

HOW TO MEASURE VEHICLE EMISSIONS



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Argonne National Laboratory is a
U.S. Department of Energy laboratory
managed by UChicago Argonne, LLC.

OUTLINE OF PRESENTATION

- **Life-Cycle Analysis Introduction**

- GREET
- GHG
- Air pollutants

- **AFLEET Demo**

- Introduction
- TCO demo

Life-Cycle Analysis (LCA) Introduction



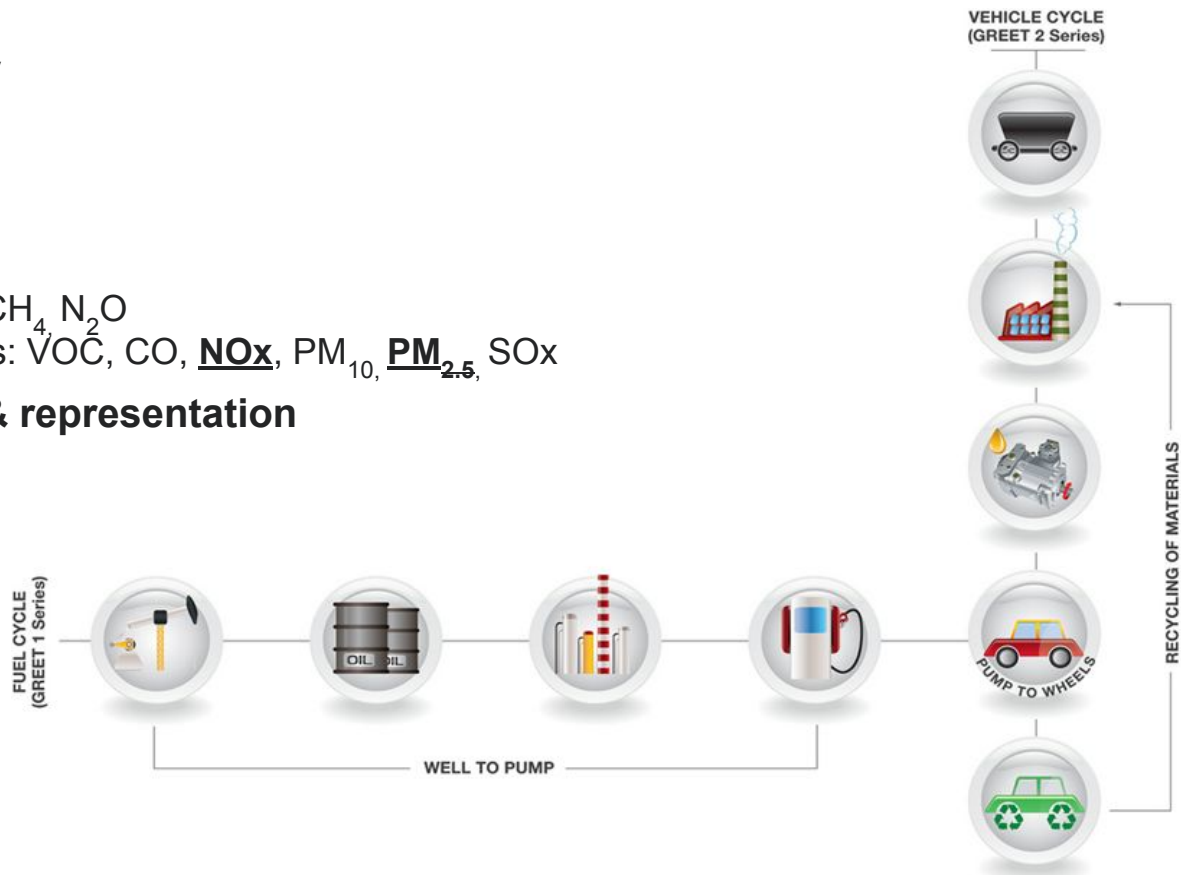
GREET LCA MODELING AT ARGONNE

- **System boundary**

- **Metrics**

- Energy
- Water use
- **Emissions**
 - **GHG**: CO₂, CH₄, N₂O
 - Air pollutants: VOC, CO, **NOx**, PM₁₀, **PM**_{2.5}, SOx

- **Data availability & representation**



See details at <https://greet.es.anl.gov>

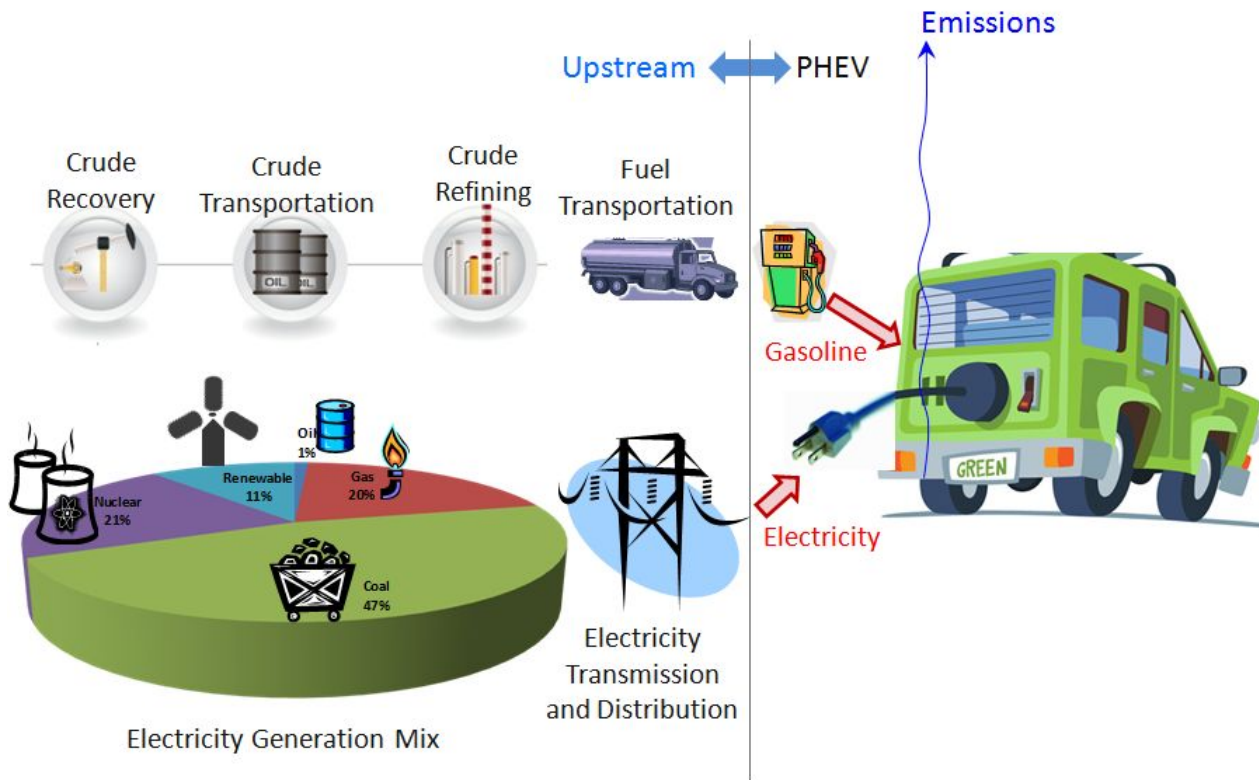
LCA FOR GHG AND AIR POLLUTANT ANALYSIS

■ GHGs

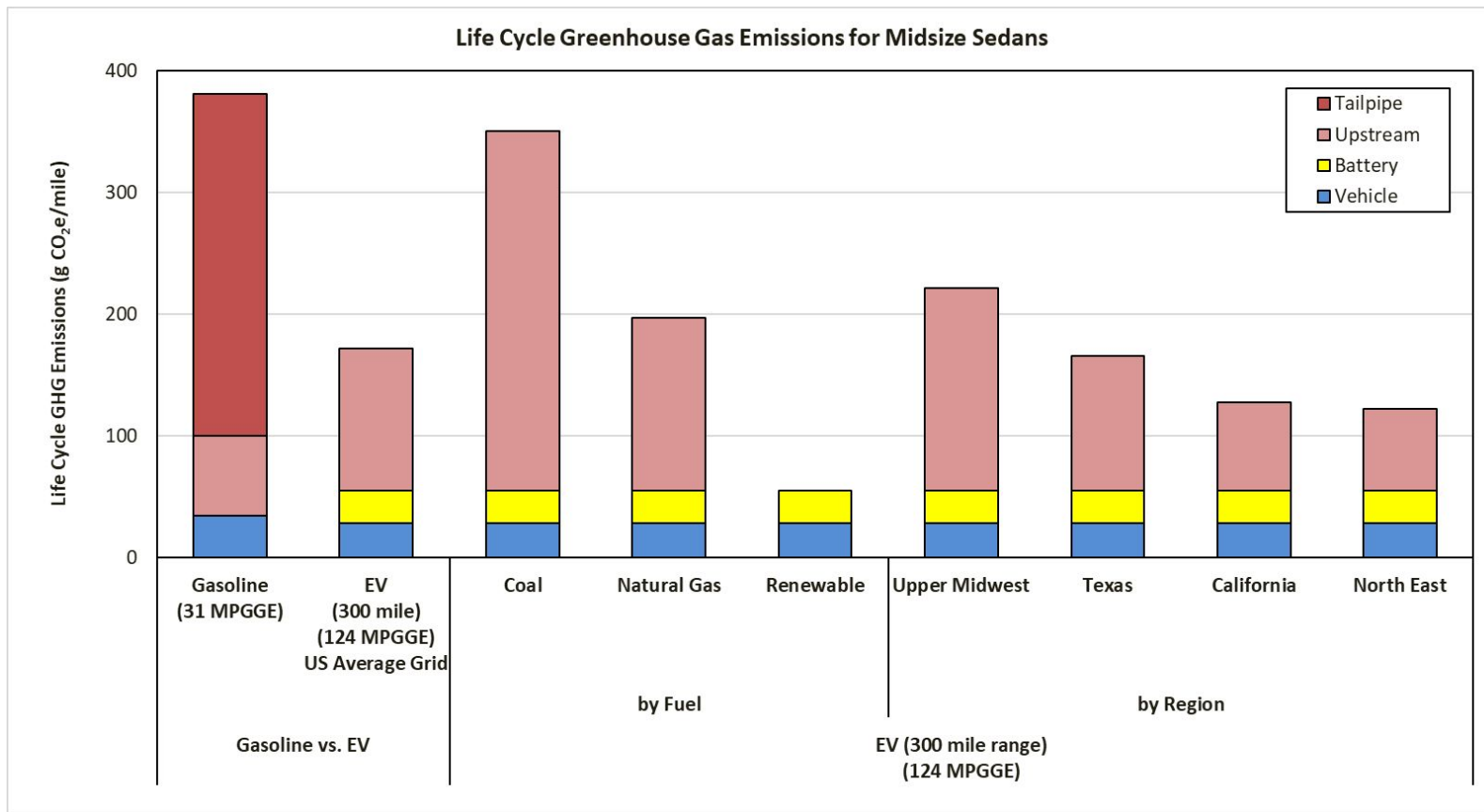
- LCA needed for proper analysis
 - Quantity matters; location doesn't

■ Air pollutants

- Vehicle operation often focus for analysis
- LCA = fuller picture when analyzing AFVs
 - Air quality/health impacts require detailed modeling
 - Quantity & location matters



GEOGRAPHIC IMPACT OF GRID MIX

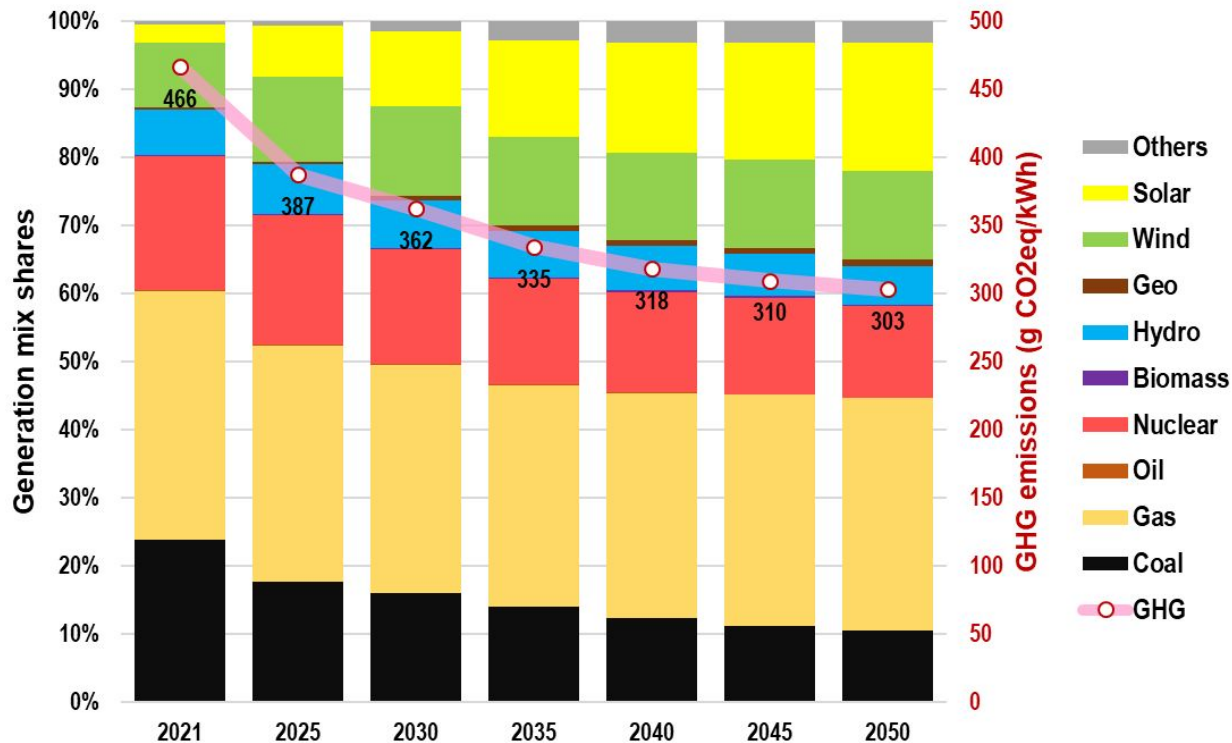


TEMPORAL IMPACT OF GRID MIX

■ U.S. 2021 vs 2050 (EIA AEO BAU projected)

- GHG intensity (g GHG/kWh at the plug)
 - 466 vs 303
- Generation mix
 - Gas 36% vs 34%
 - Coal 24% vs 11%
 - Nuclear 20% vs 19%
 - Renewable 19% vs 36%

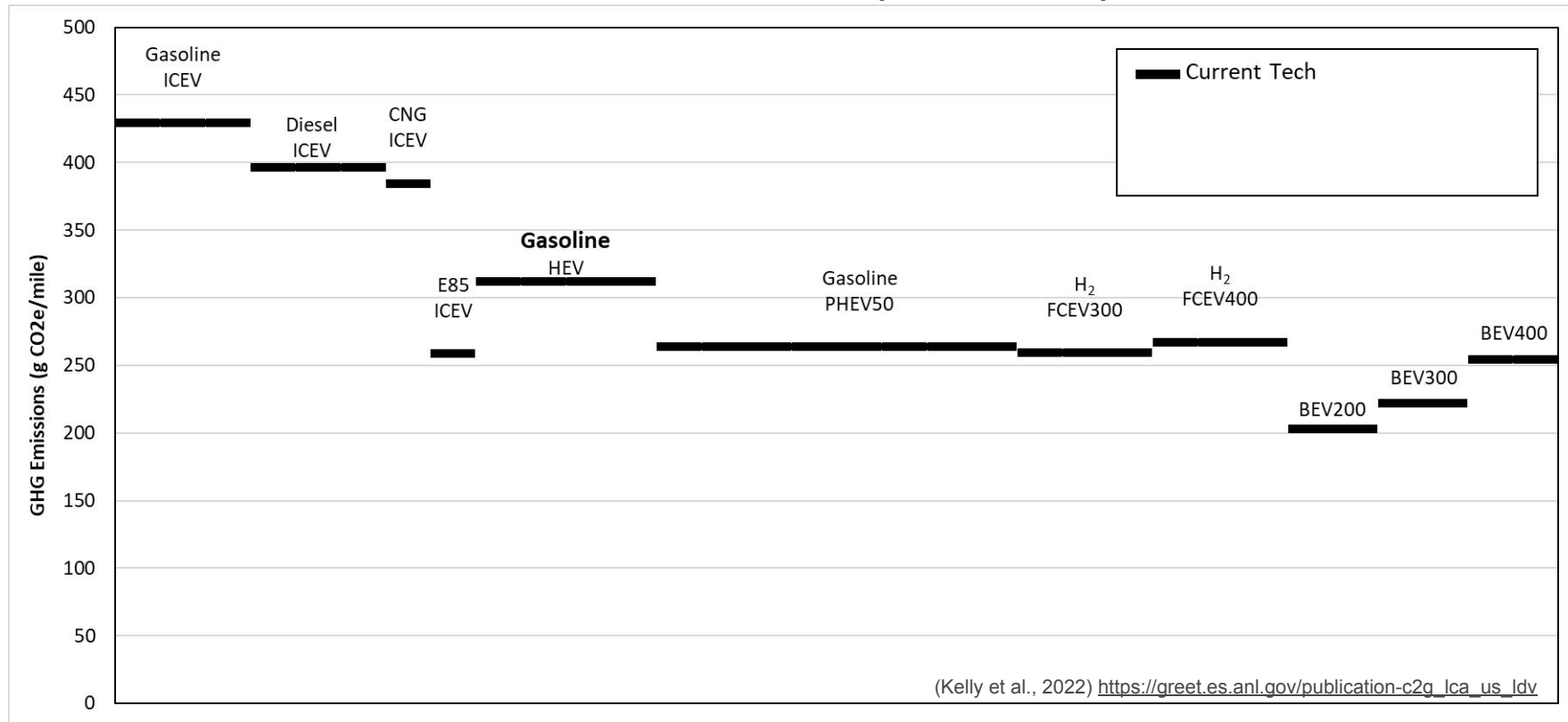
■ U.S. set goal of 100% carbon pollution-free electricity by 2035



TEMPORAL IMPACT OF VEHICLE EFFICIENCY

Current (2020)

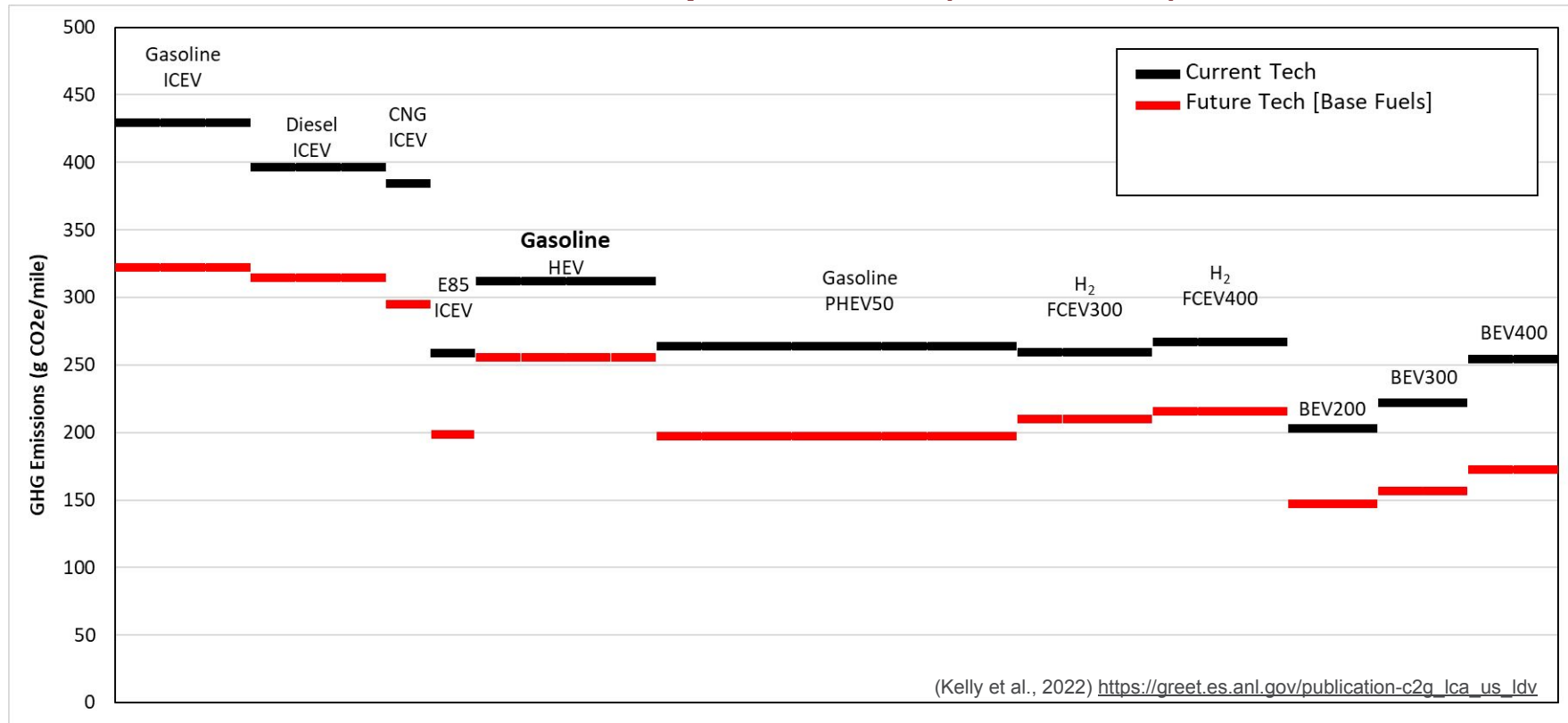
Current Conditions (Small SUV)



TEMPORAL IMPACT OF VEHICLE EFFICIENCY

Current (2020) and Future (2030-2035)

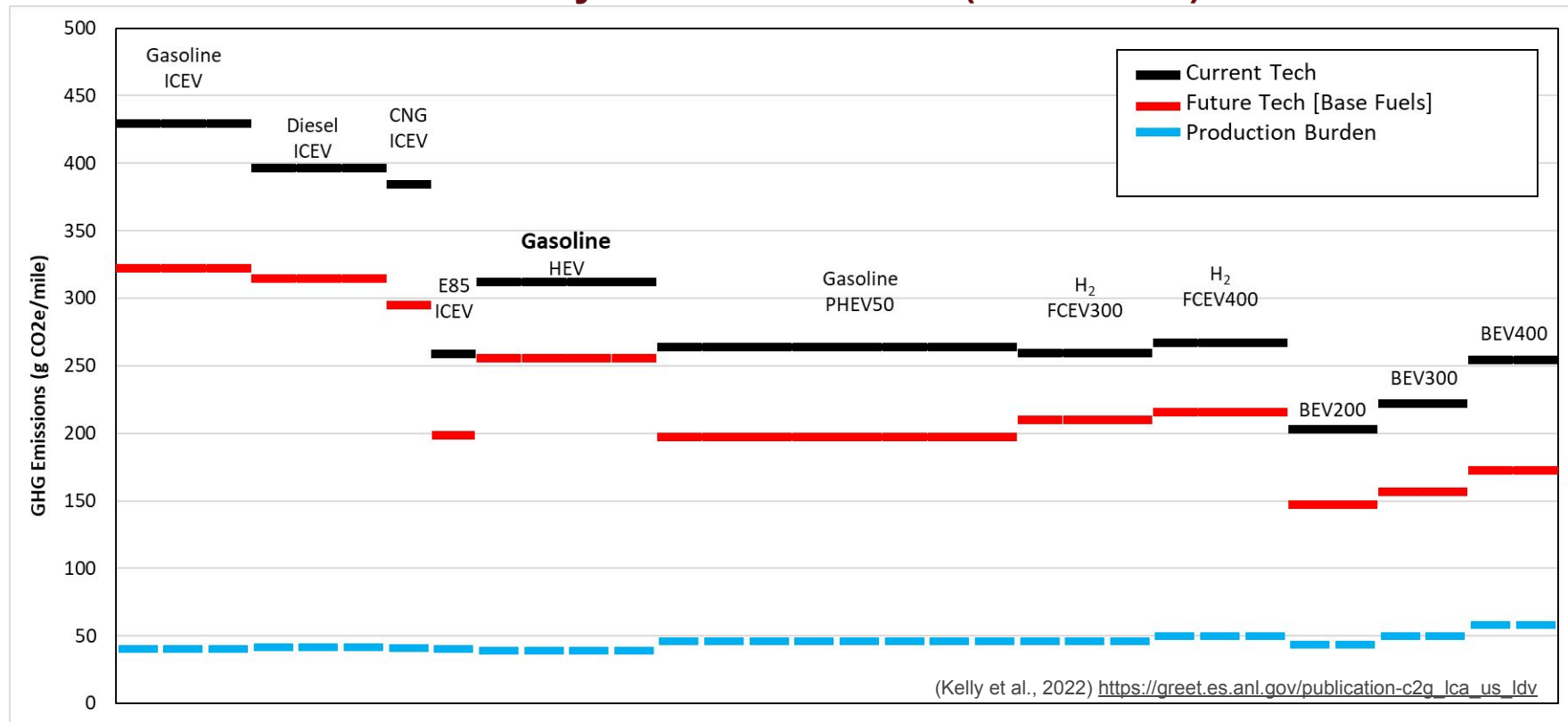
Powertrain Improvements (Small SUV)



VEHICLE PRODUCTION IMPORTANCE INCREASES W/ IMPROVED FUEL EFFICIENCY

Current (2020) and Future (2030-2035)

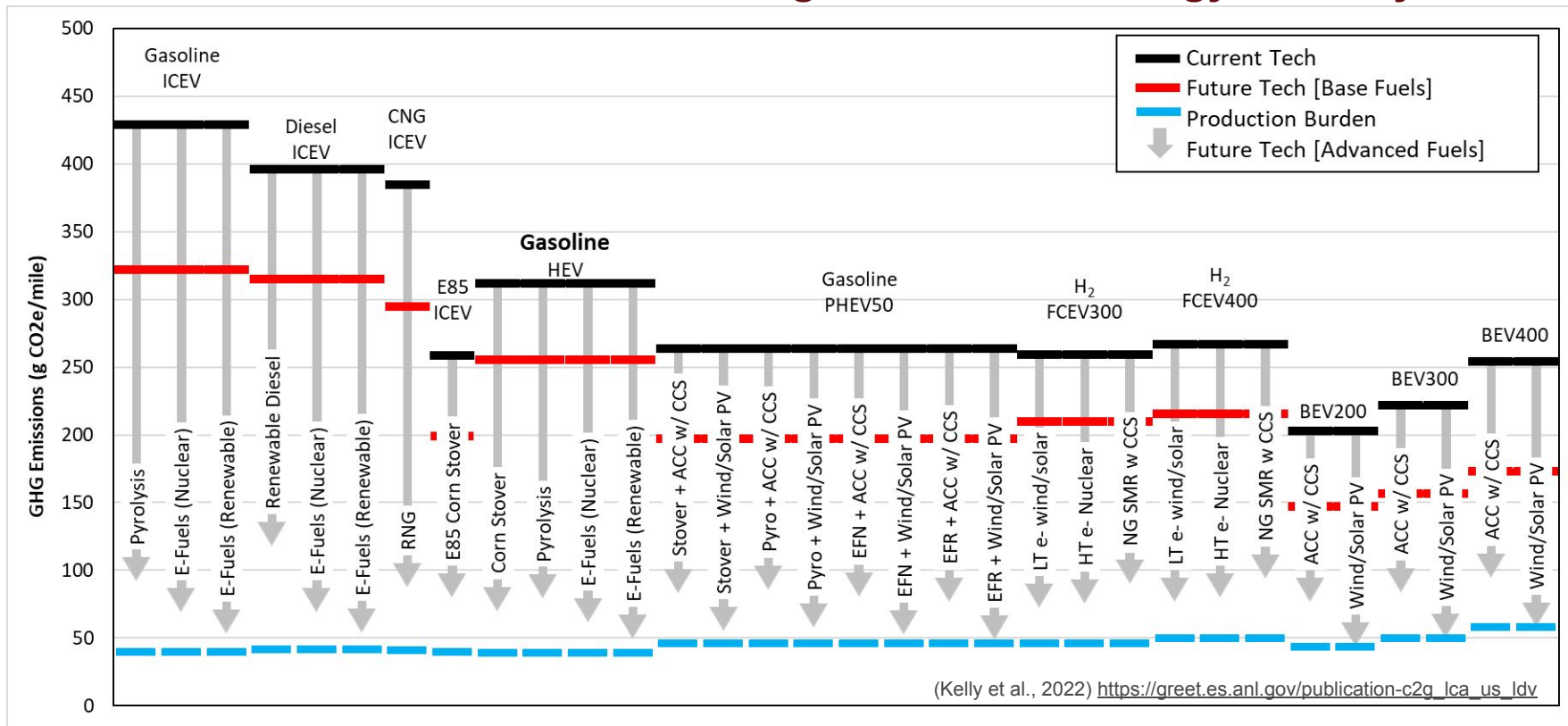
Vehicle Cycle Contributions (Small SUV)



LOW CARBON FUELS ARE BEING EXPLORED FOR ALL POWERTRAINS

Current (2020) and Future (2030-2035)

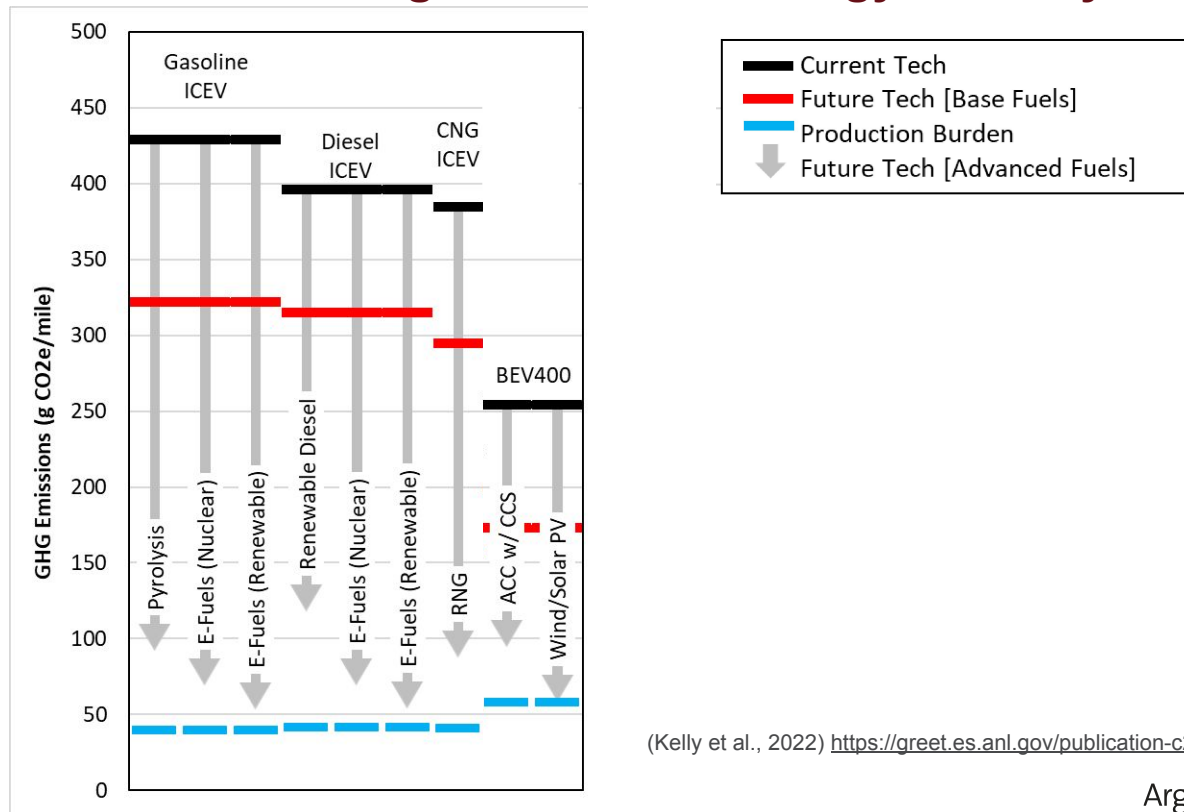
Decarbonization Potential through Alternative Energy Pathways



LOW CARBON FUELS ARE BEING EXPLORED FOR ALL POWERTRAINS

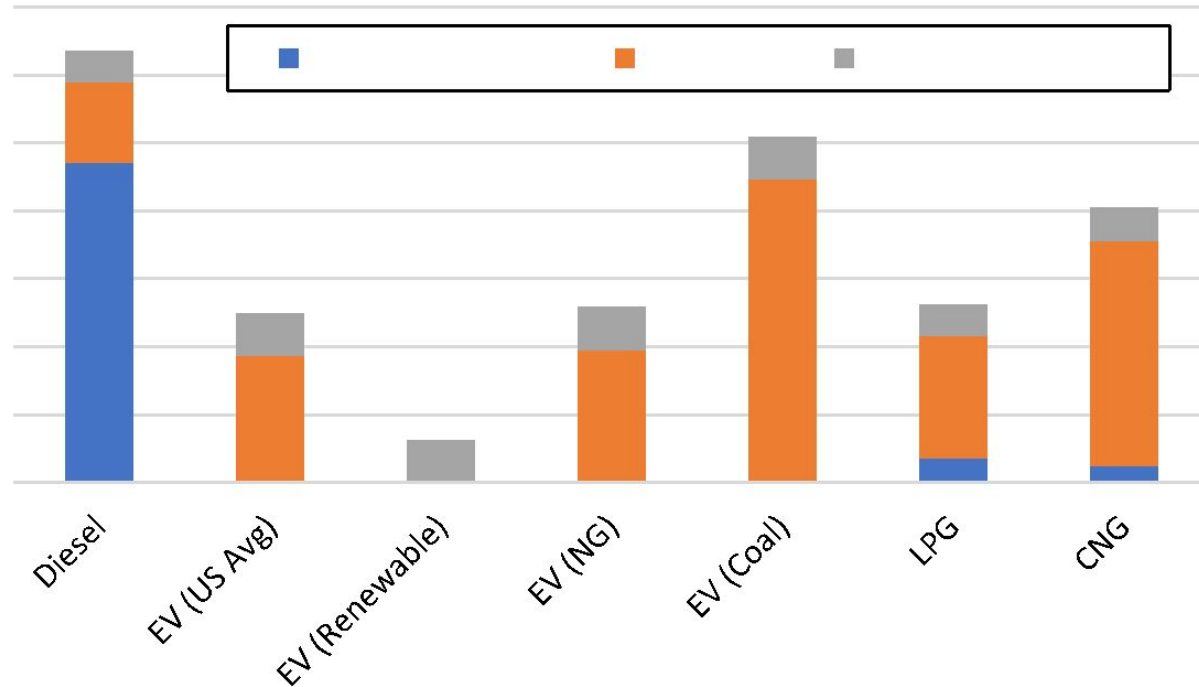
Current (2020) and Future (2030-2035)

Decarbonization Potential through Alternative Energy Pathways

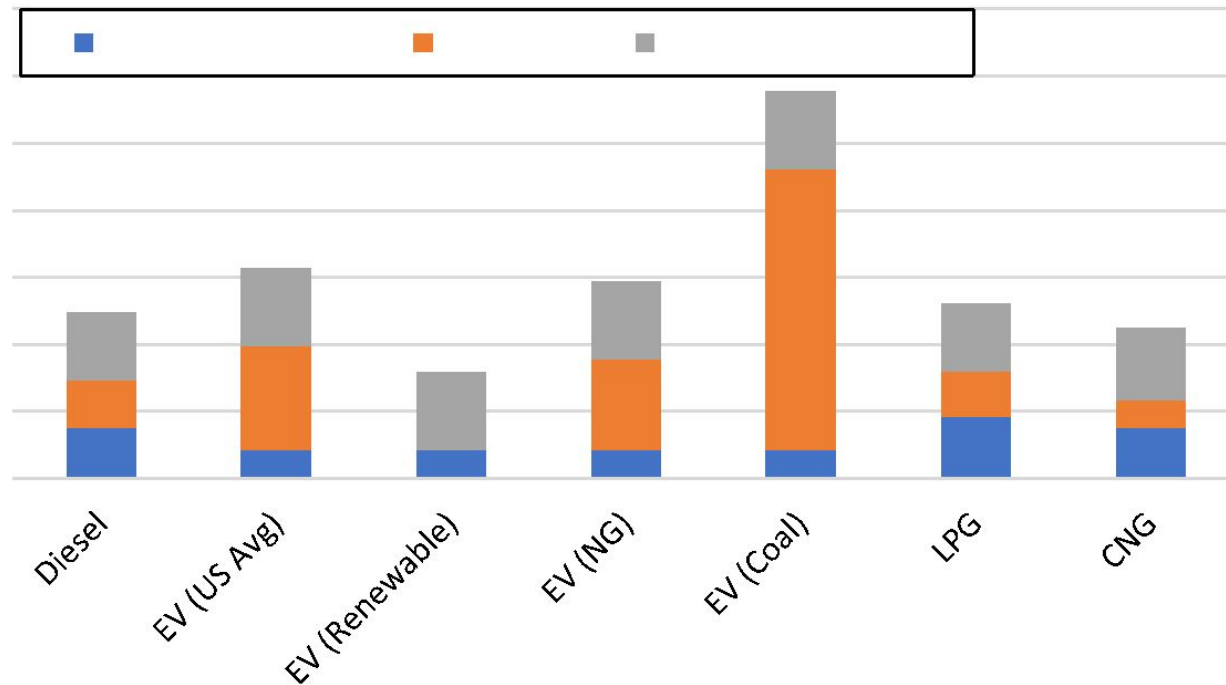


(Kelly et al., 2022) https://greet.es.anl.gov/publication-c2g_lca_us_ldv

LCA OF SCHOOL BUS NO_x EMISSIONS



LCA OF SCHOOL BUS PM_{2.5} EMISSIONS



AFLEET DEMO

EXAMINES ON-ROAD AND OFF-ROAD FLEET

- ✓ Environmental footprint
- ✓ Cost of ownership
- ✓ Refueling infrastructure
- ✓ Idle reduction

CURRENT FLEET



AFLEET

Helps identify vehicle replacement

10,000+ USERS



TOTAL COST OF OWNERSHIP



CARBON FOOTPRINT



AIR POLLUTION

18 ALTERNATIVE FUEL/TECHNOLOGY COMBINATIONS



PETROLEUM USE



VEHICLE OPTIONS



QUANTIFY BENEFITS



IDENTIFY VEHICLES TO REPLACE

CALCULATORS



□ Spreadsheet-based



□ Online web-based

OPTIMIZED FLEET



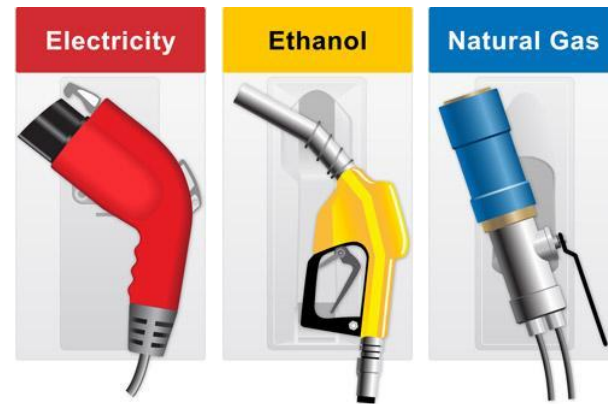
BENEFITS OF NEW TECHNOLOGIES

- ✓ Save on cost of ownership
- ✓ Reduce carbon footprint
- ✓ Contribute to cleaner air
- ✓ Reduce petroleum use

To learn more, visit afleet.es.anl.gov

AFLEET TOOL

- **Examines light-duty, heavy-duty, & off-road vehicle:**
 - Petroleum use
 - GHGs
 - Air pollutants
 - Cost of ownership
- **Contains 18 fuel/vehicle technologies**
 - Conventional
 - Hybrids
 - Plug-in electrics
 - Alternative fuels: CNG, LNG, LPG, H₂, ethanol, biodiesel, renewable diesel
- **AFLEET Spreadsheet and Online; HDVEC: afleet.es.anl.gov**
 - New version coming soon
 - EV rate and charging TCO calculators
 - Online TCO and off-road payback calculators



AFLEET ONLINE TUTORIAL - START PAGE

- About, Tool Selection

AFLEET ONLINE

The Department of Energy has enlisted the expertise at Argonne to develop the Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool for Clean Cities Coalition stakeholders. This online version of AFLEET compares new alternative fuel vehicles to gasoline (light-duty) and diesel (heavy-duty) vehicles.

Below are the calculators implemented by the online version from the AFLEET Tool 2020 spreadsheet. Select one of the options below to get started:

SELECT A TOOL TO GET STARTED

PAYBACK ON-ROAD CALCULATOR

- Annual petroleum use
- Annual greenhouse gas emissions
- Annual air pollutant emissions
- Simple payback on-road

PAYBACK OFF-ROAD CALCULATOR

- Annual petroleum use
- Annual greenhouse gas emissions
- Annual air pollutant emissions
- Simple payback off-road

TCO CALCULATOR

- Lifetime petroleum use
- Lifetime greenhouse gas emissions
- Lifetime air pollutant emissions
- Total cost of ownership

For any questions please contact: afleet@anl.gov

[Copyright Statement](#)

AFLEET ONLINE TUTORIAL - TCO

- **1st step: select vehicle type**
 - LDV (compare to gasoline)
 - HDV (compare to diesel)

AFLEET Online

Home Payback On-road Payback Off-road TCO

Vehicle Info Fuel Prices Other Costs Fuel Options

Vehicle Type: School Bus

State: LIGHT DUTY - GASOLINE COMPARISON

Quantity: Passenger Car

Vehicle Mileage: Passenger Truck

Planned Ownership: Light Commercial Truck

HEAVY DUTY - DIESEL COMPARISON

Powertrains to Compare

Powertrain	Fuel (MPG)	Total Cost	TCO
<input type="checkbox"/> Gasoline			
<input checked="" type="checkbox"/> Diesel			
<input checked="" type="checkbox"/> EV			
<input type="checkbox"/> FCV	11.28	\$0	\$0.56
<input type="checkbox"/> Diesel HEV	11.03	\$160,000	\$0.81
<input type="checkbox"/> Diesel HHV	10.54	\$0	\$0.81
<input checked="" type="checkbox"/> B20	8.17	\$100,000	\$0.93
<input type="checkbox"/> B100	8.17	\$100,000	\$0.93
<input type="checkbox"/> RD20	8.17	\$100,000	\$0.93
<input type="checkbox"/> RD100	8.17	\$100,000	\$0.93
<input type="checkbox"/> E85	6.81	\$0	\$0.61
<input checked="" type="checkbox"/> LPG	6.81	\$108,000	\$0.61
<input checked="" type="checkbox"/> CNG	6.94	\$130,000	\$0.93
<input type="checkbox"/> LNG	6.94	\$120,000	\$0.93
<input type="checkbox"/> LNG/D	7.76	\$0	\$0.97

Save Load

AFLEET ONLINE TUTORIAL - TCO

- **2nd step:**
 - state
 - # of vehicles
 - mileage
 - years of ownership

- **3rd step: select alternative fuels/powertrains**

- **4th step:**
 - fuel economy
 - purchase price
 - maintenance

AFLEET Online

Home Payback On-road Payback Off-road TCO

Vehicle Info Fuel Prices Other Costs Fuel Options

Vehicle Type School Bus

State Illinois

Quantity 1 vehicle(s)

Vehicle Mileage 15,000 mi/year

Planned Ownership 15 years

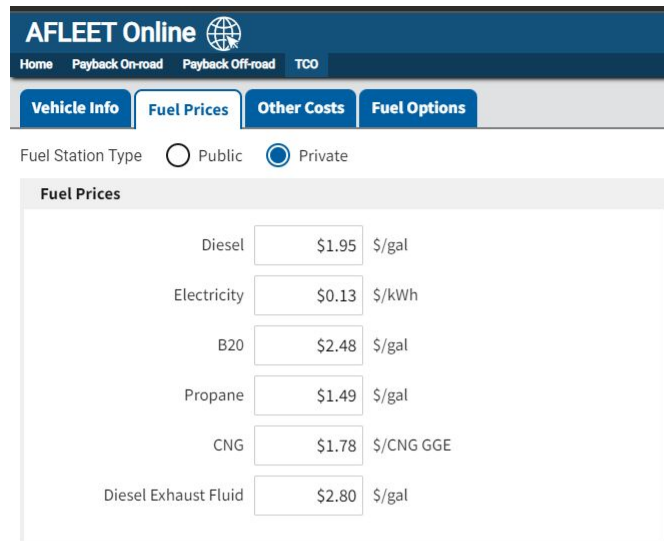
Powertrains to Compare

<input type="checkbox"/> Powertrain	Fuel Economy (MPDGE)	Purchase Price (\$/vehicle)	Maintenance (\$/mi)
<input type="checkbox"/> Gasoline	6.81	\$0	\$0.61
<input checked="" type="checkbox"/> Diesel	8.17	\$100,000	\$0.93
<input checked="" type="checkbox"/> EV	23.96	\$300,000	\$0.56
<input type="checkbox"/> FCV	11.28	\$0	\$0.56
<input type="checkbox"/> Diesel HEV	11.03	\$160,000	\$0.81
<input type="checkbox"/> Diesel HHV	10.54	\$0	\$0.81
<input checked="" type="checkbox"/> B20	8.17	\$100,000	\$0.93
<input type="checkbox"/> B100	8.17	\$100,000	\$0.93
<input type="checkbox"/> RD20	8.17	\$100,000	\$0.93
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<input checked="" type="checkbox"/> LPG	6.81	\$108,000	\$0.61
<input checked="" type="checkbox"/> CNG	6.94	\$130,000	\$0.93
<input type="checkbox"/> LNG	6.94	\$120,000	\$0.93
<input type="checkbox"/> LNG/D	7.76	\$0	\$0.97

Save Load

AFLEET ONLINE TUTORIAL - TCO

- 5th step: fuel prices



The screenshot shows the AFLEET Online TCO calculator interface. The top navigation bar includes links for Home, Payback On-road, Payback Off-road, and TCO. Below this is a tabbed interface with four tabs: Vehicle Info, Fuel Prices (selected), Other Costs, and Fuel Options. Under the Fuel Prices tab, there are radio buttons for Fuel Station Type: Public (unselected) and Private (selected). The main content area is titled "Fuel Prices" and contains a list of fuel types with input fields for their prices and units.

Fuel Type	Price	Unit
Diesel	\$1.95	\$/gal
Electricity	\$0.13	\$/kWh
B20	\$2.48	\$/gal
Propane	\$1.49	\$/gal
CNG	\$1.78	\$/CNG GGE
Diesel Exhaust Fluid	\$2.80	\$/gal

AFLEET ONLINE TUTORIAL - TCO

- **6th step:**
 - fuel production sources
 - petroleum use, GHGs, and air pollutants options

The screenshot shows the AFLEET Online TCO calculator interface. The top navigation bar includes links for Home, Payback On-road, Payback Off-road, and TCO. Below this is a tabbed interface with four tabs: Vehicle Info, Fuel Prices, Other Costs, and Fuel Options. The Fuel Options tab is currently selected.

The main content area is divided into two sections:

Fuel Production Sources

- Biodiesel Feedstock: A dropdown menu showing "Soy".
- CNG Feedstock: A dropdown menu showing "North American NG".
- North American NG Feedstock Source: Two input fields for "Conventional" (66%) and "Shale" (34%).
- LPG Feedstock Source: Two input fields for "NG" (69%) and "Petroleum" (31%).
- Electricity: A dropdown menu showing "Average U.S. Mix".

Below the Fuel Production Sources section is a link: [View Electricity Source Map](#).

Calculation Options

- GHG Calculations: A dropdown menu showing "Well-to-Wheels Petroleum Use and GHGs & Vehicle Operation Air Pollutants".
- Use Diesel-In-Use Multiplier?: An unchecked checkbox.
- Use Low NOx Engines?: A checked checkbox.

AFLEET ONLINE TUTORIAL - TCO

- 7th step: view TCO, GHG, petroleum, air pollutant results



AFLEET ONLINE TUTORIAL - TCO

- 7th step: view TCO, GHG, petroleum, air pollutant results



AFLEET ONLINE TUTORIAL - TCO

- 8th step: export and view results

1	AFLEET TCO Export									
2	School Bus									
3										
4										
5	Powertrain	Fuel Economy	Purchase Price	Maintenance Cost		Comparison Quantity	Vehicle Mileage			
6	Diesel	8.2	\$100,000	\$0.930		1	15,000			
7	EV	24.0	\$300,000	\$0.560						
8	B20	8.2	\$100,000	\$0.930						
9	LPG	6.8	\$108,000	\$0.610						
10	CNG	6.9	\$130,000	\$0.930						
11										
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Powertrains Other Costs Fuel Prices Fuel Options Results										

THANK YOU!!!

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CRADLE-TO-GRAVE LCA OF U.S. LIGHT-DUTY VEHICLE-FUEL PATHWAYS

	CURRENT TECHNOLOGY cases	FUTURE TECHNOLOGY Cases
Gasoline (E10)	U.S. average crude mix (blended with 10% corn ethanol)	Bio-renewable gasoline (pyrolysis)
		E-fuels (Nuclear electricity + CO ₂)
		E-fuels (Renewable electricity + CO ₂)
Diesel	U.S. average crude mix	Bio-renewable diesel (pyrolysis)
		Hydroprocessed renewable diesel (HRD) from soybeans
		20% Fatty Acid Methyl Ester (FAME) drop-in bio-based diesel (B20) from soybeans
		Gas-to-liquid Fischer-Tropsch Diesel (GTL FTD)
		E-fuels (Nuclear electricity + CO ₂)
		E-fuels (Renewable electricity + CO ₂)
CNG	U.S. average of conventional and shale gas mix	Renewable natural gas (NG) (from landfill gas)
Ethanol (E85)	85% corn ethanol (blended with 15% petroleum gasoline blendstock)	85% Cellulosic from corn stover (blended with 15% petroleum gasoline blendstock)
Hydrogen	Centralized production from Steam Methane Reforming (SMR)	Low temperature electrolysis from wind/solar
		High-temperature electrolysis using nuclear energy
		Natural gas SMR with Carbon Capture and Storage (CCS)
Electricity	EIA-AEO U.S. average electricity generation mix in 2020	Natural gas Advanced Combined Cycle (ACC)
		Natural gas ACC with CCS
		Wind
		Solar photovoltaic (PV)