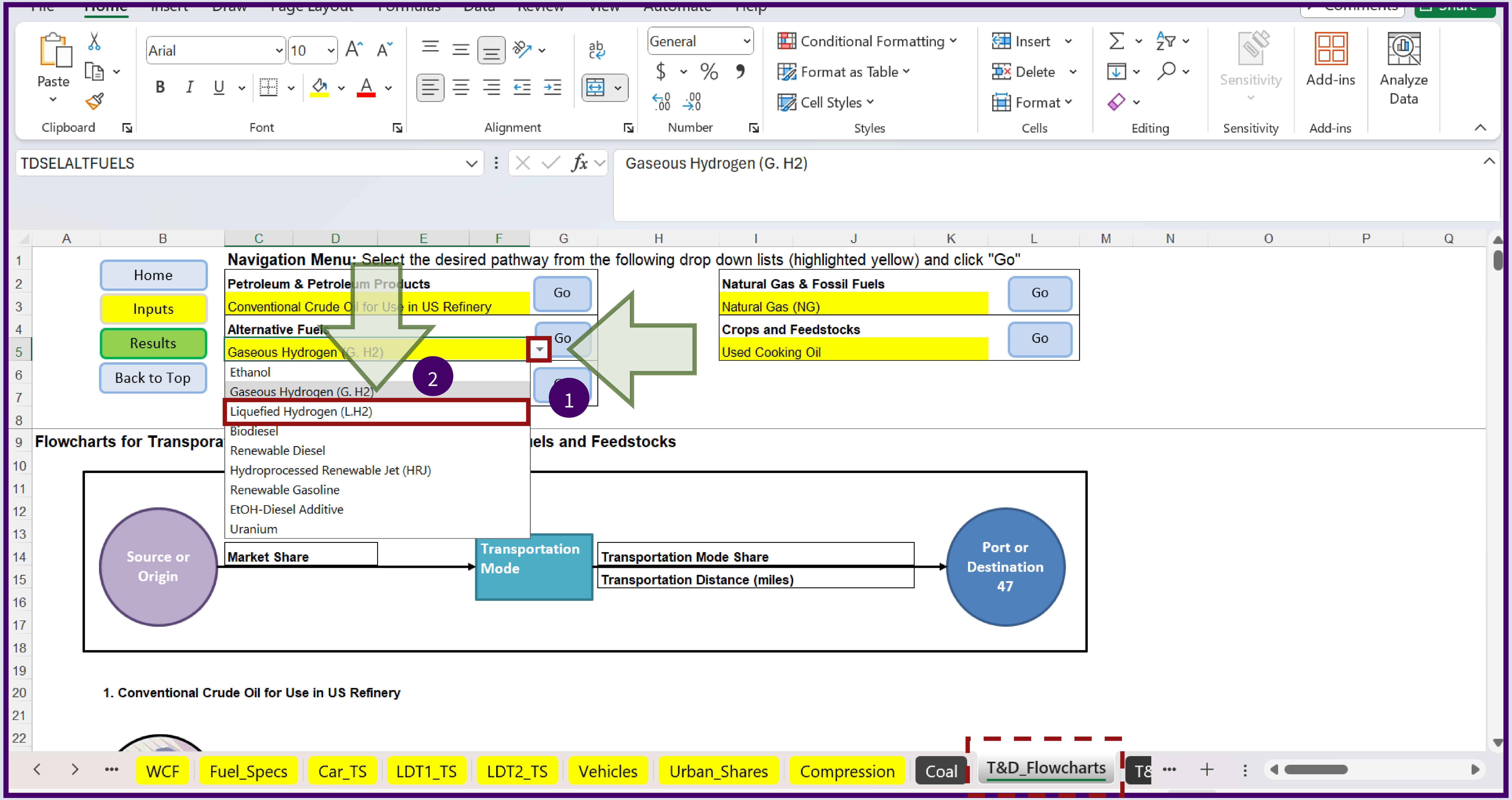

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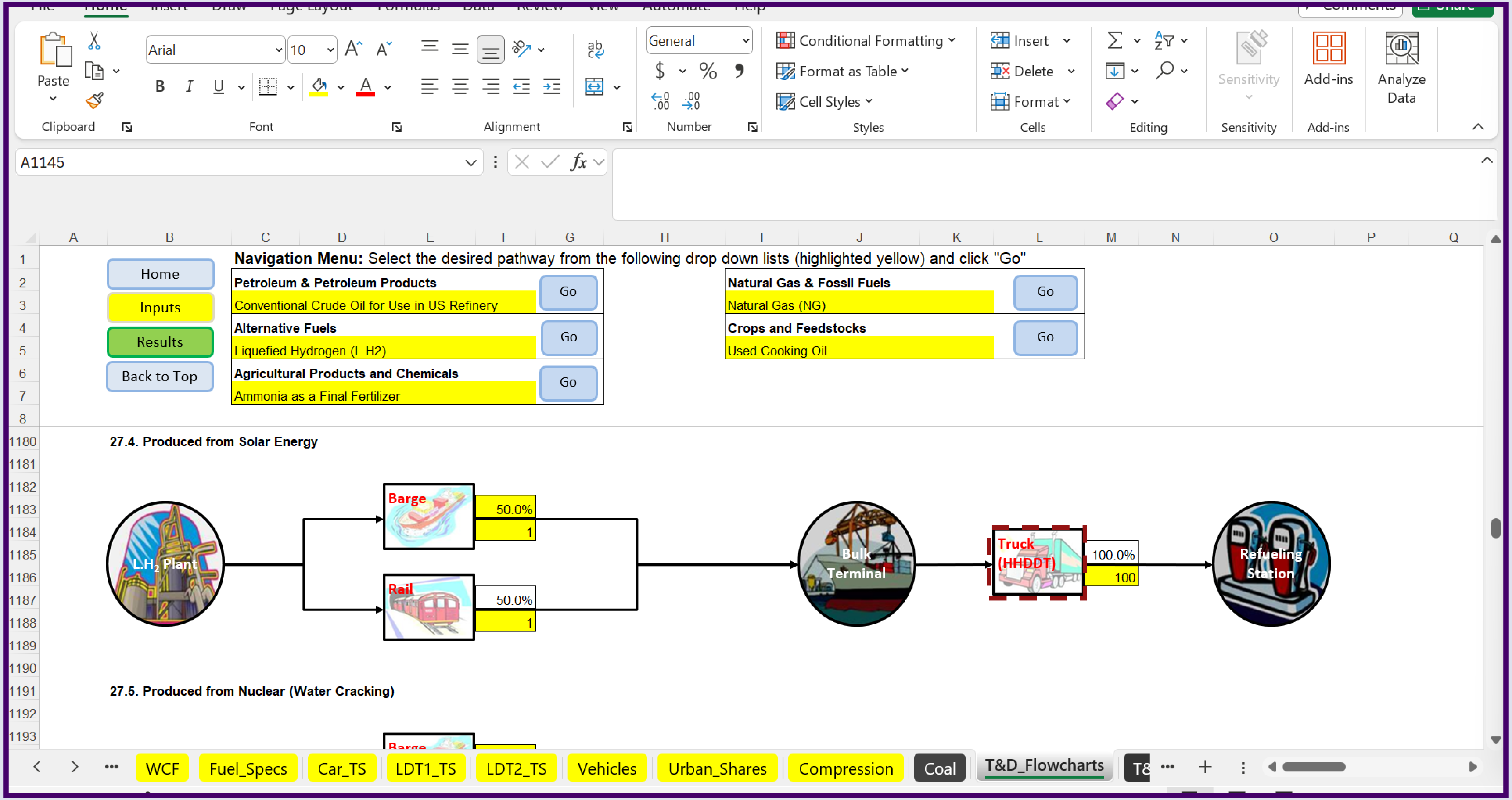
Default Transportation Mode for Liquified Hydrogen to the Refueling Station



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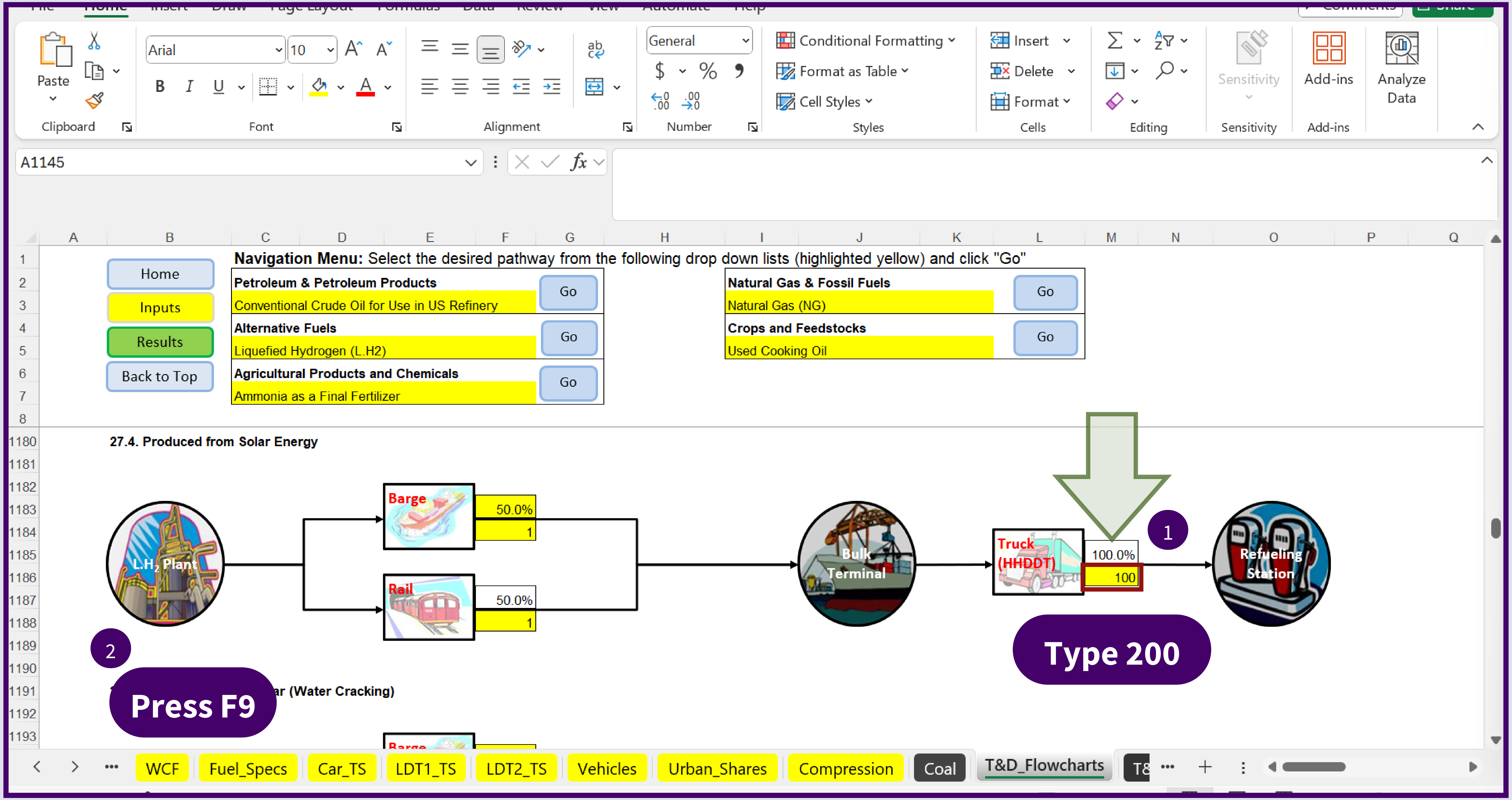
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Home
Inputs
Results
Back to Top
Petroleum & Petroleum Products
Conventional Crude Oil for Use in US Refinery
Alternative Fuels
Liquefied Hydrogen (L.H2)
Agricultural Products and Chemicals
Ammonia as a Final Fertilizer
Natural Gas & Fossil Fuels
Natural Gas (NG)
Crops and Feedstocks
Used Cooking Oil
Go
27.4. Produced from Solar Energy
L.H2 Plant
Barge
50.0%
1
Rail
50.0%
1
Bulk Terminal
Truck (HHDDT)
100.0%
100
Refueling Station
1
Type 200
2
Press F9
ar (Water Cracking)
WCF
Fuel_Specs
Car_TS
LDT1_TS
LDT2_TS
Vehicles
Urban_Shares
Compression
Coal
T&D_Flowcharts

Well-to-Pump (WTP) GHG Emissions

WTP emissions

WTP =
(feedstock x loss factor) +
fuel

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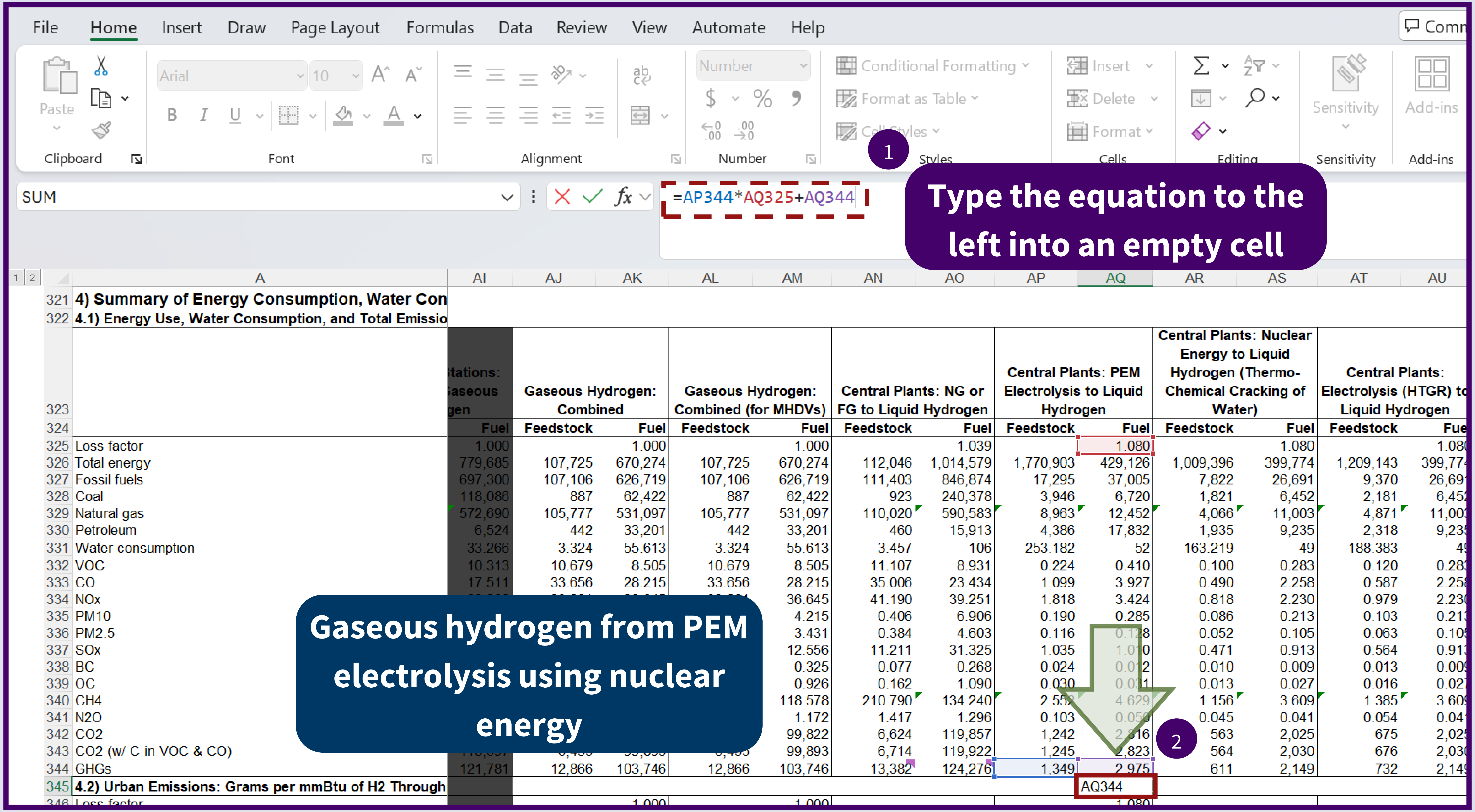
G98

4) Summary of Energy Consumption, Water Consumption, and Emissions: Btu or Gallons or Grams per mmBtu of H2 Throughput at Each Stage

4.1) Energy Use, Water Consumption, and Total Emissions

	Central Plants: NG to Gaseous Hydrogen		Central Plants: PEM electrolysis to Gaseous Hydrogen via Solar		Central Plants: Nuclear Energy to Gaseous Hydrogen (Thermo-Chemical Cracking of Water)		Central Plants: Electrolysis (HTGR) to Gaseous Hydrogen		Central Plants: Coal to Gaseous Hydrogen with CCS		Central Plants: Biomass to Gaseous Hydrogen	
	Feedstock	Fuel	Feedstock	Fuel	Feedstock	Fuel	Feedstock	Fuel	Feedstock	Fuel	Feedstock	Fuel
Loss factor		0.961		1.000		1.000		1.000		1.000		1.000
Total energy	112,046	670,274	1,750,297	226,234	1,009,396	226,234	1,209,143	168,148	20,047	983,539	38,325	1,554,825
Fossil fuels	111,403	626,719	0	184,686	7,822	184,686	9,370	94,489	19,144	927,837	37,895	308,872
Coal	923	62,422	0	59,546	1,821	59,546	2,181	23,761	1,926	761,366	615	68,699
Natural gas	110,020	531,097	0	92,213	4,066	92,213	4,871	38,810	3,418	123,540	10,236	174,563
Petroleum	460	33,201	0	32,927	1,935	32,927	2,318	31,918	13,800	42,931	27,043	65,610
Water consumption	3.457	55.613	87.055	16.796	163.219	16.796	188.383	14.307	3.863	79.680	1.537	51.426
VOC	11.107	8.505	0.000	1.798	0.100	1.798	0.120	0.972	7.322	9.990	1.747	4.794
CO	35.006	28.215	0.000	10.873	0.490	10.873	0.587	7.942	1.754	18.735	7.552	23.578
NOx	41.190	36.645	0.000	12.729	0.818	12.729	0.979	7.535	4.847	18.863	10.995	34.148
PM10	0.406	4.215	0.000	1.480	0.086	1.480	0.103	0.727	8.507	7.684	0.789	2.805
PM2.5	0.384	3.431	0.000	0.772	0.052	0.772	0.063	0.347	1.184	1.810	0.688	1.898
SOx	11.211	12.556	0.000	7.401	0.471	7.401	0.564	3.041	6.799	27.179	1.172	26.823
BC	0.077	0.325	0.000	0.044	0.010	0.044	0.013	0.021	0.035	0.080	0.386	0.545
OC	0.162	0.926	0.000	0.208	0.013	0.208	0.016	0.089	0.071	0.321	0.134	0.483
CH4	210.790	118.578	0.000	27.165	1.156	27.165	1.385	12.777	147.657	135.939	4.225	46.586
N2O	1.417	1.172	0.000	0.237	0.045	0.237	0.054	0.103	0.030	0.332	2.956	3.923
CO2	6,624	99,822	0	14,052	563	14,052	675	7,210	1,490	30,116	3,133	22,831
CO2 (w/ C in VOC & CO)	6,714	99,893	0	14,075	564	14,075	676	7,225	1,516	30,177	3,150	22,883
GHGs	13,382	103,746	0	14,949	611	14,949	732	7,634	5,924	34,319	4,083	25,342
4.2) Urban Emissions: Grams per mmBtu of H2 Throughput at Each Stage												
Loss factor												
VOC	0.594	1.048	0.000	0.314	0.008	0.314	0.010	0.258	0.041	0.372	0.082	0.456

Petroleum | Co_processing | NG | MeOH_FTD | EtOH | Electric | Generation_mixes | Bio_electricity | Hydrogen | BioOil



WTP GHG emissions

4,431 g CO_2e/mmBtu

4,431.81

Ammonia Production

Determine the Emissions of CO_2 Associated with Ammonia Production Utilizing H_2 Production Produced from PEM Electrolysis with an Operating Efficiency for the Electrolyzer at 60 kWh/kg H_2 and a Hydropower Power Source

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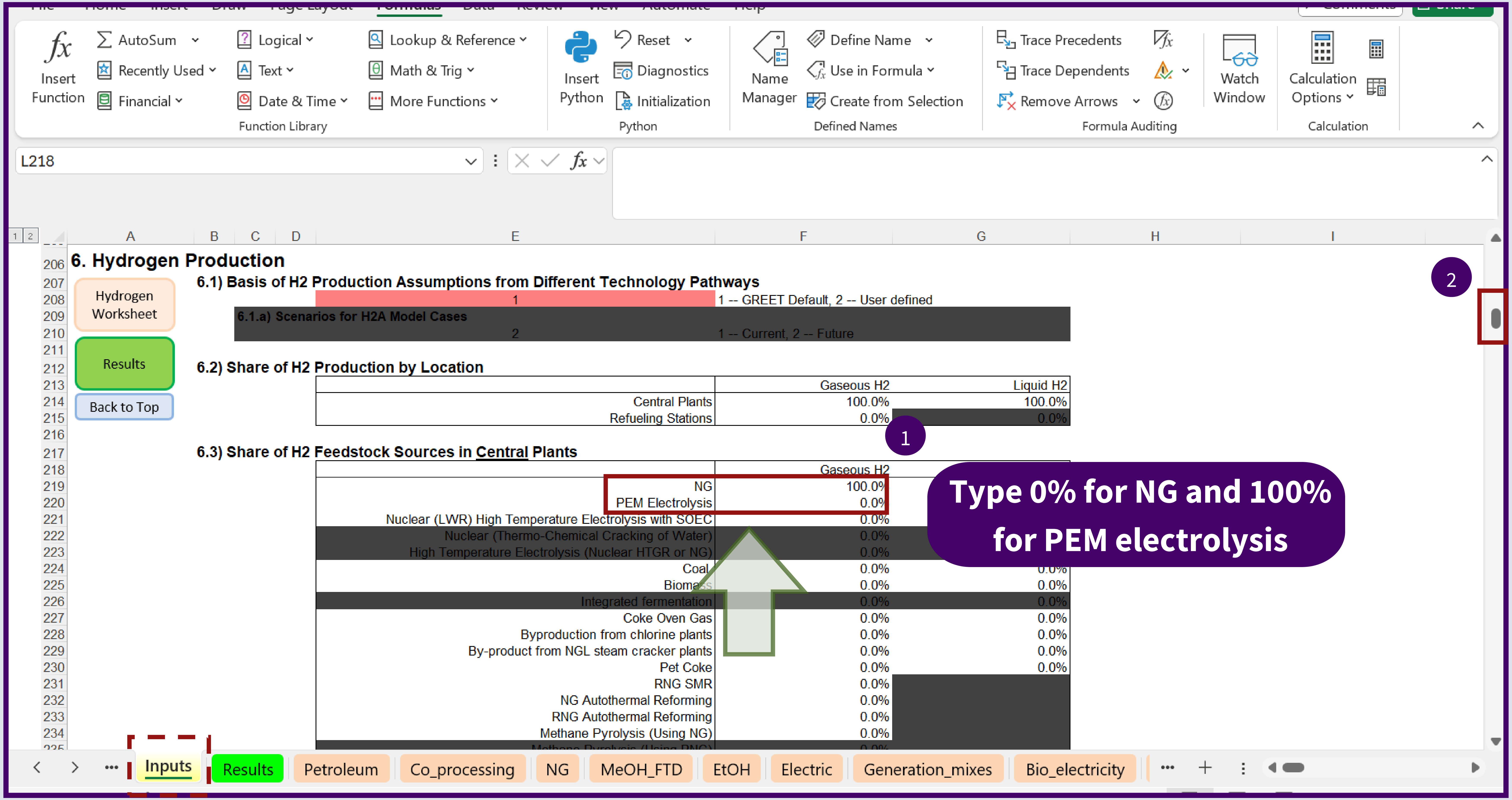

L218
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Type 0% for NG and 100% for PEM electrolysis
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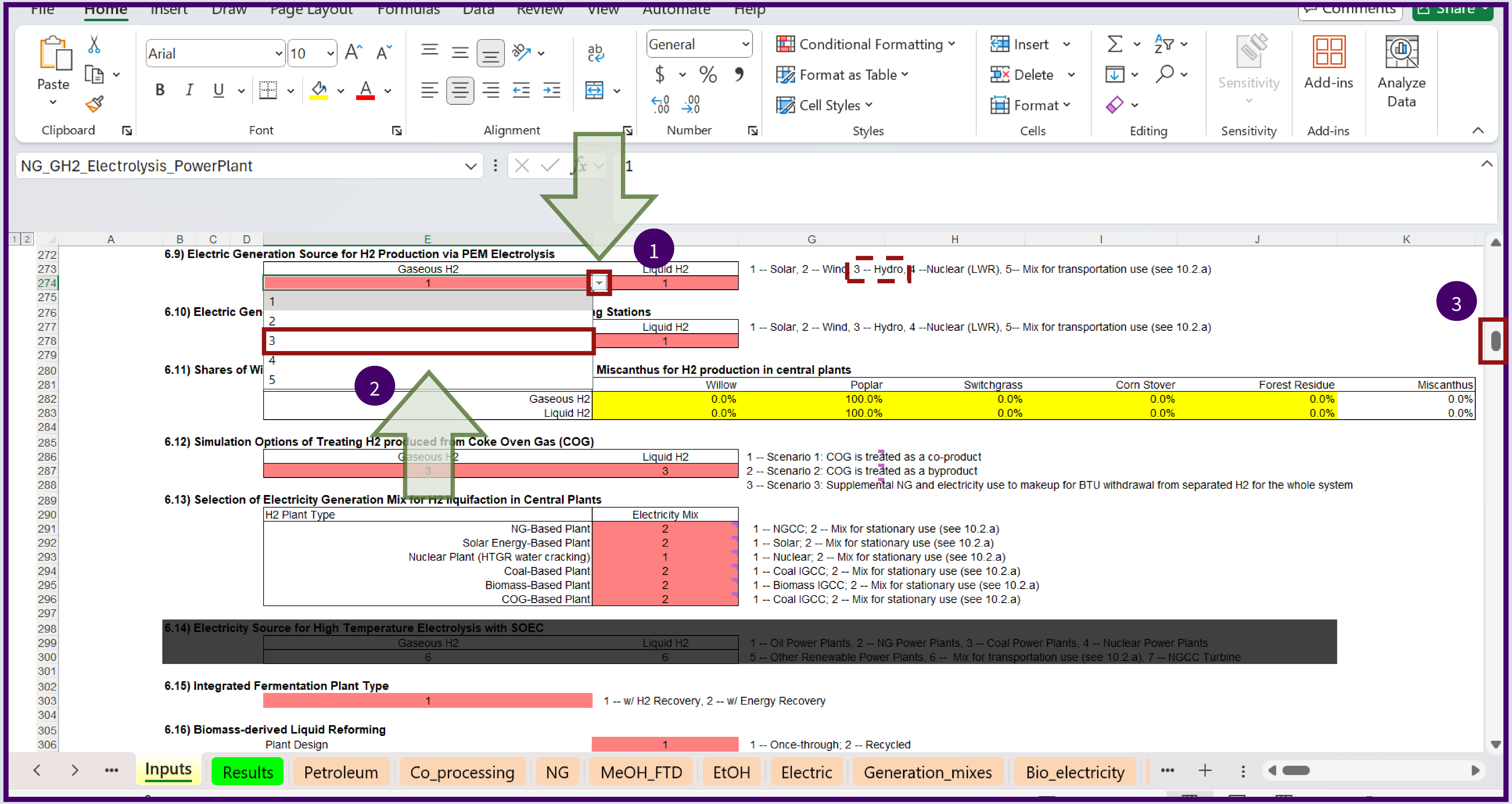

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Efficiency of the Electrolysis Unit

Calculating the efficiency of the electrolysis unit

Hydrogen LHV (in Btu/kg)

G. LHV (Btu/ft^3) / Density of G. Hydrogen (g/ft^3)

Convert from g to kg

Direct Unit Conversion

60 kWh/kg to Btu/kg

Efficiency

LHV (Btu/kg) / Efficiency (Btu/kg)

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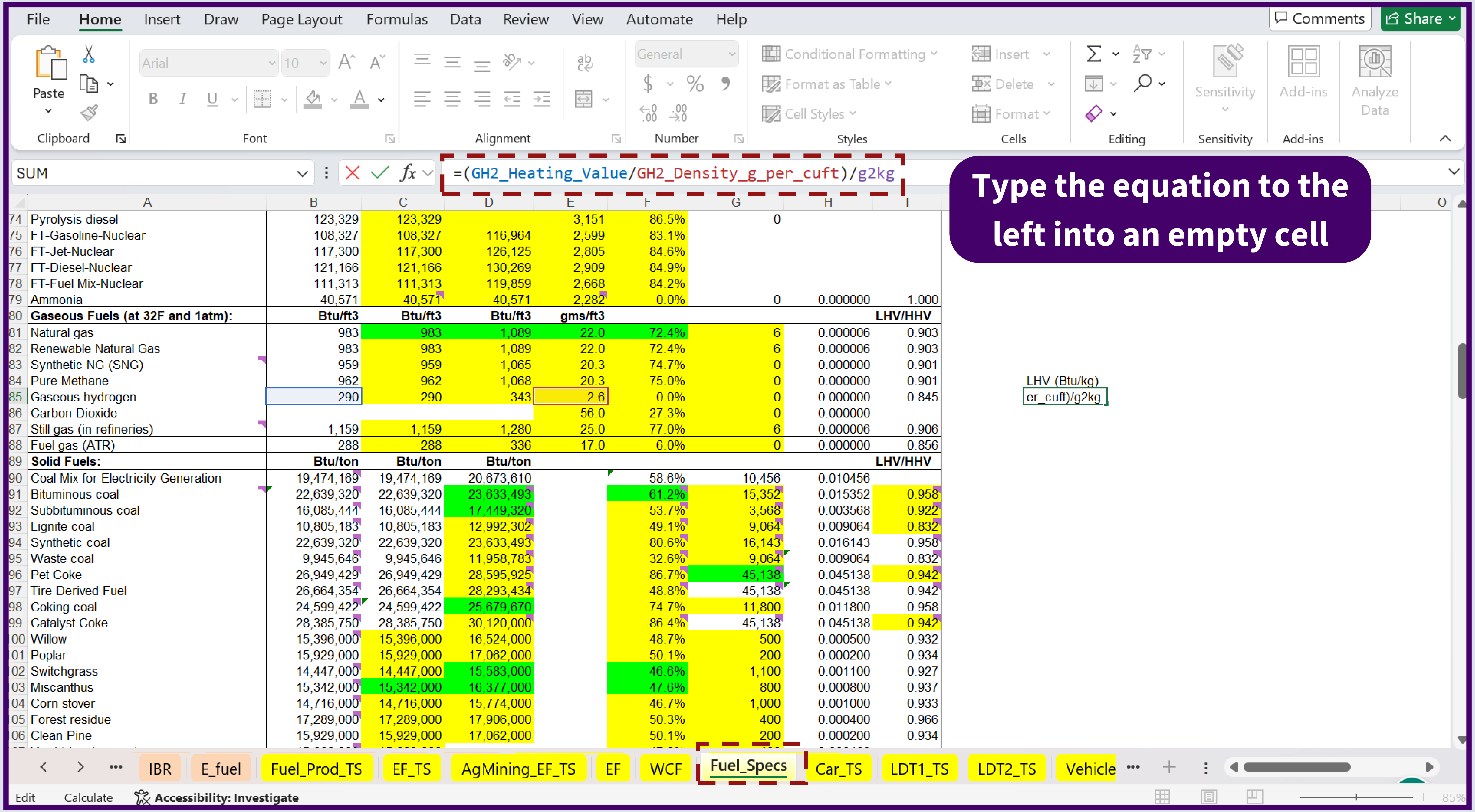

	A	B	C	D	E	F	G	H	I
74	Pyrolysis diesel	123,329	123,329		3,151	86.5%	0		
75	FT-Gasoline-Nuclear	108,327	108,327	116,964	2,599	83.1%			
76	FT-Jet-Nuclear	117,300	117,300	126,125	2,805	84.6%			
77	FT-Diesel-Nuclear	121,166	121,166	130,269	2,909	84.9%			
78	FT-Fuel Mix-Nuclear	111,313	111,313	119,859	2,668	84.2%			
79	Ammonia	40,571	40,571	40,571	2,282	0.0%	0	0.000000	1.000
80	**Gaseous Fuels (at 32F and 1atm):**	**Btu/ft3**	**Btu/ft3**	**Btu/ft3**	**gms/ft3**				**LHV/HHV**
81	Natural gas	983	983	1,089	22.0	72.4%	6	0.000006	0.903
82	Renewable Natural Gas	983	983	1,089	22.0	72.4%	6	0.000006	0.903
83	Synthetic NG (SNG)	959	959	1,065	20.3	74.7%	0	0.000000	0.901
84	Pure Methane	962	962	1,068	20.3	75.0%	0	0.000000	0.901
85	Gaseous hydrogen	290	290	343	2.6	0.0%	0	0.000000	0.845
86	Carbon Dioxide				56.0	27.3%	0	0.000000	
87	Still gas (in refineries)	1,159	1,159	1,280	25.0	77.0%	6	0.000006	0.906
88	Fuel gas (ATR)	288	288	336	17.0	6.0%	0	0.000000	0.856
89	**Solid Fuels:**	**Btu/ton**	**Btu/ton**	**Btu/ton**					**LHV/HHV**
90	Coal Mix for Electricity Generation	19,474,169	19,474,169	20,673,610		58.6%	10,456	0.010456	
91	Bituminous coal	22,639,320	22,639,320	23,633,493		61.2%	15,352	0.015352	0.958
92	Subbituminous coal	16,085,444	16,085,444	17,449,320		53.7%	3,568	0.003568	0.922
93	Lignite coal	10,805,183	10,805,183	12,992,302		49.1%	9,064	0.009064	0.832
94	Synthetic coal	22,639,320	22,639,320	23,633,493		80.6%	16,143	0.016143	0.958
95	Waste coal	9,945,646	9,945,646	11,958,783		32.6%	9,064	0.009064	0.832
96	Pet Coke	26,949,429	26,949,429	28,595,925		86.7%	45,138	0.045138	0.942
97	Tire Derived Fuel	26,664,354	26,664,354	28,293,434		48.8%	45,138	0.045138	0.942
98	Coking coal	24,599,422	24,599,422	25,679,670		74.7%	11,800	0.011800	0.958
99	Catalyst Coke	28,385,750	28,385,750	30,120,000		86.4%	45,138	0.045138	0.942
00	Willow	15,396,000	15,396,000	16,524,000		48.7%	500	0.000500	0.932
01	Poplar	15,929,000	15,929,000	17,062,000		50.1%	200	0.000200	0.934
02	Switchgrass	14,447,000	14,447,000	15,583,000		46.6%	1,100	0.001100	0.927
03	Miscanthus	15,342,000	15,342,000	16,377,000		47.6%	800	0.000800	0.937
04	Corn stover	14,716,000	14,716,000	15,774,000		46.7%	1,000	0.001000	0.933
05	Forest residue	17,289,000	17,289,000	17,906,000		50.3%	400	0.000400	0.966
06	Clean Pine	15,929,000	15,929,000	17,062,000		50.1%	200	0.000200	0.934

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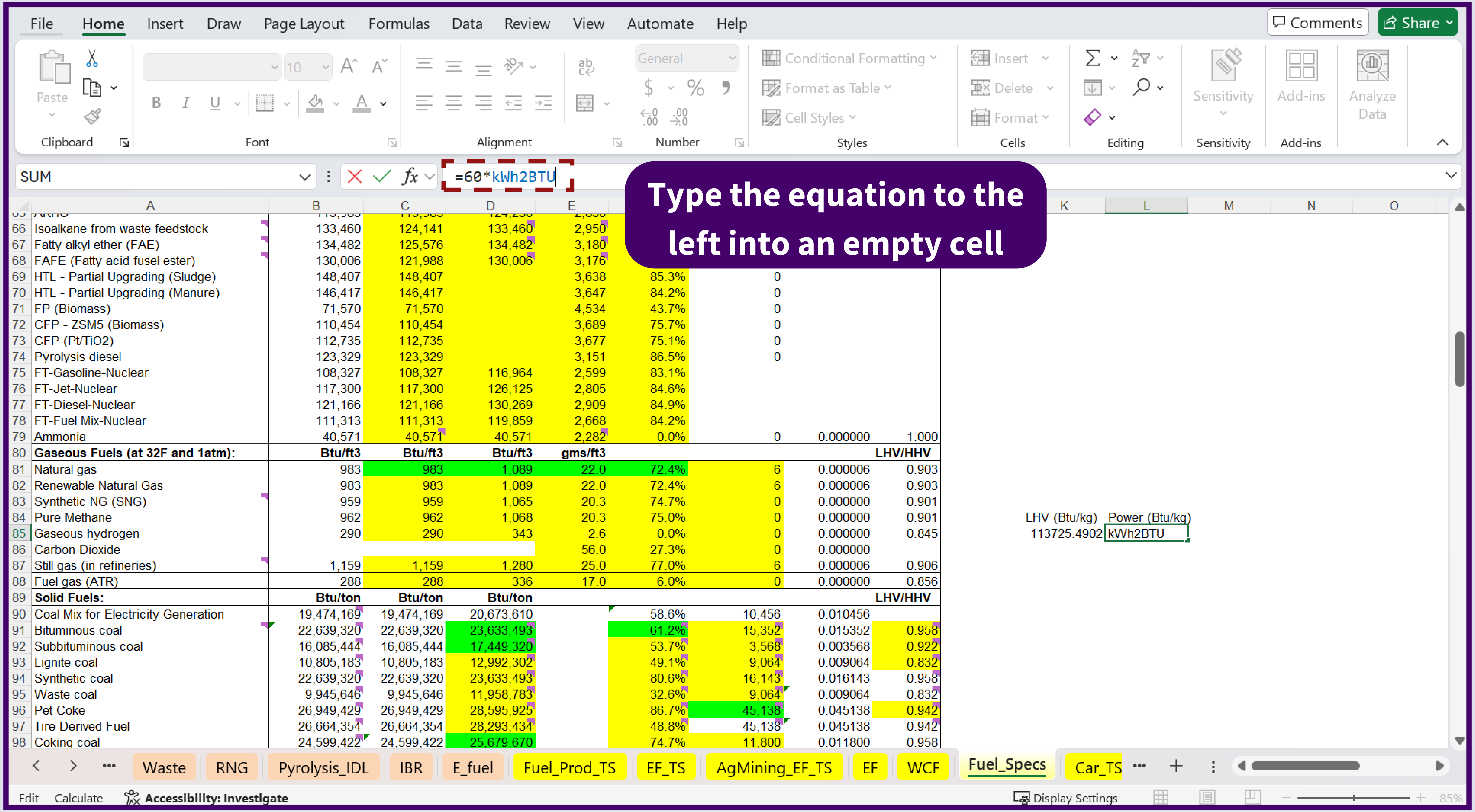
LHV in Btu/kg

113725.4902



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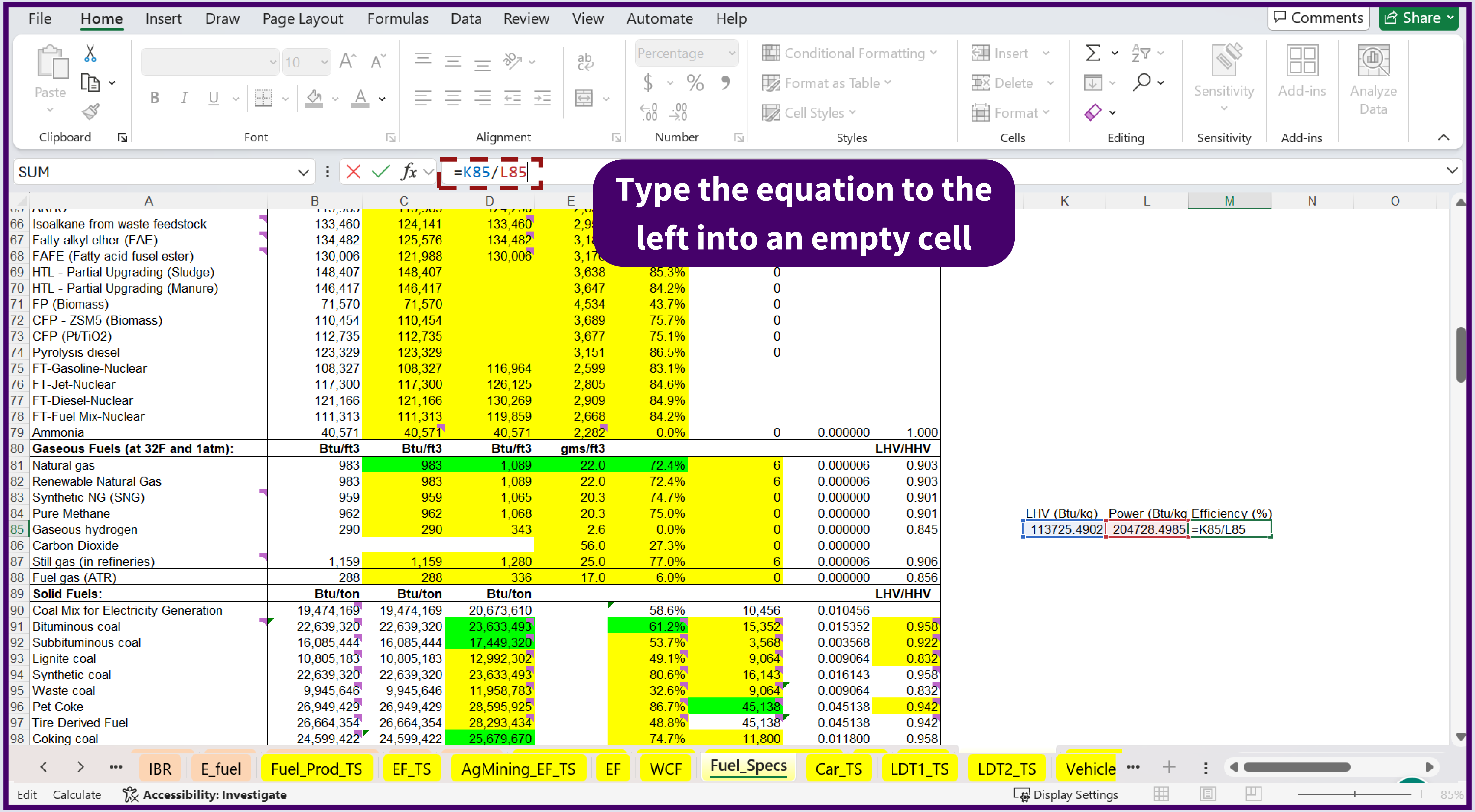
Power in Btu/kg

204728.4985



	A	B	C	D	E				
66	Isoalkane from waste feedstock	133,460	124,141	133,460	[illegible]				
67	Fatty alkyl ether (FAE)	134,482	125,576	134,482	[illegible]				
68	FAFE (Fatty acid fusel ester)	130,006	121,988	130,006	[illegible]				
69	HTL - Partial Upgrading (Sludge)	148,407	148,407		3,638	85.3%	0		
70	HTL - Partial Upgrading (Manure)	146,417	146,417		3,647	84.2%	0		
71	FP (Biomass)	71,570	71,570		4,534	43.7%	0		
72	CFP - ZSM5 (Biomass)	110,454	110,454		3,689	75.7%	0		
73	CFP (Pt/TiO2)	112,735	112,735		3,677	75.1%	0		
74	Pyrolysis diesel	123,329	123,329		3,151	86.5%	0		
75	FT-Gasoline-Nuclear	108,327	108,327	116,964	2,599	83.1%			
76	FT-Jet-Nuclear	117,300	117,300	126,125	2,805	84.6%			
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86	Carbon Dioxide				56.0	27.3%	0	0.000000	
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94	Synthetic coal	22,639,320	22,639,320	23,633,493		80.6%	16,143	0.016143	0.958
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97	Tire Derived Fuel	26,664,354	26,664,354	28,293,434		48.8%	45,138	0.045138	0.942
98	Coking coal	24,599,422	24,599,422	25,679,670		74.7%	11,800	0.011800	0.958

	K	L	M
84	LHV (Btu/kg)	Power (Btu/kg	Efficiency (%)
85	113725.4902	204728.4985	=K85/L85

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Efficiency in %

55.55%

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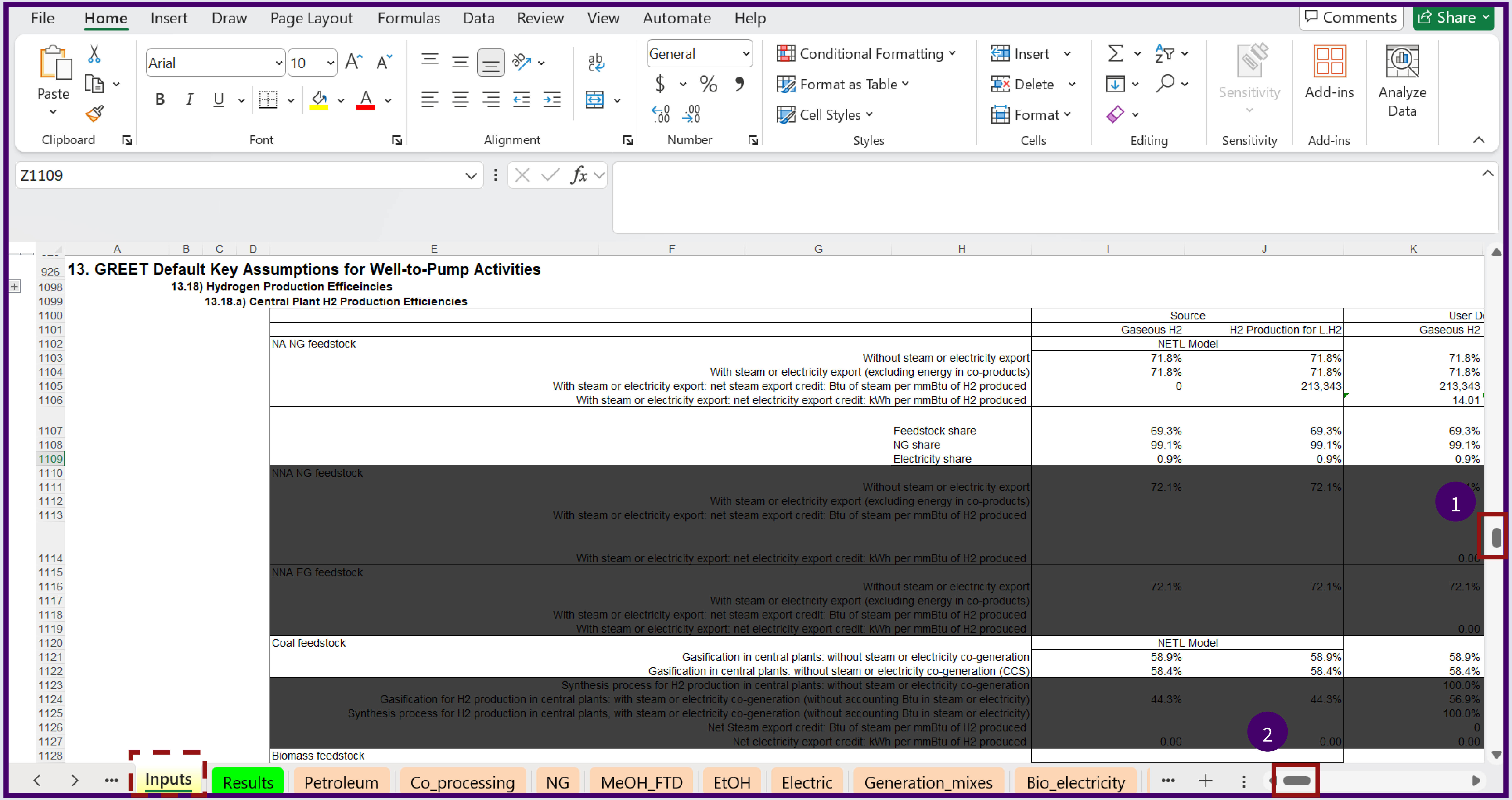

926 **13. GREET Default Key Assumptions for Well-to-Pump Activities**

1098 **13.18) Hydrogen Production Efficeincies**

1099 **13.18.a) Central Plant H2 Production Efficiencies**

Row	E	I	J	K
1100		Source		User D
1101		Gaseous H2	H2 Production for L.H2	Gaseous H2
1102	NA NG feedstock	NETL Model		
1103	Without steam or electricity export	71.8%	71.8%	71.8%
1104	With steam or electricity export (excluding energy in co-products)	71.8%	71.8%	71.8%
1105	With steam or electricity export: net steam export credit: Btu of steam per mmBtu of H2 produced	0	213,343	213,343
1106	With steam or electricity export: net electricity export credit: kWh per mmBtu of H2 produced			14.01
1107	Feedstock share	69.3%	69.3%	69.3%
1108	NG share	99.1%	99.1%	99.1%
1109	Electricity share	0.9%	0.9%	0.9%
1110	NNA NG feedstock			
1111	Without steam or electricity export	72.1%	72.1%	[illegible]
1112	With steam or electricity export (excluding energy in co-products)			
1113	With steam or electricity export: net steam export credit: Btu of steam per mmBtu of H2 produced			
1114	With steam or electricity export: net electricity export credit: kWh per mmBtu of H2 produced			0.00
1115	NNA FG feedstock			
1116	Without steam or electricity export	72.1%	72.1%	72.1%
1117	With steam or electricity export (excluding energy in co-products)			
1118	With steam or electricity export: net steam export credit: Btu of steam per mmBtu of H2 produced			
1119	With steam or electricity export: net electricity export credit: kWh per mmBtu of H2 produced			0.00
1120	Coal feedstock	NETL Model		
1121	Gasification in central plants: without steam or electricity co-generation	58.9%	58.9%	58.9%
1122	Gasification in central plants: without steam or electricity co-generation (CCS)	58.4%	58.4%	58.4%
1123	Synthesis process for H2 production in central plants: without steam or electricity co-generation			100.0%
1124	Gasification for H2 production in central plants: with steam or electricity co-generation (without accounting Btu in steam or electricity)	44.3%	44.3%	56.9%
1125	Synthesis process for H2 production in central plants, with steam or electricity co-generation (without accounting Btu in steam or electricity)			100.0%
1126	Net Steam export credit: Btu of steam per mmBtu of H2 produced			0
1127	Net electricity export credit: kWh per mmBtu of H2 produced	0.00	0.00	0.00
1128	Biomass feedstock			

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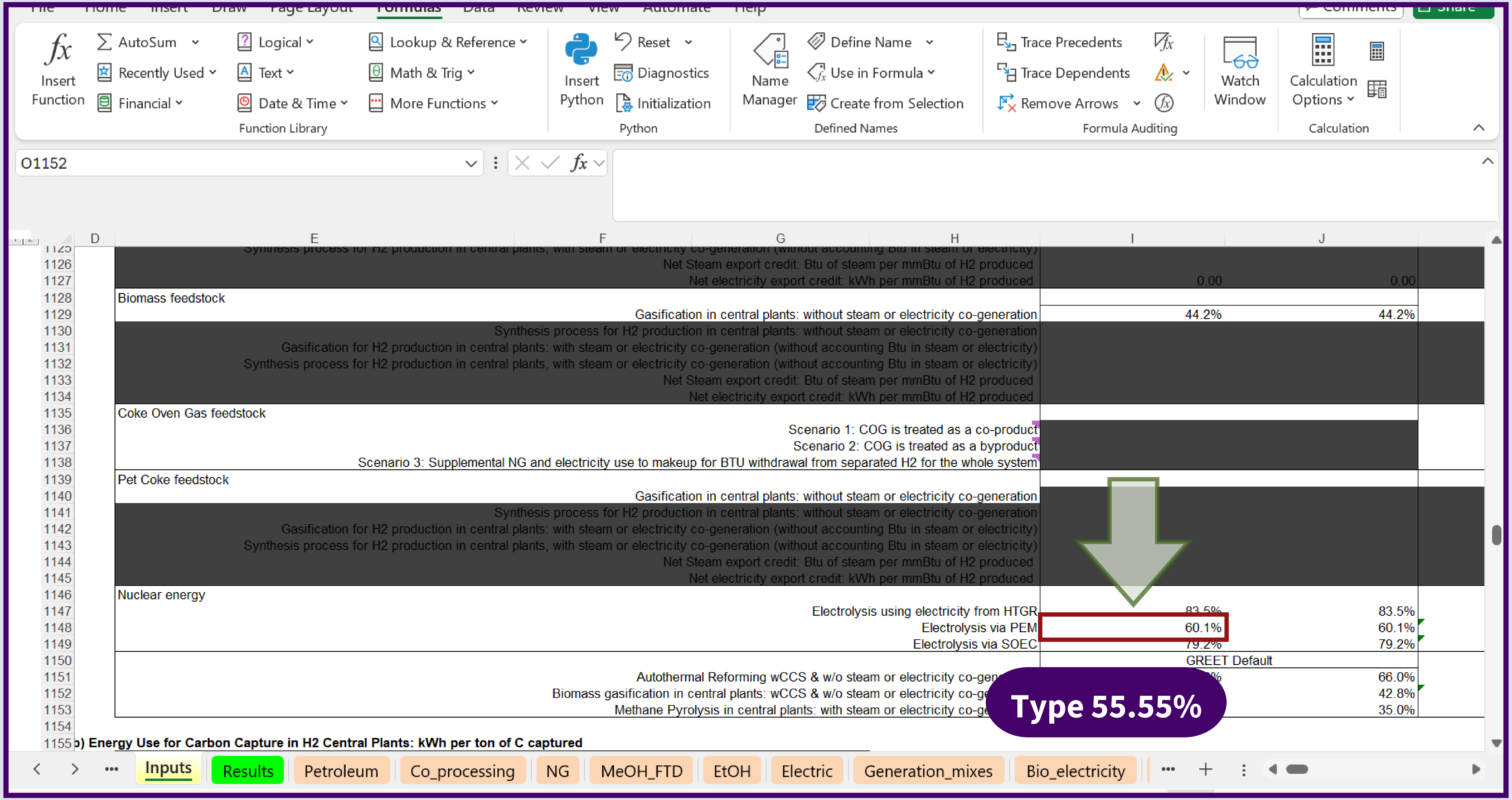
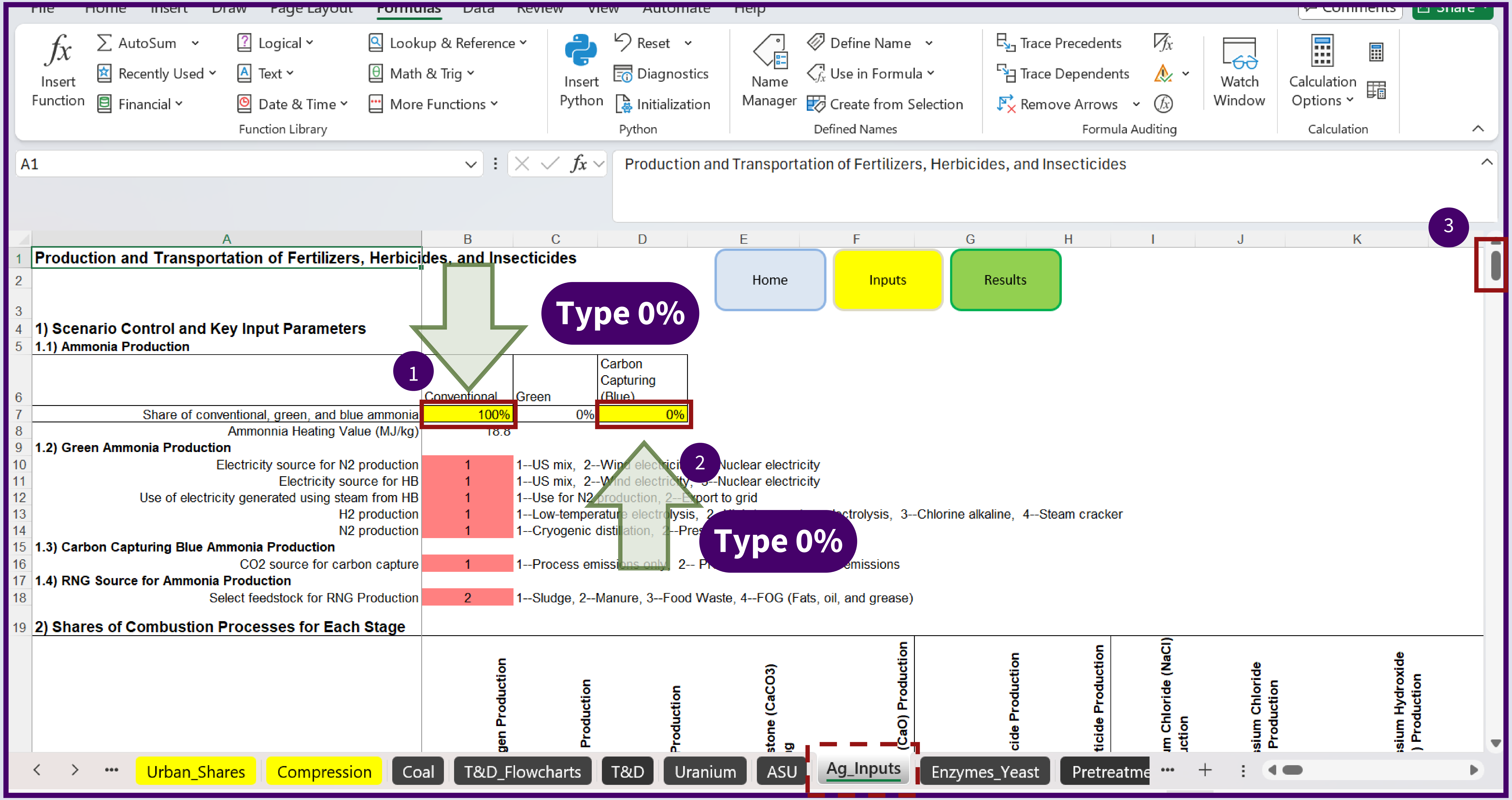


=NG_GH2_Cntrl_Prod_Eff_PEM_Electrolysis_TS*0+55.55%



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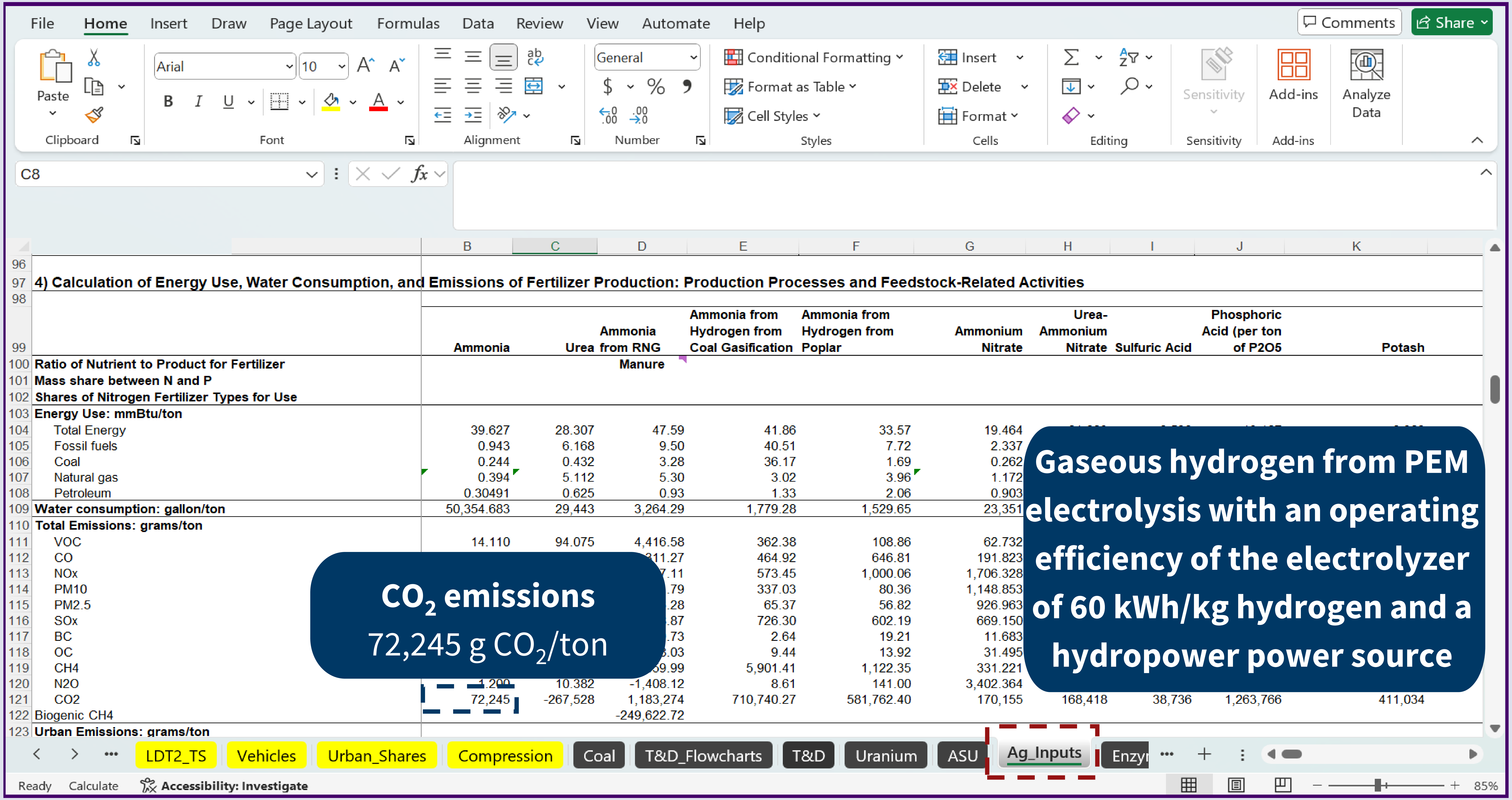
Carbon Dioxide Emitted from the Ammonia Production



Row		Ammonia	Urea	Ammonia from RNG Manure	Ammonia from Hydrogen from Coal Gasification	Ammonia from Hydrogen from Poplar	Ammonium Nitrate	Urea-Ammonium Nitrate	Sulfuric Acid	Phosphoric Acid (per ton of P2O5	Potash
100	**Ratio of Nutrient to Product for Fertilizer**										
101	**Mass share between N and P**										
102	**Shares of Nitrogen Fertilizer Types for Use**										
103	**Energy Use: mmBtu/ton**										
104	Total Energy	39.627	28.307	47.59	41.86	33.57	19.464				
105	Fossil fuels	0.943	6.168	9.50	40.51	7.72	2.337				
106	Coal	0.244	0.432	3.28	36.17	1.69	0.262				
107	Natural gas	0.394	5.112	5.30	3.02	3.96	1.172				
108	Petroleum	0.30491	0.625	0.93	1.33	2.06	0.903				
109	**Water consumption: gallon/ton**	50,354.683	29,443	3,264.29	1,779.28	1,529.65	23,351				
110	**Total Emissions: grams/ton**										
111	VOC	14.110	94.075	4,416.58	362.38	108.86	62.732				
112	CO			311.27	464.92	646.81	191.823				
113	NOx			7.11	573.45	1,000.06	1,706.328				
114	PM10			.79	337.03	80.36	1,148.853				
115	PM2.5			.28	65.37	56.82	926.963				
116	SOx			.87	726.30	602.19	669.150				
117	BC			.73	2.64	19.21	11.683				
118	OC			.03	9.44	13.92	31.495				
119	CH4			59.99	5,901.41	1,122.35	331.221				
120	N2O	1.200	10.382	-1,408.12	8.61	141.00	3,402.364				
121	CO2	72,245	-267,528	1,183,274	710,740.27	581,762.40	170,155	168,418	38,736	1,263,766	411,034
122	Biogenic CH4			-249,622.72							
123	**Urban Emissions: grams/ton**										

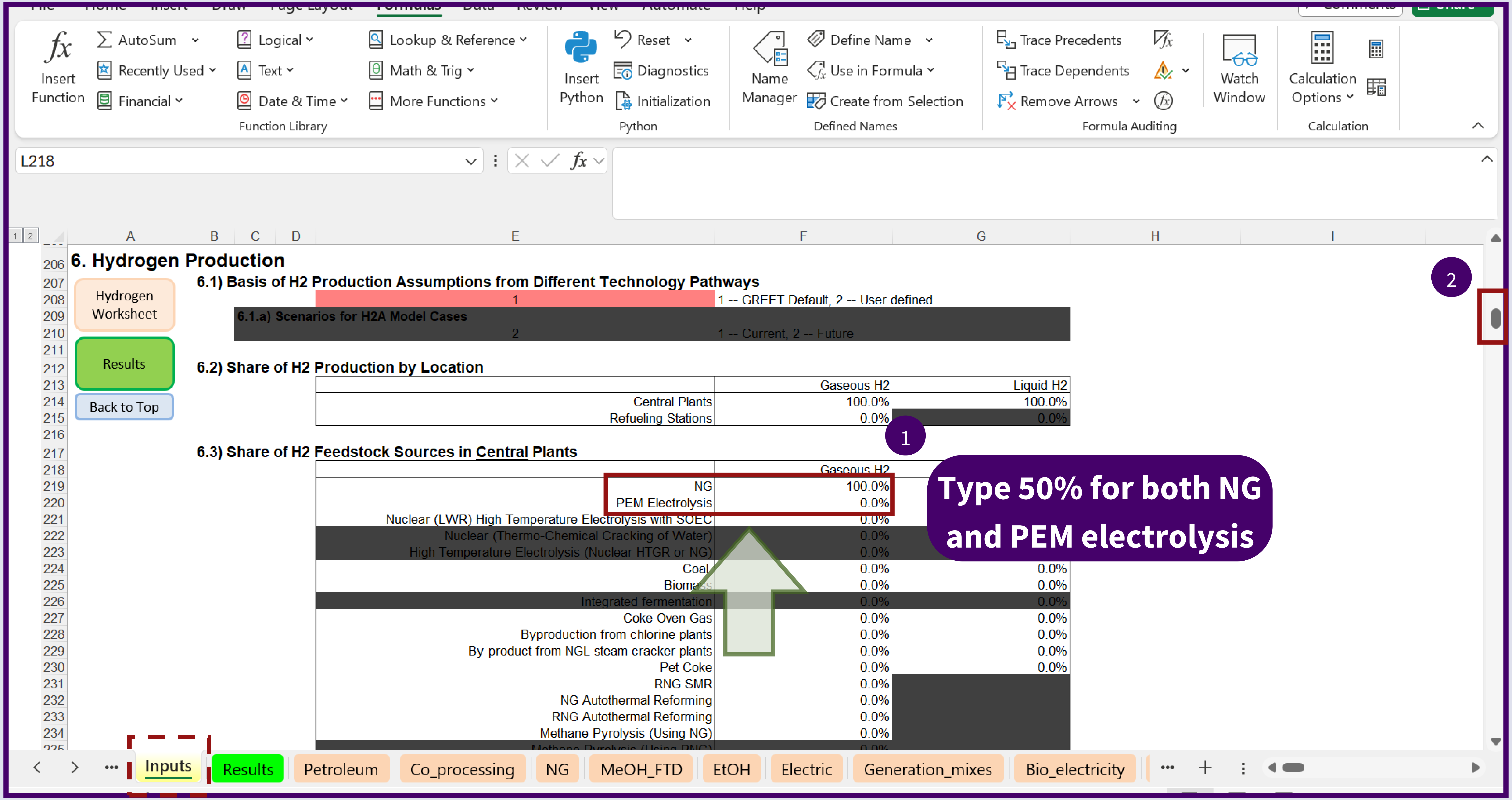
CO_2 emissions

72,245 g CO_2/ton

Gaseous hydrogen from PEM electrolysis with an operating efficiency of the electrolyzer of 60 kWh/kg hydrogen and a hydropower power source

FCV Using SMR and PEM

Model a Fuel-Cell Electric Vehicle (FCV) Fueled Equally Using Gaseous Hydrogen from SMR (w/ 95% CCS) and Wind-powered PEM Electrolysis Transported 200 Miles Via Tube Truck



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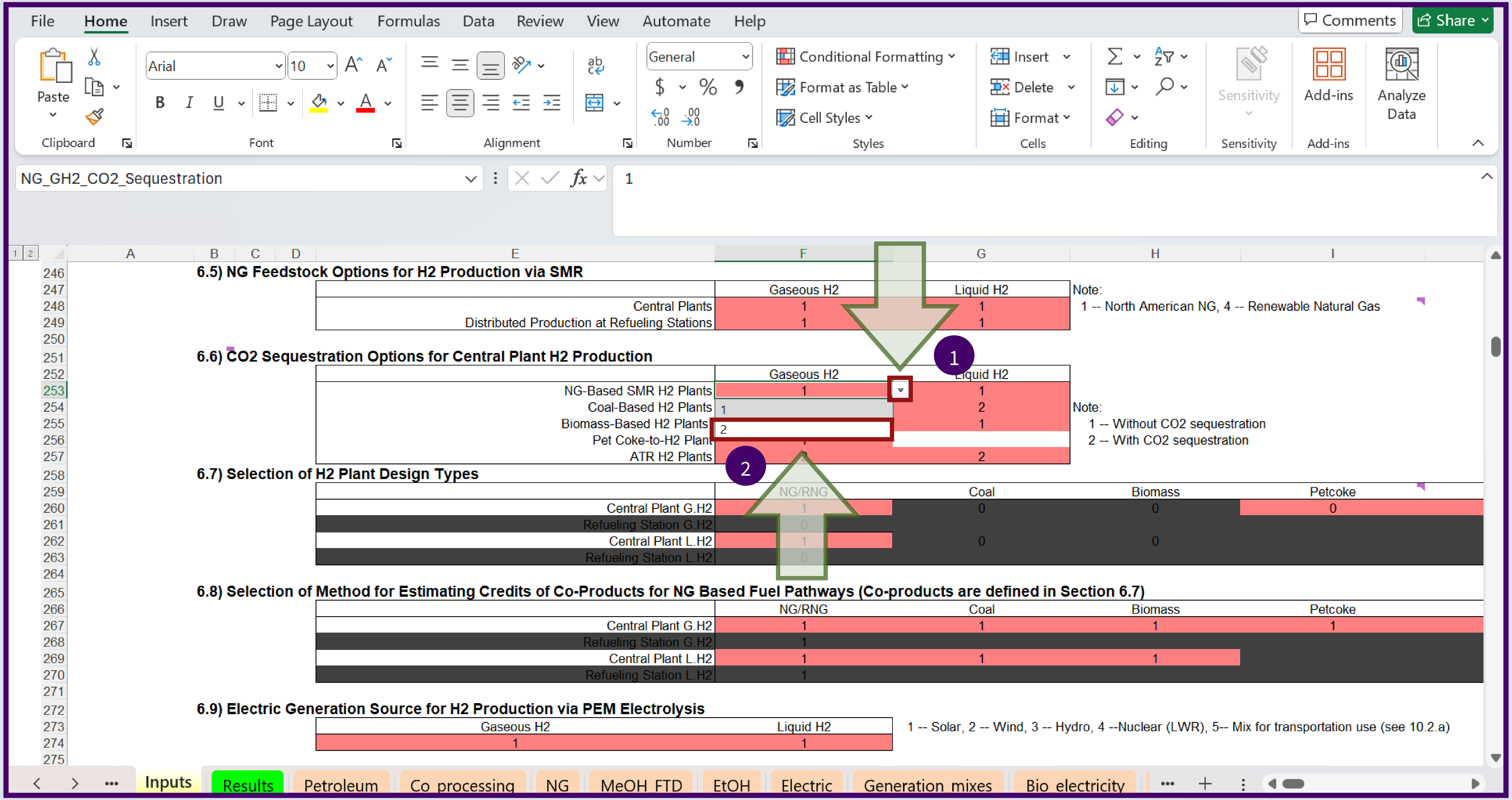

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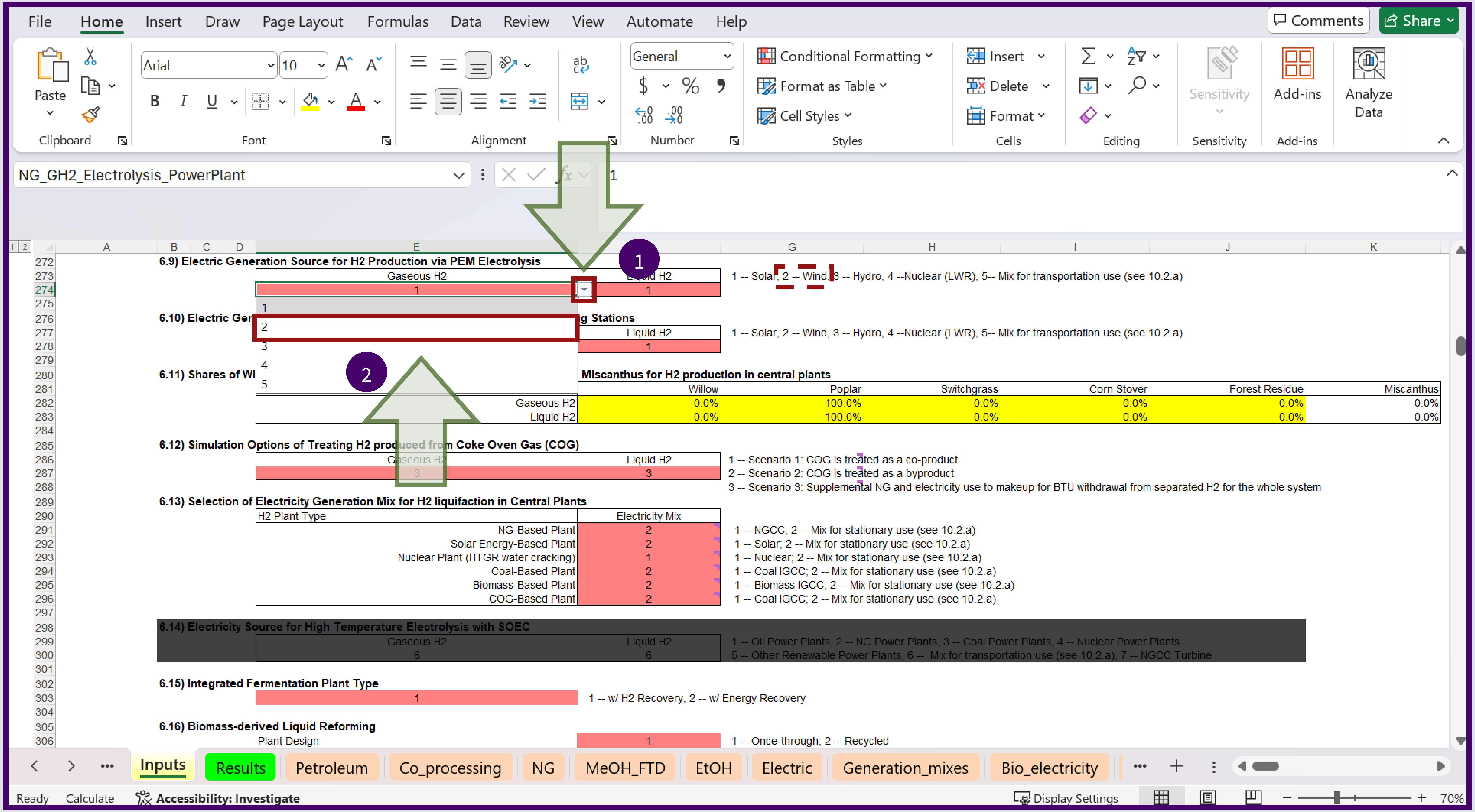

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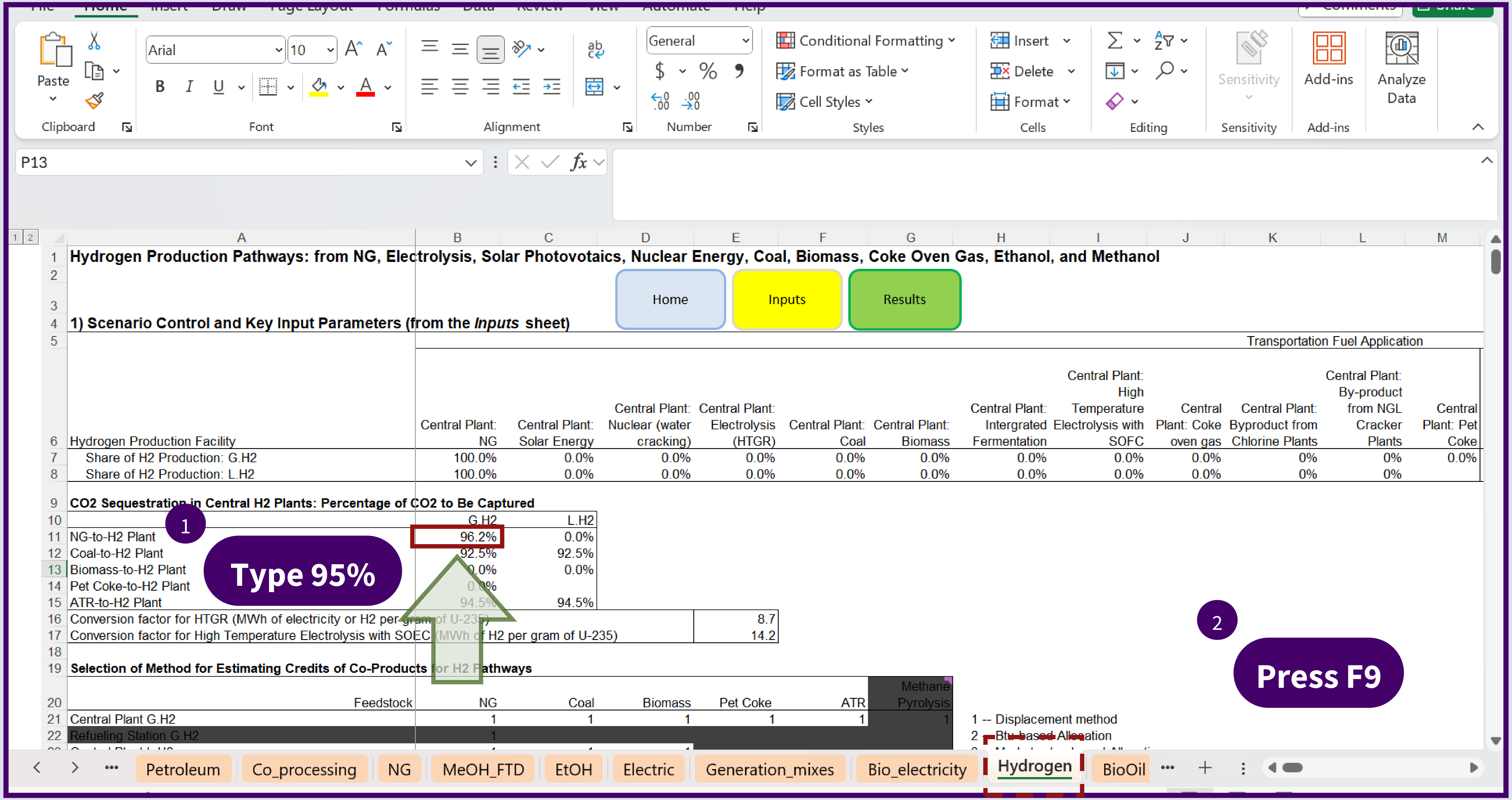

Hydrogen Production Facility	Central Plant: NG	Central Plant: Solar Energy	Central Plant: Nuclear (water cracking)	Central Plant: Electrolysis (HTGR)	Central Plant: Coal	Central Plant: Biomass	Central Plant: Intergrated Fermentation	Central Plant: High Temperature Electrolysis with SOFC	Central Plant: Coke oven gas	Central Plant: Byproduct from Chlorine Plants	Central Plant: By-product from NGL Cracker Plants	Central Plant: Pet Coke
Share of H2 Production: G.H2	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%	0%	0.0%
Share of H2 Production: L.H2	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0%	0%	

CO2 Sequestration in Central H2 Plants: Percentage of CO2 to Be Captured

	G.H2	L.H2
NG-to-H2 Plant	96.2%	0.0%
Coal-to-H2 Plant	92.5%	92.5%
Biomass-to-H2 Plant	0.0%	0.0%
Pet Coke-to-H2 Plant	0.0%	
ATR-to-H2 Plant	94.5%	94.5%

Conversion factor for HTGR (MWh of electricity or H2 per gram of U-235)	8.7
Conversion factor for High Temperature Electrolysis with SOEC (MWh of H2 per gram of U-235)	14.2

Selection of Method for Estimating Credits of Co-Products for H2 Pathways

Feedstock	NG	Coal	Biomass	Pet Coke	ATR	Methane Pyrolysis
Central Plant G.H2	1	1	1	1	1	1
Refueling Station G.H2	1					

1 -- Displacement method
2 -- Btu-based Allocation

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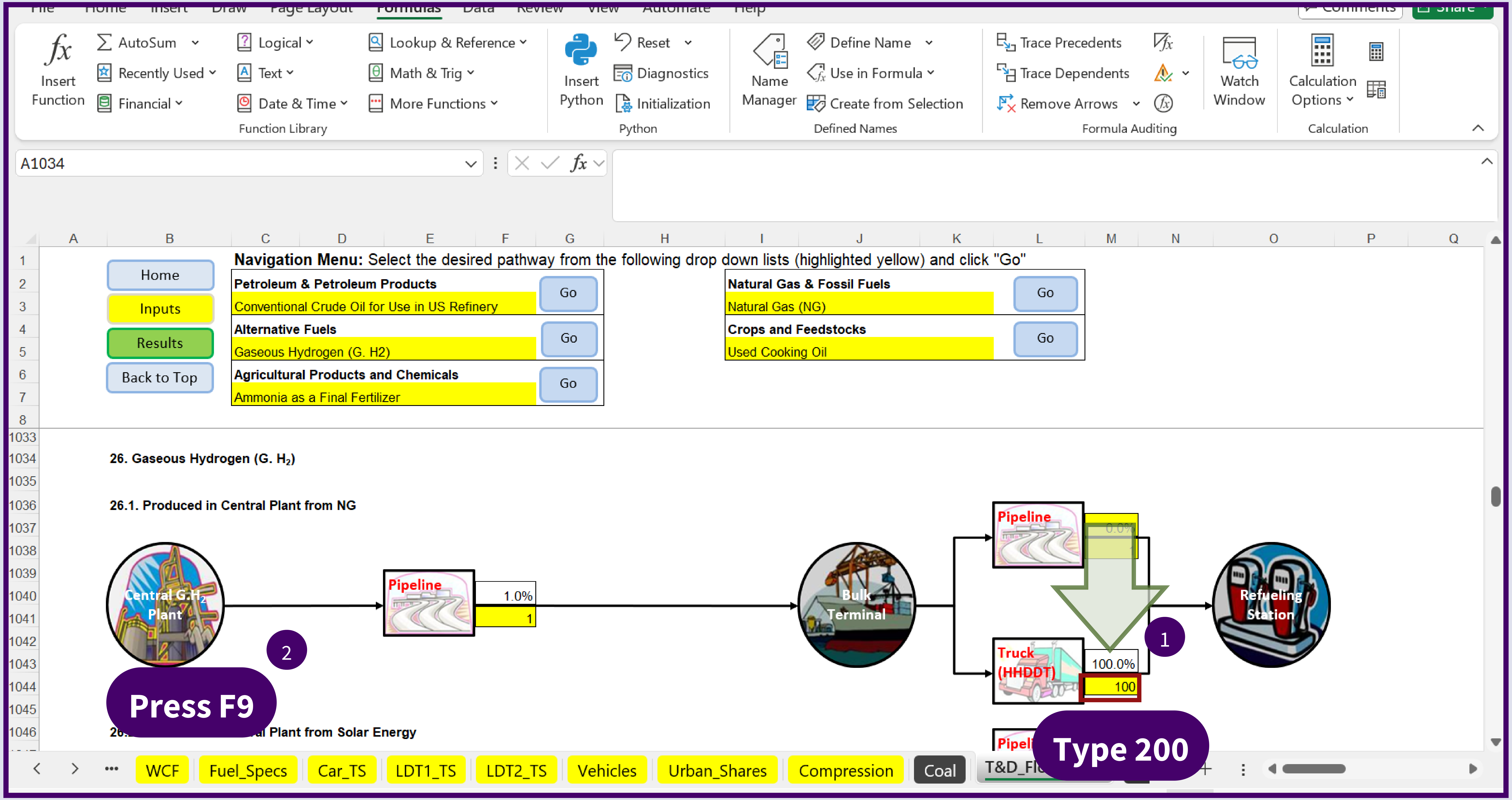

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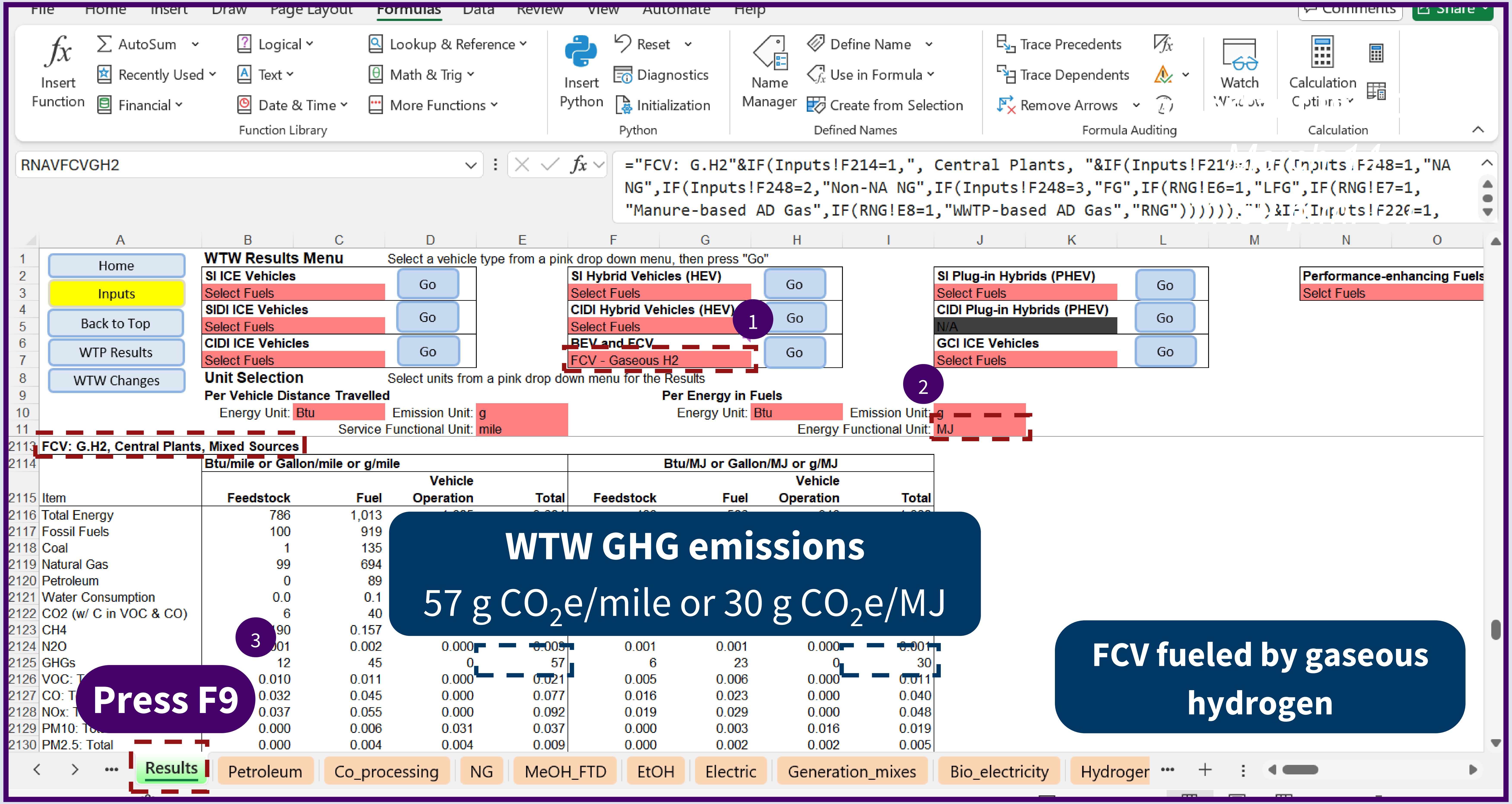
Well-to-Wheels (WTW) GHG Emissions



WTW GHG emissions

57 g CO_2e/mile or 30 g CO_2e/MJ

Press F9

FCV fueled by gaseous hydrogen

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