

March 3, 2025

Demo for ICEVs, HEVs, PHEVs, EVs, and FCVs in R&D GREET[®]

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

Instructors

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Argonne National Laboratory Subject Matter Experts

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 - c. Obtain Life Cycle Impacts of FCV SUVs with Different Hydrogen Pathways



Outline Steps ICEV, HEV, PHEV, EV, and FCV Scenarios



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Types of powertrains in R&D GREET

ICEV

Internal combustion engine vehicle

HEV (Hybrid Electric Vehicle)

A vehicle with an internal combustion engine and a battery; this vehicle cannot run on battery power alone

PHEV (Plug-in Hybrid Electric Vehicle)

A vehicle with an internal combustion engine and a battery; this vehicle can run on battery power alone

BEV (Battery Electric Vehicle)

A vehicle that runs solely on battery power

FCV (Fuel-Cell Vehicle)

A vehicle that uses a fuel cell to power its electric motor; this vehicle runs on oxygen (from air) and compressed hydrogen



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Main Outputs for Light-duty Vehicles (LDVs)



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R&D GREET 1

RSELSIICEV

Select Fuels

WTW Results Menu

Select a vehicle type from a pink drop down menu, then press "Go"

SI ICE Vehicles	Select Fuels	Go	SI Hybrid Vehicles (HEV)	Select Fuels	Go	SI Plug-in Hybrids (PHEV)	Select Fuels	Go	Performance-enhancing Fuels	Select Fuels
SIDI ICE Vehicles	Select Fuels	Go	CIDI Hybrid Vehicles (HEV)	Select Fuels	Go	CIDI Plug-in Hybrids (PHEV)	N/A	Go		
CIDI ICE Vehicles	Select Fuels	Go	BEV and FCV	Select Fuels	Go	GCI ICE Vehicles	Select Fuels	Go		

Unit Selection

Select units from a pink drop down menu for the Results

Per Vehicle Distance Travelled

Energy Unit: Btu Emission Unit: g Service Functional Unit: mile

Per Energy in Fuels

Energy Unit: Btu Emission Unit: g Energy Functional Unit: mmBtu

Gasoline Vehicle: Gasoline

Item	Btu/mile or Gallon/mile or g/mile				Btu/mmBtu or Gallon/mmBtu or g/mmBtu			
	Feedstock	Fuel	Vehicle Operation	Total	Feedstock	Fuel	Vehicle Operation	Total
Total Energy	217	944	4,289	5,450	50,498	220,096	1,000,000	1,270,595
Fossil Fuels	203	837	4,003	5,042	47,218	195,069	933,326	1,175,613
Coal	19	30	0	49	4,492	6,898	0	11,390
Natural Gas	147	538	0	685	34,251	125,536	0	159,787
Petroleum	36	269	4,003	4,308	8,474	62,635	933,326	1,004,435
Water Consumption	0.1	0.2	0	0	15	38	0	53
CO2 (w/ C in VOC & CO)	-4	63	329	388	-839	14,592	76,702	86,455
CH4	0.315	0.173	0.015	0.503	73.544	40.320	3.414	117.278
N2O	0.000	0.012	0.004	0.016	0.066	2.787	0.911	3.764
GHGs	6	71	330	407	1,371	16,554	77,053	95,078
VOC: Total	0.013	0.114	0.230	0.356	2.988	26.524	53.597	83.109
CO: Total	0.026	0.043	2.741	2.810	6.071	10.068	639.104	655.243
NOx: Total	0.039	0.071	0.082	0.193	9.137	16.540	19.209	44.886
PM10: Total	0.002	0.010	0.035	0.047	0.443	2.360	8.044	10.847
PM2.5: Total	0.002	0.006	0.007	0.015	0.372	1.502	1.729	3.603

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

Major Outputs for Medium and Heavy-duty Vehicles (MHDVs)

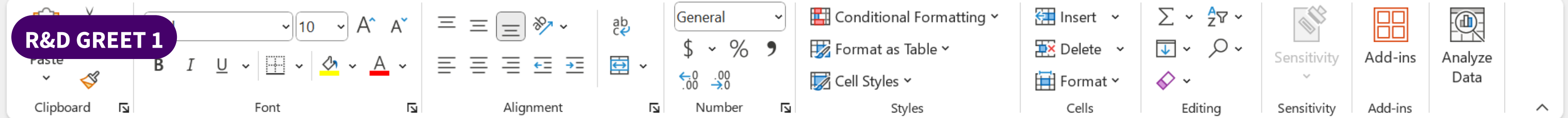


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R&D GREET 1



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WTW Results Menu Select a vehicle type from a pink drop down menu, then press "Go"

Heavy-Duty Vehicles
Select Heavy-Duty Vehicle Subcategory
Select Fuels and Vehicle Technologies

Go

Unit Selection: Select units from a pink drop down menu for the Results

Per Vehicle Distance Travelled or Cargo Distance Transported
Energy Unit: Btu Emission Unit: g
Service Functional Unit for Heavy-Duty Vans and Trucks: mile
Service Functional Unit for Buses: mile

Per Energy in Fuels
Energy Unit: Btu Emission Unit: g
Energy Functional Unit: mmBtu

Per Vehicle Distnace Travelled		
Energy Unit	Btu	mBtu
	1.000	0.001
Emission Unit	g	mg
	1.000	1000
Functional Unit	mile	km
	1.000	1.609

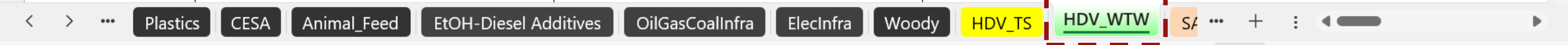
Well-to-Wheels Energy Consumption, Water Consumption, and Emissions of Heavy-Duty Vehicles

CIDI Combination Long-Haul Trucks: Conventional and LS Diesel

Urea use in SCR (g/mile) 6.78 Include urea-u: No DEF use (% of fuel consumption) 3.80

Item	Btu/mile or Gallon/mile or g/mile				Btu/mmBtu or Gallon/mmBtu or g/mmBtu			
	Feedstock	Fuel	Vehicle Operation	Total	Feedstock	Fuel	Vehicle Operation	Total
Total Energy	1,079	2,034	17,233	20,346	62,595	118,049	1,000,000	1,180,644
Fossil Fuels	1,009	2,002	17,233	20,244	58,557	116,164	1,000,000	1,174,721
Coal	95	46	0	142	5,527	2,694	0	8,221
Natural Gas	732	1,349	0	2,081	42,462	78,301	0	120,763
Petroleum	182	606	17,233	18,021	10,568	35,168	1,000,000	1,045,737
Water Consumption	0	0	0	0	19	5	0	23
CO2 (w/ C in VOC & CO)	89	132	1,363	1,583	5,157	7,635	79,070	91,862
CH4	2	0	0	1.902	91.325	18.197	0.829	110.350
N2O	0	0	0	0.006	0.081	0.153	0.111	0.345
GHGs	136	142	1,364	1,641	7,900	8,219	79,125	95,244
VOC: Total	0.064	0.065	0.104	0.233	3.717	3.762	6.044	13.523
CO: Total	0.130	0.081	2.899	3.110	7.544	4.725	168.225	180.493
NOx: Total	0.198	0.120	1.819	2.137	11.503	6.945	105.582	124.031

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



How Would You Further Explore On-Road (ICEVs, HEVs, PHEVs, EVs, and FCVs) Vehicles Scenarios?



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On-road vehicle tabs in R&D GREET

Primary

Vehicles

Car_TS

LDT1_TS

LDT2_TS

MHDV_TS

in R&D GREET 1

Some Secondary

Results

MHDV_WTW

in R&D GREET 1

Some Secondary

All tabs

in R&D GREET 2

Some tabs are on material impacts that feed into vehicle-cycle impact calculations, while other tabs are about vehicles or vehicle-cycle impact calculations



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On-Road Vehicle Scenarios



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Steps to model a scenario in R&D GREET 1



Go to the “Results” or "MHDV_WTW" Tab
Are the results for your scenario generated by default?

Go to the “Inputs” Tab
Are the changes I want to make altered on this tab?

If Yes,
*Make your changes and go to the
“Results” tab to see your results*

If No,
*Go to the fuel-specific/vehicle-
specific tabs for the fuel/vehicle you
want to model*

Dive into the formulas on the “Results” tab

Vehicle Operation Inputs
Go to the “Vehicles” tab

Fuel and Feedstock
Go to the “Fuel-specific” tab



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Steps to model an LDV scenario in R&D GREET 2



Go to the “TEC_Results” tab

Are the results for your scenario generated by default?

Go to the “Inputs (R&D GREET 1),” “Vehi_Inputs,” and “Mat_Inputs” tab

Have I made the necessary changes on all these tabs?

If Yes,

Make your changes and go to the “TEC_Results” tab to see your results

If No,

Determine whether the changes are related to the vehicle/material type, vehicle fluids/processing, or battery

Dive into the formulas on the “TEC_Results” tab

Vehicle/Material Type

Go to the “vehicle/material-specific” tab

Vehicle Fluids/Processing

Go to “Vehi_Fluids,” “Vehi_ADR,” “Vehi_Sum,” “Vehi_Comp_Sum,” or technology-specific tab

Battery

Go to one of the “Battery_Assembly/Sum/Materials/Recycling” tab



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Steps to model an MHDV scenario in R&D GREET 2



Go to the “MHDV_TEC_Results” tab

Are the results for your scenario generated by default?

Go through the full LDV chart and the “MHDV_Inputs” tab

Have I made the necessary changes on all these tabs?

If Yes,

Make your changes and go to the “MHDV_TEC_Results” tab to see your results

If No,

Determine whether the changes are related to the material parameters, vehicle fluids/processing, or battery

Dive into the formulas on the “MHDV_TEC_Results” tab

Material Parameters

Go to the “MHDV_Mat_Parameters” or “vehicle-specific” tab

Vehicle Fluids/Processing

Go to the “MHDV_Fluids/Trailer_Fluids” “MHDV_ADR/Trailer_ADR,” “MHDV_Sum” or “MHDV_Comp_Sum/Trailer_Comp_Sum” tab

Battery

Go to the “MHDV_Battery_Sum” tab



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Inputs **Results**

Petroleum Ethanol Natural Gas MeOH & RNG

Electric Hydrogen BioOil Pyrolysis & IDL Integrated Biorefiner

Fuel Production Time Series Emission Factors Time Series Agricultural and Mining Machinery Emission Factors Time Series

Water Consumption Factors Passenger Car Time Series Light Duty Truck 1 Time Series Light Duty Truck 2 Time Series

Fuel Specifications Vehicles Ag Inputs

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

Open R&D GREET 1
Fuel cycle results

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A1

Note: there are fewer vehicles modeled in R&D GREET 2 than R&D GREET 1

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Open R&D GREET 2 Vehicle cycle results

Overview Vehi_Inputs Mat_Inputs Car SUV PUT Steel C.Iron W.AI C.AI Lead Nickel Cobalt Copper Zinc N ... +



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R&D GREET 1 10 A^ A^

Clipboard Font Alignment Number Styles Cells Editing Sensitivity Add-ins Analyze Data

N15

Home Results Petroleum MeOH & Ethanol Electric Vehicles Car_TS Tab LDV1_TS Tab LDV2_TS Tab
 Natural Gas Hydrogen Bio Oil Pyrolysis WTP Fuel Economy Vehicles Tab HDV_TS Tab HDV_WTW Tab

Scenario Control Variables and Input Assumptions

1. Key Options for Simulation

1.1) Target Year for Simulation: 2022

1.2) Point-Estimation or Probability-Estimation Option: Load Stochastic Toolkit

Link with GREET2: Reactivate GREET2 Links (highlighted), Deactivate GREET2 Links

2. Vehicle Types for Simulation

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

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	Lati
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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R&D GREET 1 10 A A

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N15

Home Results Petroleum MeOH & Ethanol Electric Vehicles Car_TS Tab LDV1_TS Tab LDV2_TS Tab
 Natural Gas Hydrogen Bio Oil Pyrolysis WTP Vehicles Tab HDV_TS Tab HDV_WTW Tab
 Fuel Economy

Scenario Control Variables and Input Assumptions

1. Key Options for Simulation

1.1) Target Year for Simulation: 2022

1.2) Point-Estimation or Probability-Estimation Option

Link with GREET2: Reactivate GREET2 Links, Deactivate GREET2 Links

Load Stochastic Toolkit ... To load the stochastic toolkit
 Unload Stochastic Toolkit ... To unload the stochastic toolkit

2. Vehicle Types for Simulation

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

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	Lati
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 FtoH Electric Generation mixes Bio



12. Vehicle Operations

12.1) Share of Alternative Fuel in Conventional fuel and Alternative Fuel Blend: Volumetric Percentage

BSI (Boosted Spark Ignition) or MM (Multi-mode) fuel blend level selection

Isobutanol	2	2--20%, 3--30%
ARHC	2	2--20%, 3--30%
MeOH	2	2--20%, 3--30%

Methanol in FFV fuel	85.0%
Methanol in dedicated vehicle fuel	90.0%
Ethanol in low-level blend of gasoline and ethanol	10.0%
Ethanol in FFV fuel	85.0%
Ethanol in dedicated vehicle fuel	85.0%
Butanol in FFV fuel	100.0%
FT diesel in CIDI fuel	100.0%
Biodiesel in CIDI fuel	20.0%
Renewable diesel in CIDI fuel	100.0%
Renewable gasoline in SI fuel	100.0%
Ethanol in EtOH-diesel	10.0%
Additives in EtOH-diesel	1.0%
Isobutanol in BSI (gasoline) fuel	20.0%
ARHC (Aromatics-rich hydrocarbon fuel) in BSI (gasoline) fuel	20.0%
Methanol in MM (gasoline) fuel	20.0%
Isoalkane in MCCI fuel	20.0%
FAE (Fatty alkyl ether) in MCCI fuel	20.0%
FAFE (Fatty acid fusel esters) in MCCI fuel	20.0%
Renewable diesel in MCCI fuel	10.0%

2.0% Share of gasoline by volume added in EtOH as denaturant
 2.0% Share of gasoline by volume added in EtOH as denaturant
 2.0% Share of gasoline by volume added in EtOH as denaturant

12.2) Type of Gasoline or Diesel for Alternative Fuel Blends

Share of Gasoline out of Gasoline and Blendstock	
Gasoline for methanol blend	0.0%
Gasoline for low-level ethanol blend	0.0%

Vehicles Worksheet
 Results
 Back to Top

Microsoft Excel ribbon showing tabs: Clipboard, Font, Alignment, Number, Styles, Cells, Editing, Sensitivity, Add-ins, Analyze Data.

NavInputsZoomElectric 10. Electric Generation

898		Diesel for FFAE (Fatty acid tuser esters) diesel blend	100.0%	
899		Share of LSD out of LSD and CD		
900		Diesel for Fischer-Tropsch diesel blend	100.0%	
901		Diesel for biodiesel blend	100.0%	
902		Diesel for renewable diesel blend	100.0%	
903		Diesel for ETOH-diesel blend	100.0%	
904				
905		12.3) Key Parameters for Grid-Connected (Plug-in) Hybrid Electric Passenger Vehicle Technologies		
906		12.3.a) Rated All Electric Range (RAER) [miles]		
907		PHEVs	50	(Note: PHEVs with RAER longer than or equal to 30 miles are series hybrid while PHEVs with RAER st
908		BEVs	300	
909		12.3.b) Grid-Connected (Plug-in) HEV and EV charger efficiency		
910			85.0%	
911				
912		12.4) Efficiency Improvement		
913		12.4.a) Boosted Spark Ignition (BSI)		
914			Generic case	Isobutanol
915		Relative Engine Efficiency Increase	4.0%	4.57%
916		Powertrain Losses	20%	20%
917		Relative Vehicle Efficiency Increase	3.2%	3.7%
918		Fuel Economy Increase Relative to Gaseoline ICEV	3.3%	3.8%
919				ARHC
920				MeOH
921		Relative Engine Efficiency Increase	4.0%	1.86%
922		Powertrain Losses	20%	20%
923		Relative Vehicle Efficiency Increase	3.2%	1.5%
924		Fuel Economy Increase Relative to Gaseoline ICEV	3.3%	1.5%
925				11.0%
926		12.4.b) MultiMode (MM)		
927			Generic case	MeOH
928		Relative Engine Efficiency Increase	4.0%	24.39%
929		Powertrain Losses	20%	20%
930		Relative Vehicle Efficiency Increase	3.2%	19.5%
931		Fuel Economy Increase Relative to Gaseoline ICEV	3.3%	24.2%
932				
933		13. GREET Default Key Assumptions for Well-to-Pump Activities		
934		13.18) Hydrogen Production Efficencies		

Navigation tabs: Inputs, Results, Petroleum, Co_processing, NG, MeOH_FTD, EtOH, Electric, Generation_mixes, Bio_electricity

Microsoft Excel ribbon showing tabs: Clipboard, Font, Alignment, Number, Styles, Cells, Editing, Sensitivity, Add-ins, Analyze Data.

Y5

Fuel Economy and Emission Rates of LDT1 Vehicles: Baseline Vehicles and New Vehicles

Navigation buttons: Home (blue), Inputs (yellow), Results (green)

1) Fuel Economy and Emission Rates of LDT1 Baseline Vehicles: gasoline-equivalent MPG and grams/mile emissions

(fuel economy is adjusted for on-road performance using the EPA mpg-based method, and using 43%city/57%highway VMT split)

Model Year 2017

Lag year 5

Gasoline LDT1: Values from non-stochastic simulations and for adjustments to distribution functions

Model year is 5 years earlier than simulated technology year

20.06	0.074	0.116	2.882	0.103	0.006	0.031	0.005	0.004	0.003	0.002	0.016	0.005
20.06	0.074	0.116	2.882	0.103	0.006	0.031	0.005	0.004	0.003	0.002	0.016	0.005

Default values from times series or user input

Gasoline LDT1: stochastic simulation distrib

Distribution Functions of Fuel Economy and Em

Model Year	MPGGE	VOC (Exhaust)	VOC (Evap.)	CO	NOx	PM10 (Exhaust)	PM10 (TBW)	PM2.5 (Exhaust)	PM2.5 (TBW)	BC	OC	CH4	N2O
MY 1990	16.60	1.564	1.774	25.201	4.396	0.027	0.031	0.024	0.004	0.005	0.013	0.262	0.077
MY 1995	16.20	0.937	1.766	16.021	2.911	0.019	0.031	0.016	0.004	0.003	0.009	0.157	0.056
MY 2000	16.30	0.310	1.759	6.841	1.427	0.010	0.031	0.009	0.004	0.002	0.005	0.052	0.034
MY 2005	17.30	0.117	0.130	4.042	0.232	0.003	0.031	0.003	0.004	0.001	0.002	0.024	0.007
MY 2010	20.06	0.075	0.120	3.027	0.107	0.004	0.031	0.003	0.004	0.001	0.002	0.016	0.007
MY 2015	20.06	0.074	0.116	2.882	0.103	0.006	0.031	0.005	0.004	0.003	0.002	0.016	0.005
MY 2020	26.54	0.044	0.085	1.530	0.050	0.006	0.031	0.005	0.004	0.003	0.001	0.009	0.005
MY 2025	26.86	0.031	0.076	0.984	0.025	0.004	0.031	0.004	0.004	0.003	0.001	0.006	0.005
MY 2030	29.69	0.031	0.075	0.982	0.025	0.004	0.031	0.004	0.004	0.003	0.001	0.006	0.005
MY 2035	32.33	0.031	0.075	0.982	0.025	0.004	0.031	0.004	0.004	0.003	0.001	0.006	0.005
MY 2050	37.67	0.030	0.073	0.971	0.024	0.004	0.031	0.004	0.004	0.003	0.001	0.005	0.005

Model Year	MPGGE	VOC (Exhaust)	VOC (Evap.)
MY 1990	20.80	1.114	0.545
MY 1995	20.80	0.668	0.426
MY 2000	20.80	0.203	0.112
MY 2005	20.80	0.144	0.069
MY 2010	20.80	0.115	0.067
MY 2015	21.30	0.115	0.067
MY 2020	21.70	0.112	0.067
MY 2025	21.70	0.112	0.067
MY 2030	21.70	0.112	0.067
MY 2035	21.70	0.112	0.067
MY 2050	21.70	0.112	0.067

Diesel LDT1: Values from non-stochastic simulations and for adjustments to distribution functions

Model year is 5 years earlier than simulated technology year

25.54	0.211	0.006	4.946	0.089	0.003	0.031	0.003	0.004	0.002	0.000	0.135	0.001
25.54	0.211	0.006	4.946	0.089	0.003	0.031	0.003	0.004	0.002	0.000	0.135	0.001

Default values from times series or user input

Diesel LDT1: stochastic simulation distribut

Distribution Functions of Fuel Economy and Em

Model Year	MPGGE	VOC (Exhaust)	VOC (Evap.)	CO	NOx	PM10 (Exhaust)	PM10 (TBW)	PM2.5 (Exhaust)	PM2.5 (TBW)	BC	OC	CH4	N2O
------------	-------	---------------	-------------	----	-----	----------------	------------	-----------------	-------------	----	----	-----	-----

Model Year	MPGGE	VOC (Exhaust)	VOC (Evap.)
------------	-------	---------------	-------------

Excel sheet tabs: Pyrolysis_IDL, IBR, E_fuel, Fuel_Prod_TS, EF_TS, AgMining_EF_TS, EF, WCF, Fuel_Specs, Car_TS, LDT1_TS (selected), LD

Microsoft Excel ribbon showing tabs: Clipboard, Font, Alignment, Number, Styles, Conditional Formatting, Format as Table, Cell Styles, Insert, Delete, Format, Cells, Editing, Sensitivity, Add-ins, Analyze Data.

A1 Scenario Control Variables and Input Assumptions Related to Vehicle and its Components

A B C D E F G H I J K L M N O

1 Scenario Control Variables and Input Assumptions Related to Vehicle and its Components

1. Selection of Vehicle Types for Simulation

1	1 -- Passenger Cars
2	2 -- Sport Utility Vehicles
3	3 -- Pick-Up Trucks

When the "Passenger Cars" option is selected, select one of the following two vehicles for ICEVs

1	1 -- Passenger Cars 1, 2 -- Passenger Cars 2
---	--

When the "Sport Utility Vehicles" option is selected, select one of the following two vehicles for ICEVs

1	1 -- Sport Utility Vehicles 1, 2 -- Sport Utility Vehicles 2
---	--

When the "Pick-Up Trucks" option is selected, select one of the following two vehicles for ICEVs

1	1 -- Pick-Up Trucks 1, 2 -- Pick-Up Trucks 2
---	--

2. Specification of Total Vehicle Weight, pounds

ICEV: Conventional Material	ICEV: Lightweight Material	HEV: Conventional Material	HEV: Lightweight Material	PHEV: Conventional Material	PHEV: Lightweight Material	EV: Conventional Material	EV: Lightweight Material	FCV: Conventional Material	FCV: Lightweight Material
3,183	2,692	3,429	2,839	3,713	3,007	4,026	3,193	3,644	2,930

3. Vehicle Battery and Fluids Weight, pounds per vehicle

3.1) Battery Weight

	ICEV: Conventional Material	ICEV: Lightweight Material	HEV: Conventional Material	HEV: Lightweight Material	PHEV: Conventional Material	PHEV: Lightweight Material	EV: Conventional Material	EV: Lightweight Material	FCV: Conventional Material	FCV: Lightweight Material
Lead-Acid	36.0	23.4	22.1	14.4	22.1	14.4	22.1	14.4	22.1	14.4
Ni-MH			89.1	75.3	635.3	495.8	2,853.2	2,162.3	105.6	94.1
Li-Ion			30.0	25.3	196.6	153.4	1,049.7	795.5	31.2	27.8

Vehi_Inputs Mat_Inputs Car SUV PUT Steel C.Iron W.AI C.AI Lead Nickel Cobalt Copper Zinc Magnesium

R&D GREET 2

Microsoft Excel ribbon showing tabs: Home, Insert, Draw, Page Layout, Formulas, Data, Review, View, Automate, Help. The ribbon includes various toolbars for font, alignment, number, styles, cells, editing, and sensitivity.

A1 Scenario Control Variables and Input Assumptions Related to Vehicle and its Components

5.3) Battery Size in Peak Battery Energy (High Energy Applications), kWh

	Ni-MH	Li-Ion
PHEV: Conventional Material	15	15
PHEV: Lightweight Material	12	12
EV: Conventional Material	84	84
EV: Lightweight Material	64	64

5.4) Battery Replacements During Lifetime of Vehicle

	Lead-Acid	Ni-MH	Li-Ion
ICEV	2		
HEV	2	0	0
PHEV	2	0	0
EV	2	0	0
FCV	2	0	0

5.5) Li-Ion Battery Cathode Material

HEV	2	1. LMO, 2. NMC111, 3.LFP: Hydrothermal, 4. LFP: Solid State, 5. NMC622, 6. NMC811, 7. NCA, 8. NMC532, 9. NMC95
PHEV	2	1. LMO, 2. NMC111, 3.LFP: Hydrothermal, 4. LFP: Solid State, 5. NMC622, 6. NMC811, 7. NCA, 8. NMC532, 9. NMC95
EV	2	1. LMO, 2. NMC111, 3.LFP: Hydrothermal, 4. LFP: Solid State, 5. NMC622, 6. NMC811, 7. NCA, 8. NMC532, 9. NMC95
FCV	2	1. LMO, 2. NMC111, 3.LFP: Hydrothermal, 4. LFP: Solid State, 5. NMC622, 6. NMC811, 7. NCA, 8. NMC532, 9. NMC95

5.6) Battery Specific Power

	Ni-MH		Li-Ion		Li-Ion specific power by type (W/kg)							
	W/kg	W/lb	W/kg	W/lb	LMO	NMC111	LFP	NMC622	NMC811	NCA	NMC532	NMC95
HEV	800	363	2,378	1,079	2,221	2,378	1,982	2,421	2,484	2,438	2,419	2,527
FCV	800	363	2,708	1,228	2,517	2,708	2,227	2,761	2,839	2,788	2,759	2,893

5.7) Battery Specific Energy

	Ni-MH		Li-Ion		Li-Ion Battery Specific Energy (Wh/kg)							
	Wh/kg	Wh/lb	Wh/kg	Wh/lb	LMO	NMC111	LFP	NMC622	NMC811	NCA	NMC532	NMC95
PHEV: 35-mile	53	24	171	78	136	157	131	163	178	166	162	183

Navigation tabs: Vehi_Inputs, Mat_Inputs, Car, SUV, PUT, Steel, C.Iron, W.AI, C.AI, Lead, Nickel, Cobalt, Copper, Zinc, Magnesium

Obtain Life Cycle Impacts of SUVs with Different Powertrains



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Powertrains

Model a 2022 Sport Utility Vehicle (SUV) with the
Following Powertrains: ICEV, HEV, PHEV (50-mi
range), BEV (400-mi range), FCV (Gaseous Hydrogen)



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File Home Insert Draw Page Layout Formulas Data Review View Automate Help

R&D GREET 1

Paste B I U Font Alignment Number Styles Cells Editing Sensitivity Add-ins Analyze Data

Veh_Type_Option 1

Home Results Petroleum MeOH & Ethanol Electric Vehicles Car_TS Tab LDV1_TS Tab LDV2_TS Tab
 Natural Gas Hydrogen Bio Oil Pyrolysis WTP Fuel Economy Vehicles Tab HDV_TS Tab HDV_WTW Tab

Scenario Control Variables and Input Assumptions

1. Key Options for Simulation

1.1) Target Year for Simulation: 2022

1.2) Point-Estimation or Probability-Estimation Option: Load Stochastic Toolkit

Link with GREET2: Reactivate GREET2 Links, Deactivate GREET2 Links

Load Stochastic Toolkit ... To load the stochastic toolkit
 Load Stochastic Toolkit ... To unload the stochastic toolkit

2. Vehicle Types for Simulation

1 -- Passenger Cars 2 -- Light-Duty Trucks 1 (LDT1) (Sports utility vehicles [SUV]) 3 -- Light-Duty Trucks 2 (LDT2) (Pickup Truck [F

3. Petroleum-Based Fuels

3.1) Petroleum R 3

3.1.a) Share of crude oil sources

	1	2	Basis of share of crude oil sources: 1 -- E
			U.S. Domestic C
EIA projection			80.8%
User defined			0.0%
Used in calculation			80.8%
API gravity			34.0
S Content (wt %)			1.4
Average transportation distances (mi)			See T&D_Flowcharts tab

Inputs Results Petroleum Co_processing NG MeOH_FTD EtOH Electric Generation mixes Bio_electricity

Note:
 this scenario is modeling an SUV built in 2022

R&D GREET 1

BEV_AER 300

12.3) Key Parameters for Grid-Connected (Plug-in) Hybrid Electric Passenger Vehicle Technologies

12.3.a) Rated All Electric Range (RAER) [miles]

PHEVs	50
BEVs	300

(Note: PHEVs with RAER longer than or equal to 30 miles are series hybrid while PHEVs with RAER st

12.3.b) Grid-Connected (Plug-in) HEV and EV charger efficiency

150
85.0%
200
300
400

12.4) Efficiency Improvement

12.4.a) Boosted Spark Ignition (BSI)

	Generic case	Isobutanol	ARHC	MeOH
Relative Engine Efficiency Increase	4.0%	4.57%	1.86%	12.39%
Powertrain Losses	20%	20%	20%	20%
Relative Vehicle Efficiency Increase	3.2%	3.7%	1.5%	9.9%
Fuel Economy Increase Relative to Gaseoline ICEV	3.3%	3.8%	1.5%	11.0%

12.4.b) MultiMode (MM)

	Generic case	MeOH
Relative Engine Efficiency Increase	4.0%	
Powertrain Losses	20%	
Relative Vehicle Efficiency Increase	3.2%	
Fuel Economy Increase Relative to Gaseoline ICEV	3.3%	

PHEV: 50-mi range
BEV: 400-mi range

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

13.18) Hydrogen Production Efficiencies

13.18.a) Central Plant H2 Production Efficiencies

	Source
	Gaseous H2
	NETL Model
NA NG feedstock	

Inputs

Results

Petroleum

Co_processing

NG

MeOH_FTD

EtOH

Electric

Generation_mixes

Bio_electricity

Fuel Economy and Emission Rates of LDT1 Vehicles: Baseline Vehicles and New Vehicles

1) Fuel Economy and Emission Rates of LDT1 Baseline Vehicles: gasoline-equivalent MPG and grams/mile emissions
 (fuel economy is adjusted for ... using the EPA mpg-based method, and using 43%city/57%highway VMT split)

Home Inputs Results

Type 0

Model Year 2017
 Lag year 0
 Gasoline LDT1: Values from ... and for adjustments to distribution functions
 Model year is 5 years earlier than simulated technology year

Model Year	MPGGE	VOC (Exhaust)	VOC (Evap.)	CO	NOx	PM10 (Exhaust)	PM10 (TBW)	PM2.5 (Exhaust)	PM2.5 (TBW)	BC	OC	CH4	N2O
1990	16.60	1.564	1.774	25.201	4.396	0.027	0.031	0.024	0.004	0.005	0.013	0.262	0.077
1995	16.20	0.937	1.766	16.021	2.911	0.019	0.031	0.016	0.004	0.003	0.009	0.157	0.056
2000	16.30	0.310	1.759	6.841	1.427	0.010	0.031	0.009	0.004	0.002	0.005	0.052	0.034
2005	17.30	0.117	0.130	4.042	0.232	0.003	0.031	0.003	0.004	0.001	0.002	0.024	0.007
2010	20.06	0.075	0.120	3.027	0.107	0.004	0.031	0.003	0.004	0.001	0.002	0.016	0.007
2015	20.06	0.074	0.116	2.882	0.103	0.006	0.031	0.005	0.004	0.003	0.002	0.016	0.005
2020	26.54	0.044	0.085	1.530	0.050	0.006	0.031	0.005	0.004	0.003	0.001	0.009	0.005
2025	26.86	0.031	0.076	0.984	0.025	0.004	0.031	0.004	0.004	0.003	0.001	0.006	0.005
2030	29.69	0.031	0.075	0.982	0.025	0.004	0.031	0.004	0.004	0.003	0.001	0.006	0.005
2035	32.33	0.075	0.075	0.982	0.025	0.004	0.031	0.004	0.004	0.003	0.001	0.006	0.005
2050	37.67	0.073	0.073	0.971	0.024	0.004	0.031	0.004	0.004	0.003	0.001	0.005	0.005

Gasoline LDT1: stochastic simulation distribution

Default values from times series or user input

Distribution Functions of Fuel Economy and Em

Model Year	MPGGE	VOC (Exhaust)	VOC (Evap.)
1990	20.80	1.114	0.545
1995	20.80	0.668	0.426
2000	20.80	0.203	0.112
2005	20.80	0.144	0.069
2010	20.80	0.115	0.067
2015	21.30	0.115	0.067
2020	21.70	0.112	0.067
2025	21.70	0.112	0.067
2030	21.70	0.112	0.067
2035	21.70	0.112	0.067
2050	21.70	0.112	0.067

Press F9

Diesel LDT1: stochastic simulations and for adjustments to distribution functions
 Model year is 5 years earlier than simulated technology year

Model Year	MPGGE	VOC (Exhaust)	VOC (Evap.)	CO	NOx	PM10 (Exhaust)	PM10 (TBW)	PM2.5 (Exhaust)	PM2.5 (TBW)	BC	OC	CH4	N2O
1990	16.60	1.564	1.774	25.201	4.396	0.027	0.031	0.024	0.004	0.005	0.013	0.262	0.077
1995	16.20	0.937	1.766	16.021	2.911	0.019	0.031	0.016	0.004	0.003	0.009	0.157	0.056
2000	16.30	0.310	1.759	6.841	1.427	0.010	0.031	0.009	0.004	0.002	0.005	0.052	0.034
2005	17.30	0.117	0.130	4.042	0.232	0.003	0.031	0.003	0.004	0.001	0.002	0.024	0.007
2010	20.06	0.075	0.120	3.027	0.107	0.004	0.031	0.003	0.004	0.001	0.002	0.016	0.007
2015	20.06	0.074	0.116	2.882	0.103	0.006	0.031	0.005	0.004	0.003	0.002	0.016	0.005
2020	26.54	0.044	0.085	1.530	0.050	0.006	0.031	0.005	0.004	0.003	0.001	0.009	0.005
2025	26.86	0.031	0.076	0.984	0.025	0.004	0.031	0.004	0.004	0.003	0.001	0.006	0.005
2030	29.69	0.031	0.075	0.982	0.025	0.004	0.031	0.004	0.004	0.003	0.001	0.006	0.005
2035	32.33	0.075	0.075	0.982	0.025	0.004	0.031	0.004	0.004	0.003	0.001	0.006	0.005
2050	37.67	0.073	0.073	0.971	0.024	0.004	0.031	0.004	0.004	0.003	0.001	0.005	0.005

Diesel LDT1: stochastic simulation distribution

Default values from times series or user input

Distribution Functions of Fuel Economy and Em

Model Year	MPGGE	VOC (Exhaust)	VOC (Evap.)
1990	20.80	1.114	0.545
1995	20.80	0.668	0.426
2000	20.80	0.203	0.112
2005	20.80	0.144	0.069
2010	20.80	0.115	0.067
2015	21.30	0.115	0.067
2020	21.70	0.112	0.067
2025	21.70	0.112	0.067
2030	21.70	0.112	0.067
2035	21.70	0.112	0.067
2050	21.70	0.112	0.067

R&D GREET 2

B3 1

Scenario Control Variables and Input Assumptions Related to Vehicle and its Components

1. Selection of Vehicle Types for Simulation

1 Passenger Cars

2 -- Sport Utility Vehicles

3 -- Pick-Up Trucks

When the "Passenger Cars" option is selected, select one of the following two vehicles for ICEVs

1 -- Passenger Cars 1, 2 -- Passenger Cars 2

When the "Sport Utility Vehicles" option is selected, select one of the following two vehicles for ICEVs

1 -- Sport Utility Vehicles 1, 2 -- Sport Utility Vehicles 2

When the "Pick-Up Trucks" option is selected, select one of the following two vehicles for ICEVs

1 -- Pick-Up Trucks 1, 2 -- Pick-Up Trucks 2

2. Specification of Total Vehicle Weight, pounds

ICEV:	ICEV:	HEV:	HEV:	PHEV:	PHEV:	EV:	EV:	FCV:	FCV:
Conventional	ICEV: Lightweight	Conventional	HEV: Lightweight	Conventional	Lightweight	Conventional	Lightweight	Conventional	Lightweight
Material	Material	Material	Material	Material	Material	Material	Material	Material	Material
3,264	2,692	3,517	2,839	3,626	3,007	3,861	3,193	3,401	2,930

3. Vehicle Battery and Fluids Weight, pounds per vehicle

3.1) Battery Weight

ICEV:	ICEV:	HEV:	HEV:	PHEV:	PHEV:	EV:	EV:	FCV:	FCV:
Conventional	ICEV: Lightweight	Conventional	HEV: Lightweight	Conventional	Lightweight	Conventional	Lightweight	Conventional	Lightweight
Material	Material	Material	Material	Material	Material	Material	Material	Material	Material
36.0	23.4	22.1	14.4	22.1	14.4	22.1	14.4	22.1	14.4
Li-Ion		90.8	75.3	716.1	495.8	2,625.6	2,162.3	145.4	94.1
		30.6	25.3	221.6	153.4	966.0	795.5	42.9	27.8

Press F9

Vehi_Inputs



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R&D GREET 2

197

Scenario Control Variables and Input Assumptions Related to Vehicle and its Components

1. Selection of Vehicle Types for Simulation

2
1 -- Passenger Cars
2 -- Sport Utility Vehicles
3 -- Pick-Up Trucks

When the "Passenger Cars" option is selected, select one of the following

1 1 -- Passenger Cars 1, 2 -- Passenger Cars

When the "Sport Utility Vehicles" option is selected, select one of the following

1 1 -- Sport Utility Vehicles 1, 2 -- Sport Utility Vehicles

When the "Pick-Up Trucks" option is selected, select one of the following

1 1 -- Pick-Up Trucks 1, 2 -- Pick-Up Trucks

2. Specification of Total Vehicle Weight, pounds

ICEV:	
Conventional Material	ICEV: Lightweight Material
3,427	

FCV:	FCV:
Conventional Material	Lightweight Material
3,566	3,639

3. Vehicle Battery and Fluids Weight, pounds per vehicle

3.1) Battery Weight

	ICEV: Conventional Material	ICEV: Lightweight Material	HEV: Conventional Material	HEV: Lightweight Material	PHEV: Conventional Material	PHEV: Lightweight Material	EV: Conventional Material	EV: Lightweight Material	FCV: Conventional Material	FCV: Lightweight Material
Lead-Acid	53.5	35.0	36.0	23.8	36.0	23.8	36.0	23.8	36.0	23.8
Ni-MH			90.8	103.5	859.8	637.9	3,040.0	2,827.1	109.0	103.5
Li-Ion			30.6	34.8	262.0	194.4	1,117.3	1,039.1	34.7	33.0

Microsoft Excel

You have changed the type of vehicles. You must ensure the GREET1 setting matches with this selection to have correct LCA results. Do you want to proceed? If you click the Cancel button, the cell will use the default.

1

OK Cancel

Maintain these settings throughout the rest of the demonstration



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Fuel Cycle GHG Emissions for an Internal Combustion Engine Vehicle (ICEV)



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File Home Insert Draw Page Layout Formulas Data Review View Automate Help

R&D GREET 1 10 A^ A^

Paste B I U Font Alignment Number Styles Cells Editing Sensitivity Add-ins Analyze Data

RNAV GASCRFG Gasoline Vehicle: Gasoline

1 Home 2 Inputs 3 Back to Top 4 WTP Results 5 WTW Changes

WTW Results Menu Select a vehicle type from a pink drop down menu, then press "Go"

SI ICE Vehicles SI - Gasoline Go
 SI ICE Vehicles Select Fuels Go
 CIDI ICE Vehicles Select Fuels Go

SI Hybrid Vehicles (HEV) Select Fuels Go
 CIDI Hybrid Vehicles (HEV) Select Fuels Go
 BEV and FCV Select Fuels Go

SI Plug-in Hybrids (PHEV) Select Fuels Go
 CIDI Plug-in Hybrids (PHEV) N/A Go
 GCI ICE Vehicles Select Fuels Go

Performance-enhancing Fuels Select Fuels

Unit Selection Select units from a pink drop down menu for the Results

Per Vehicle Distance Travelled Energy Unit: Btu Emission Unit: g Service Functional Unit: mile

Per Energy in Fuels Energy Unit: Btu Emission Unit: g Energy Functional Unit: MJ

Gasoline Vehicle: Gasoline

Item	Btu/mile or Gallon/mile or g/mile			Btu/MJ or Gallon/MJ or g/MJ		
	Feedstock	Fuel	Vehicle	Feedstock	Fuel	Operation
Total Energy	282	1,576	7,107	48	209	948
Fossil Fuels	264	1,576	6,576	45	185	885
Coal			63	4	7	0
Natural Gas			893	32	119	0
Petroleum			5,619	8	59	885
Water Consumption			0	0	0	0
CO2 (w/ C in VOC & CH4)		0.226	0.653	0.070	0.038	0.003
N2O	0.000	0.016	0.021	0.000	0.003	0.001
GHGs	8	93	431	1	16	73
VOC: Total	0.017	0.148	0.335	0.003	0.025	0.032
CO: Total	0	2.8	0.504	0.006	0.010	0.488
NOx: Total	0	0	0.042	0.009	0.016	0.017
PM10: Total	0	0	0.009	0.000	0.002	0.006
PM2.5: Total	0	0	0.003	0.000	0.001	0.002

Results Petro... Processing ID EtOH Electric Generation_mixes Bio_electricity Hydroger

1

2

3

Press F9

Feedstock
GHG emissions

Vehicle
operation
GHG emissions

Fuel
GHG emissions

Total WTW
GHG emissions

ICEV SUV built and used in 2022 and fueled by gasoline

File Home Insert Draw Page Layout Formulas Data Review View Automate Help

R&D GREET 1

Paste **B** *I* U Font Alignment Number Styles

General Conditional Formatting Insert Delete Format Sensitivity Add-ins Analyze Data

RNAV GASCRFG Gasoline Vehicle: Gasoline

WTW Results Menu Select a vehicle type from a pink drop down menu, then press "Go"

SI ICE Vehicles: SI - Gasoline, SIDI ICE Vehicles, CIDI ICE Vehicles

SI Hybrid Vehicles (HEV): Select Fuels, CIDI Hybrid Vehicles (HEV), BEV and FCV

SI Plug-in Hybrids (PHEV): Select Fuels, CIDI Plug-in Hybrids (PHEV), GCI ICE Vehicles

Performance-enhancing Fuels: Select Fuels

Unit Selection Select units from a pink drop down menu for the Results

Per Vehicle Distance Travelled Energy Unit: Btu Emission Unit: g Service Functional Unit: mile

Per Energy in Fuels Energy Unit: Btu Emission Unit: g Energy Functional Unit: MJ

43 Gasoline Vehicle: Gasoline

Item	Btu/mile or Gallon/mile or g/mile				Btu/MJ or Gallon/MJ or g/MJ			
	Feedstock	Fuel	Vehicle Operation	Total	Feedstock	Fuel	Vehicle Operation	Total
Total Energy	282	1,231	5,594	7,107	48	209	948	1,204
Fossil Fuels	264	1,091	5,221	6,576	45	185	885	1,114
Coal	25	39	0	63	4	7	0	11
Natural Gas		702	0	893	32	119	0	151
Petroleum		350	5,221	5,619	8	59	885	952
Water Consumption		0.2	0	0	0	0	0	0
CO2 (w/ C in VOC & CO)		82	429	506	-1	14	73	86
CH4	0.411	0.226	0.016	0.653	0.070	0.038	0.003	0.111
N2O	0.000	0.016	0.005	0.021	0.000	0.003	0.001	0.004
GHGs	8	93	431	531	1	16	73	90
VOC: Total	0.017	0.148	0.190	0.355	0.003	0.025	0.032	0.060
CO: Total	0.034	0.056	2.882	2.973	0.006	0.010	0.488	0.504
NOx: Total	0.052	0.093	0.103	0.247	0.009	0.016	0.017	0.042
PM10: Total	0.003	0.013	0.037	0.053	0.000	0.002	0.006	0.009
PM2.5: Total	0.002	0.008	0.009	0.020	0.000	0.001	0.002	0.003

Ctrl C

Results Petroleum Co_processing NG MeOH_FTD EtOH Electric Generation_mixes Bio_electricity Hydroger

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R&D GREET 1

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RNAV GASCRFG Gasoline Vehicle: Gasoline

WTW Results Menu Select a vehicle type from a pink drop down menu, then press "Go"

SI ICE Vehicles	Go	SI Hybrid Vehicles (HEV)	Go	SI Plug-in Hybrids (PHEV)	Go	Performance-enhancing Fuels	Select Fuels
SI - Gasoline		Select Fuels		Select Fuels			
SIDI ICE Vehicles	Go	CIDI Hybrid Vehicles (HEV)	Go	CIDI Plug-in Hybrids (PHEV)	Go		
Select Fuels		Select Fuels		N/A			
CIDI ICE Vehicles	Go	BEV and FCV	Go	GCI ICE Vehicles	Go		
Select Fuels		Select Fuels		Select Fuels			

Unit Selection Select units from a pink drop down menu for the Results

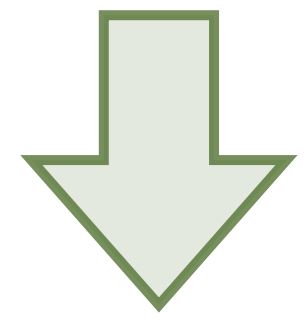
Per Vehicle Distance Travelled Energy Unit: Btu Emission Unit: g Service Functional Unit: mile

Per Energy in Fuels Energy Unit: Btu Emission Unit: g Energy Functional Unit: MJ

Gasoline Vehicle: Gasoline

Item	Btu/mile or Gallon/mile or g/mile				Btu/MJ or Gallon/MJ or g/MJ			
	Feedstock	Fuel	Vehicle Operation	Total	Feedstock	Fuel	Vehicle Operation	Total
Total Energy	282	1,231	5,594	7,107	48	209	948	1,204
Fossil Fuels	264	1,091	5,221	6,576	45	185	885	1,114
Coal	25	39	0	63	4	7	0	11
Natural Gas	191	702	0	893	32	119	0	151
Petroleum	48	350	5,221	5,619	8	59	885	952
Water Consumption	0.1	0.2	0	0	0	0	0	0
CO2 (w/ C in VOC & CO)	-5	82	429	506	-1	14	73	86
CH4	0.411	0.226	0.016	0.653	0.070	0.038	0.003	0.111
N2O	0.000	0.016	0.005	0.021	0.000	0.003	0.001	0.004
GHGs	8	93	431	531	1	16	73	90
VOC: Total	0.017	0.148	0.190	0.355	0.003	0.025	0.032	0.060
CO: Total	0.034	0.056	2.882	2.973	0.006	0.010	0.488	0.504
NOx: Total	0.052	0.093	0.103	0.247	0.009	0.016	0.017	0.042
PM10: Total	0.003	0.013	0.037	0.053	0.000	0.002	0.006	0.009
PM2.5: Total	0.002	0.008	0.009	0.020	0.000	0.001	0.002	0.003

Use empty cells or a new sheet



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R&D GREET 1

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V10

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Fuel Stage GHG Emissions												
2		Feedstock	Fuel	Vehicle Operation	Total Fuel Cycle								
3	Powertrain												
4	ICEV												
5	HEV												
6	PHEV												
7	BEV												
8	FCV												
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Create a table as shown on the left

Inputs Results Sheet1 Petroleum Co_processing NG MeOH_FTD EtOH Electric Generation_mixes Bio_ele ...



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R&D GREET 1 10 A^ A^

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Q6

	A	B	C	D	E	F	G	H	I	J	K	L	M
1		Fuel Stage GHG Emissions											
2		Feedstock	Fuel	Vehicle Operation	Total Fuel Cycle								
3	Powertrain												
4	ICEV	8	93	431	531								
5	HEV												
6	PHEV												
7	BEV												
8	FCV												
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13													
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15													
16													
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Right click

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2

Inputs Results Sheet1 Petroleum Co_processing NG MeOH_FTD EtOH Electric Generation_mixes Bio_ele



Obtain Fuel Cycle GHG Emissions for a Hybrid Electric Vehicle (**HEV**), Plug-in Hybrid Electric Vehicle (**PHEV**), Battery Electric Vehicle (**BEV/EV**), and Fuel-Cell Vehicle (**FCV**)



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R&D GREET 1

Clipboard Font Alignment Number Styles Cells Editing Sensitivity Add-ins Analyze Data

R8

	A	B	C	D	E	F	G	H	I	J	K	L	M	
1		Fuel Stage GHG Emissions												
2		Feedstock	Fuel	Vehicle Operation	Total Fuel Cycle									
3	Powertrain													
4	ICEV	8	93	431	531									
5	HEV	5	63	292	360									
6	PHEV	17	148	136	300									
7	BEV	26	215	0	240									
8	FCV	34	220	0	253									
9														
10														
11														
12														
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15														
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17														

Right click

Paste as Values

1

2

Inputs Results Sheet1 Petroleum Co_processing NG MeOH_FTD EtOH Electric Generation_mixes Bio_ele ...

ICEV: Gasoline
HEV: Gasoline
PHEV: Gasoline and Electricity
BEV: Electricity
FCV: Gaseous Hydrogen

List the Powertrains from Lowest to Highest Feedstock GHG Emissions



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Feedstock GHG emissions results

PHEVs and BEVs

Feedstock emissions come from the electricity from the electric grid

Much of the electricity from the U.S. Mix in GREET is produced using natural gas and/or coal, which have upstream GHG impacts

FCVs

Feedstock emissions come from hydrogen production

Hydrogen is produced from conventional steam natural reforming of natural gas, which is highly GHG emission-intensive and produces higher feedstock and fuel emissions

	A	B	C	D	E
1	Fuel Stage GHG Emissions				
2		Feedstock	Fuel	Vehicle Operation	Total Fuel Cycle
3	Powertrain				
4	ICEV	8	93	431	531
5	HEV	5	63	292	360
6	PHEV	17	148	136	300
7	BEV	26	215	0	240
8	FCV	34	220	0	253
9					
10					
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16					
17					

HEV < ICEV < PHEV < BEV < FCV



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List the Powertrains from Lowest to Highest Total Fuel Cycle GHG Emissions



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Total fuel cycle emissions results

BEV and FCV have No Vehicle Operation GHG Emissions

You avoid all GHG emissions from petroleum-based fuels
In an FCV, hydrogen reacts with oxygen resulting in water

FCVs have lower total fuel cycle GHG emissions than all powertrains except BEVs

BEV < FCV < PHEV < HEV < ICEV

	A	B	C	D	E
1	Fuel Stage GHG Emissions				
2		Feedstock	Fuel	Vehicle Operation	Total Fuel Cycle
3	Powertrain				
4	ICEV	8	93	431	531
5	HEV	5	63	292	360
6	PHEV	17	148	136	300
7	BEV	26	215	0	240
8	FCV	34	220	0	253
9					
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Vehicle Cycle GHG Emissions for an Internal Combustion Engine Vehicle (ICEV)



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Paste B I U Font Alignment Number Styles Cells Editing Sensitivity Add-ins Analyze Data

A1 Energy Use and Emissions of Well-to-Pump, Vehicle Cycle and Vehicle Operation

1 Energy Use and Emissions of Well-to-Pump, Vehicle Cycle and Vehicle Operation

2 1) Well-to-Pump, Vehicle Cycle and Vehicle Operation Energy Use and Emissions: Btu or g per mile

3 Energy Unit: Btu Emission Unit: g

4 Service Functional Unit: mile

5 Gasoline Vehicle: CG and RFG, Conventional Material

Item	Btu/mile or g/mile				Vehicle Cycle Credits	Percentage of each stage				Vehicle Cycle Credits
	WTP	Vehicle Cycle	Vehicle Operation	Total		WTP	Vehicle Cycle	Vehicle Operation	Total	
Total energy	1,496	5,117	1,500	7,613	0	19.6%	7.7%	72.6%	100.0%	0.0%
Fossil fuels	1,340	3,699	0	7,039	0	19.0%	7.6%	73.3%	100.0%	0.0%
Coal	0	205	0	205	0	30.5%	69.5%	0.0%	100.0%	0.0%
Natural gas	0	150	0	150	0	76.8%	23.2%	0.0%	100.0%	0.0%
Petroleum	0	684	0	684	0	6.9%	2.3%	90.8%	100.0%	0.0%
Water consumption	0	0.332	0	0.332	0	87.9%	12.1%	0.0%	100.0%	0.0%
CO2 (VOC, CO, CO2)	0	537	0	537	0	14.1%	6.9%	79.0%	100.0%	0.0%
CH4	0	0.733	0	0.733	0	85.9%	12.0%	2.1%	100.0%	0.0%
N2O	0	0.022	0	0.022	0	72.1%	5.0%	22.9%	100.0%	0.0%
GHGs	99	40	426	565	0	17.5%	7.1%	75.4%	100.0%	0.0%
VOC: Total	0.163	0.354	0.190	0.688	0	23.7%	48.6%	27.6%	100.0%	0.0%
CO: Total	0.088	0	2.882	2.970	0	2.9%	3.7%	93.4%	100.0%	0.0%
NOx: Total	0	0	0	0	0	49.6%	14.6%	35.7%	100.0%	0.0%
PM10: Total	0	0	0	0	0	23.7%	20.2%	56.2%	100.0%	0.0%
PM2.5: Total	0	0	0	0	0	39.7%	25.6%	34.7%	100.0%	0.0%
SOx: Total	0	0	0	0	0	28.9%	69.2%	1.9%	100.0%	0.0%
BC: Total	0	0.003	0	0.003	0	28.4%	4.6%	67.0%	100.0%	0.0%
OC: Total	0	0.002	0.005	0.007	0	44.1%	10.0%	45.9%	100.0%	0.0%
VOC: Urban	0	0.133	0	0.133	0	20.3%	48.8%	30.9%	100.0%	0.0%
CO: Urban	0.016	0	2.018	2.035	0	0.8%	0.1%	99.1%	100.0%	0.0%
NOx: Urban	0.024	0.005	0.072	0.101	0	23.5%	5.2%	71.3%	100.0%	0.0%

WTP GHG emissions

Vehicle operation GHG emissions

Vehicle cycle GHG emissions

Total C2G GHG emissions

Per Vehicle Distance Travelled

Energy Unit	Btu	mBtu	J	kJ	0.0
	1.000	0.001	1055	1.055	0.0
Emission Unit	g	mg	kg	lb	0.0
	1.000	1000	0.001	0.002	0.0
Functional Unit	mile	km			
	1.000	1.609			

Battery_Materials Anode LiMn2O4 Li_Chemicals Other_Cathodes Battery Recycling Vehi_Comp_Sum Vehi_Sum **TEC_Results**

ICEV SUV built and used in 2022 and fueled by gasoline

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A1 Energy Use and Emissions of Well-to-Pump, Vehicle Cycle and Vehicle Operation

1 **Energy Use and Emissions of Well-to-Pump, Vehicle Cycle and Vehicle Operation**

2 **1) Well-to-Pump, Vehicle Cycle and Vehicle Operation Energy Use and Emissions: Btu or g per mile**

3 Energy Unit: Btu Emission Unit: g

4 Service Functional Unit: mile

5 **Gasoline Vehicle: CG and RFG, Conventional Material**

Item	Btu/mile or g/mile				Vehicle Cycle Credits	Percentage of each stage				Vehicle Cycle Credits
	WTP	Vehicle Cycle	Vehicle Operation	Total		WTP	Vehicle Cycle	Vehicle Operation	Total	
Total energy	1,496	587	5,531	7,613	0	19.6%	7.7%	72.6%	100.0%	0.0%
Fossil fuels	1,340	538	5,162	7,039	0	19.0%	7.6%	73.3%	100.0%	0.0%
Coal	63	143	0	205	0	30.5%	69.5%	0.0%	100.0%	0.0%
Natural gas	883	267	0	1,150	0	76.8%	23.2%	0.0%	100.0%	0.0%
Petroleum	0	0	5,162	5,162	0	6.9%	2.3%	90.8%	100.0%	0.0%
Water consumption	0	0	0.000	0.000	0	87.9%	12.1%	0.0%	100.0%	0.0%
CO2 (VOC, CO, CO2)	0	0	42	42	0	14.1%	6.9%	79.0%	100.0%	0.0%
CH4	0	0.088	0.016	0.104	0	85.9%	12.0%	2.1%	100.0%	0.0%
N2O	0.016	0.004	0.005	0.025	0	72.1%	5.0%	22.9%	100.0%	0.0%
GHGs	99	40	426	565	0	17.5%	7.1%	75.4%	100.0%	0.0%
VOC: Total	0.163	0.334	0.190	0.688	0	23.7%	48.6%	27.6%	100.0%	0.0%
CO: Total	0.089	0.115	2.882	3.087	0	2.9%	3.7%	93.4%	100.0%	0.0%
NOx: Total	0.143	0.042	0.103	0.288	0	49.6%	14.6%	35.7%	100.0%	0.0%
PM10: Total	0.016	0.013	0.037	0.066	0	23.7%	20.2%	56.2%	100.0%	0.0%
PM2.5: Total	0.010	0.007	0.009	0.026	0	39.7%	25.6%	34.7%	100.0%	0.0%
SOx: Total	0.038	0.092	0.003	0.132	0	28.9%	69.2%	1.9%	100.0%	0.0%
BC: Total	0.001	0.000	0.003	0.005	0	28.4%	4.6%	67.0%	100.0%	0.0%
OC: Total	0.002	0.001	0.002	0.005	0	44.1%	10.0%	45.9%	100.0%	0.0%
VOC: Urban	0.088	0.210	0.133	0.431	0	20.3%	48.8%	30.9%	100.0%	0.0%
CO: Urban	0.016	0.002	2.018	2.035	0	0.8%	0.1%	99.1%	100.0%	0.0%
NOx: Urban	0.024	0.005	0.072	0.101	0	23.5%	5.2%	71.3%	100.0%	0.0%

Per Vehicle Distance Travelled

Energy Unit	Btu	mBtu	J	kJ	0.0
	1.000	0.001	1055	1.055	0.0
Emission Unit	g	mg	kg	lb	0.0
	1.000	1000	0.001	0.002	0.0
Functional Unit	mile	km			
	1.000	1.609			

Battery_Materials | Anode | LiMn2O4 | Li_Chemicals | Other_Cathodes | Battery Recycling | Vehi_Comp_Sum | Vehi_Sum | **TEC_Results**



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A1 Energy Use and Emissions of Well-to-Pump, Vehicle Cycle and Vehicle Operation

1 **Energy Use and Emissions of Well-to-Pump, Vehicle Cycle and Vehicle Operation**

2 **1) Well-to-Pump, Vehicle Cycle and Vehicle Operation Energy Use and Emissions: Btu or g per mile**

3 Energy Unit: Btu Emission Unit: g

4 Service Functional Unit: mile

5 **Gasoline Vehicle: CG and RFG, Conventional Material**

Item	Btu/mile or g/mile				Vehicle Cycle Credits	Percentage of each stage				Vehicle Cycle Credits
	WTP	Vehicle Cycle	Vehicle Operation	Total		WTP	Vehicle Cycle	Vehicle Operation	Total	
Total energy	1,496	587	5,531	7,613	0	19.6%	7.7%	72.6%	100.0%	0.0%
Fossil fuels	1,340	538	5,162	7,039	0	19.0%	7.6%	73.3%	100.0%	0.0%
Coal	63	143	0	205	0	30.5%	69.5%	0.0%	100.0%	0.0%
Natural gas	883	267	0	1,150	0	76.8%	23.2%	0.0%	100.0%	0.0%
Petroleum	394	128	5,162	5,684	0	6.9%	2.3%	90.8%	100.0%	0.0%
Water consumption	0.292	0.040	0.000	0.332	0	87.9%	12.1%	0.0%	100.0%	0.0%
CO2 (VOC, CO, CO2)	76	37	424	537	0	14.1%	6.9%	79.0%	100.0%	0.0%
CH4	0.630	0.088	0.016	0.733	0	85.9%	12.0%	2.1%	100.0%	0.0%
N2O	0.016	0.001	0.005	0.022	0	72.1%	5.0%	22.9%	100.0%	0.0%
GHGs	99	40	426	565	0	17.5%	7.1%	75.4%	100.0%	0.0%
VOC: Total	0.163	0.334	0.190	0.688	0	23.7%	48.6%	27.6%	100.0%	0.0%
CO: Total	0.089	0.115	2.882	3.087	0	2.9%	3.7%	93.4%	100.0%	0.0%
NOx: Total	0.143	0.042	0.103	0.288	0	49.6%	14.6%	35.7%	100.0%	0.0%
PM10: Total	0.016	0.013	0.037	0.066	0	23.7%	20.2%	56.2%	100.0%	0.0%
PM2.5: Total	0.010	0.007	0.009	0.026	0	39.7%	25.6%	34.7%	100.0%	0.0%
SOx: Total	0.038	0.092	0.003	0.132	0	28.9%	69.2%	1.9%	100.0%	0.0%
BC: Total	0.001	0.000	0.003	0.005	0	28.4%	4.6%	67.0%	100.0%	0.0%
OC: Total	0.002	0.001	0.002	0.005	0	44.1%	10.0%	45.9%	100.0%	0.0%
VOC: Urban	0.088	0.210	0.133	0.431	0	20.3%	48.8%	30.9%	100.0%	0.0%
CO: Urban	0.016	0.002	2.018	2.035	0	0.8%	0.1%	99.1%	100.0%	0.0%
NOx: Urban	0.024	0.005	0.072	0.101	0	23.5%	5.2%	71.3%	100.0%	0.0%

Energy Unit	Btu	mBtu	J	kJ	0.0
	1.000	0.001	1055	1.055	0.0
Emission Unit	g	mg	kg	lb	0.0
	1.000	1000	0.001	0.002	0.0
Functional Unit	mile	km			
	1.000	1.609			

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Battery_Materials Anode LiMn2O4 Li_Chemicals Other_Cathodes Battery Recycling Vehi_Comp_Sum Vehi_Sum **TEC_Results** +



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	A	B	C	D	E
1		Vehicle Stage GHG Emissions			
2		WTP	Vehicle Cycle	Vehicle Operation	Total Vehicle Cycle
3	Powertrain				
4	ICEV				
5	HEV				
6	PHEV				
7	BEV				
8	FCV				

Create a table as shown on the left

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R&D GREET 2 10 A^ A^

Paste Clipboard Font Alignment Number Styles Cells Editing Sensitivity Add-ins Analyze Data

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	A	B	C	D	E	F	G	H	I	J	K	L	M
1		Vehicle Stage GHG Emissions											
2		WTP	Vehicle Cycle	Vehicle Operation	Total Vehicle Cycle								
3	Powertrain												
4	ICEV	99	40	426	565								
5	HEV												
6	PHEV												
7	BEV												
8	FCV												
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1 2

< > ... Anode LiMn2O4 Li_Chemicals Other_Cathodes Battery Recycling Vehi_Comp_Sum Vehi_Sum TEC_Results Sheet1 Electrolyzer ... + :



Obtain Vehicle Cycle GHG Emissions for a Hybrid Electric Vehicle (**HEV**), Plug-in Hybrid Electric Vehicle (**PHEV**), Battery Electric Vehicle (**BEV/EV**), and Fuel-Cell Vehicle (**FCV**)

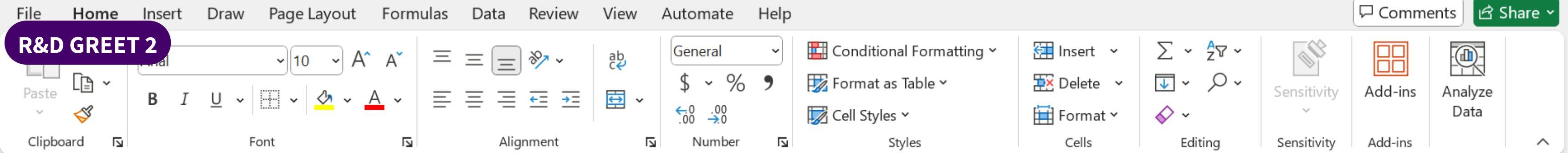


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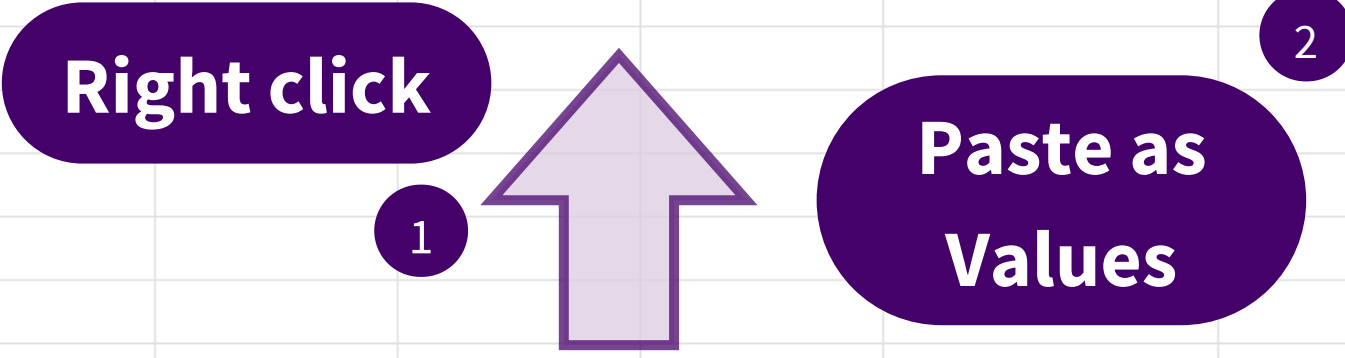
R&D GREET 2



	A	B	C	D	E	F	G
1		Vehicle Stage GHG Emissions					
2		WTP	Vehicle Cycle	Vehicle Operation	Total Vehicle Cycle		
3	Powertrain						
4	ICEV	99	40	426	565		
5	HEV	69	42	296	407		
6	PHEV	160	48	132	340		
7	BEV	240	82	0	322		
8	FCV	245	50	0	295		

Note:
model all LDV technologies using the conventional material

ICEV: Gasoline
HEV: Gasoline
PHEV: Gasoline and Electricity
BEV: Electricity
FCV: Gaseous Hydrogen



List the Powertrains from Lowest to Highest Vehicle Cycle GHG Emissions



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Vehicle cycle GHG emissions results

BEVs

BEVs use a Lithium ion battery when modeled in GREET, which is heavy and is associated with high vehicle cycle GHG emissions

FCVs

FCVs use carbon-reinforced plastic for the hydrogen tanks, which accounts for the higher vehicle cycle GHG emissions

ICEV < HEV < PHEV < FCV < BEV

	A	B	C	D	E
1			Vehicle Stage GHG Emissions		
2		WTP	Vehicle Cycle	Vehicle Operation	Total Vehicle Cycle
3	Powertrain				
4	ICEV	99	40	426	565
5	HEV	69	42	296	407
6	PHEV	160	48	132	340
7	BEV	240	82	0	322
8	FCV	245	50	0	295
9					
10					
11					
12					
13					
14					
15					
16					
17					



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List the Powertrains from Lowest to Highest Total Vehicle Cycle GHG Emissions



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Total vehicle cycle emissions results

BEV and FCV have

No Vehicle Operation GHG Emissions

This offsets the increased vehicle cycle emissions from BEVs and FCVs modeled in GREET

FCVs have lower total vehicle cycle GHG emissions than all powertrains including BEVs

FCV < BEV < PHEV < HEV < ICEV

	A	B	C	D	E
1			Vehicle Stage GHG Emissions		
2		WTP	Vehicle Cycle	Vehicle Operation	Total Vehicle Cycle
3	Powertrain				
4	ICEV	99	40	426	565
5	HEV	69	42	296	407
6	PHEV	160	48	132	340
7	BEV	240	82	0	322
8	FCV	245	50	0	295
9					
10					
11					
12					
13					
14					
15					
16					
17					



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**Calculate the Percentage Reduction in
Total Vehicle Cycle GHG Emissions
Compared to the Same Vehicle Using an
ICEV Fueled with Gasoline**



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R&D GREET 2

F5 : $=100*(1-E5/E4)$

**Percent reduction = 100 x
(1-total powertrain/total ICEV)**

Vehicle Stage GHG Emissions				
	WTP	Vehicle Cycle	Vehicle Operation	Total Vehicle Cycle
Powertrain				Reduction (%)
ICEV	99	40	426	565
HEV	69	42	296	407
PHEV	160	48	132	340
BEV	240	82	0	322
FCV	245	50	0	295

28.052515
39.955300
43.055655
47.816850

Obtain Life Cycle Impacts of SUVs with Different Battery Chemistries



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Battery chemistry

The electric vehicle industry is shifting to higher nickel chemistries

Higher nickel chemistries improve the energy capacity of the battery

Less material is needed to produce the same battery capacity, which reduces the battery weight

Lighter vehicles produce less GHG emissions



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Battery Chemistry

Model a 2022 Sport Utility Vehicle (SUV) Running on an NMC811 Battery with the Following Powertrains:
PHEV (50-mi range) and BEV (400-mi range)



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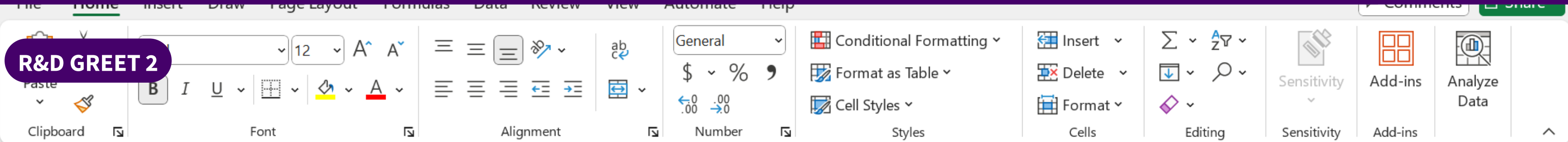
Default Battery Chemistry Used in PHEVs and BEVs



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A1 Scenario Control Variables and Input Assumptions Related to Vehicle and its Components

5.3) Battery Size in Peak Battery Energy (High Energy Applications), kWh

	Ni-MH	Li-Ion
PHEV: Conventional Material	15	15
PHEV: Lightweight Material	12	12
EV: Conventional Material	84	84
EV: Lightweight Material	64	64

5.4) Battery Replacements During Lifetime of Vehicle

	Lead-Acid	Ni-MH	Li-Ion
ICEV	2		
HEV	2	0	0
PHEV	2	0	0
EV	2	0	0
FCV	2	0	0

5.5) Li-ion Battery Cathode Material

HEV	2	1. LMO, 2. NMC111, 3.LFP: Hydrothermal, 4. LFP: Solid State, 5. NMC622, 6. NMC811, 7. NCA, 8. NMC532, 9. NMC95
PHEV	2	1. LMO, 2. NMC111, 3.LFP: Hydrothermal, 4. LFP: Solid State, 5. NMC622, 6. NMC811, 7. NCA, 8. NMC532, 9. NMC95
EV	2	1. LMO, 2. NMC111, 3.LFP: Hydrothermal, 4. LFP: Solid State, 5. NMC622, 6. NMC811, 7. NCA, 8. NMC532, 9. NMC95
FCV	2	1. LMO, 2. NMC111, 3.LFP: Hydrothermal, 4. LFP: Solid State, 5. NMC622, 6. NMC811, 7. NCA, 8. NMC532, 9. NMC95

5.6) Battery Specific Power

	Ni-MH		Li-Ion		LMO
	W/kg	W/lb	W/kg	W/lb	
HEV	800	363	2,378	1,079	2,228
FCV	800	363	2,708	1,228	2,512

5.7) Battery Specific Energy

	Ni-MH		Li-Ion		LMO
	Wh/kg	Wh/lb	Wh/kg	Wh/lb	
PHEV	53	24	171	78	183

Note:
NMC111 is the default battery chemistry, not default battery type

Microsoft Excel ribbon showing tabs: Clipboard, Font, Alignment, Number, Styles, Cells, Editing, Sensitivity, Add-ins, Analyze Data.

Formula bar: C104, fx, 2

5.5) Li-ion Battery Cathode Material

HEV	2	1. LMO, 2. NMC111, 3. LFP: Hydrothermal, 4. LFP: Solid State, 5. NMC622, 6. NMC811, 7. NCA, 8. NMC532, 9. NMC95
PHEV	2	1. LMO, 2. NMC111, 3. LFP: Hydrothermal, 4. LFP: Solid State, 5. NMC622, 6. NMC811, 7. NCA, 8. NMC532, 9. NMC95
EV	2	1. LMO, 2. NMC111, 3. LFP: Hydrothermal, 4. LFP: Solid State, 5. NMC622, 6. NMC811, 7. NCA, 8. NMC532, 9. NMC95
FCV	1	1. LMO, 2. NMC111, 3. LFP: Hydrothermal, 4. LFP: Solid State, 5. NMC622, 6. NMC811, 7. NCA, 8. NMC532, 9. NMC95

5.6) Battery Specific Power

	Type	W/lb	W/kg	Li-ion specific power by type (W/kg)							
				LMO	NMC111	LFP	NMC622	NMC811	NCA	NMC532	NMC95
HEV	Ni-MH	363	2,378	2,050	2,378	2,221	2,421	2,484	2,438	2,419	2,527
FCV	Li-Ion	363	2,513	1,890	2,513	2,342	2,565	2,635	2,584	2,558	2,677

5.7) Battery Specific Energy

	Type	Wh/lb	Wh/kg	Li-ion Battery Specific Energy (Wh/kg)							
				LMO	NMC111	LFP	NMC622	NMC811	NCA	NMC532	NMC95
PHEV	Ni-MH	24	174	PHEV: 35-mile							
EV	Li-Ion	29	177	141	165	137	173	181	177	171	187

6. Key Input Parameters for Fluids

6.1) Fluids Replacements During Lifetime of Vehicle

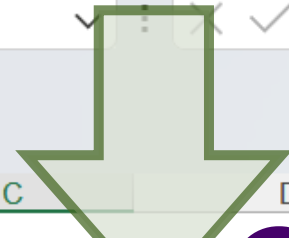
Engine Oil	Power Steering Fluid	Brake Fluid	Transmission Fluid	Powertrain Coolant	Windshield Fluid	Adhesives
44	0	4	1	4	22	0

6.2) Ratio of Waste to Product when Fluids is Disposed

Engine Oil	Power Steering Fluid	Brake Fluid	Transmission Fluid	Powertrain Coolant	Windshield Fluid	Adhesives
66.7%	66.7%	66.7%	66.7%	66.7%	0.0%	66.7%

7. GREET Default Key Assumptions for Vehicle Assembly

Vehi_Inputs | Mat_Inputs | Car | SUV | PUT | Steel | C.Iron | W.AI | C.AI | Lead | Nickel | Cobalt | Copper | Zinc | Magnesium



1

2

5.4) Battery Replacements During Lifetime of Vehicle

	Lead-Acid	Ni-MH	Li-Ion
ICEV	2	0	0
HEV	2	0	0
PHEV	2	0	0
EV	2	0	0
FCV	2	0	0

5.5) Li-ion Battery Cathode Material

HEV	2	1. LMO, 2. NMC111, 3. LFP: Hydrothermal, 4. LFP: Solid State, 5. NMC622, 6. NMC811, 7. NCA, 8. NMC532, 9. NMC95
PHEV	6	1. LMO, 2. NMC111, 3. LFP: Hydrothermal, 4. LFP: Solid State, 5. NMC622, 6. NMC811, 7. NCA, 8. NMC532, 9. NMC95
EV	2	1. LMO, 2. NMC111, 3. LFP: Hydrothermal, 4. LFP: Solid State, 5. NMC622, 6. NMC811, 7. NCA, 8. NMC532, 9. NMC95
FCV	1	1. LMO, 2. NMC111, 3. LFP: Hydrothermal, 4. LFP: Solid State, 5. NMC622, 6. NMC811, 7. NCA, 8. NMC532, 9. NMC95

5.6) Battery Specific Power

		Ni-MH	Li-Ion		Li-Ion specific power by type (W/kg)							
			W/lb	W/kg	W/lb	LMO	NMC111	LFP	NMC622	NMC811	NCA	NMC532
HEV	5	363	2,378	1,079	2,050	2,378	2,221	2,421	2,484	2,438	2,419	2,527
FCV	6	363	2,513	1,140	1,890	2,513	2,342	2,565	2,635	2,584	2,558	2,677

5.7) Battery Specific Energy

		Ni-MH	Li-Ion	
			Wh/lb	Wh/kg
PHEV	5	24	174	79
EV	65	29	187	85

Li-ion Battery Specific Energy (Wh/kg)

PHEV: 35-mile								
LMO	NMC111	LFP	NMC622	NMC811	NCA	NMC532	NMC95	LMO
141	165	137	173	181	177	171	187	

6. Key Input Parameters for Fluids

6.1) Fluids Replacements During Lifetime of Vehicle

Power Steering	Transmission	Windshield
----------------	--------------	------------

Default Battery Replacement Assumption



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Microsoft Excel ribbon showing tabs: File, Home, Insert, Draw, Page Layout, Formulas, Data, Review, View, Automate, Help. The Home tab is active, showing groups for Clipboard, Font, Alignment, Number, Styles, Cells, and Editing.

R103

5.4) Battery Replacements During Lifetime of Vehicle

	Lead-Acid	Ni-MH	Li-Ion
ICEV	2		0
HEV	2	0	0
PHEV	2	0	0
EV	2	0	0
FCV	2	0	0

5.5) Li-ion Battery Cathode Material

HEV	2	1. LMO, 2. NMC111, 3.LFP: Hydrothermal, 4. LFP: Solid State, 5. NMC622, 6. NMC811, 7. NCA, 8. NMC532, 9. NMC95
PHEV	6	1. LMO, 2. NMC111, 3.LFP: Hydrothermal, 4. LFP: Solid State, 5. NMC622, 6. NMC811, 7. NCA, 8. NMC532, 9. NMC95
EV	6	1. LMO, 2. NMC111, 3.LFP: Hydrothermal, 4. LFP: Solid State, 5. NMC622, 6. NMC811, 7. NCA, 8. NMC532, 9. NMC95
FCV	2	1. LMO, 2. NMC111, 3.LFP: Hydrothermal, 4. LFP: Solid State, 5. NMC622, 6. NMC811, 7. NCA, 8. NMC532, 9. NMC95

5.6) Battery Specific Power

	Ni-MH		Li-Ion		Li-Ion specific power by type (W/kg)							
	W/kg	W/lb	W/kg	W/lb	LMO	NMC111	LFP	NMC622	NMC811	NCA	NMC532	NMC95
HEV	800	363	2,378	1,079	2,050	2,378	2,221	2,421	2,484	2,438	2,419	2,527
FCV	800	363	2,513	1,140	1,890	2,513	2,342	2,565	2,635	2,584	2,558	2,677

5.7) Battery Specific Energy

	Ni-MH		Li-Ion	
	Wh/kg	Wh/lb	Wh/kg	Wh/lb
PHEV	53	24	174	79
EV	65	29	187	85

Li-ion Battery Specific Energy (Wh/kg)

PHEV: 35-mile									
LMO	NMC111	LFP	NMC622	NMC811	NCA	NMC532	NMC95	LMO	
141	165	137	173	181	177	171	187		

6. Key Input Parameters for Fluids

6.1) Fluids Replacements During Lifetime of Vehicle

Power Steering	Transmission	Windshield

Obtain Vehicle Cycle GHG Emissions for a Plug-in Hybrid Electric Vehicle (**PHEV**) and a Battery Electric Vehicle (**BEV/EV**)



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R&D GREET 2

B197 =HLOOKUP(GREET1_Import_Export!\$B\$375,\$N\$9:\$R\$10,2,FALSE)/HLOOKUP(GREET1_Import_Export!\$D\$374,\$N\$7:\$R\$8,2,FALSE)*HLOOKUP(\$D\$3,\$N\$7:\$R\$8,2,FALSE)/HLOOKUP(\$D\$4,\$N\$9:\$R\$10,2,FALSE)*(GREET1_Import_Export!\$T390+GREET1_Import_Export!\$U390)/Vehi_Inputs!\$E\$150

Item	Btu/mile or g/mile				Vehicle Cycle Credits	Percentage of each stage				Vehicle Cycle Credits
	WTP	Vehicle Cycle	Vehicle Operation	Total		WTP	Vehicle Cycle	Vehicle Operation	Total	
128 Total energy	1,485	679	0	2,164	0	30.5%	14.0%	55.5%	100.0%	0.0%
129 Fossil fuels	1,226	620	0	1,846	0	29.1%	14.7%	56.1%	100.0%	0.0%
130 Coal	177	0	0	177	0	39.2%	21.4%	39.4%	100.0%	0.0%
131 Natural gas	31	0	0	31	0	50.4%	20.6%	29.0%	100.0%	0.0%
132 Petroleum	878	0	0	878	0	7.3%	7.0%	85.7%	100.0%	0.0%
133 Water consumption	48	0	0	48	0	84.5%	15.5%	0.0%	100.0%	0.0%
134 CO2 (VOC, CO, CO2)	43	0	0	43	0	45.2%	13.6%	41.2%	100.0%	0.0%
135 CH4	0.117	0	0	0.117	0	78.7%	20.7%	0.6%	100.0%	0.0%
136 N2O	0.007	0.004	0.002	0.013	0	67.3%	12.9%	19.8%	100.0%	0.0%
137 GHGs	159	47	131	337	0	47.1%	14.0%	38.9%	100.0%	0.0%
138 VOC: Total	0.085	0.337	0.007	0.429	0	13.9%	71.9%	14.2%	100.0%	0.0%
139 CO: Total	0.079	0.231	0.007	0.317	0	5.5%	9.1%	85.4%	100.0%	0.0%
140 NOx: Total	0.136	0.007	0.007	0.150	0	60.8%	22.6%	16.6%	100.0%	0.0%
141 PM10: Total	0.01	0.007	0.007	0.024	0	26.8%	23.0%	50.2%	100.0%	0.0%
142 PM2.5: Total	0.01	0.007	0.007	0.024	0	43.3%	31.4%	25.3%	100.0%	0.0%
143 SOx: Total	0.00	0.007	0.007	0.014	0	37.6%	62.1%	0.3%	100.0%	0.0%
144 BC: Total	0.00	0.007	0.007	0.014	0	29.9%	10.3%	59.8%	100.0%	0.0%
145 OC: Total	0.00	0.007	0.007	0.014	0	57.6%	13.9%	28.5%	100.0%	0.0%
146 VOC: Urban	0.028	0.007	0.007	0.042	0	9.8%	73.8%	16.4%	100.0%	0.0%
147 CO: Urban	0.016	0.007	0.007	0.030	0	1.8%	0.3%	97.9%	100.0%	0.0%
148 NOx: Urban	0.031	0.006	0.006	0.043	0	49.2%	9.1%	41.7%	100.0%	0.0%
149 PM10: Urban	0.004	0.001	0.001	0.006	0	14.4%	2.6%	83.0%	100.0%	0.0%
150 PM2.5: Urban	0.003	0.001	0.001	0.005	0	41.6%	6.0%	52.4%	100.0%	0.0%
151 SOx: Urban	0.026	0.007	0.001	0.034	0	76.6%	21.8%	1.6%	100.0%	0.0%

WTP
GHG emissions

Vehicle operation
GHG emissions

Vehicle cycle
GHG emissions

Total C2G
GHG emissions

PHEV built and used in 2022 with an NMC811 battery chemistry and fueled by gasoline and electricity

R&D GREET 2

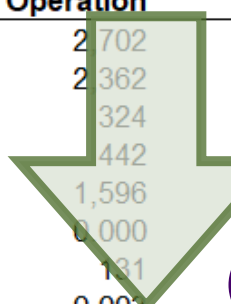
B197 =HLOOKUP(GREET1_Import_Export!\$B\$375,\$N\$9:\$R\$10,2,FALSE)/HLOOKUP(GREET1_Import_Export!\$D\$374,\$N\$7:\$R\$8,2,FALSE)*HLOOKUP(\$D\$3,\$N\$7:\$R\$8,2,FALSE)/HLOOKUP(\$D\$4,\$N\$9:\$R\$10,2,FALSE)*(GREET1_Import_Export!\$T390+GREET1_Import_Export!\$U390)/Vehi_Inputs!\$E\$150

Item	Btu/mile or g/mile				Vehicle Cycle Credits	Percentage of each stage				Vehicle Cycle Credits
	WTP	Vehicle Cycle	Vehicle Operation	Total		WTP	Vehicle Cycle	Vehicle Operation	Total	
128 Total energy	1,485	679	2,702	4,866	0	30.5%	14.0%	55.5%	100.0%	0.0%
129 Fossil fuels	1,226	620	2,362	4,208	0	29.1%	14.7%	56.1%	100.0%	0.0%
130 Coal	322	176	324	822	0	39.2%	21.4%	39.4%	100.0%	0.0%
131 Natural gas	332	314	442	1,524	0	50.4%	20.6%	29.0%	100.0%	0.0%
132 Petroleum	572	131	1,596	1,863	0	7.3%	7.0%	85.7%	100.0%	0.0%
133 Water consumption	0.48	0.000	0.000	0.308	0	84.5%	15.5%	0.0%	100.0%	0.0%
134 CO2 (VOC, CO, CO2)	43	131	131	18	0	45.2%	13.6%	41.2%	100.0%	0.0%
135 CH4	0.447	0.117	0.003	0.57	0	78.7%	20.7%	0.6%	100.0%	0.0%
136 N2O	0.007	0.001	0.002	0.011	0	67.3%	12.9%	19.8%	100.0%	0.0%
137 GHGs	159	47	131	338	0	47.1%	14.0%	38.9%	100.0%	0.0%
138 VOC: Total	0.065	0.337	0.067	0.468	0	13.9%	71.9%	14.2%	100.0%	0.0%
139 CO: Total	0.079	0.132	1.231	1.442	0	5.5%	9.1%	85.4%	100.0%	0.0%
140 NOx: Total	0.136	0.050	0.037	0.223	0	60.8%	22.6%	16.6%	100.0%	0.0%
141 PM10: Total	0.018	0.015	0.034	0.067	0	26.8%	23.0%	50.2%	100.0%	0.0%
142 PM2.5: Total	0.011	0.008	0.006	0.025	0	43.3%	31.4%	25.3%	100.0%	0.0%
143 SOx: Total	0.088	0.146	0.001	0.235	0	37.6%	62.1%	0.3%	100.0%	0.0%
144 BC: Total	0.001	0.000	0.002	0.003	0	29.9%	10.3%	59.8%	100.0%	0.0%
145 OC: Total	0.003	0.001	0.001	0.005	0	57.6%	13.9%	28.5%	100.0%	0.0%
146 VOC: Urban	0.028	0.210	0.047	0.285	0	9.8%	73.8%	16.4%	100.0%	0.0%
147 CO: Urban	0.016	0.002	0.862	0.880	0	1.8%	0.3%	97.9%	100.0%	0.0%
148 NOx: Urban	0.031	0.006	0.026	0.062	0	49.2%	9.1%	41.7%	100.0%	0.0%
149 PM10: Urban	0.004	0.001	0.024	0.028	0	14.4%	2.6%	83.0%	100.0%	0.0%
150 PM2.5: Urban	0.003	0.001	0.004	0.008	0	41.6%	6.0%	52.4%	100.0%	0.0%
151 SOx: Urban	0.026	0.007	0.001	0.034	0	76.6%	21.8%	1.6%	100.0%	0.0%

2

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R&D GREET 2

Clipboard Font Alignment Number Styles Cells Editing Sensitivity Add-ins Analyze Data

P5

	A	B	C	D	E	F	G	H	I	J	K	L	
1		Vehicle Stage GHG Emissions											
2		WTP	Vehicle Cycle	Vehicle Operation	Total Vehicle Cycle								
3	Powertrain					Reduction (%)							
4	ICEV	99	40	426	565								
5	HEV	69	42	296	407	28.052515							
6	PHEV	160	48	132	340	39.955300							
7	BEV	240	82	0	322	43.055655							
8	FCV	245	50	0	295	47.816850							
9													
10	PHEV (NMC811)	159	47	131	338								
11	BEV (NMC811)	233	80	0	313								
12													
13													
14													
15													
16													
17													

Note:
model all LDV technologies using the conventional material

PHEV: Gasoline and Electricity
BEV: Electricity

Right click (1) **Paste as Values** (2)

Anode | LiMn2O4 | Li_Chemicals | Other_Cathodes | Battery Recycling | Vehi_Comp_Sum | Vehi_Sum | TEC_Results | Sheet1 | Electrolyzer

**Calculate the Percentage Reduction in
Total Vehicle Cycle GHG Emissions
Compared to the Same Powertrain Using
an NMC111 Battery**



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F10 $=100*(1-E10/E6)$

**Percent reduction =
100 x (1-NMC811/NMC111)**

	A	B	C	D	E	
1		Vehicle Stage GHG Emissions				
2		WTP	Vehicle Cycle	Vehicle Operation	Total Vehicle Cycle	
3	Powertrain					Reduction (%)
4	ICEV	99	40	426	565	
5	HEV	69	42	296	407	28.052515
6	PHEV	160	48	132	340	39.955300
7	BEV	240	82	0	322	43.055655
8	FCV	245	50	0	295	47.816850
9						
10	PHEV (NMC811)	159	47	131	338	0.492459
11	BEV (NMC811)	233	80	0	313	2.710777
12						
13						
14						
15						
16						
17						

**PHEV reduction
0.49%**

**BEV reduction
2.71%**

Emissions reduction

As expected, the higher nickel chemistry battery produced less total vehicle cycle GHG emissions

Using a Higher-nickel Cathode is More Efficient

The battery has a higher energy density making the battery lighter and increasing the vehicle's fuel economy

The battery needs to be charged fewer times in the lifetime, reducing the amount of electricity used by the vehicle

Emissions associated with electricity production decreases



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Obtain Life Cycle Impacts of FCV SUVs with Different Hydrogen Pathways



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R&D GREET 1 10 A A

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Y220

1 2 A B C D E F G H I

206 **6. Hydrogen Production**

207 **6.1) Basis of H2 Production Assumptions from Different Technology Pathways**

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

209 Worksheet 6.1.a) Scenarios for H2A Model Cases

210 2 1 -- Current, 2 -- Future

211 Results

212 **6.2) Share of H2 Production by Location**

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

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217 **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%	0.0%
NG Autothermal Reforming	0.0%	0.0%
RNG Autothermal Reforming	0.0%	0.0%
Methane Pyrolysis (Using NG)	0.0%	0.0%

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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	Note:
Central Plants		1	1	1 -- North American NG, 4 -- Renewable Natural Gas
Distributed Production at Refueling Stations		1	1	

6.6) CO2 Sequestration Options for Central Plant H2 Production		Gaseous H2	Liquid H2	Note:
NG-Based SMR H2 Plants		1	1	1 -- Without CO2 sequestration 2 -- With CO2 sequestration
Coal-Based H2 Plants		2	2	
Biomass-Based H2 Plants		1	1	
Pet Coke-to-H2 Plant		1		
ATR H2 Plants		2	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	Note:
		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



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276 **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)

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280 **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%

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285 **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

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289 **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)

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298 **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

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302 **6.15) Integrated Fermentation Plant Type**

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

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Overview Inputs Results Petroleum Co-processing NG MeOH ETD EtOH Electric Generation mixes Bio



SMR (w/o CCS)

Model a 2022 Fuel-Cell Vehicle (FCV) Sport Utility Vehicle (SUV) Fueled by Gaseous Hydrogen Produced from Steam Methane Reforming (SMR) without Carbon Capture and Sequestration (CCS)



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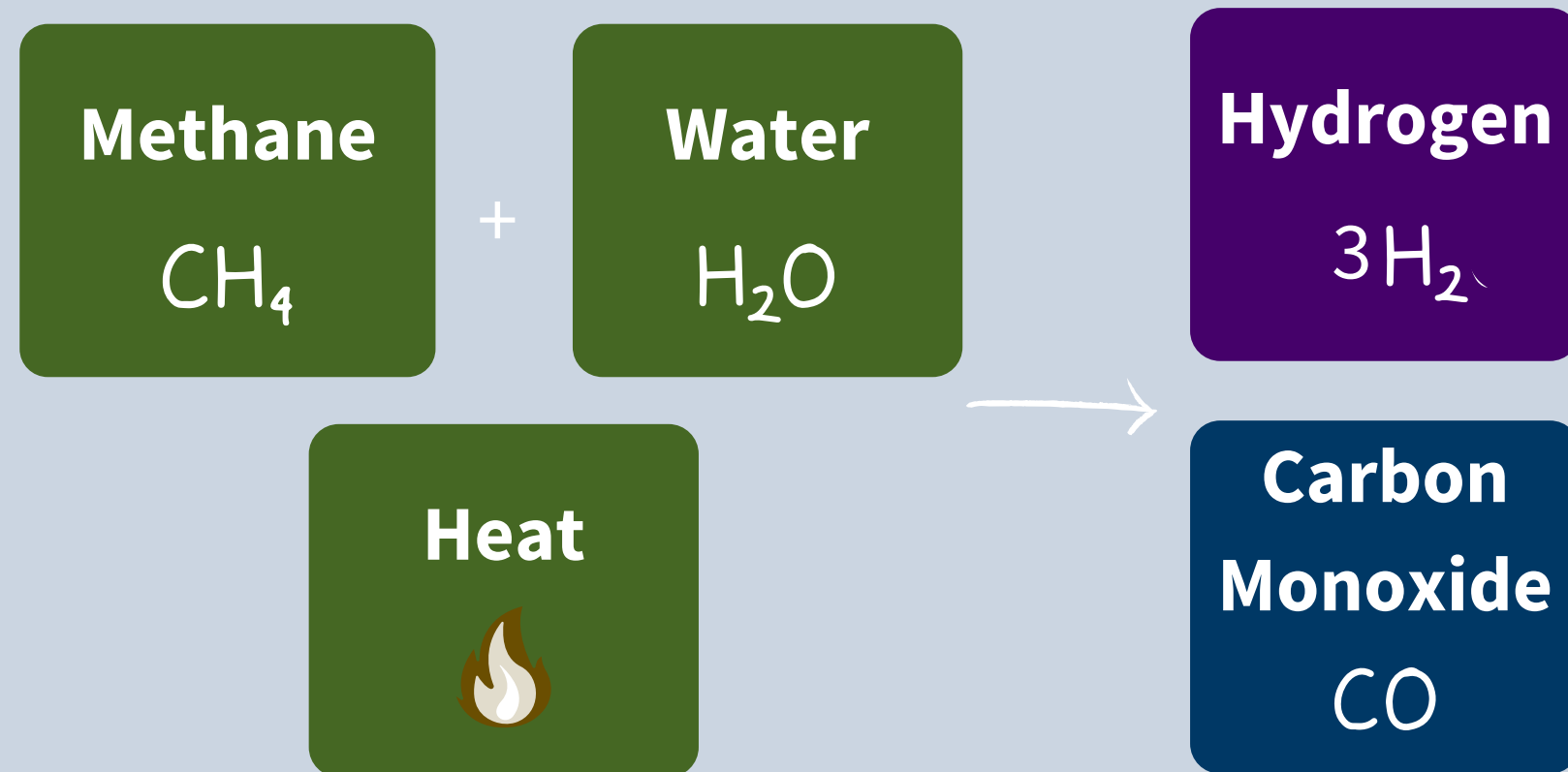
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Natural gas reforming

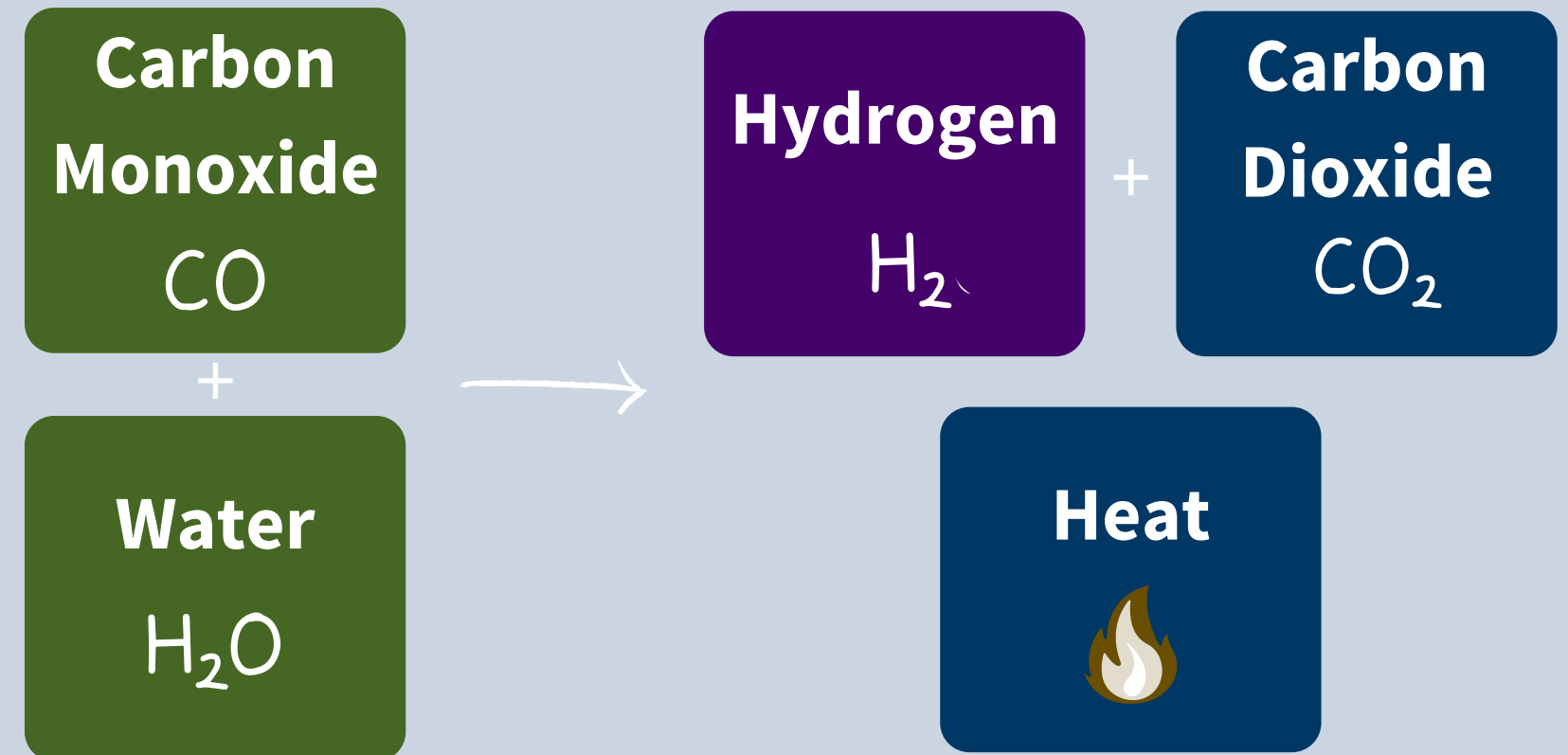
Step 1

Apply high-temperature steam to natural gas (which contains methane) in the presence of a catalyst



Step 2

The carbon monoxide and the steam react over a catalyst in a water-gas shift reactor to produce more hydrogen



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206 **6. Hydrogen Production**

207 **6.1) Basis of H2 Production Assumptions from Different Technology Pathways**

208 Hydrogen Worksheet 1 -- GREET Default, 2 -- User defined

209 6.1.a) Scenarios for H2A Model Cases

210 2 1 -- Current, 2 -- Future

211 Results

212 **6.2) Share of H2 Production by Location**

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

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217 **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%
Byproduct 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%	0.0%
NG Autothermal Reforming	0.0%	0.0%
RNG Autothermal Reforming	0.0%	0.0%
Methane Pyrolysis (Using NG)	0.0%	0.0%
Methane Pyrolysis (Using RNG)	0.0%	0.0%

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Overview Inputs Results Petroleum Co processing NG MeOH FTD EtOH Electric Generation mixes Bio



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1 2 A B C D E F G H I

246 **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

251 **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

258 **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			

265 **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			

272 **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



Fuel Cycle GHG Emissions



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Formula Bar: `= "FCV: G.H2"&IF(Inputs!F214=1, "Central Plants, "&IF(Inputs!F219=1, IF(Inputs!F248=1, "NA NG", IF(Inputs!F248=2, "Non-NA NG", IF(Inputs!F248=3, "FG", IF(RNG!E6=1, "LFG", IF(RNG!E7=1, "Manure-based AD Gas", IF(RNG!E8=1, "WWTP-based AD Gas", "RNG"))))))), "")&IF(Inputs!F220=1, "Solar", "")&IF(Inputs!F222=1, "Nuclear", "")&IF(Inputs!F223=1,`

WTW Results Menu
 Select a vehicle type from a pink drop down menu, then press "Go"
 SI ICE Vehicles (Go)
 SIDI ICE Vehicles (Go)
 CIDI ICE Vehicles (Go)
 SI Hybrid Vehicles (HEV) (Go)
 CIDI Hybrid Vehicles (HEV) (Go)
 BEV and FCV (Go)
 FCV - Gaseous H2 (Go)
 SI Plug-in Hybrids (PHEV) (Go)
 CIDI Plug-in Hybrids (PHEV) (Go)
 GCI ICE Vehicles (Go)
 Performance-enhancing Fuels (Select Fuels)

Unit Selection
 Select units from a pink drop down menu for the Results
 Per Vehicle Distance Travelled: Energy Unit: Btu, Emission Unit: g, Service Functional Unit: mile
 Per Energy in Fuels: Energy Unit: Btu, Emission Unit: g, Energy Functional Unit: MJ

Results Summary:
 FCV: G.H2, Central Plants, NA NG

Item	Btu/mile or Gallon/mile or g/mile			Btu/MJ or Gallon/MJ or g/MJ			
	Feedstock	Fuel	Vehicle Operation	Feedstock	Fuel	Vehicle Operation	Total
Total Energy	281		3,860	102	354	948	1,404
Fossil Fuels	279		3,746	102	313	948	1,362
Coal			164	1	59	0	60
Natural Gas			3,494	100	223	948	1,271
Petroleum			87	0	31	0	32
Water Consumption			0	0	0	0	0
CO2 (w/ C in VOC & CH4)			231	6	78	0	84
CH4		0.16	0.690	0.192	0.059	0.000	0.251
N2O	0.004	0.002	0.005	0.001	0.001	0.000	0.002
GHGs	34	220	253	12	80	0	92
VOC: Total	0.028	0.013	0.041	0.010	0.005	0.000	0.015
CO: Total				0.032	0.012	0.000	0.044
NOx: Total				0.038	0.015	0.000	0.053
PM10: Total				0.000	0.003	0.011	0.015
PM2.5: Total				0.000	0.002	0.002	0.004

Annotations:
 1: SI Hybrid Vehicles (HEV) - CIDI Hybrid Vehicles (HEV)
 2: Per Energy in Fuels - Emission Unit: g
 3: Performance-enhancing Fuels - Select Fuels
 Press F9
 FCV SUV built and used in 2022 and fueled by NG SMR gaseous hydrogen
 Feedstock GHG emissions
 Vehicle operation GHG emissions
 Fuel GHG emissions
 Total WTW GHG emissions

Solar-Powered Hydrogen

Model a 2022 Fuel Cell Vehicle (FCV) Sport Utility Vehicle (SUV) Fueled by Gaseous Hydrogen Produced from Solar-Powered PEM Electrolysis



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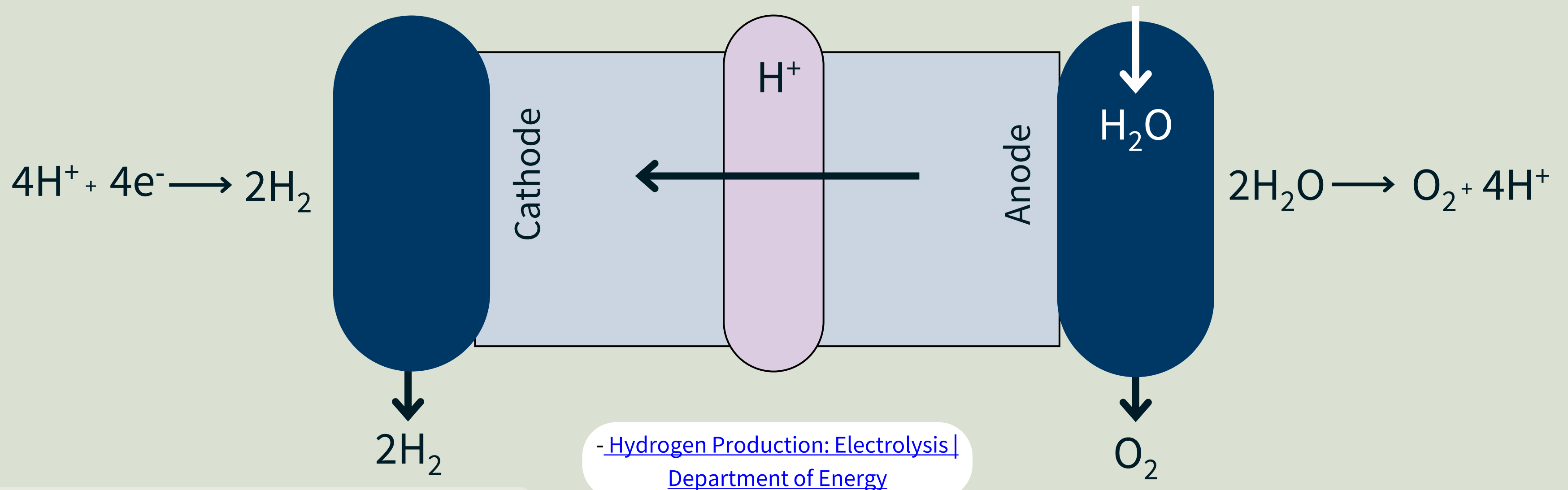
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Electrolysis

Electrolysis: splitting water in an electrolyzer

Electrolyzers have a cathode and an anode separated by an electrolyte



R&D GREET 1

Trace Precedents



Use trace precedence to adjust the hydrogen feedstock

6. Hydrogen Production

6.1) Basis of H2 Production Assumptions from Different Technology Pathways

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

6.2) Share of H2 Production by Location

	Gaseous H2
Central Plants	100.0%
Refueling Stations	0.0%

6.3) Share of H2 Feedstock Sources in Central Plants

	Gaseous H2	Liquid H2
NG	0.0%	100.0%
PEM Electrolysis	100.0%	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%
Byproduct 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%	0.0%
NG Autothermal Reforming	0.0%	0.0%
RNG Autothermal Reforming	0.0%	0.0%
Methane Pyrolysis (Using NG)	0.0%	0.0%

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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



Fuel Cycle GHG Emissions



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R&D GREET 1

Logical Lookup & Reference Math & Trig Python

Text Date & Time More Functions

Reset Diagnostics Initialization

Name Manager Define Name Use in Formula Create from Selection

Trace Precedents Trace Dependents Remove Arrows

Watch Window Calculation Options

```
= "FCV: G.H2"&IF(Inputs!F214=1," Central Plants, "&IF(Inputs!F219=1,IF(Inputs!F248=1,"NA NG",IF(Inputs!F248=2,"Non-NA NG",IF(Inputs!F248=3,"FG",IF(RNG!E6=1,"LFG",IF(RNG!E7=1,"Manure-based AD Gas",IF(RNG!E8=1,"WWTP-based AD Gas","RNG"))))))),""&IF(Inputs!F220=1,"Solar","")&IF(Inputs!F222=1,"Nuclear","")&IF(Inputs!F223=1,
```

WTW Results Menu Select a vehicle type from a pink drop down menu, then press "Go"

SI ICE Vehicles Select Fuels Go

SIDI ICE Vehicles Select Fuels Go

CIDI ICE Vehicles Select Fuels Go

SI Hybrid Vehicles (HEV) Select Fuels Go

CIDI Hybrid Vehicles (HEV) Select Fuels Go

BEV and FCV Select Fuels Go

FCV - Gaseous H2

SI Plug-in Hybrids (PHEV) Select Fuels Go

CIDI Plug-in Hybrids (PHEV) N/A Go

GCI ICE Vehicles Select Fuels Go

Performance-enhancing Fuels Select Fuels

Unit Selection Select units from a pink drop down menu for the Results

Per Vehicle Distance Travelled Energy Unit: Btu Emission Unit: g Service Functional Unit: mile

Per Energy in Fuels Energy Unit: Btu Emission Unit: g Energy Functional Unit: MJ

2113 FCV: G.H2, Central Plants, Solar

Item	Btu/mile or Gallon/mile or g/mile			Btu/MJ or Gallon/MJ or g/MJ			
	Feedstock	Fuel	Vehicle	Feedstock	Fuel	Operation	Total
Total Energy	1,955	58	5,150	711	214	948	1,873
Fossil Fuels	0		481	0	175	0	175
Coal			155	0	56	0	56
Natural Gas			240	0	87	0	87
Petroleum			86	0	31	0	31
Water Consumption			0	0	0	0	0
CO2 (w/ C in VOC & CH4)			37	0	13	0	13
CH4		0.071	0.071	0.000	0.026	0.000	0.026
N2O	0.000	0.001	0.001	0.000	0.000	0.000	0.000
GHGs	0	39	39	0	14	0	14
VOC: Total	0.000	0.005	0.005	0.000	0.002	0.000	0.002
CO: Total	0.000	0.000	0.000	0.000	0.010	0.000	0.010
NOx: Total	0.000	0.000	0.000	0.000	0.012	0.000	0.012
PM10: Total	0.000	0.000	0.000	0.000	0.001	0.011	0.013
PM2.5: Total	0.000	0.000	0.000	0.000	0.001	0.002	0.002

Feedstock GHG emissions

Vehicle operation GHG emissions

Fuel GHG emissions

Total WTW GHG emissions

Press F9

FCV SUV built and used in 2022 and fueled by solar PEM gaseous hydrogen

FCV SUV fueled by gaseous hydrogen made from NG SMR

FCV SUV fueled by gaseous hydrogen made from solar PEM

RNAVFCVGH2 = "FCV: G.H2"&IF(Inputs!F214=1,"", Central P...
 =2,"Non-NA NG",IF(Inputs!F248=3,"FG",IF(RNG...
 based AD Gas","RNG")))))),"")&IF(Inputs!F2...

WTW Results Menu Select a vehicle type from a pink drop down menu, then press "Go"

- SI ICE Vehicles Select Fuels Go
- SIDI ICE Vehicles Select Fuels Go
- CIDI ICE Vehicles Select Fuels Go
- SI Hybrid Vehicles (HEV) Select Fuels Go
- CIDI Hybrid Vehicles (HEV) Select Fuels Go
- BEV and FCV Select Fuels Go
- FCV - Gaseous H2 Select Fuels Go

Unit Selection Select units from a pink drop down menu for the Results

Per Vehicle Distance Travelled Energy Unit: Btu Emission Unit: g Service Functional Unit: mile

Per Energy in Fuels Energy Unit: Btu Energy Fun...

2113 FCV: G.H2, Central Plants, NA NG

Item	Feedstock	Btu/mile or Gallon/mile or g/MJ		Btu/MJ or Gallon/MJ or g/MJ		Vehicle	
						Fuel	Operation
2116 Total Energy	281					354	948
2117 Fossil Fuels	279					313	948
2118 Coal	2					59	0
2119 Natural Gas	276					223	948
2120 Petroleum	1					31	0
2121 Water Consumption	0.0					0	0
2122 CO2 (w/ C in VOC & CO)	17	214				78	0
2123 CH4	0.528	0.162	0.000	0.690	0.192	0.059	0.000
2124 N2O	0.004	0.002	0.000	0.005	0.001	0.001	0.000
2125 GHGs	34	220	0	253	12	80	0
2126 VOC: Total	0.028	0.013	0.000	0.047	0.010	0.005	0.000
2127 CO: Total	0.088	0.034	0.000	0.121	0.032	0.012	0.000
2128 NOx: Total	0.103	0.042	0.000	0.145	0.038	0.015	0.000
2129 PM10: Total	0.001	0.008	0.031	0.041	0.000	0.003	0.011
2130 PM2.5: Total	0.001	0.006	0.004	0.011	0.000	0.002	0.002

Ready Calculate Accessibility: Investigate

WTW GHG emissions
253 g CO₂e/mile

RNAVFCVGH2 = "FCV: G.H2"&IF(Inputs!F214=1,"", Central P...
 =2,"Non-NA NG",IF(Inputs!F248=3,"FG",IF(RNG...
 based AD Gas","RNG")))))),"")&IF(Inputs!F22...

WTW Results Menu Select a vehicle type from a pink drop down menu, then press "Go"

- SI ICE Vehicles Select Fuels Go
- SIDI ICE Vehicles Select Fuels Go
- CIDI ICE Vehicles Select Fuels Go
- SI Hybrid Vehicles (HEV) Select Fuels Go
- CIDI Hybrid Vehicles (HEV) Select Fuels Go
- BEV and FCV Select Fuels Go
- FCV - Gaseous H2 Select Fuels Go

Unit Selection Select units from a pink drop down menu for the Results

Per Vehicle Distance Travelled Energy Unit: Btu Emission Unit: g Service Functional Unit: mile

Per Energy in Fuels Energy Unit: Btu Energy Fun...

2113 FCV: G.H2, Central Plants, Solar

Item	Feedstock	Btu/mile or Gallon/mile or g/MJ		Btu/MJ or Gallon/MJ or g/MJ		Vehicle	
						Fuel	Operation
2116 Total Energy	1,955					214	948
2117 Fossil Fuels	0					175	0
2118 Coal	0					56	0
2119 Natural Gas	0					87	0
2120 Petroleum	0					31	0
2121 Water Consumption	0.2					0	0
2122 CO2 (w/ C in VOC & CO)	0	37				13	0
2123 CH4	0.000	0.071	0.000	0.071	0.000	0.026	0.000
2124 N2O	0.000	0.001	0.000	0.001	0.000	0.000	0.000
2125 GHGs	0	39	0	39	0	14	0
2126 VOC: Total	0.000	0.005	0.000	0.005	0.000	0.002	0.000
2127 CO: Total	0.000	0.028	0.000	0.028	0.000	0.010	0.000
2128 NOx: Total	0.000	0.033	0.000	0.033	0.000	0.012	0.000
2129 PM10: Total	0.000	0.004	0.031	0.035	0.000	0.001	0.011
2130 PM2.5: Total	0.000	0.002	0.004	0.006	0.000	0.001	0.002

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WTW GHG emissions
39 g CO₂e/mile



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Fossil fuel hydrogen compared to renewable hydrogen

As expected, the hydrogen made from renewable energy produced less total fuel cycle GHG emissions

Solar-powered Hydrogen Produces Fuel Emissions

1. Transportation of hydrogen at plant gate to the hydrogen fuel pump
2. Compression of hydrogen
3. Loading hydrogen into the tube trailer

NG-SMR-produced hydrogen produces feedstock and fuel emissions



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Solar Infrastructure

Model a 2022 Fuel-Cell Vehicle (FCV) Sport Utility Vehicle (SUV) Fueled by Gaseous Hydrogen Produced from Solar-Powered PEM Electrolysis Including the Embodied Emissions of the Solar Infrastructure and Storage



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R&D GREET 1

Logical Lookup & Reference Math & Trig Diagnostics Initialization Python

Trace Precedents Trace Dependents Remove Arrows

K216

6. Hydrogen Production

6.1) Basis of H2 Production Assumptions from Different Technology Pathways

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	0.0%	100.0%
PEM Electrolysis	100.0%	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%
Byproduct 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%	0.0%
NG Autothermal Reforming	0.0%	0.0%
RNG Autothermal Reforming	0.0%	0.0%
Methane Pyrolysis (Using NG)	0.0%	0.0%

Inputs Results Petroleum Co_processing NG MeOH_FTD EtOH Electric Generation_mixes Bio_electricity

Use trace precedence to adjust the hydrogen feedstock

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R&D GREET 1

Clipboard Font Alignment Number Styles Cells Editing Sensitivity Add-ins Analyze Data

Y220

6.5) NG Feedstock Options for H2 Production via SMR				
	Gaseous H2	Liquid H2	Note:	
Central Plants	1	1	1 -- North American NG, 4 -- Renewable Natural Gas	
Distributed Production at Refueling Stations	1	1		

6.6) CO2 Sequestration Options for Central Plant H2 Production				
	Gaseous H2	Liquid H2	Note:	
NG-Based SMR H2 Plants	1	1	1 -- Without CO2 sequestration	
Coal-Based H2 Plants	2	2	2 -- With CO2 sequestration	
Biomass-Based H2 Plants	1	1		
Pet Coke-to-H2 Plant	1			
ATR H2 Plants	2	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)

Overview Inputs Results Petroleum Co_processing NG MeOH_FTD EtOH Electric Generation mixes Bio



Electric_Infra_Option No

	A	B	C	D	E	F	G	H	I	
808	10.4) Share of Feedstock for Biomass Power Plants					Willow	Poplar	Switchgrass	Miscanthus	Forest Residue
809						0.0%	0.0%	0.0%	0.0%	100.0%
811	10.5) Share of Geothermal Technologies and Fugitive CO2 emissions from geofluid					Hydrothermal-Flash	Hydrothermal-Binary	Geothermal-EGS		
812	Shares of Geothermal Technologies					100.0%	0.0%	0.0%		
813	Fugitive CO2 emissions from geofluid (g CO2/kWh)					91	0	0		
816	10.6) Energy Use of Power Plant Construction Materials									
817	No					Do you consider energy and emissions for infrastructure of power plants?				
818	Yes					Do you include battery storage for solar PV system?				
819	10.7) The Types					NG-based, Coal-based, and Biomass-based Fuel Plants for Export to Grid				
820	10.7.a) NG-Based Fuel Plants (Including NG to MeOH, FT Diesel, FT Naptha, and H2)									
821	1					1-- Electricity generation mix (Could be U.S. mix, NE U.S. mix, CA mix, or user defined mix, which is diefined for stationary use in sec				
822						2-- NGCC electricity				
823						3-- Coal IGCC electricity				
824						4-- Biomass IGCC electricity				
825	10.7.b) Biomass-Based Fuel Plants (Including Biomass to EtOH, MeOH, DME, FT Diesel, and H2)									
826	1					1-- Electricity generation mix (Could be U.S. mix, NE U.S. mix, CA mix, or user defined mix, which is diefined for stationary use in sec				
827						2-- NGCC electricity				
828						3-- Biomass IGCC electricity				
829	10.7.c) Coal-Based Fuel Plants (Including Coal to H2, and MeOH, DME, and FT Diesel)									
830	1					1-- Electricity generation mix (Could be U.S. mix, NE U.S. mix, CA mix, or user defined mix, which is diefined for stationary use in sec				
831						2-- NGCC electricity				
832						3-- Coal IGCC electricity				
833	10.7.d) Pet Coke-Based Fuel Plants (Including Pet Coke to H2)									
834	1					1-- Electricity generation mix (Could be U.S. mix, NE U.S. mix, CA mix, or user defined mix, which is diefined for stationary use in sec				
835						2-- NGCC electricity				
836						3-- Coal IGCC electricity				

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Comments Share

R&D GREET 1

Logical Lookup & Reference Text Math & Trig Python

Insert Python

Reset Diagnostics Initialization

Name Manager

Define Name Use in Formula Create from Selection

Trace Precedents Trace Dependents Remove Arrows

Formula Auditing

Watch Window

Calculation Options

Calculation

E818 No

808				Willow	Poplar	Switchgrass	Miscanthus	Forest Residue
809				0.0%	0.0%	0.0%	0.0%	100.0%

10.5) Share of Geothermal Technologies and Fugitive CO2 emissions from geofluid

	Hydrothermal-Flash	Hydrothermal-Binary	Geothermal-EGS
Shares of Geothermal Technologies	100.0%	0.0%	0.0%
Fugitive CO2 emissions from geofluid (g CO2/kWh)	91	0	0

10.6) Energy Use of Power Plant Construction Materials

Yes No

To consider energy and emissions for infrastructure of power plants?
 To include battery storage for solar PV system?

10.7) The Types of Fuel-based, Coal-based, and Biomass-based Fuel Plants for Export to Grid

10.7.a) NG-Based Fuel Plants (Including Biomethane, and H2)

Yes No

1-- Electricity generation mix (Could be U.S. mix, NE U.S. mix, CA mix, or user defined mix, which is defined for stationary use in section 10.7.a)
 2-- NGCC electricity
 3-- Coal IGCC electricity
 4-- Biomass IGCC electricity

10.7.b) Biomass-Based Fuel Plants (Including Biomass to EtOH, MeOH, DME, FT Diesel, and H2)

1

1-- Electricity generation mix (Could be U.S. mix, NE U.S. mix, CA mix, or user defined mix, which is defined for stationary use in section 10.7.a)
 2-- NGCC electricity
 3-- Biomass IGCC electricity

10.7.c) Coal-Based Fuel Plants (Including Coal to H2, and MeOH, DME, and FT Diesel)

1

1-- Electricity generation mix (Could be U.S. mix, NE U.S. mix, CA mix, or user defined mix, which is defined for stationary use in section 10.7.a)
 2-- NGCC electricity
 3-- Coal IGCC electricity

10.7.d) Pet Coke-Based Fuel Plants (Including Pet Coke to H2)

1

1-- Electricity generation mix (Could be U.S. mix, NE U.S. mix, CA mix, or user defined mix, which is defined for stationary use in section 10.7.a)
 2-- NGCC electricity
 3-- Coal IGCC electricity

Inputs Results Petroleum Co_processing NG MeOH_FTD EtOH Electric Generation mixes Bio_electricity



Fuel Cycle GHG Emissions



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R&D GREET 1

Logical Lookup & Reference Python Diagnostics Initialization Python

Define Name Use in Formula Create from Selection

Trace Precedents Trace Dependents Remove Arrows

Watch Window Calculation Options

```
RNAVFCVGH2 = "FCV: G.H2"&IF(Inputs!F214=1,"", Central Plants, "&IF(Inputs!F219=1,IF(Inputs!F248=1,"NA NG",IF(Inputs!F248=2,"Non-NA NG",IF(Inputs!F248=3,"FG",IF(RNG!E6=1,"LFG",IF(RNG!E7=1,"Manure-based AD Gas",IF(RNG!E8=1,"WWTP-based AD Gas","RNG"))))))),""&IF(Inputs!F220=1,"Solar","")&IF(Inputs!F222=1,"Nuclear","")&IF(Inputs!F223=1,
```

Home Inputs Back to Top WTP Results WTW Changes

WTW Results Menu Select a vehicle type from a pink drop down menu, then press "Go"

SI ICE Vehicles Select Fuels Go

SIDI ICE Vehicles Select Fuels Go

CIDI ICE Vehicles Select Fuels Go

SI Hybrid Vehicles (HEV) Select Fuels Go

CIDI Hybrid Vehicles (HEV) Select Fuels Go

BEV and FCV Select Fuels Go

FCV - Gaseous H2

SI Plug-in Hybrids (PHEV) Select Fuels Go

CIDI Plug-in Hybrids (PHEV) Select Fuels Go

N/A

GCI ICE Vehicles Select Fuels Go

Performance-enhancing Fuels Select Fuels

Unit Selection Select units from a pink drop down menu for the Results

Per Vehicle Distance Travelled Energy Unit: Btu Emission Unit: g Service Functional Unit: mile

Per Energy in Fuels Energy Unit: Btu Emission Unit: g Energy Functional Unit: MJ

FCV: G.H2, Central Plants, Solar

Item	Btu/mile or Gallon/mile or g/mile			Btu/MJ or Gallon/MJ or g/MJ		
	Feedstock	Fuel	Vehicle	Feedstock	Fuel	Vehicle
Total Energy	2,736	56	5,934	995	216	948
Fossil Fuels	695		1,179	253	176	0
Coal			517	131	57	0
Natural Gas			531	105	88	0
Petroleum			132	17	31	0
Water Consumption			0	0	0	0
CO2 (w/ C in VOC & CH4)			95	21	13	0
CH4		0.071	0.212	0.051	0.026	0.000
N2O	0.002	0.001	0.003	0.001	0.000	0.000
GHGs	63	39	102	23	14	0
VOC: Total	0.033	0.005	0.038	0.012	0.002	0.000
CO: Total	0.000	0.000	0.000	0.080	0.011	0.000
NOx: Total	0.000	0.000	0.000	0.024	0.012	0.000
PM10: Total	0.000	0.000	0.000	0.008	0.001	0.011
PM2.5: Total	0.000	0.000	0.000	0.004	0.001	0.002

Feedstock GHG emissions

Vehicle operation GHG emissions

Fuel GHG emissions

Total WTW GHG emissions

Press F9

FCV SUV built and used in 2022 and fueled by solar PEM gaseous hydrogen including infrastructure

Wind Infrastructure

Model a 2022 Fuel-Cell Vehicle (FCV) Sport Utility Vehicle (SUV) Fueled by Gaseous Hydrogen Produced from Wind-Powered PEM Electrolysis Including the Embodied Emissions of the Wind Turbine Infrastructure



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R&D GREET 1

Insert Function Recently Used Financial Date & Time More Functions

Logical Lookup & Reference Math & Trig More Functions

Reset Diagnostics Initialization Python

Name Manager Define Name Use in Formula Create from Selection Defined Names

Trace Precedents Trace Dependents Remove Arrows

Watch Window Calculation Options

K216

1 2 A B C D E F G

6. Hydrogen Production

206 **6.1) Basis of H2 Production Assumptions from Different Technology Pathways**

207 Hydrogen Worksheet

208 1 -- GREET Default, 2 -- User defined

209 6.1.a) Scenarios for H2A Model Cases

210 2 1 -- Current, 2 -- Future

211 Results

212 **6.2) Share of H2 Production by Location**

213

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

214 Back to Top

215

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217 **6.3) Share of H2 Feedstock Sources in Central Plants**

	Gaseous H2	Liquid H2
NG	0.0%	100.0%
PEM Electrolysis	100.0%	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%
Byproduct 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%	0.0%
NG Autothermal Reforming	0.0%	0.0%
RNG Autothermal Reforming	0.0%	0.0%
Methane Pyrolysis (Using NG)	0.0%	0.0%

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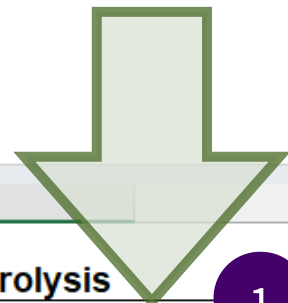
Inputs Results Petroleum Co_processing NG MeOH_FTD EtOH Electric Generation_mixes Bio_electricity

Use trace precedence to adjust the hydrogen feedstock

R&D GREET 1

Function Library: AutoSum, Logical, Text, Date & Time, More Functions, Financial, Math & Trig, Lookup & Reference, Python, Diagnostics, Initialization, Python, Name Manager, Define Name, Use in Formula, Create from Selection, Trace Precedents, Trace Dependents, Remove Arrows, Formula Auditing, Watch Window, Calculation Options, Calculation

NG_GH2_Electrolysis_PowerPlant



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)

6.10) Electric Generation Source for Fueling Stations

Liquid H2
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, 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
Solar Energy-Based Plant	2
Nuclear Plant (HTGR water cracking)	1
Coal-Based Plant	2
Biomass-Based Plant	2
COG-Based Plant	2

1 -- NGCC; 2 -- Mix for stationary use (see 10.2.a)
 1 -- Solar; 2 -- Mix for stationary use (see 10.2.a)
 1 -- Nuclear; 2 -- Mix for stationary use (see 10.2.a)
 1 -- Coal IGCC; 2 -- Mix for stationary use (see 10.2.a)
 1 -- Biomass IGCC; 2 -- Mix for stationary use (see 10.2.a)
 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

Navigation: Inputs, Results, Petroleum, Co_processing, NG, MeOH_FTD, EtOH, Electric, Generation_mixes, Bio_electricity

Electric_Infra_Option No

808	10.4) Share of Feedstock for Biomass Power Plants				
809	Willow	Poplar	Switchgrass	Miscanthus	Forest Residue
810	0.0%	0.0%	0.0%	0.0%	100.0%
811	10.5) Share of Geothermal Technologies and Fugitive CO2 emissions from geofluid				
812		Hydrothermal-Flash	Hydrothermal-Binary	Geothermal-EGS	
813	Shares of Geothermal Technologies	100.0%	0.0%	0.0%	
814	Fugitive CO2 emissions from geofluid (g CO2/kWh)	91	0	0	
816	10.6) Energy Use of Power Plant Construction Materials				
817	No <input type="checkbox"/> To consider energy and emissions for infrastructure of power plants?				
818	Yes <input type="checkbox"/> To include battery storage for solar PV system?				
819	10.7) The Types of NG-based, Coal-based, and Biomass-based Fuel Plants for Export to Grid				
820	10.7.a) NG-Based Fuel Plants (Including NG to MeOH, FT Diesel, FT Naptha, and H2)				
821	1	1-- Electricity generation mix (Could be U.S. mix, NE U.S. mix, CA mix, or user defined mix, which is diefined for stationary use in sec			
822		2-- NGCC electricity			
823		3-- Coal IGCC electricity			
824		4-- Biomass IGCC electricity			
825	10.7.b) Biomass-Based Fuel Plants (Including Biomass to EtOH, MeOH, DME, FT Diesel, and H2)				
826	1	1-- Electricity generation mix (Could be U.S. mix, NE U.S. mix, CA mix, or user defined mix, which is diefined for stationary use in sec			
827		2-- NGCC electricity			
828		3-- Biomass IGCC electricity			
829	10.7.c) Coal-Based Fuel Plants (Including Coal to H2, and MeOH, DME, and FT Diesel)				
830	1	1-- Electricity generation mix (Could be U.S. mix, NE U.S. mix, CA mix, or user defined mix, which is diefined for stationary use in sec			
831		2-- NGCC electricity			
832		3-- Coal IGCC electricity			
833	10.7.d) Pet Coke-Based Fuel Plants (Including Pet Coke to H2)				
834	1	1-- Electricity generation mix (Could be U.S. mix, NE U.S. mix, CA mix, or user defined mix, which is diefined for stationary use in sec			
835		2-- NGCC electricity			
836		3-- Coal IGCC electricity			

Fuel Cycle GHG Emissions



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R&D GREET 1

Logical Lookup & Reference Python Reset Diagnostics Name Manager Define Name Use in Formula Create from Selection

Text Math & Trig Initialization Python

Trace Precedents Trace Dependents Remove Arrows Watch Window Calculation Options

RNAVFCVGH2

```
= "FCV: G.H2" & IF(Inputs!F214=1, "", Central Plants, "&IF(Inputs!F219=1, IF(Inputs!F248=1, "NA NG", IF(Inputs!F248=2, "Non-NA NG", IF(Inputs!F248=3, "FG", IF(RNG!E6=1, "LFG", IF(RNG!E7=1, "Manure-based AD Gas", IF(RNG!E8=1, "WWTP-based AD Gas", "RNG"))))))), "") & IF(Inputs!F220=1, "Solar", "") & IF(Inputs!F222=1, "Nuclear", "") & IF(Inputs!F223=1,
```

WTW Results Menu Select a vehicle type from a pink drop down menu, then press "Go"

SI ICE Vehicles Select Fuels Go

SIDI ICE Vehicles Select Fuels Go

CIDI ICE Vehicles Select Fuels Go

Unit Selection Select units from a pink drop down menu for the Results

Per Vehicle Distance Travelled Energy Unit: Btu Emission Unit: g Service Functional Unit: mile

Per Energy in Fuels Energy Unit: Btu Emission Unit: g Energy Functional Unit: MJ

SI Hybrid Vehicles (HEV) Select Fuels Go

CIDI Hybrid Vehicles (HEV) Select Fuels Go

~~BEV and FCV~~

FCV - Gaseous H2

SI Plug-in Hybrids (PHEV) Select Fuels Go

CIDI Plug-in Hybrids (PHEV) Select Fuels Go

N/A

GCI ICE Vehicles Select Fuels Go

Performance-enhancing Fuels Select Fuels

211 FCV: G.H2, Central Plants, Solar

Item	Btu/mile or Gallon/mile or g/mile			Btu/MJ or Gallon/MJ or g/MJ		
	Feedstock	Fuel	Vehicle	Feedstock	Fuel	Vehicle
Total Energy	2,119	5	5,317	771	216	948
Fossil Fuels	152		636	55	176	0
Coal			214	21	57	0
Natural Gas			286	16	88	0
Petroleum			136	18	31	0
Water Consumption			0	0	0	0
CO2 (w/ C in VOC & CH4)			49	5	13	0
CH4		0.071	0.092	0.008	0.026	0.000
N2O	0.000	0.001	0.001	0.000	0.000	0.000
GHGs	13	39	52	5	14	0
VOC: Total	0.008	0.005	0.013	0.003	0.002	0.000
CO: Total	0.000	0.000	0.000	0.018	0.011	0.000
NOx: Total	0.000	0.000	0.000	0.005	0.012	0.000
PM10: Total	0.000	0.000	0.000	0.002	0.001	0.011
PM2.5: Total	0.000	0.000	0.000	0.001	0.001	0.002

Feedstock
GHG emissions

Vehicle operation
GHG emissions

Fuel
GHG emissions

Total WTW
GHG emissions

Press F9

FCV SUV built and used in 2022 and fueled by wind PEM gaseous hydrogen including infrastructure

Gaseous hydrogen made from solar-powered PEM electrolysis

Gaseous hydrogen made from wind-powered PEM electrolysis

Excel interface showing the 'Formulas' tab and a spreadsheet with a 'WTW Results Menu' and a data table. The formula bar contains: `=FCV: G.H2"&IF(Inputs!F214=1," Central P=2,"Non-NA NG",IF(Inputs!F248=3,"FG",IF(RNG based AD Gas","RNG")))))),"")&IF(Inputs!F2`

WTW Results Menu (Left Column):

- SI ICE Vehicles (Go)
- SIDI ICE Vehicles (Go)
- CIDI ICE Vehicles (Go)

WTW Results Menu (Right Column):

- SI Hybrid Vehicles (HEV) (Go)
- CIDI Hybrid Vehicles (HEV) (Go)
- BEV and FCV (Go)
- FCV - Gaseous H2 (Go)

Unit Selection

Per Vehicle Distance Travelled: Energy Unit: Btu, Emission Unit: g, Service Functional Unit: mile

Per Energy in Fuels: Energy Unit: Btu, Emission Unit: g, Service Functional Unit: mile

Item	Feedstock	Fuel	Fuel	Vehicle Operation
2115				
2116 Total Energy	2,543	592	216	948
2117 Fossil Fuels	524	484	176	0
2118 Coal	293	156	57	0
2119 Natural Gas	203	241	88	0
2120 Petroleum	27	86	31	0
2121 Water Consumption	0.4	0.0	0	0
2122 CO2 (w/ C in VOC & CO)	45	37	13	0
2123 CH4	0.087	0.071	0.026	0.000
2124 N2O	0.001	0.001	0.000	0.000
2125 GHGs	48	39	17	14
2126 VOC: Total	0.026	0.005	0.010	0.002
2127 CO: Total	0.173	0.029	0.063	0.011
2128 NOx: Total	0.050	0.033	0.018	0.012
2129 PM10: Total	0.018	0.004	0.006	0.001
2130 PM2.5: Total	0.009	0.002	0.003	0.001

WTW GHG emissions: 87 g CO₂e/mile

Excel interface showing the 'Formulas' tab and a spreadsheet with a 'WTW Results Menu' and a data table. The formula bar contains: `=FCV: G.H2"&IF(Inputs!F214=1," Central Pla=2,"Non-NA NG",IF(Inputs!F248=3,"FG",IF(RNG based AD Gas","RNG")))))),"")&IF(Inputs!F226`

WTW Results Menu (Left Column):

- SI ICE Vehicles (Go)
- SIDI ICE Vehicles (Go)
- CIDI ICE Vehicles (Go)

WTW Results Menu (Right Column):

- SI Hybrid Vehicles (HEV) (Go)
- CIDI Hybrid Vehicles (HEV) (Go)
- BEV and FCV (Go)
- FCV - Gaseous H2 (Go)

Unit Selection

Per Vehicle Distance Travelled: Energy Unit: Btu, Emission Unit: g, Service Functional Unit: mile

Per Energy in Fuels: Energy Unit: Btu, Emission Unit: g, Service Functional Unit: mile

Item	Feedstock	Fuel	Fuel	Vehicle Operation
2115				
2116 Total Energy	2,119	592	216	948
2117 Fossil Fuels	152	484	176	0
2118 Coal	58	156	57	0
2119 Natural Gas	45	241	88	0
2120 Petroleum	49	86	31	0
2121 Water Consumption	0.1	0.0	0	0
2122 CO2 (w/ C in VOC & CO)	12	37	13	0
2123 CH4	0.021	0.071	0.026	0.000
2124 N2O	0.000	0.001	0.000	0.000
2125 GHGs	13	39	17	14
2126 VOC: Total	0.008	0.005	0.010	0.002
2127 CO: Total	0.050	0.029	0.063	0.011
2128 NOx: Total	0.014	0.033	0.018	0.012
2129 PM10: Total	0.006	0.004	0.006	0.001
2130 PM2.5: Total	0.003	0.002	0.003	0.001

WTW GHG emissions: 52 g CO₂e/mile



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Questions?

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