MATERIAL HANDLING

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# FORK(LIFTS) IN THE (OFF-)ROAD: Should We Ban Internal Combustion Engines for Electric?



**By Gokul Vishwanathan**
Director of Research & Sustainability
Propane Education &
Research Council (PERC)


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# I. Executive Summary

# I. Executive Summary

The California Air Resources Board (CARB) recently proposed a ban on Internal Combustion Engine (ICE) forklifts based on the California Governor's Executive Order N 79 20. The proposed ban would impact ICE material handling applications up to 12,000 lbs. of lift capacity with some exceptions[1] (e.g., rough terrain forklifts, military tactical vehicles, pallet jacks, and forklifts owned and operated by facilities subject to the mobile carbon handling equipment at ports and intermodal railyards regulation). As written, CARB's proposal accelerates "zero"-emissions forklift (e.g., battery electric and hydrogen fuel cell electric) adoption through mandating "zero"-emission-only forklift sales by 2025, with a forced retirement of all ICE forklifts over a CARB-defined 13-year useful lifespan. Specifically, CARB is mandating ICE forklifts up to 12,000-lb. (6-ton) capacity, which predominantly includes Class 4 (cushion tire) & Class 5 (pneumatic tire) forklifts. Several fuels are used in material handling operations including diesel, propane, natural gas, and gasoline. The mandate would ban all equipment that uses these fuels, including hybrid electric solutions, and only allow battery electric and hydrogen fuel cell electric forklifts.

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This white paper analyzes whether the rulemaking constitutes a favorable solution for the environment not only for California but for the entire U.S. To this point, the Propane Education & Research Council (PERC) conducted an internal analysis using available certification emissions data and the Environmental Protection Agency's (EPA) MOtor Vehicle Emission Simulator (MOVES3) tool for comparing lifecycle equivalent carbon dioxide (CO2eq) and nitrogen oxide (NOx) emissions chiefly between propane and electric forklifts. Note, the white paper does not address the capital costs, infrastructure costs, and practicality of the implementation of this rulemaking, including loss of revenue (e.g., charging an electric forklift during a shift, impact of public safety power shutoffs or PSPS on a business operating forklifts) but analyzes it only from a technical standpoint. In this white paper, an energy cycle analysis compares propane and battery electric forklifts for each individual state, taking into account each state's electricity mix. Note, hydrogen fuel cell forklifts have not been considered in this analysis, as nearly 95% of hydrogen in the U.S. is produced using a highly endothermic process of conventional natural gas steam methane reforming.[2] For electric forklifts, both state electric grid average and marginal emissions have been accounted for. Since this "zero"-emission forklift transition is expected to occur by 2025, the marginal electric grid emission is a better metric for comparison with propane forklifts since electric forklifts do not currently constitute toward the baseload.

1 https://ww2.arb.ca.gov/our-work/programs/zero-emission-forklifts/zero-emission-forklifts-meetings-workshops

2 https://www.energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming#:~:text=Most%20hydrogen%20produced%20today%20in,source%2C%20such%20as%20natural%20gas

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> *"Figure 1(b) shows hybrid electric forklift performance compared with electric forklifts, where the performance of hybrid electric forklifts, with both conventional and renewable fuels, is superior to the performance of electric forklifts, particularly when comparing marginal CO2eq emissions."*

*Figures 1(a-c)* show a variety of cases that were simulated in this study with available certification data for propane forklifts and emissions comparisons with electric forklifts for California. Similar charts are available for all states and the District of Columbia (D.C.) in the Appendix section. In the charts, the emissions are expressed in grams per kWh of delivered power.

In California, propane forklifts (two different propane forklifts are shown, i.e., PSI2-2.4L and EDI6.2L engines) do emit more lifecycle CO2eq emissions *(Figure 1(a))* as compared to electric forklifts even when considering marginal electric grid emissions. The propane industry is investing in renewable propane and blends of propane with renewable dimethyl ether (rDME). Performance of forklifts operating with renewable propane extracted from U.S.-based used cooking oil (termed as Renew. Propane(oil) in the chart) and Asia Pacific-based animal tallow (termed as Renew. Propane(tallow) in the chart) is superior to that of electric forklifts, especially when considering marginal emissions. Blended propane/rDME fuels (blend 1 and blend 2) also lead to a lower carbon footprint compared with baseline conventional propane forklifts. *Figure 1(b)* shows hybrid electric forklift performance compared with electric forklifts, where the performance of hybrid electric forklifts, with both conventional and renewable fuels, is superior to the performance of electric forklifts, particularly when comparing marginal CO2eq emissions. Finally, *Figure 1(c)* shows the lifecycle NOx emissions, where it is clearly seen that the two propane engines' performance is superior to electric forklifts.

***Figure 1(a):***
*Lifecycle emissions of electric vs. propane forklifts: CO2eq for ICE forklifts*

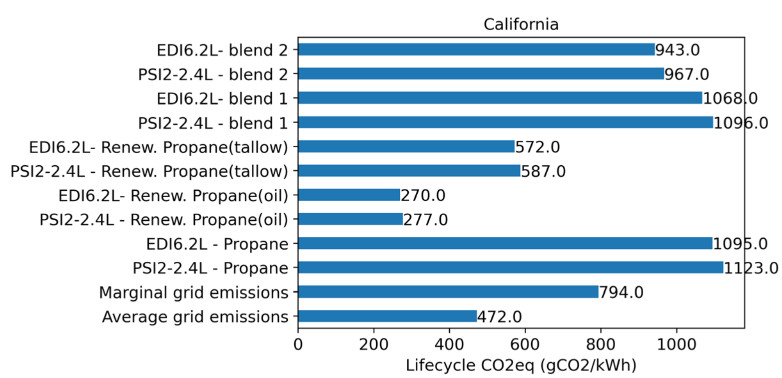



***Figure 1(b):***
*Lifecycle emissions of electric vs. propane forklifts: CO2eq for hybrid electric forklifts*

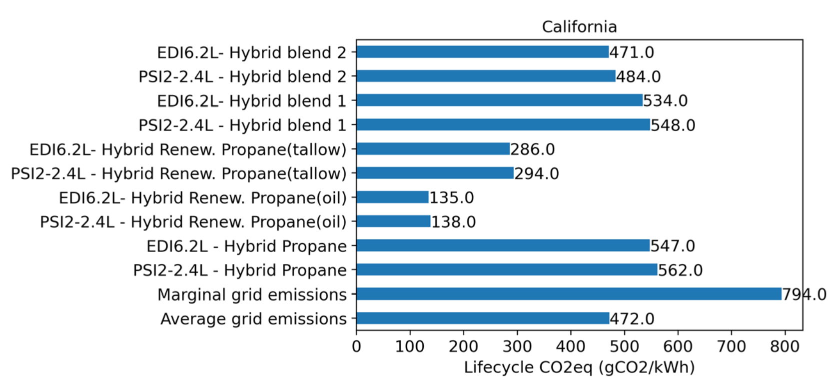
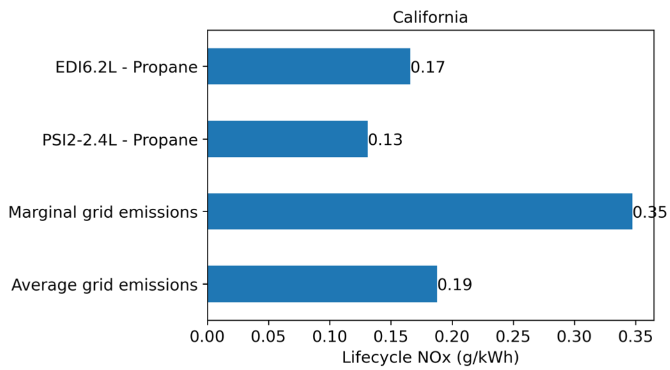


***Figure 1(c):***
*Lifecycle emissions of electric vs. propane forklifts: NOx for ICE forklifts.*




***"Figure 1(c) shows the lifecycle NOx emissions, where it is clearly seen that the two propane engines' performance is superior to electric forklifts."***

Since it is clearly shown that "zero"-emission forklifts may not indeed result in significant emissions reduction under all conditions and in some scenarios may indeed lead to degradation of lifecycle emissions, we make the following recommendations:

***"Regulatory agencies should conduct detailed lifecycle analyses... before considering a ban on specific technologies."***

- *Regulatory agencies should conduct detailed lifecycle analyses for gasoline, diesel, propane, natural gas, battery electric, and hydrogen fuel cell electric forklifts before considering a ban on specific technologies.*
- *Criteria pollutant emission standards for non-road spark-ignited engines have not been updated since 2007; however, most current ICE technologies are capable of meeting lower criteria pollutant standards.*
- *Fuel innovation (e.g., renewable propane, blends of propane and rDME) and technology innovation, including hybridization, must be further developed and utilized in parallel. This co-optimization is key to the success of achieving decarbonization and reducing criteria pollutants.*
- *An abrupt transition to battery electric-only forklifts would not necessarily reduce CO2eq emissions and NOx emissions will only be displaced from warehouses to power plants.*
- *Replacing all ICE forklifts in the state of California with battery electric forklifts would warrant nearly 10 GWh/day charging capacity. This is extremely challenging to achieve for a state that depends on electricity imports from neighboring states and where PSPS are becoming more frequent.*
- *Propane and other low-carbon fuels qualify for California LCFS for forklift applications. An abrupt shift toward "zero"-emission forklifts will be a missed opportunity for accelerating decarbonization using low-carbon, renewable, and blends of renewable and low-carbon fuels.*

***"An abrupt shift toward 'zero'-emission forklifts will be a missed opportunity for accelerating decarbonization using low-carbon, renewable, and blends of renewable and low-carbon fuels."***

As good stewards of environmental justice, we need to ensure that we are not displacing the problem in space and/or time but are indeed solving a problem for the greater good of humanity and all life on Earth.

# II. Assumptions of the Analyses

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In this study, two types of analysis are conducted, one using available certification data for Non-Road Spark-Ignition (NRSI) engines from the EPA database[3] from which a fuel/energy lifecycle analysis was conducted for propane forklifts and compared to electric forklifts for each state and two, a comparative tailpipe emissions analysis was conducted for diesel, gasoline, natural gas, and propane forklifts using the EPA MOVES3 tool.[4]

### a. Certification Data Analysis

For the certification data analysis, the data for Model Year 2021 (MY2021) was selected. The EPA database houses the data for all typical non-road spark-ignition fuels including gasoline, natural gas, and propane/liquified petroleum gas (LPG). The data for the test cycle, Part 1048 Transient, was chosen as it represents emissions under transient engine/equipment operation and is more representative of real-world operating conditions than steady-state data. Though these engines are typically certified for nitrogen oxides plus hydrocarbons (NOx + HC) emissions and carbon monoxide (CO) emissions, the database provides individual NOx, HC, and CO emissions with the transient deterioration factors (used as a proxy for catalyst aging), which have been accounted for here. In addition, tailpipe carbon dioxide (CO2) emissions, nitrous oxide (N2O), and methane (CH4) emissions, which are all greenhouse gases, have been measured and reported for most engines under study. A tailpipe equivalent CO2 emission (CO2eq) is calculated using equation 1, where the Global Warming Potential (GWP) of N2O is assumed to be 298 and GWP of CH4 is assumed to be 28 over 100 years. It is assumed the cumulative fuel energy consumed by the engine during the transient certification cycle is sufficient to overcome transmission and other power conversion losses and provide the net lifting energy to the forklift application, i.e., the engine dynamometer certification test-based fuel consumption is representative of the fuel consumption during equipment operation.

$$CO2eq\left(\frac{g}{kWh}\right) = CO2\left(\frac{g}{kWh}\right) + N2O\left(\frac{g}{kWh}\right) * 298 + CH4\left(\frac{g}{kWh}\right) * 28 \qquad (1)$$

[3] https://www.epa.gov/system/files/documents/2021-08/large-spark-ignition-2011-present.xlsx

[4] https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves

In addition, the Brake Thermal Efficiencies (BTE) of the propane engines were evaluated using the tailpipe CO2 numbers using equation 2, where $CO2_{fac}$ is 5760 gCO2/gallon[5] for propane and propane Lower Heating Value (LHV) is assumed to be 24.88 kWh/gallon (or 84,900 BTU/gallon).

$$BTE\,(-) = \frac{1}{\frac{CO2\left(\frac{g}{kWh}\right)}{CO2_{fac\left(\frac{gCO2}{gallon}\right)}} * LHV\left(\frac{kWh}{gallon}\right)} \quad (2)$$

The lifecycle CO2eq emission per unit delivered energy (kWh) was calculated using tailpipe CO2eq emissions, LHV of the fuel, and the cradle-to-grave Carbon Intensity (CI) of the fuel as per equation 3.

$$CO2eq_{LC}\left(\frac{gCO2eq}{kWh}\right) = \frac{CO2\left(\frac{g}{kWh}\right)}{CO2_{fac\left(\frac{gCO2}{gallon}\right)}} * LHV\left(\frac{MJ}{gallon}\right) * CI_{fuel}\left(\frac{gCO2eq}{MJ}\right) \quad (3)$$

Several fuels were evaluated in this analysis including conventional propane, renewable propane with two different carbon intensities, blends of conventional propane, and rDME, details of which are given in Table 1.

Computation of lifecycle NOx emission for propane engines is challenging as there is not much documented evidence of upstream (or feedstock) NOx emissions when compared to the data available for CO2eq emissions. We chose a reasonable method here by using the upstream emissions based on Argonne National Laboratory's Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET) 2020 model.[6] As per GREET, the propane upstream NOx emissions per unit of energy delivered was found to be 0.086 g/kWh. This value was added to the tailpipe emissions for all the U.S. states, assuming the upstream emissions were fairly the same for all the U.S. states, which is a reasonable assumption considering the CI variation of propane within the U.S. is less than 5%.

[5] https://www.eia.gov/environment/emissions/co2_vol_mass.php
[6] https://greet.es.anl.gov/

***Table 1:*** *Fuels and carbon intensities for this analysis.*

| Fuel | Composition (%w) | CI (gCO2eq/MJ) | Comment |
|---|---|---|---|
| Conventional propane | – | 79.5 - 83.2 | CI calculation was adopted using CARB methodology[7] for each U.S. state in a specific Petroleum Administration for Defense District (PADD). Variation in propane CI is due to the share of propane extracted from natural gas to the share of propane extracted from oil refining, which is PADD dependent. Nonetheless, the variation is small. |
| Renewable propane (North America-sourced used cooking oil feedstock) | – | 20.5[8] | For fuel produced in Geismar, LA, and transported to CA. Lower CIs expected for use near production facility. Note, CA has defined 9 pathways of renewable propane this year and this feedstock has the lowest CI. |
| Renewable propane (Asia Pacific-sourced animal tallow feedstock) | – | 43.5[8] | For fuel produced in Geismar, LA, and transported to CA. Lower CIs expected for use near production facility. Note, CA has defined 9 pathways of renewable propane this year and this feedstock has the highest CI. |
| Conventional propane/rDME[9] blend 1 | 5% by mass of rDME (3.2% by energy) | 77.6 - 81.2 | Assuming rDME has a CI of 20 gCO2eq/MJ.[10] |
| Conventional propane/rDME blend 2 | 5% by mass of rDME (3.2% by energy) | 68.0 - 71.6 | Assuming rDME has a CI of -278 gCO2eq/MJ.[11] |

7 https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/ca-greet/lut-doc.pdf?_ga=2.22521528.22462776.1631111968-171843523.1619709467

8 https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities

9 Note, the fuel consumption in gallons/kWh is assumed to be the same due to minor impact on the fuel LHV. DME is also a clean-burning fuel and will have no measurable impact on NOx and particular matter emissions. It is effectively non-sooting due to the absence of C-C bonds

10 A detailed review of renewable DME CIs has been performed by Lee, Uisung, et al. "Well-to-wheels emissions of Greenhouse gases and air pollutants of dimethyl ether from natural gas and renewable feedstocks in comparison with petroleum gasoline and diesel in the United States and Europe." SAE International Journal of Fuels and Lubricants 9.3 (2016): 546-557

11 https://www.greencarcongress.com/2020/02/20200212-oberon.html

PERC is conducting a research project with the University of Kentucky and a renowned material handling/forklift Original Equipment Manufacturer (OEM) to develop a series hybrid electric forklift. Preliminary laboratory results from the ongoing project indicate that the fuel consumption of the forklift is 47-58% lower than similarly sized ICE propane forklifts (5,000-lb. lift capacity) under similar duty cycles of operation. Note, the engine was significantly downsized for this application as it only acts as a generator to charge the batteries. The testing was performed under the severely transient Verein Deutscher Ingenieure (VDI) drive cycle. This forklift employs a Thin Plate Pure Lead Acid battery for which the recycling supply chain is well established and is not considered to have a significant impact on the overall carbon footprint. In addition, the series architecture operates the engine at a single speed in fairly steady-state conditions so the criteria pollutant emissions will be better than transient ICE forklift operation. Hence, series hybrid electric forklifts with 50% lower fuel consumption were also evaluated for comparisons.

For the electric forklift, the power generation emissions of both CO2eq and NOx were obtained from the EPA Emissions and Generation Resource Integrated Database (eGRID 2019) for each state.[12] Both average and marginal CO2eq and NOx emissions were considered for this analysis. Since there is imminent pressure to convert all material-handling forklifts to electric models in California, the marginal emissions are more relevant to compare to ICE forklifts.

The average and marginal upstream (or feedstock) CO2eq emissions were computed using the average and marginal electricity mix (i.e., share of coal, natural gas, oil, nuclear, biomass, and other fossil resources, etc.) for each state, respectively. The calculation of the upstream emissions from renewable resources of solar, wind, and geothermal is beyond the scope of this study and has been considered as negligible. The upstream CO2eq emissions were calculated using the procedure documented by CARB for the Low Carbon Fuel Standard (LCFS) Program.[13] There is not much evidence in available literature on upstream NOx emissions and those have been neglected in this analysis for electric forklifts. Theoretically, the electricity mix for each U.S. state could be simulated using the GREET model to compute each individual state's upstream NOx emissions, but that is beyond the scope of this study. Furthermore, it was assumed that the energy efficiency of the electric forklift was 85% (including charging, battery round-trip, and power conversion efficiencies). This was needed to convert both the upstream (CO2eq only) and power generation (CO2eq and NOx) emissions to units of grams per unit of delivered energy to the forklift (kWh).

The battery manufacturing CO2eq emissions were calculated using a carbon footprint of 140 kgCO2eq/kWh as per Hall and Lutsey.[14] This value is representative of a Lithium-ion battery manufactured in the U.S. An energy consumption of 6.5 kWh/hour was assumed here based on OEM data for VDI drive cycle for a typical 5,000-lb. lift capacity forklift.[15] It was assumed

12 https://www.epa.gov/egrid/data-explorer

13 https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/fuelpathways/comments/tier2/elec_update.pdf

14 https://theicct.org/publications/EV-battery-manufacturing-emissions

15 https://www.linde-mh.com/media/Datasheets/EN_ds_e20_e35_1252_en_a_0621_view.pdf

that the electric forklift operates for 2,000 hours per year and has a 5-year life (or 10,000-hour life). The cycle life of the battery is assumed to be 1,000 cycles. These factors when combined, for a forklift operating roughly 5.5 hours per day (considering there is significant idle time in an 8-hour shift), dictate a battery size of 36 kWh and a total of 2 batteries (i.e., 1 replacement battery) in the product lifecycle. Note, the battery size is somewhat irrelevant here as emissions are being calculated per unit kWh delivered and hence normalized. The carbon footprint of the replacement battery was also assumed to be 140 kgCO2eq/kWh. The efficiency of the energy delivered from the battery to the forklift use was assumed to be 92.5% (note, this number is higher than the 85% efficiency assumed above as it does not include charging losses and a portion of battery round-trip energy losses). This efficiency was required to convert the CO2eq emissions (attributed to battery manufacturing) to units of grams per unit of delivered energy to the forklift (kWh).

Quantifying NOx emissions from battery manufacturing processes is beyond the scope of the present study.

### b. EPA MOVES3 Tool

The EPA MOVES3 tool was used for non-road industrial simulations for all available fuels including diesel, Compressed Natural Gas (CNG), gasoline, and propane. MY2020 equipment was chosen for the comparisons and emissions profiles (g/hr) of CO2, CH4, non-methane hydrocarbons (NMHC), particulate matter (PM2.5), NOx, volatile organic compounds (VOC), and CO were compared for a forklift with a power rating between 40-50 hp.

### c. Are Marginal Grid Emissions the Right Metric?

While doing comparisons with battery electric equipment, the question always arises whether one should account for either average or marginal electric grid emissions? In addition, how should the electricity transaction between states be accounted for (i.e., if a coal power plant in Idaho is supplying power to California, then which state should the emissions be attributed to)?[16] Getting to that level of granularity is beyond the scope of this study. State-level (and not eGRID sub region-level) average and non-baseload (or marginal equivalent) output emissions rates were used from eGRID 2019. There is significant debate whether marginal emissions are the right metric when it comes to evaluating carbon footprint.[17,18] In this case it makes sense due to the rapid retirement of ICE forklifts (<5 years) and a significant ramp-up in electric forklifts and charging infrastructure for powering those forklifts, while electric grid capacity additions may be severely lagging. For example, it is estimated that about 314,000 ICE forklifts (both spark ignition and compression ignition) are operating in the state of California according to the "Survey of Large Spark-Ignited (LSI) Engines Operating within California" report.[19] If the

16 de Chalendar, J. A., Taggart, J., & Benson, S. M. (2019). Tracking emissions in the US electricity system. Proceedings of the National Academy of Sciences, 116(51), 25497-25502

17 https://www.paloaltoonline.com/blogs/p/2019/09/29/marginal-emissions-what-they-are-and-when-to-use-them

18 https://www.linkedin.com/posts/tristan-burton-55697731_as-part-of-the-ongoing-debate-about-the-appropriate-activity-6843554686495203328-0N6F

19 https://ww2.arb.ca.gov/sites/default/files/2020-08/ssrc_2017.pdf

average electric load is assumed to be 30 kWh per daily charge per forklift (a rough assumption considering most of the forklifts have less than 5,000-lb. lift capacity as per the survey data), it would equate to nearly 10 GWh/day electricity consumption and additional capacity requirement. Thus, it is natural to depend on less-efficient power plants and electric imports to support the huge spike in electricity demand. Nonetheless, both electric grid average and marginal emissions are included for comparisons.

# III. Data Analysis

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## a. Current State of the Art

In terms of certification data, first an analysis of all MY2021 NRSI engines was conducted to gauge their performance relative to the emissions standards. As per CFR §1048.101,[20] for MY2007 and beyond, transient exhaust emissions are not supposed to exceed Tier 2 emission standards, which are mandated at 2.7 g/kWh for HC + NOx and 4.4 g/kWh for CO. In addition, equation 4 may be used to optionally certify the engines; however, OEMs may not select a standard that is higher than 2.7 g/kWh for HC + NOx emissions or higher than 20.6 g/kWh for CO emissions. Table 2 shows the range of possible values for HC + NOx and CO emissions (rounded to the nearest 0.1 g/kWh) using equation 4.

$$(\mathrm{HC} + \mathrm{NOx}) * \mathrm{CO}^{0.784} \leq 8.57 \qquad (4)$$

***Table 2:*** *Examples of possible Tier 2 duty cycle HC + NOx and CO emissions standards.*

| HC + NOx (g/kWh) | CO (g/kWh) |
|---|---|
| 2.7 | 4.4 |
| 2.2 | 5.6 |
| 1.7 | 7.9 |
| 1.3 | 11.1 |
| 1.0 | 15.5 |
| 0.8 | 20.6 |

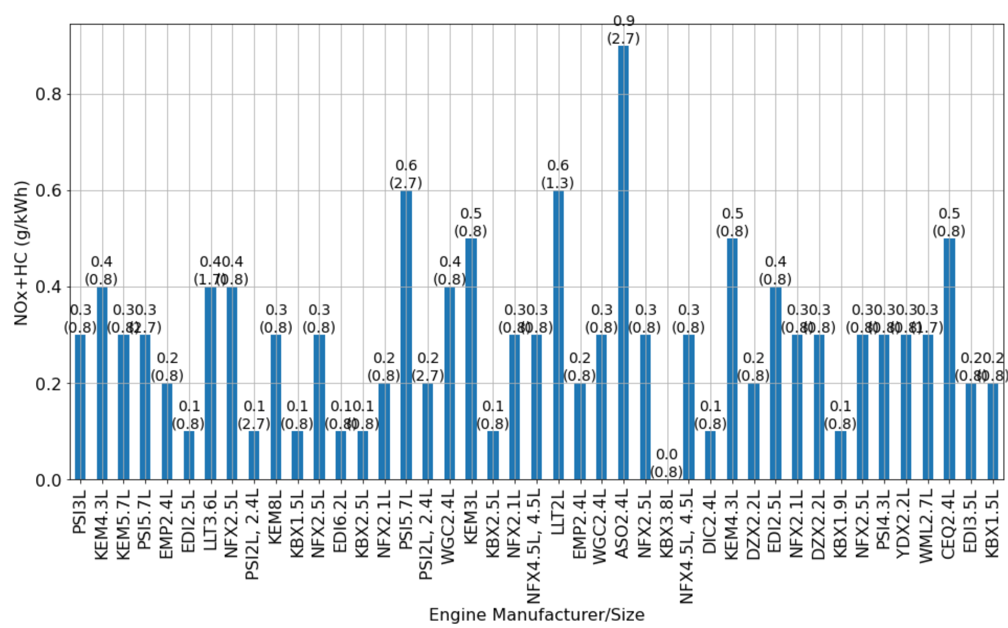
[20] https://www.ecfr.gov/cgi-bin/text-idx?SID=214d4e1ee771f9bd1639f70a7f7e3d22&mc=true&node=se40.36.1048_1101&rgn=div8

> *"It is interesting to note that several propane engines are indeed under 0.1 g/kWh NOx and 0.1 g/kWh HC emissions under transient conditions."*

*Figure 2* shows the performance of MY2021 propane NRSI engines relative to the transient emissions standards. The numbers in the parentheses indicate the standard for which the engine has been certified to. For the sake of brevity, the x-axis values only indicate the manufacturer code and the size of the engine. (Please refer to the Appendix for manufacturer names and codes.) Duplicate x-axis entries such as PSI2L,2.4L or EDI2.5L correspond to either the same engine family with different power ratings or different engine families. As seen from *Figure 2(a)*, several propane engines are well below the HC + NOx emissions standard of 0.8 g/kWh. Note, the values are rounded to the nearest 0.1 g/kWh in the EPA database, so the values that are 0 g/kWh in the charts are probably less than 0.05 g/kWh. Similarly, several engines are also well below the CO emissions limit of 20.6 g/kWh *(Figure 2(b))*. Note that some engines are also certified to other emissions standards as noted in Table 2. Nonetheless, most of the engines are operating well below the transient emissions standards. Since the EPA data also includes individual values of NOx and HC, those are plotted in *Figure 3(a)* and *Figure 3(b)*, respectively. It is interesting to note that several propane engines are indeed under 0.1 g/kWh NOx and 0.1 g/kWh HC emissions under transient conditions. These observed NRSI engine emission trends are extremely encouraging.

***Figure 2:*** *Propane NRSI tailpipe engine emissions relative to certification requirements for a) HC + NOx and b) CO. The numbers in the parentheses indicate the standard for which the engine has been certified to.*

*a)*



b)

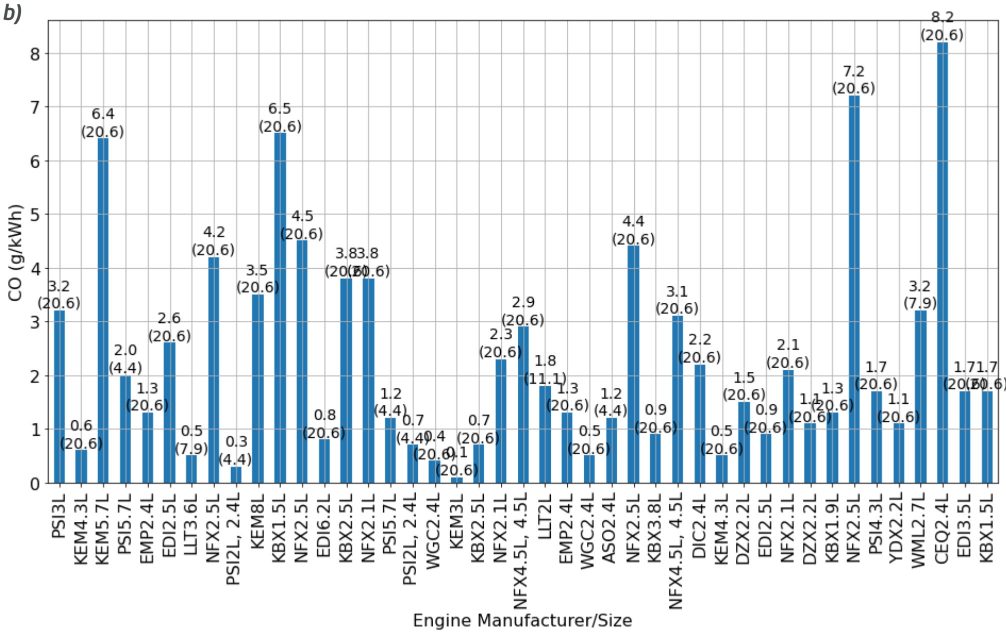
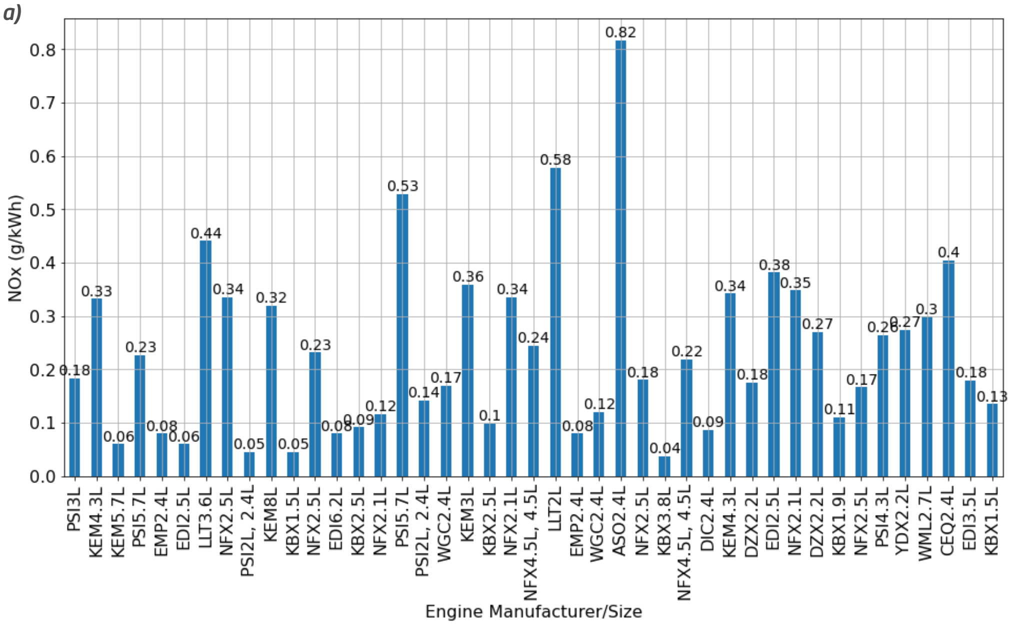
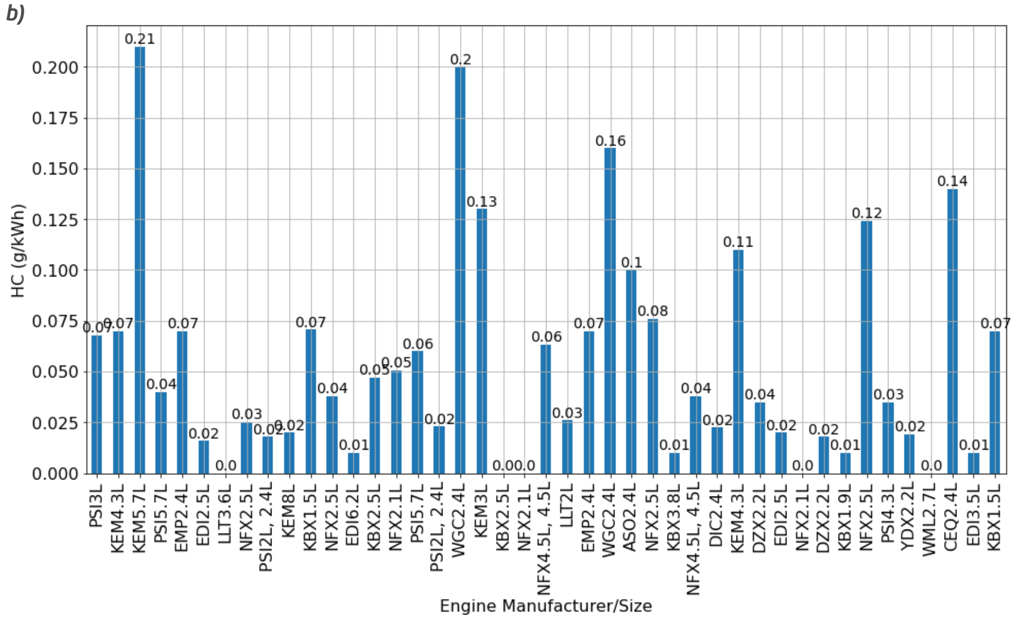



***Figure 3:*** *a) Tailpipe NOx and b) HC emissions from propane NRSI engines.*

a)



*b)*



HC (g/kWh)
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
Engine Manufacturer/Size
PSI3L
KEM4.3L
KEM5.7L
PSI5.7L
EMP2.4L
EDI2.5L
LLT3.6L
NFX2.5L
PSI2L, 2.4L
KEM8L
KBX1.5L
NFX2.5L
EDI6.2L
KBX2.5L
NFX2.1L
PSI5.7L
PSI2L, 2.4L
WGC2.4L
KEM3L
KBX2.5L
NFX2.1L
NFX4.5L, 4.5L
LLT2L
EMP2.4L
WGC2.4L
ASO2.4L
NFX2.5L
KBX3.8L
NFX4.5L, 4.5L
DIC2.4L
KEM4.3L
DZX2.2L
EDI2.5L
NFX2.1L
DZX2.2L
KBX1.9L
NFX2.5L
PSI4.3L
YDX2.2L
WML2.7L
CEQ2.4L
EDI3.5L
KBX1.5L

## b. Performance comparisons of propane engines vs. gasoline and natural gas spark-ignited engines

This section focuses on the performance of propane NRSI engines compared to gasoline and natural gas NRSI engines. For fairness and consistency, the identical engine family of a specific OEM that are certified for identical HC + NOx and CO emissions standards were compared for the three fuels. *Figure 4*, *Figure 5*, and *Figure 6* show the comparisons of NOx, HC, CO, and CO2eq emissions for the KBX1.9L, KBX2.5L, and EDI6.2L engines, respectively.

*Figure 4* shows the comparisons for the KBX1.9L engine (30-33 kW power rating). It must be mentioned that total HC emission in *Figure 4* for the natural gas engine is not really zero, as methane emissions were reported to be 0.109 g/kWh, however, since those are accounted for in the CO2eq emissions, they are not again duplicated in the HC emissions bucket. NMHC emissions were reported to be 0 for the natural gas engine (probably so low that it could not be measured). In general, the propane engine emits lower NOx, comparable HC emissions, and lower CO emissions than the gasoline engine and is comparable to the performance of the natural gas engine. The propane engine demonstrates a 16% reduction in CO2eq emissions compared to its gasoline counterpart, but the natural gas engine performs the best in terms of CO2eq tailpipe emissions.

***Figure 4:*** *Performance of propane, natural gas, and gasoline engines for KBX1.9L engine family (30-33 kW peak power rating).*

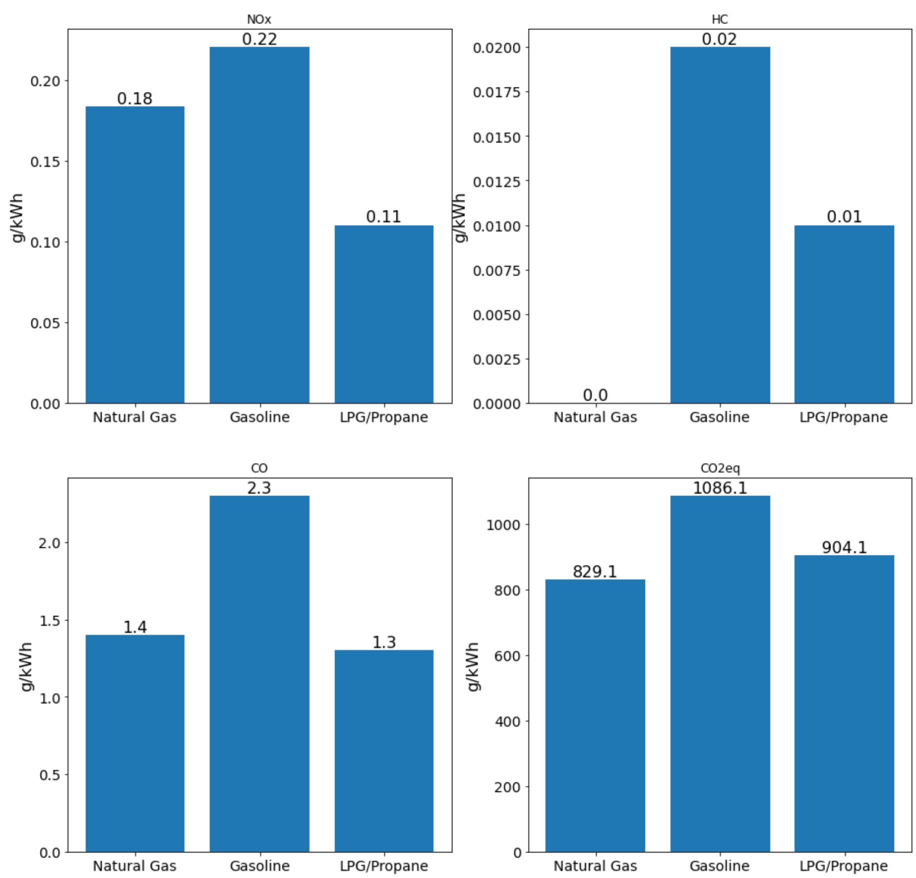
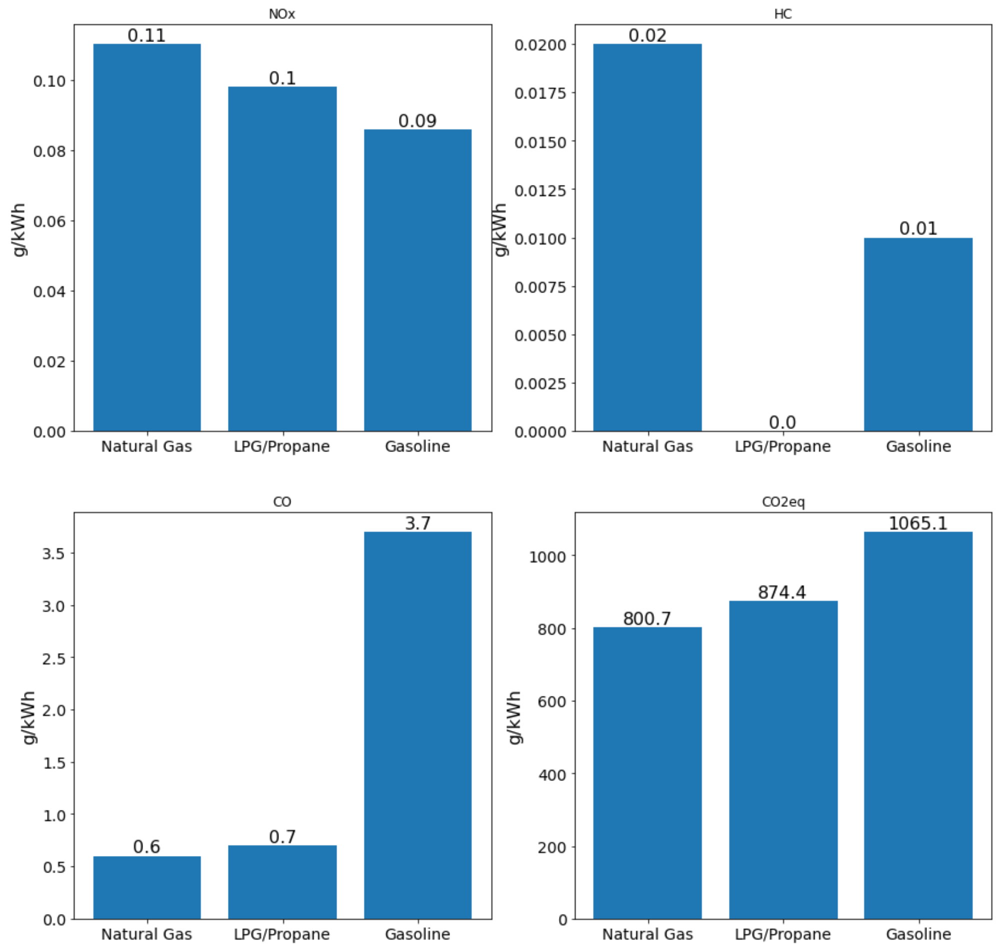


*Figure 5* shows the comparisons for the KBX2.5L engine (44.5 kW power rating). Similar trends in emissions are seen here. Here, the NOx emissions are comparable between the three fuels while propane engine's HC emissions were reported to be 0 (probably so low that it could not be measured). Gasoline and natural gas engines also yield very low HC emissions. The propane and natural gas engines yield significantly lower CO emissions compared to the gasoline engine, while similar trends in CO2eq are observed here as before.

***Figure 5:*** *Performance of propane, natural gas, and gasoline engines for KBX2.5L engine family (44.5 kW peak power rating).*



“Overall, a 16-18% reduction in CO2eq emissions is observed for propane engines relative to gasoline engines, while natural gas engines lead to a reduction of 23-28% in CO2eq emissions relative to gasoline engines.”

Finally, *Figure 6* shows the results for a larger engine (EDI6.2L) with a power rating of 146 kW. Here, significant reductions in NOx and CO emissions are seen for the propane engine compared to gasoline and natural gas. The HC emissions are all the same while the same trends in CO2eq emissions are seen as before. Overall, a 16-18% reduction in CO2eq emissions is observed for propane engines relative to gasoline engines, while natural gas engines lead to a reduction of 23-28% in CO2eq emissions relative to gasoline engines. Similar trends were seen for several other engine families with different power ratings and for the sake of brevity, they are not included here. From a performance standpoint, propane engines are roughly at 25% BTE under transient operating conditions. This is observed in *Figure 7*. The mean of the BTE data represented in *Figure 7* is 25.3% (with 2.6% standard deviation) and the median is 25.6%. These BTE values demonstrate that there is definite room for significant improvement, however these improvements in BTE have stalled since there has been no regulatory push for mandating tailpipe CO2eq emissions for an extremely cost-sensitive application such as forklifts. In fact, as mentioned before, the regulatory mandates have not been updated since 2007.

***Figure 6:*** *Performance of propane, natural gas, and gasoline engines for EDI6.2L engine family (146 kW peak power rating).*

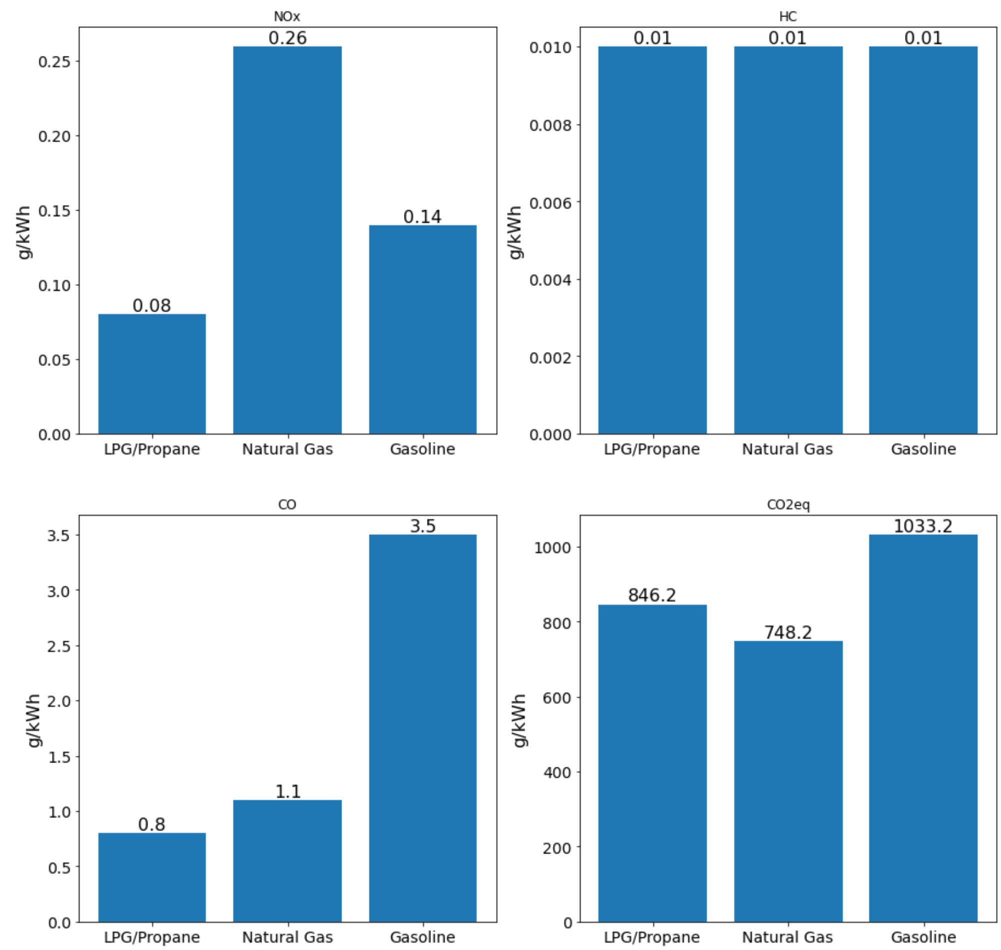
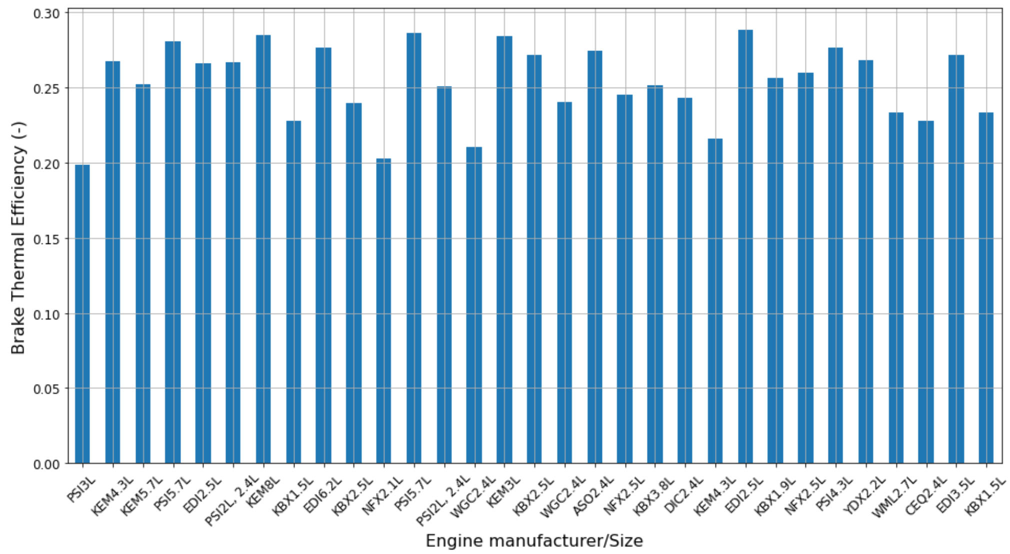


*Figure 7:* BTE of propane NRSI engines.

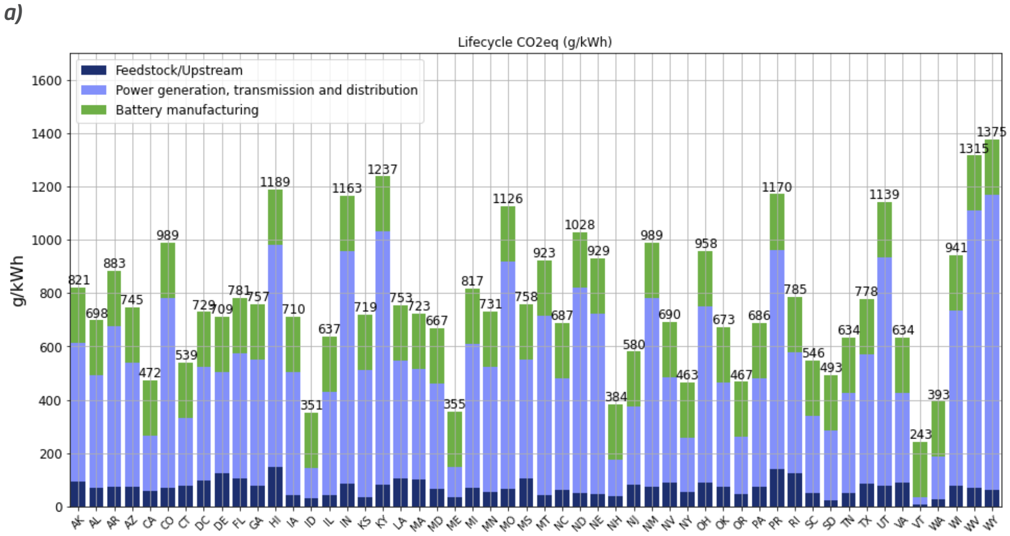



## c. Emissions lifecycle assessment for conventional propane, hybrid propane, and electric material handling equipment

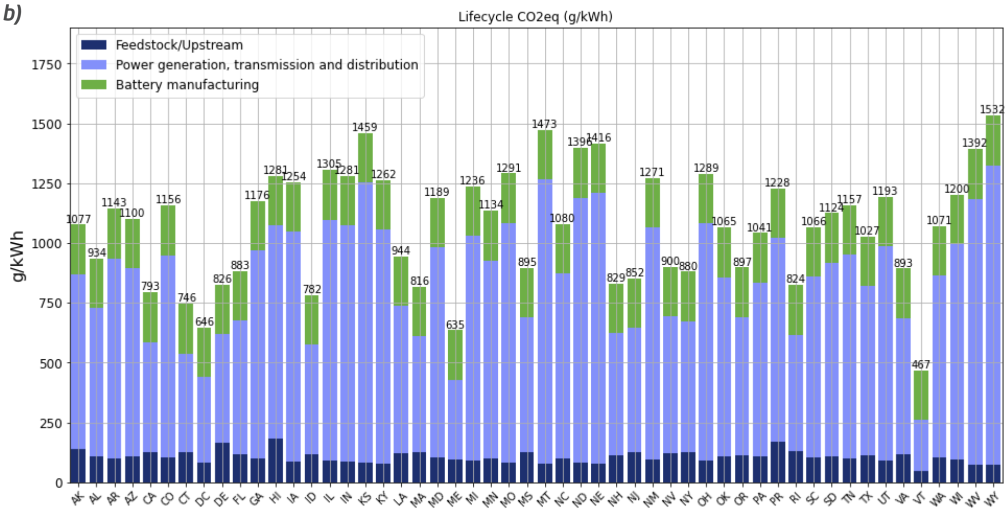
*Figures 8(a-b)* show the average and marginal lifecycle CO2eq emissions, respectively, for each U.S. state along with the individual attributions to feedstock/upstream, power generation, transmission and distribution, and battery manufacturing. As noted in the assumptions section, both average and marginal emissions of CO2eq and NOx were extracted from eGRID 2019 for each U.S. state.

*Figure 8:* a) Average CO2eq and b) marginal CO2eq emissions from the electric grid for an electric forklift per unit of delivered power.

***a)***



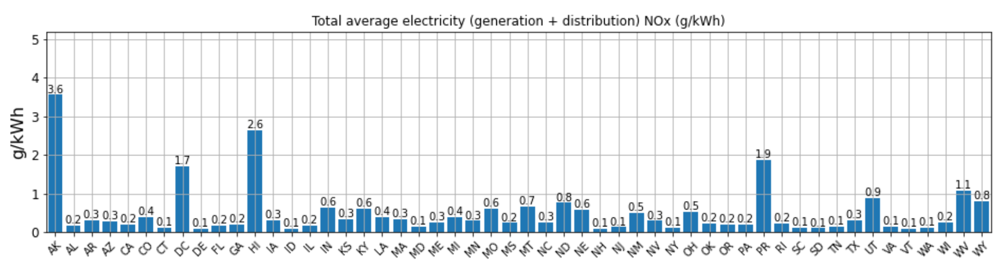
b)



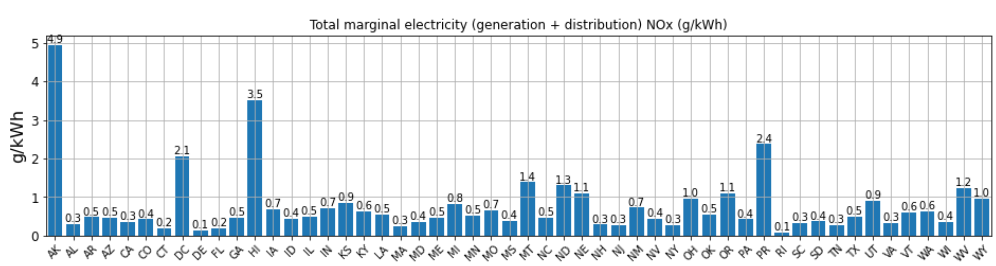

*Figures 9(a-b)* show the average and marginal NOx emissions, respectively, for each U.S. state. **Again, it is noted that upstream/feedstock and battery manufacturing emissions of NOx were not included here and thus the NOx emissions values will be underestimated.**

***Figure 9:*** *a) Average NOx and b) marginal NOx emissions from the electric grid for an electric forklift per unit of delivered power.*
***Note, this does not include emissions attributed to battery manufacturing and upstream (feedstock) for power generation.***

a)




b)

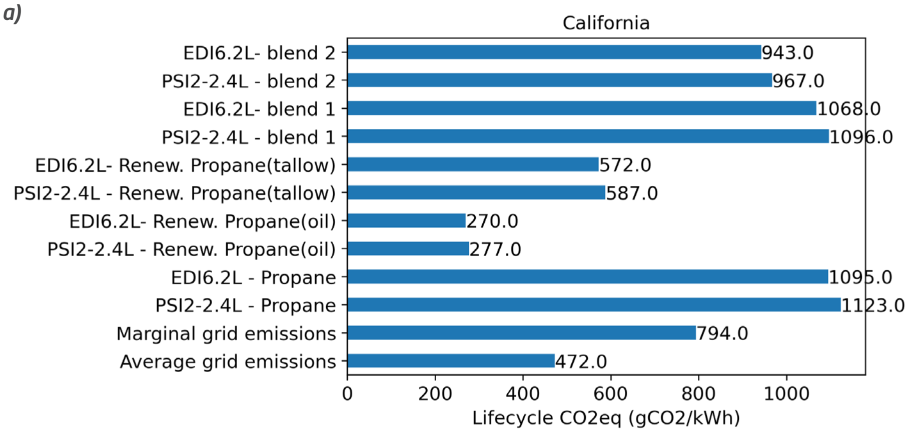


*"...lifecycle CO2eq emissions from propane engines are indeed higher than both the electric grid average and marginal CO2eq emissions, however these can be readily reduced by either hybridizing the engines or using renewable propane, blends of conventional propane and rDME, or both."*

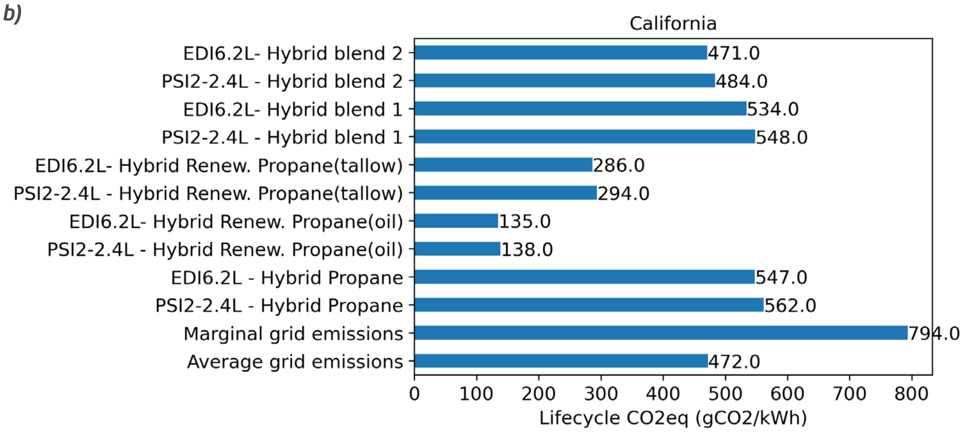
Putting all the pieces together, charts such as those shown in *Figure 10* and *Figure 11* are obtained for each U.S. state. *Figure 10* shows the charts for the state of California. *Figure 10(a)* shows the total lifecycle CO2eq emissions for two engines EDI6.2L (146 kW rating) and PSI2-2.4L engine family (41 kW rating), when operated with conventional propane, renewable propane (one sourced using North American used cooking oil and one sourced using Asia Pacific animal tallow), and two blends of rDME with propane (5% by wt. of rDME) with two different carbon intensities as defined in Section II. The lifecycle CO2eq emissions of an electric forklift are also included in *Figure 10(a)*. *Figure 10(b)* shows the same comparisons now with a series hybrid electric forklift, whose energy consumption is nearly 50% of the conventional ICE forklift. Note that this will require engine resizing and optimization for operating the system in a series hybrid architecture. Also note that the same nomenclature is being used in the charts for the engine size for the sake of consistency even though the hybrid system will employ a downsized engine. Finally, *Figure 10(c)* shows the lifecycle NOx emissions for both the engines when compared to the electric grid average and electric grid marginal NOx emissions. As seen from the charts, for the state of California, the lifecycle CO2eq emissions from propane engines are indeed higher than both the electric grid average and marginal CO2eq emissions, however these can be readily reduced by either hybridizing the engines or using renewable propane, blends of conventional propane and rDME, or both. A higher fraction of rDME in propane such as 20% by wt. will be beneficial for significantly reducing the carbon footprint but this would also require engine calibration/optimization as the octane rating of the blended fuel will be lower than the octane rating of propane as DME is a high cetane fuel.

***Figure 10:*** *Lifecycle emissions for the state of California showing a) comparisons of CO2eq emissions from propane ICE forklifts and electric forklifts, b) comparisons of CO2eq emissions from hybridized forklifts and electric forklifts, and c) comparisons of NOx emissions from propane ICE forklifts and electric forklifts.*

***a)***

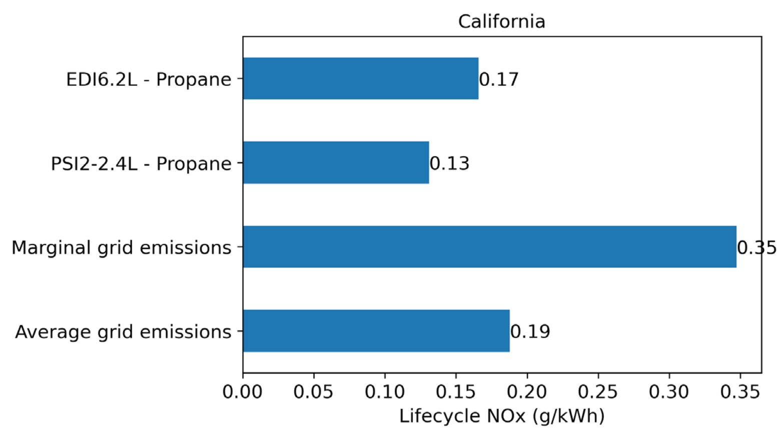


b)




*"It is observed here that we are purely displacing NOx emissions from the site to the power plant, which has other significant health implications for populations with lower standard of living and/or people of color…."*

c)

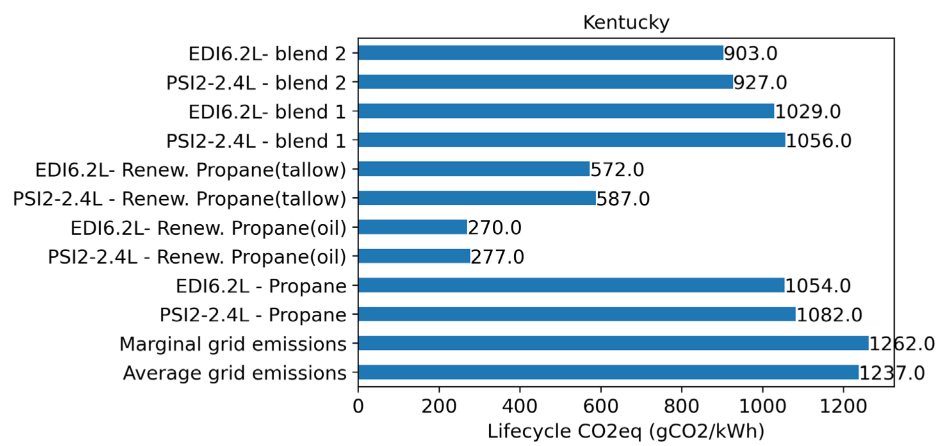



Finally, *Figure 10(c)* shows that the lifecycle NOx emissions of the engines are much lower compared to both grid average and marginal NOx emissions **(without accounting for upstream and battery manufacturing NOx emissions)**. It is observed here that we are purely displacing NOx emissions from the site to the power plant, which has other significant health implications for populations with lower standard of living and/or people of color. It must be noted that renewable propane, blends of rDME, and conventional propane qualify for CARB's LCFS credits for forklift applications and hence there is a tremendous benefit in using renewable fuels for the greater goal of decarbonization and this momentum must not be impeded.

*Figures 11(a-c)* show the charts for the state of Kentucky. It must be noted that in several states where coal is the dominant electricity generation fuel (such as Kentucky) or where highly polluting and less efficient power plants are used for supporting marginal electric loads, conventional propane ICE material handling equipment performs better in terms of lifecycle emissions of CO2eq and NOx, i.e., compared to both grid average and marginal emissions. With increasing penetration of hybrids, renewable fuels, and blends of conventional and renewable fuels, the situation can be rapidly and markedly improved. Similar charts for all the other U.S. states are provided in the Appendix section.

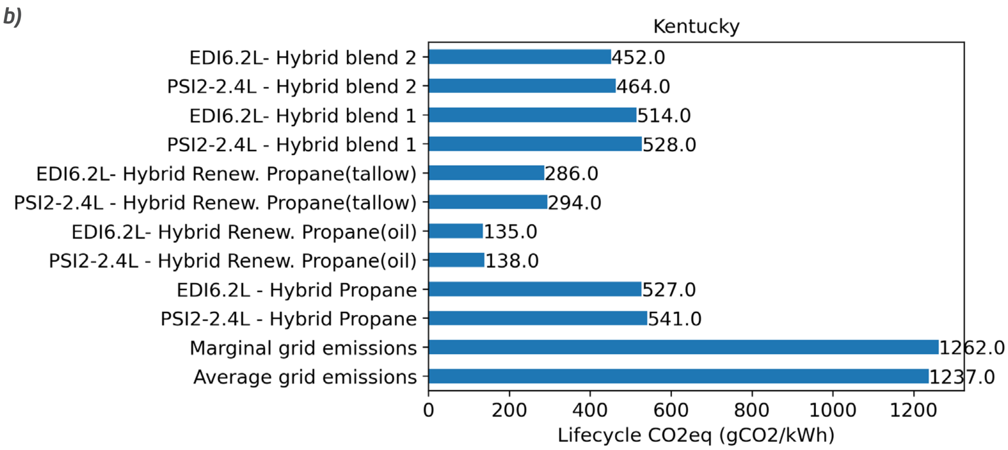
***Figure 11:*** *Lifecycle emissions for the state of Kentucky showing a) comparisons of CO2eq emissions from propane ICE forklifts and electric forklifts, b) comparisons of CO2eq emissions from hybridized forklifts and electric forklifts, and c) comparisons of NOx emissions from propane ICE forklifts and electric forklifts.*

***a)***

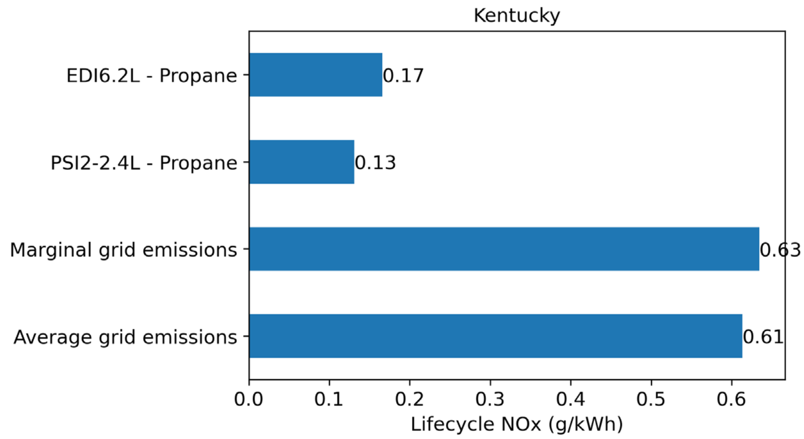



***"...in several states where coal is the dominant electricity generation fuel... conventional propane ICE material handling equipment performs better in terms of lifecycle emissions of CO2eq and NOx..."***

***b)***



*c)*




It is again noted that the emissions comparisons of the ICE and hybridized forklifts with the electric grid marginal emissions are appropriate, as rapid and imminent full electrification of this sector is being pursued. There is tremendous opportunity in employing hybrids, renewable fuels, and blends of conventional and renewable fuels for immediately making a dent on the carbon footprint of this sector. If price is not a governing criterion, several innovations for improving the ICE efficiency could be readily adopted from the on-road spark-ignition engine market. An array of technologies is provided below:

1. *Better air-to-fuel ratio control (e.g., dithering) for further emissions reduction using three-way catalyst.*
2. *Adoption of ultra-low NOx catalysts for forklifts such as those employed in on-road engines.*
3. *Port injection. Most of the current propane engines employ a vaporizer.*
4. *High-compression ratio for high-octane fuels such as propane. Currently, the same engine is used for gasoline and propane irrespective of the fuel octane number.*
5. *Improving in-cylinder tumble/mixing and rate of combustion with intake design and pent-roof cylinder head.*
6. *Miller cycling for reducing pumping losses. This will be complemented with intake boosting for compensating for the loss in volumetric efficiency.*
7. *Exhaust gas recirculation with boosting.*

8. *Stoichiometric operation with a three-way catalyst in advanced combustion modes such as Spark Assisted Compression Ignition (SACI) with EGR dilution.*

9. *Series hybrid architecture, which will enable the engine to operate under steady-state conditions only to charge a battery (when the state-of-charge goes below 20%) thereby significantly improving engine efficiency. The battery in turns supplies the energy for the forklift operation. In addition, advanced combustion modes such as SACI can be easily adopted to single-point steady-state operation, thereby further improving system efficiency.*

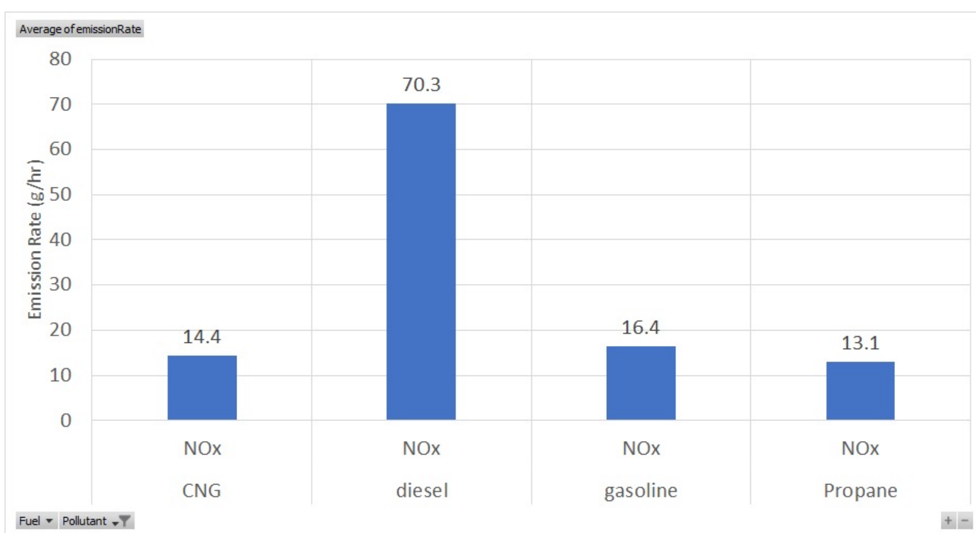
Accordingly, it is extremely critical that all these advanced ICE and hybrid strategies are actively pursued along with full electrification for rapid decarbonization of the forklift sector.

## d. Results from EPA MOVES3

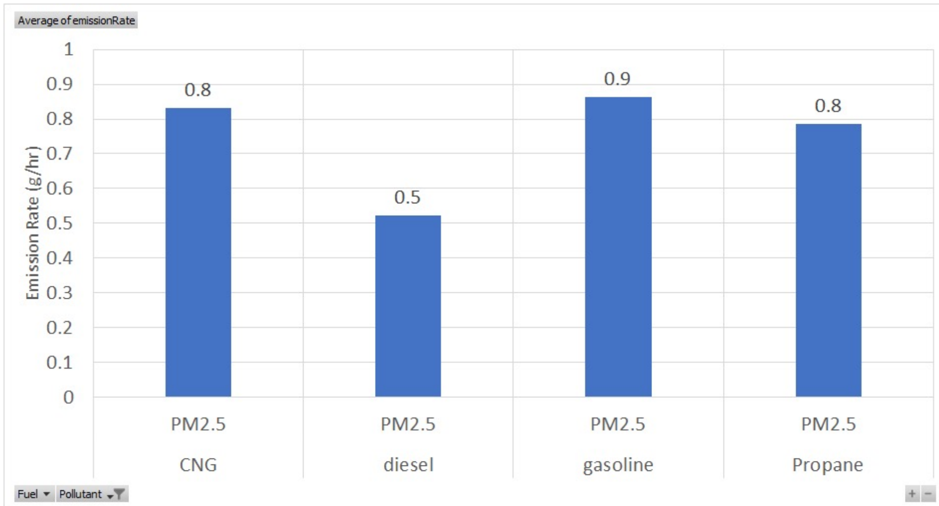
As mentioned above, the MOVES3 tool was exercised for MY2020 non-road industrial equipment. The emissions data was analyzed for forklifts at several power levels but data for all the fuels was only found for engines that were in the 40-50 hp bucket (29.8 – 37.3 kW) and hence included here. *Figures 12(a-f)* show the tailpipe out emissions of NOx, PM2.5, NMHC, CH4, CO2, and CO for CNG, diesel, gasoline, and propane forklifts with a power rating between 29.8-37.3 kW.

***Figure 12:*** *Comparisons of tailpipe emissions of a) NOx, b) PM2.5, c) NMHC, d) CH4, e) CO2, and f) CO between CNG, diesel, gasoline, and propane forklifts (40-50 hp power rating).*

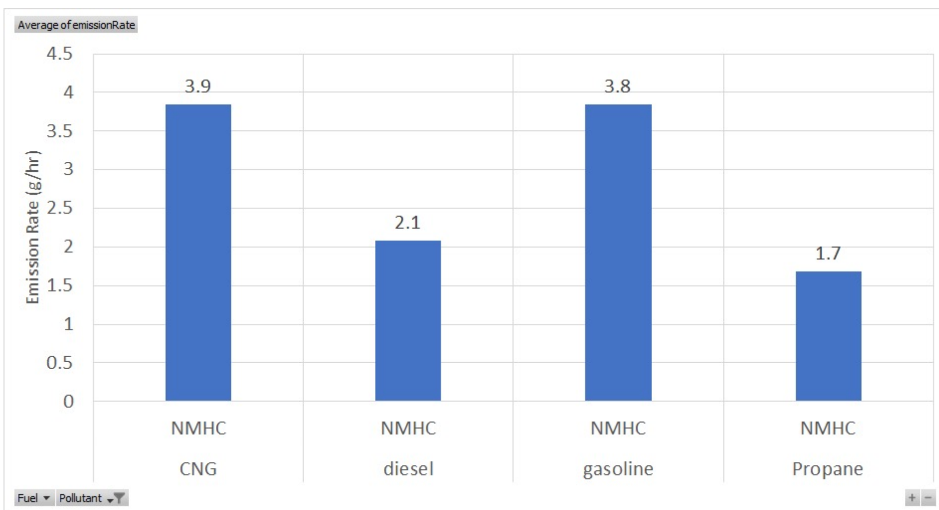
***a)***



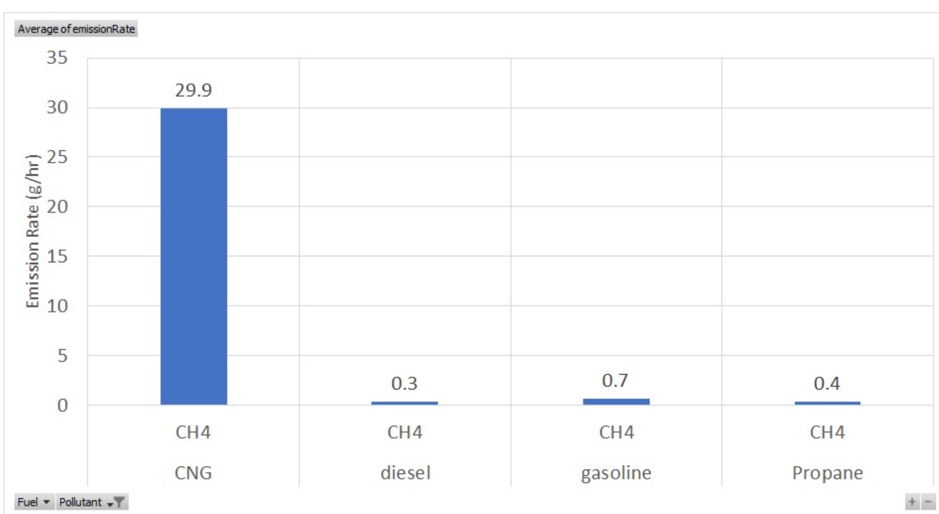
*b)*


Average of emissionRate
Emission Rate (g/hr)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.8
0.5
0.9
0.8
PM2.5
CNG
PM2.5
diesel
PM2.5
gasoline
PM2.5
Propane
Fuel
Pollutant

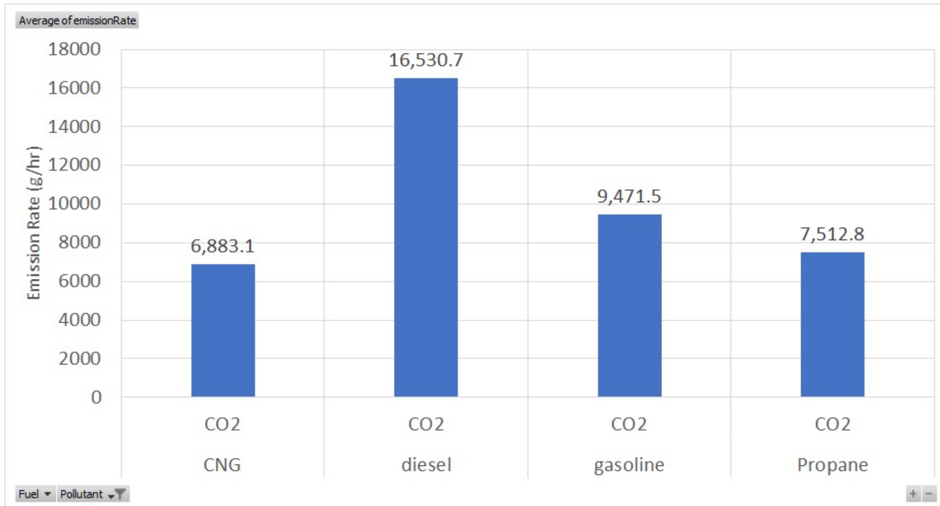
*c)*


Average of emissionRate
Emission Rate (g/hr)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
3.9
2.1
3.8
1.7
NMHC
CNG
NMHC
diesel
NMHC
gasoline
NMHC
Propane
Fuel
Pollutant

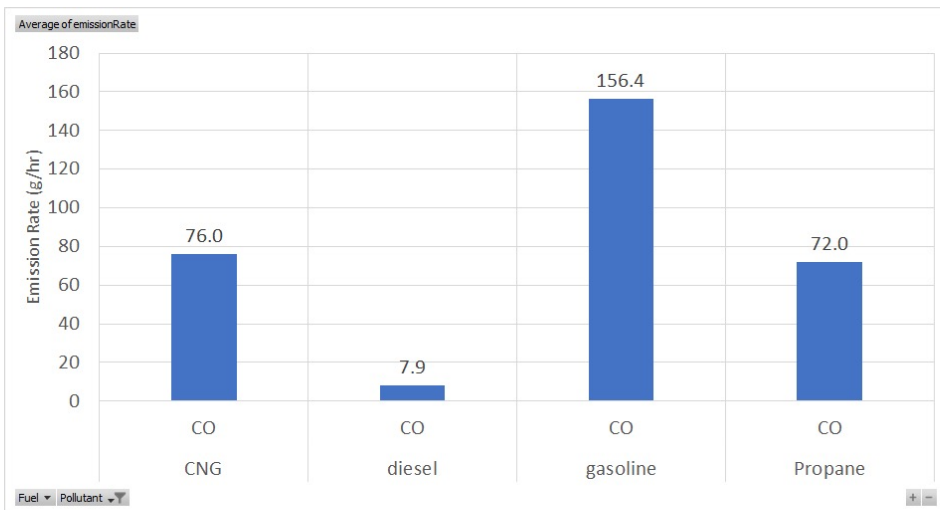
*d)*


Average of emissionRate
Emission Rate (g/hr)
35
30
25
20
15
10
5
0
29.9
0.3
0.7
0.4
CH4
CNG
CH4
diesel
CH4
gasoline
CH4
Propane
Fuel
Pollutant

*e)*


Average of emissionRate
Emission Rate (g/hr)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
16,530.7
9,471.5
7,512.8
6,883.1
CO2
CNG
CO2
diesel
CO2
gasoline
CO2
Propane
Fuel
Pollutant

*f)*


Average of emissionRate
Emission Rate (g/hr)
180
160
140
120
100
80
60
40
20
0
156.4
76.0
72.0
7.9
CO
CNG
CO
diesel
CO
gasoline
CO
Propane
Fuel
Pollutant

Per MOVES3 results for 40-50 hp forklifts, propane ICE forklifts have the lowest NOx and NMHC emissions compared to their counterparts. Tailpipe CO2 emissions of natural gas forklifts are the lowest; however if the CH4 emissions are accounted for with a GWP of 28, then CO2eq emissions of natural gas forklifts are the same as propane, which are both lower than diesel and gasoline. PM2.5 emissions are comparable for all forklifts, which indicates that the diesel forklifts most probably employ a diesel particulate filter. It is interesting, while simultaneously confounding, to observe that diesel forklift tailpipe CO2 emissions are twice when compared to those from spark-ignited forklifts. This is contrary to conventional wisdom, as diesel engines (compression ignition) are typically more efficient compared to their spark-ignited counterparts for the same output power unless they have poor part load efficiencies, which could be plausible for forklifts with significant idling. Finally, as expected, CO emissions for spark-ignited engines are higher than for compression-ignited diesel engines. This is where a better air-to-fuel ratio controller could assist in lowering the CO emissions further by operating at the sweet spot of the three-way catalyst. Overall, per the observations here, performance of a propane forklift exceeds that of gasoline and diesel (except CO) and is particularly better in HC emissions compared to a natural gas forklift.

*"Overall, per the observations here, performance of a propane forklift exceeds that of gasoline and diesel (except CO) and is particularly better in HC emissions compared to a natural gas forklift."*

The above 40-50 hp category forklift results are critical, as propane ICE proves to be the best solution compared to other conventional fuels. As per the "Survey of Large Spark-Ignited (LSI) Engines Operating within California" report,[19] nearly 54% of the forklifts that operate in California are propane fueled and about 57% of those propane forklifts have less than 51 hp rating.

# IV. Conclusions and Recommendations

## IV. Conclusions and Recommendations

The push toward full electrification as a means of decarbonization sounds attractive for various sectors that are currently being dominated by internal combustion engines. Although this may make sense in certain locations, applications, and use cases, it must not be considered as a panacea to decarbonization without complete consideration to lifecycle emissions. This is a position taken by even the former U.S. Energy secretary (under the Obama administration), Dr. Ernest Moniz.[21] As the electric grid gets cleaner, emphasis to full electrification must be given while paying attention to other strategies that can immediately reduce the carbon footprint and criteria pollutants including low-carbon fuels, renewable fuels, blends of renewable and low-carbon fuels, and equipment hybridization and operation with these fuels. Although arguments can be made that full electrification of equipment results in zero tailpipe emissions at point of use, in most cases it is displaced from the point of use to the power plant, which begs the argument for environmental justice as there is enough evidence to show that populations with a lower standard of living and/or people of color are affected by power plant emissions more than the average American.[22,23] Propane, renewable propane, blends of propane and renewable propane, and rDME along with equipment hybridization are powerful ways to not only reduce the carbon footprint of off-road equipment but also to mitigate criteria pollutants, particularly NOx and PM emissions. MOVES3 simulations demonstrate that propane forklifts emit lower criteria pollutants and tailpipe CO2 emissions when compared to gasoline, diesel (except CO), and natural gas.

Since it is clearly shown that "zero"-emission forklifts may not indeed result in significant emissions reduction under all conditions and in some scenarios may indeed lead to degradation of lifecycle emissions, we make the following recommendations:

- *We urge the regulatory agencies to conduct detailed lifecycle analyses for gasoline, diesel, propane, natural gas, battery electric, and hydrogen fuel cell electric forklifts before proposing a ban on specific technologies. In addition, regulatory agencies should consider mandating lower criteria pollutant emissions for spark-ignited engines, which have not been updated since 2007 and which seem to be achievable with current generation technologies. In addition, mandating lower CO2eq targets than the status quo for forklift engines would be a good middle ground solution for achieving rapid decarbonization. A standard, like the Corporate Average Fuel Economy (CAFE) standards, for the light-duty on-road vehicle sector could be implemented for material-handling fleets, which will encourage the industry to improve not only engine thermal efficiency but also to have a mix of high-thermal-efficiency conventional forklifts, hybridized forklifts, and electric forklifts. This creates a level playing field for all technologies and is not financially onerous to the fleet owners and end-customers, who will finally bear the costs of regulatory policies. The forklift market is an*

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21 https://www.spglobal.com/platts/en/market-insights/latest-news/oil/091521-moniz-wants-to-turn-more-focus-to-clean-alternative-fuels-negative-emissions

22 https://www.epa.gov/airmarkets/power-plants-and-neighboring-communities

23 Thind, M. P., Tessum, C. W., Azevedo, I. L., & Marshall, J. D. (2019). Fine particulate air pollution from electricity generation in the US: Health impacts by race, income, and geography. Environmental science & technology, 53(23), 14010-14019

*extremely cost-sensitive market and improvements in the industry will likely only occur if there is a regulatory push toward lower emissions. Several on-road high-efficiency and low-emissions technologies could be readily adopted to the material-handling market. Regulatory agencies must also focus on mandating engine idle emissions as engine idle is characteristic of forklift duty cycles.*

- *The propane industry is not only innovating the fuel (e.g., renewable propane, blends of propane, and rDME) but also innovating on technologies and products including hybridization. This co-optimization is key to the success of achieving decarbonization and reducing criteria pollutants.*
- *Battery electric forklifts will seldom reduce CO2eq emissions, especially if the transition from ICE forklifts to battery electric forklifts occurs abruptly. The electric loads will all be non-baseload or marginal, and marginal grid emissions, in most cases, are several times higher than average grid emissions. NOx emissions are purely displaced from warehouses to power plants. In most cases, an increase in NOx emissions is seen when compared to the best-performing propane engines.*
- *A back-of-envelope estimate indicates that replacing all ICE forklifts in the state of California with battery electric forklifts would warrant nearly 10 GWh/day charging capacity. Assuming the charging is done over 8 hours, this indicates a capacity addition of 1.25 GW. This is extremely challenging to achieve for a state that depends on electricity imports from neighboring states and where PSPS are becoming more frequent. Currently, propane and other low-carbon fuels qualify for California LCFS for forklift applications and hence the abrupt shift toward "zero"-emission forklifts will be a missed opportunity for accelerating decarbonization using low-carbon, renewable and blends of renewable, and low-carbon fuels.*

As good stewards of environmental justice, we need to ensure that we are not displacing the problem in space and/or time but are indeed solving a problem for the greater good of humanity and all life on Earth.

# V. Appendix

# V. Appendix

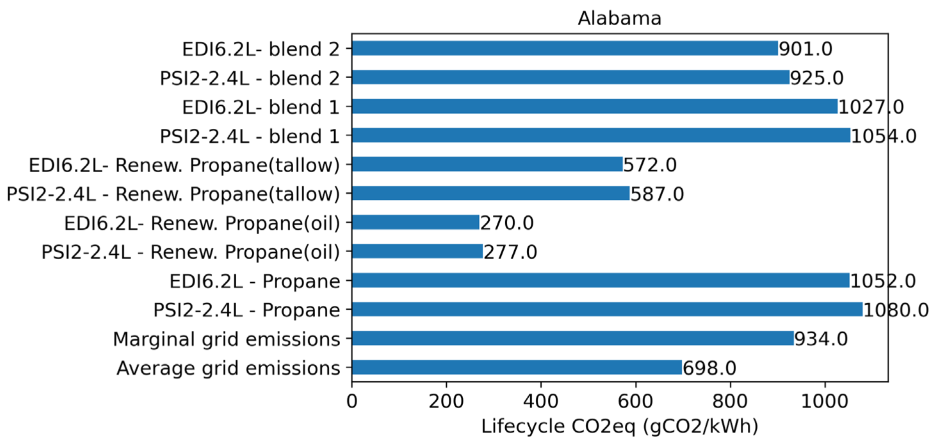
## a. Manufacturer names and codes

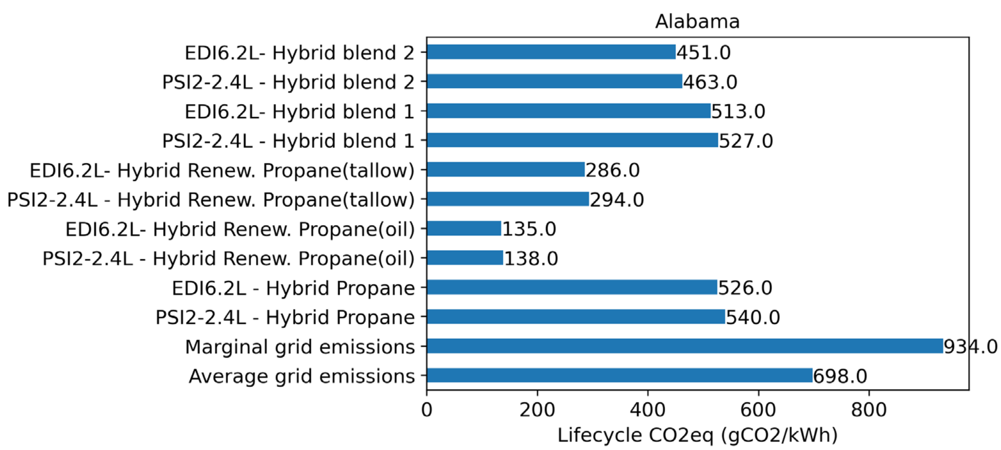
| MANUFACTURER CODE | MANUFACTURER NAME |
|---|---|
| ASO | Atech Sns Co., Ltd. |
| CEQ | Crown Equipment Corporation |
| DIC | Doosan Infracore Co., Ltd. |
| DZX | Deutz AG |
| EDI | Engine Distributors, Inc. |
| EMP | EMPCO, LLC |
| KBX | Kubota Corporation |
| KEM | KEM Equipment, Inc. |
| LLT | KION North America Corp. |
| NFX | Global Component Technologies Corporation |
| PSI | Power Solutions International, Inc. |
| WGC | Woodward, Inc. |
| WML | Wisconsin Engines, LLC |
| YDX | Yanmar Power Technology Co., Ltd. |

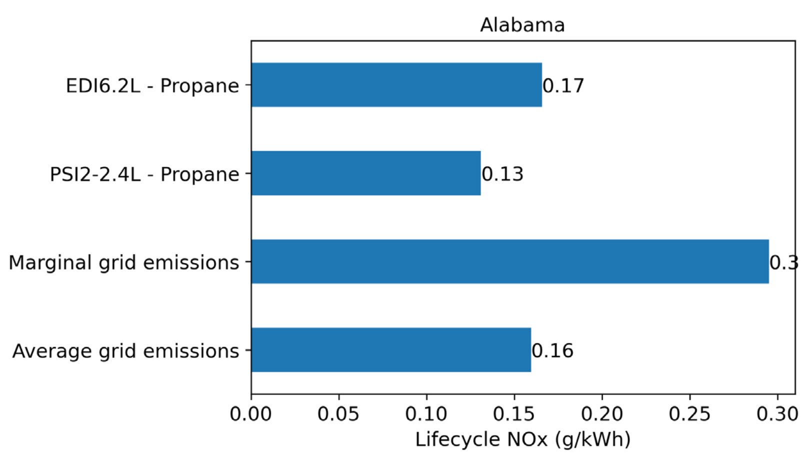
## b. U.S. state-level emission profiles

The state-level emission profiles are shown as a set of triads as in the body of this white paper. For each state-level, the first chart compares the electric forklift lifecycle CO2eq emissions to lifecycle emissions from two propane engines operated with conventional propane, renewable propane (with two different carbon intensities), and blends of conventional propane with rDME (5% wt.). The second chart shows the same plot but now for series hybrid propane engines. The third chart shows the comparisons of lifecycle NOx emissions between electric forklifts and propane forklifts.

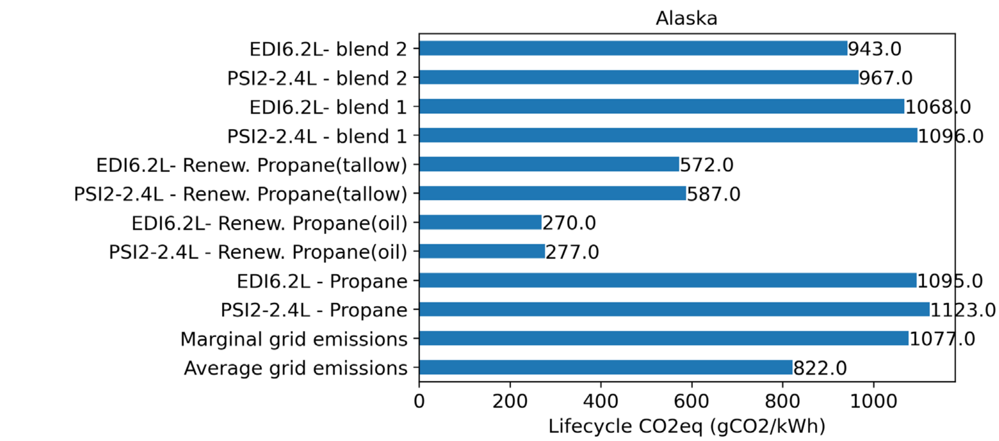
## Alabama

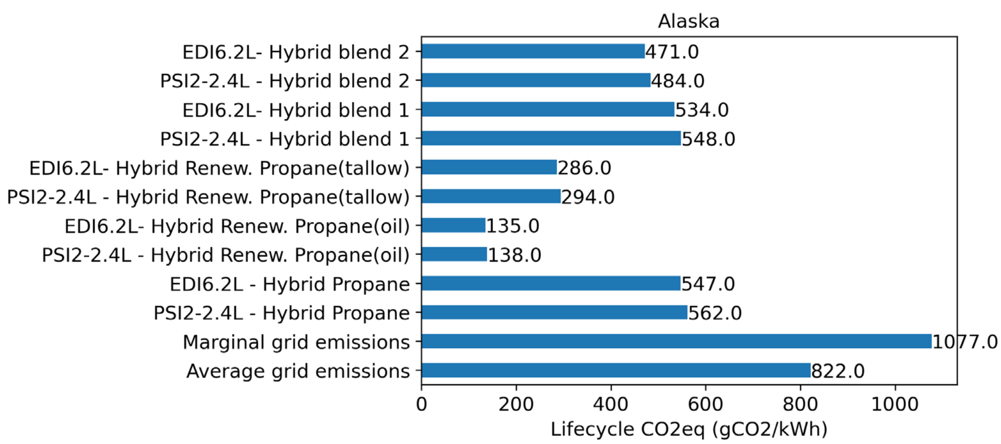

Alabama
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
901.0
925.0
1027.0
1054.0
572.0
587.0
270.0
277.0
1052.0
1080.0
934.0
698.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)

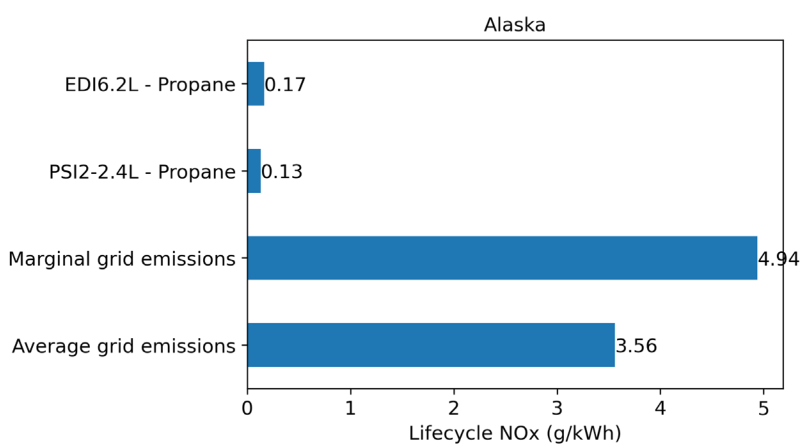

Alabama
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
451.0
463.0
513.0
527.0
286.0
294.0
135.0
138.0
526.0
540.0
934.0
698.0
0
200
400
600
800
Lifecycle CO2eq (gCO2/kWh)


Alabama
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.3
0.16
0.00
0.05
0.10
0.15
0.20
0.25
0.30
Lifecycle NOx (g/kWh)

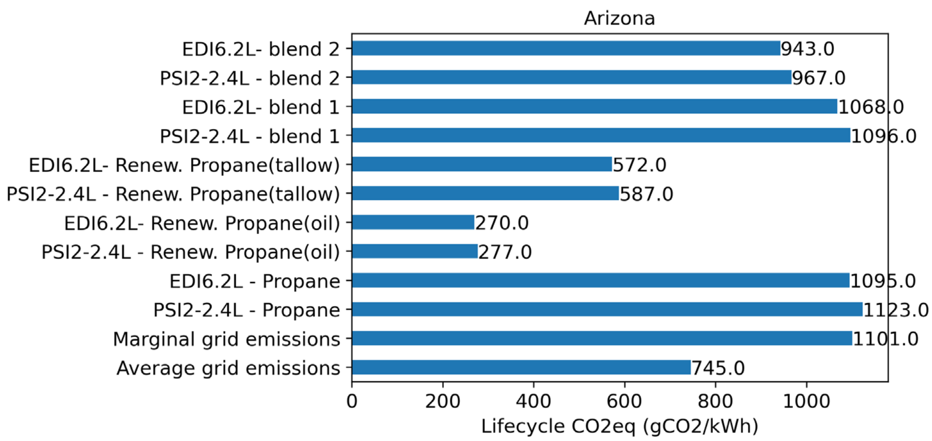
## Alaska


Alaska
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
943.0
967.0
1068.0
1096.0
572.0
587.0
270.0
277.0
1095.0
1123.0
1077.0
822.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)

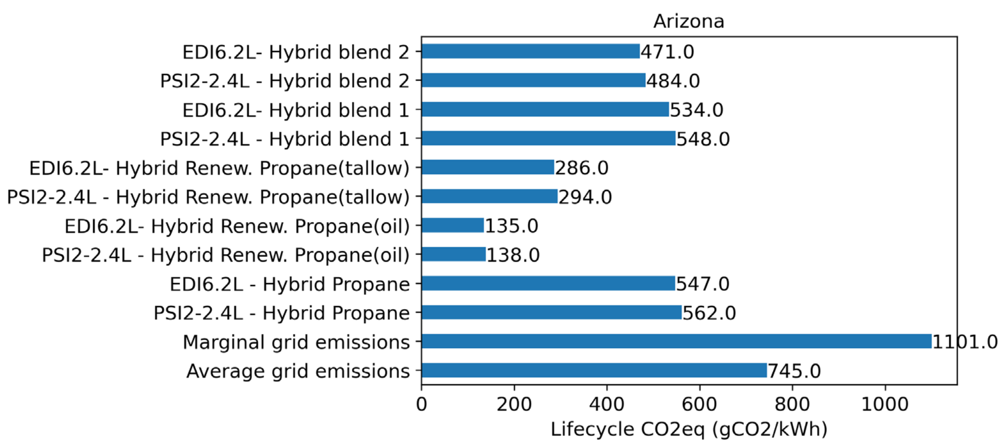

Alaska
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
471.0
484.0
534.0
548.0
286.0
294.0
135.0
138.0
547.0
562.0
1077.0
822.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)


Alaska
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
4.94
3.56
0
1
2
3
4
5
Lifecycle NOx (g/kWh)

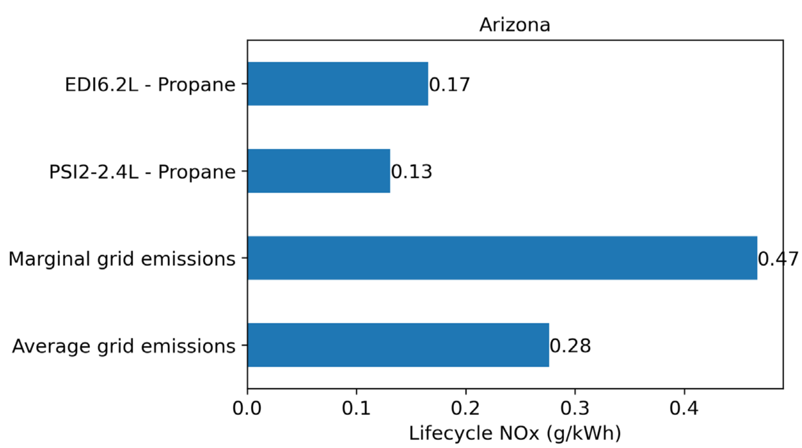
## Arizona



Arizona
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
943.0
967.0
1068.0
1096.0
572.0
587.0
270.0
277.0
1095.0
1123.0
1101.0
745.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)

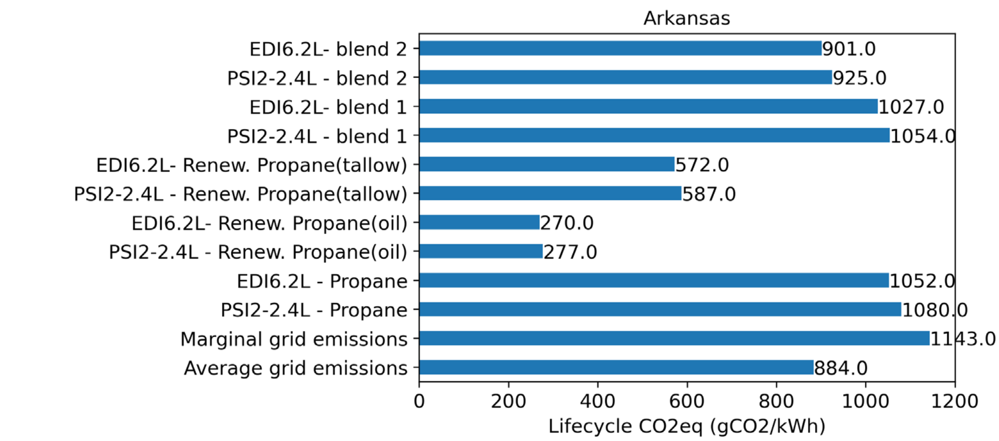



Arizona
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
471.0
484.0
534.0
548.0
286.0
294.0
135.0
138.0
547.0
562.0
1101.0
745.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)

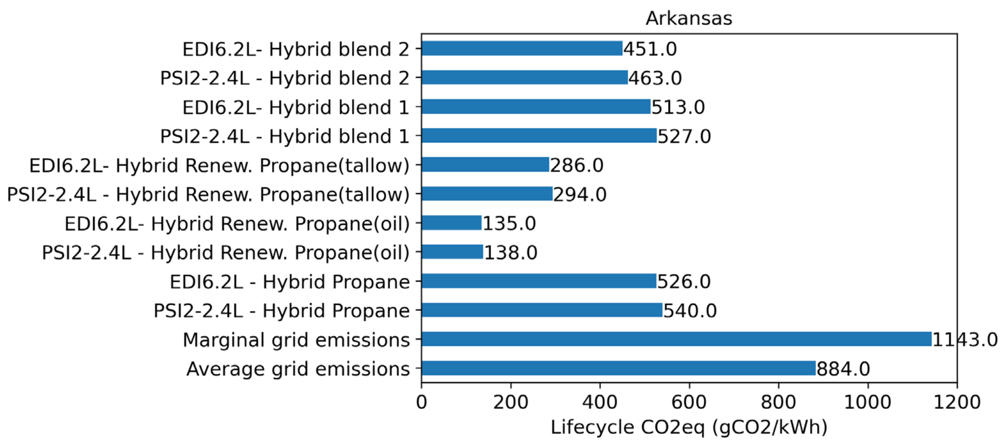



Arizona
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.47
0.28
0.0
0.1
0.2
0.3
0.4
Lifecycle NOx (g/kWh)

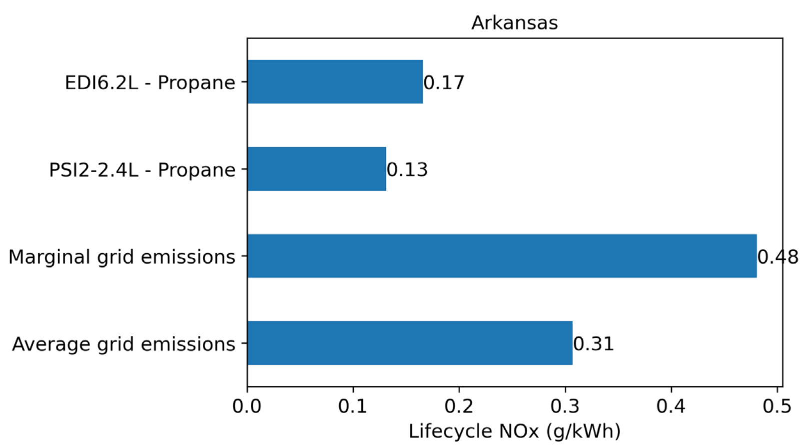
## Arkansas



Arkansas
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
901.0
925.0
1027.0
1054.0
572.0
587.0
270.0
277.0
1052.0
1080.0
1143.0
884.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)

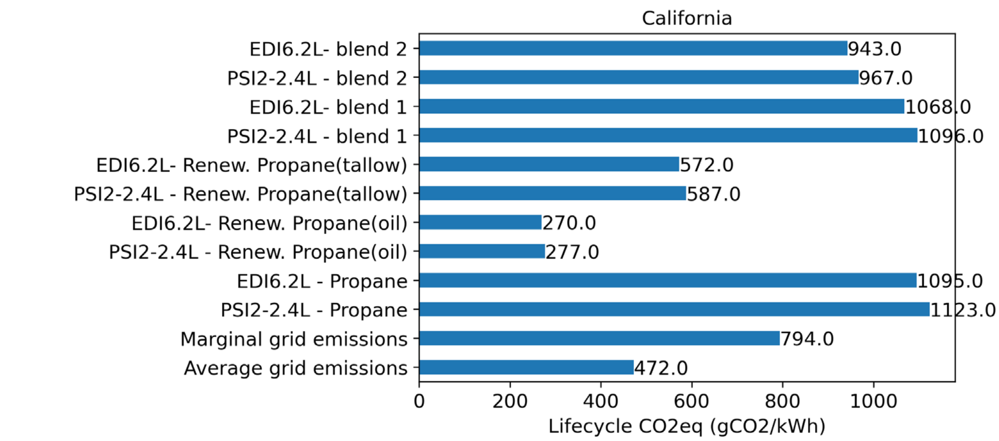



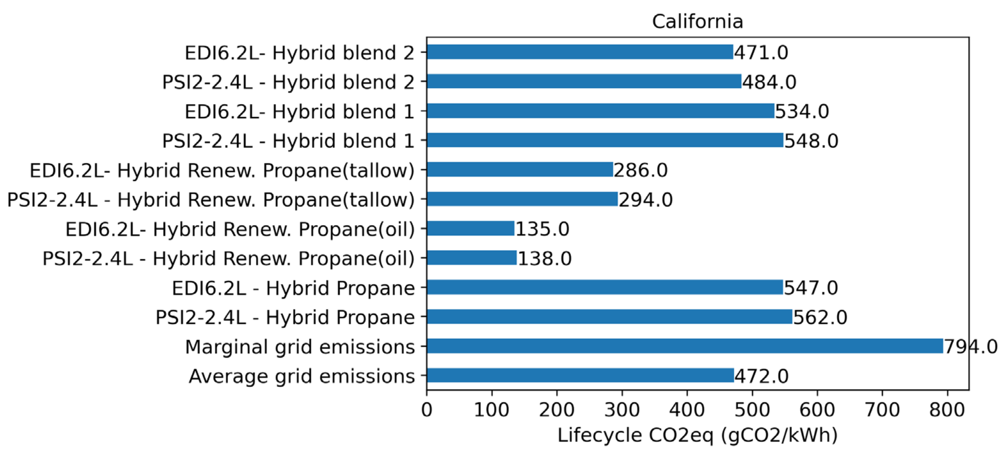
Arkansas
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
451.0
463.0
513.0
527.0
286.0
294.0
135.0
138.0
526.0
540.0
1143.0
884.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)

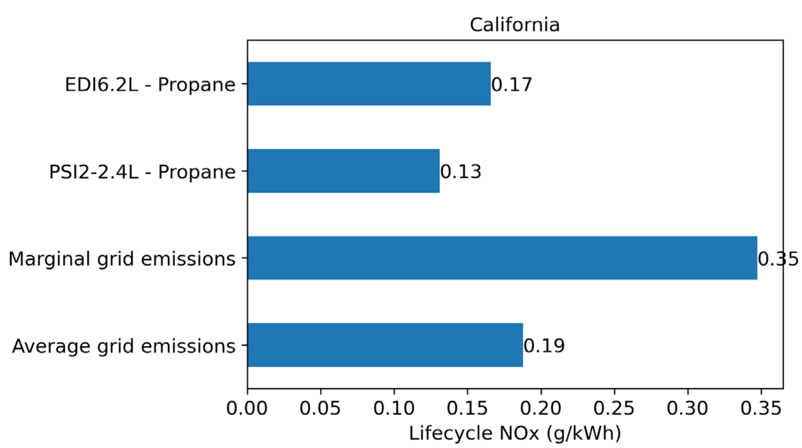



Arkansas
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.48
0.31
0.0
0.1
0.2
0.3
0.4
0.5
Lifecycle NOx (g/kWh)

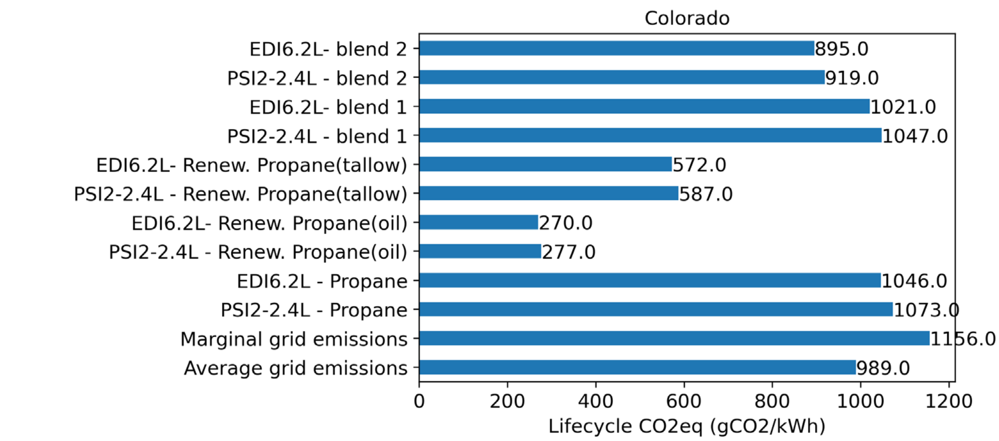
## California

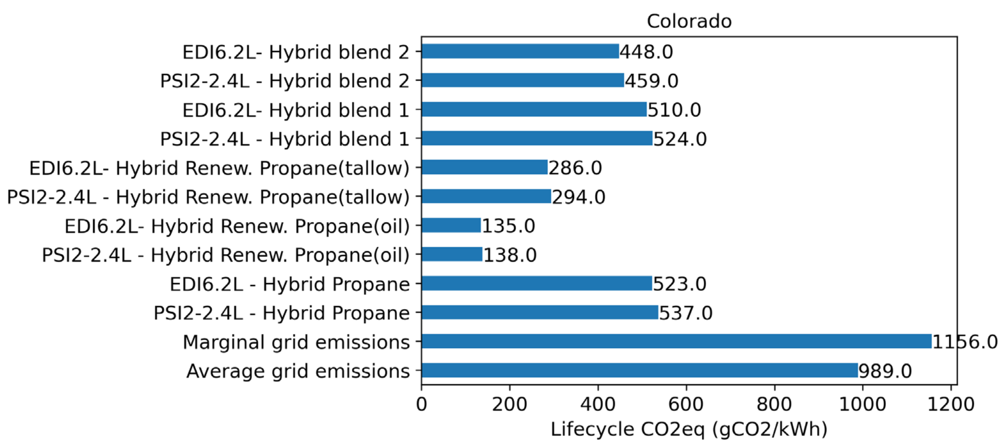

California
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
943.0
967.0
1068.0
1096.0
572.0
587.0
270.0
277.0
1095.0
1123.0
794.0
472.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)

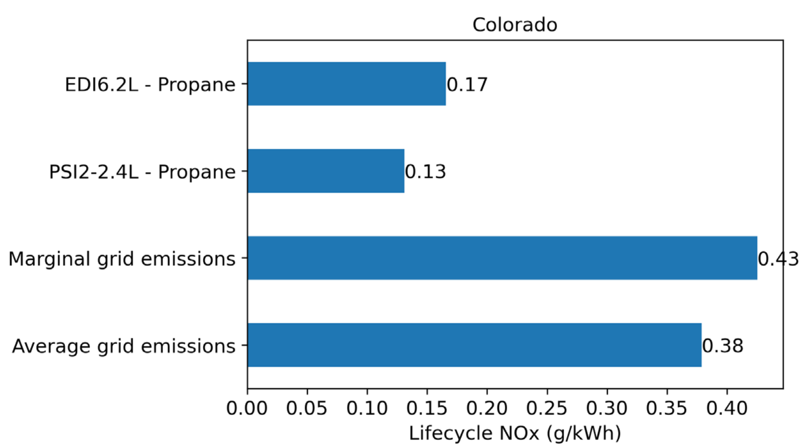

California
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
471.0
484.0
534.0
548.0
286.0
294.0
135.0
138.0
547.0
562.0
794.0
472.0
0
100
200
300
400
500
600
700
800
Lifecycle CO2eq (gCO2/kWh)


California
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.35
0.19
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Lifecycle NOx (g/kWh)

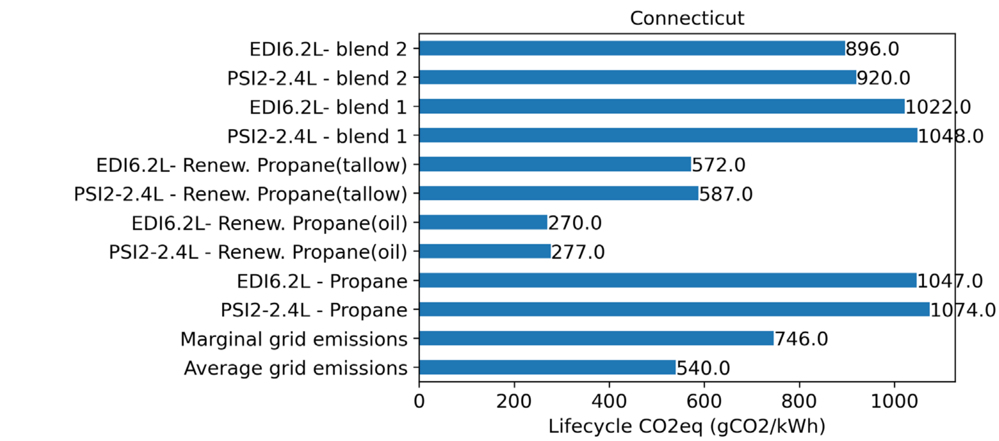
## Colorado

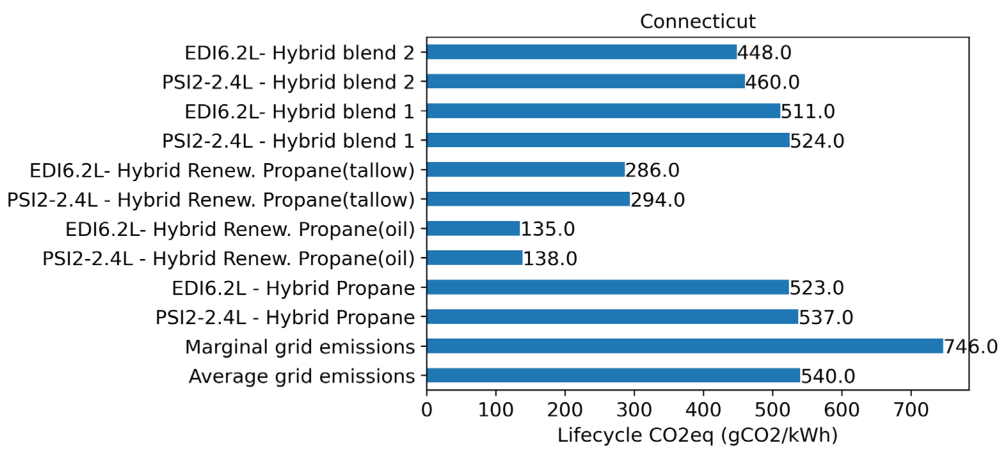

Colorado
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
895.0
919.0
1021.0
1047.0
572.0
587.0
270.0
277.0
1046.0
1073.0
1156.0
989.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)

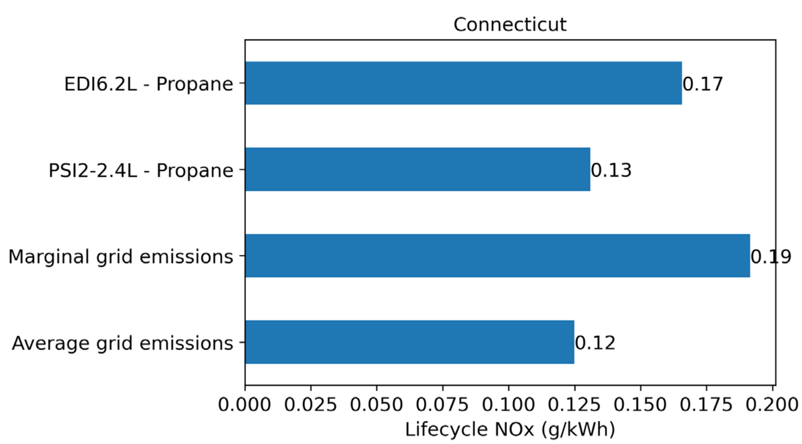

Colorado
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
448.0
459.0
510.0
524.0
286.0
294.0
135.0
138.0
523.0
537.0
1156.0
989.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)


Colorado
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.43
0.38
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
Lifecycle NOx (g/kWh)

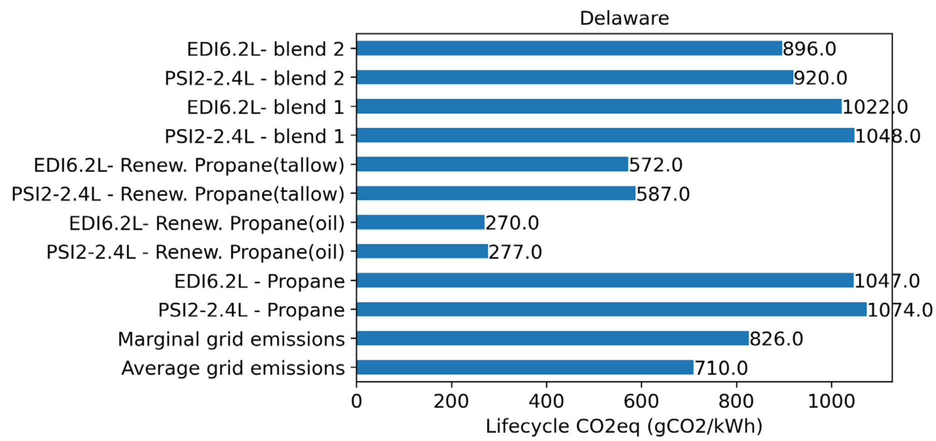
## Connecticut

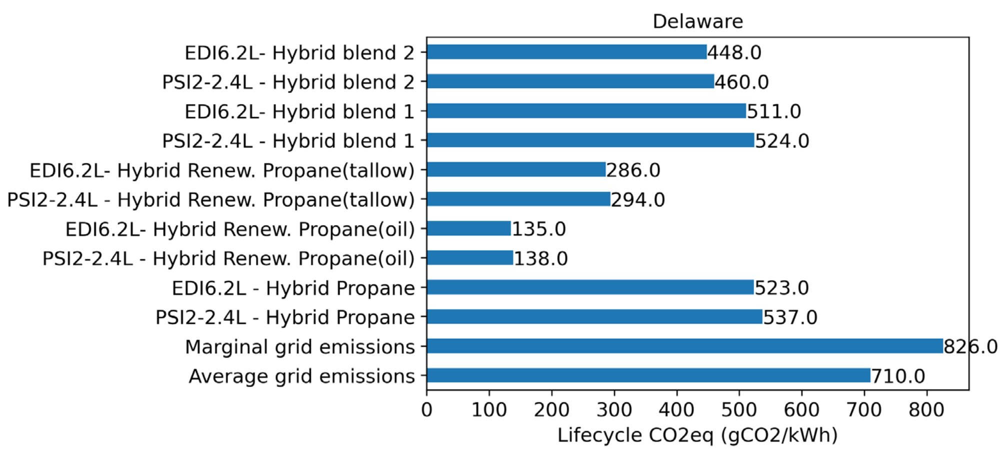


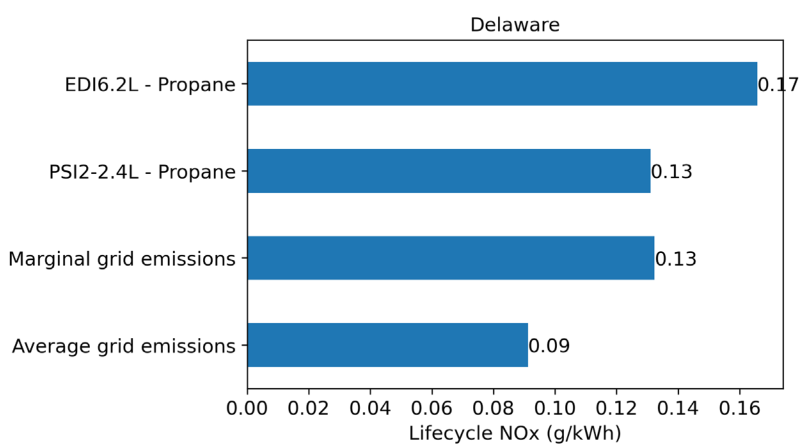



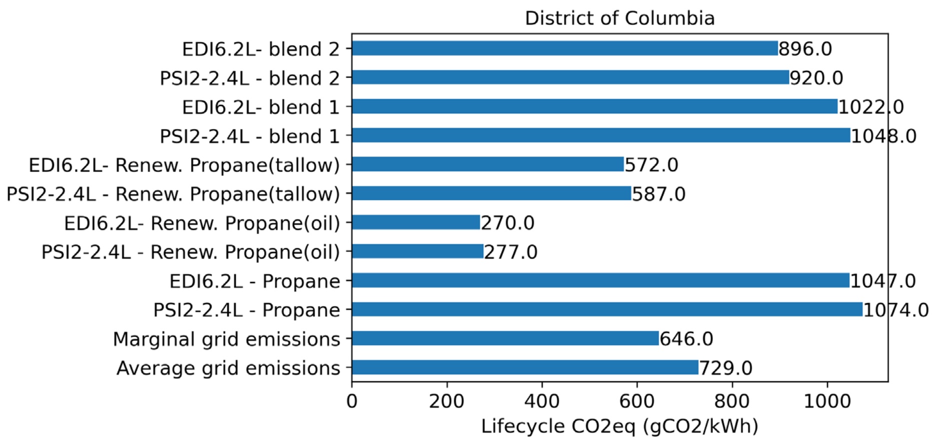
## Delaware

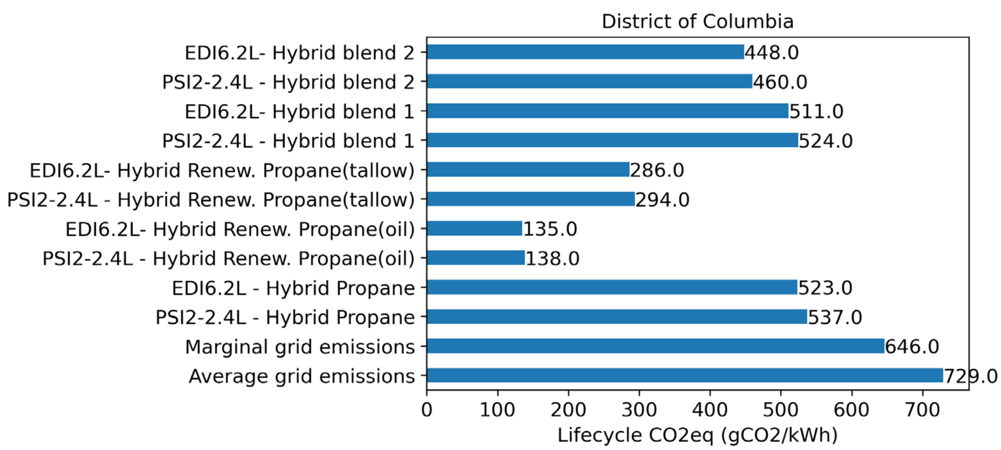

Delaware
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
896.0
920.0
1022.0
1048.0
572.0
587.0
270.0
277.0
1047.0
1074.0
826.0
710.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)

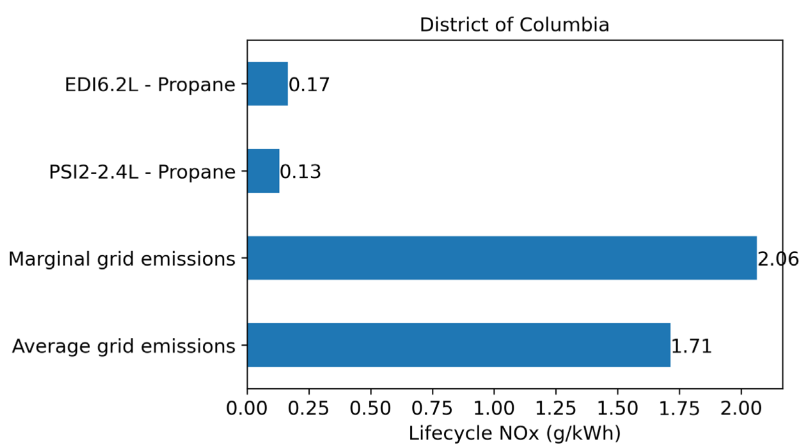

Delaware
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
448.0
460.0
511.0
524.0
286.0
294.0
135.0
138.0
523.0
537.0
826.0
710.0
0
100
200
300
400
500
600
700
800
Lifecycle CO2eq (gCO2/kWh)


Delaware
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.13
0.09
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
Lifecycle NOx (g/kWh)

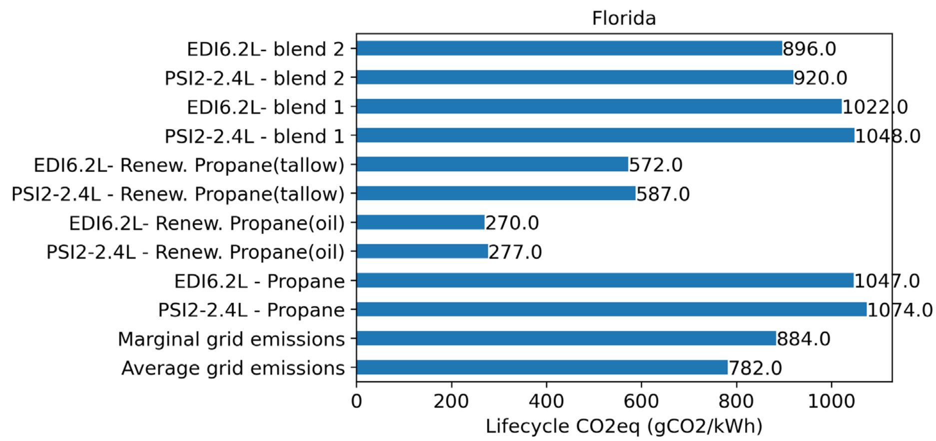
## District of Columbia

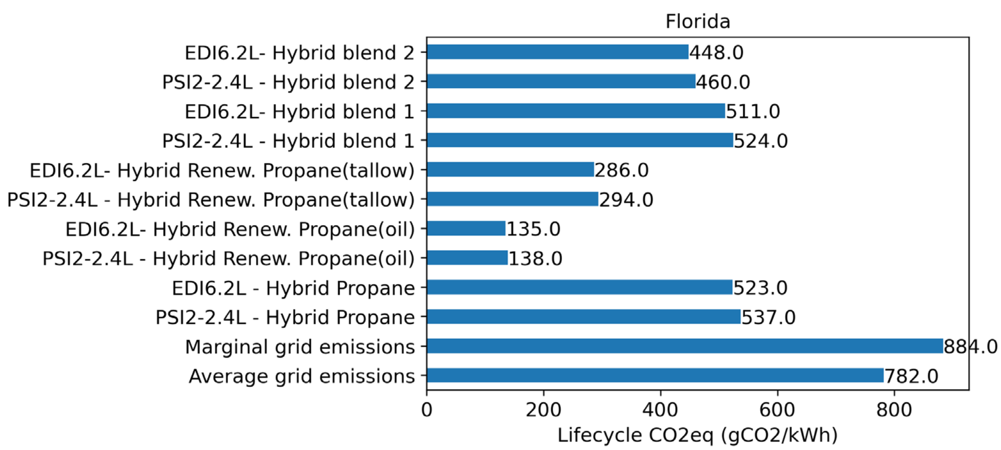


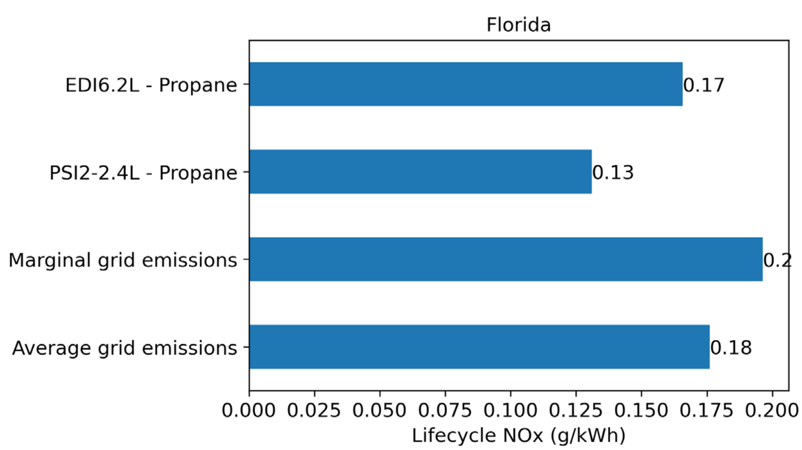



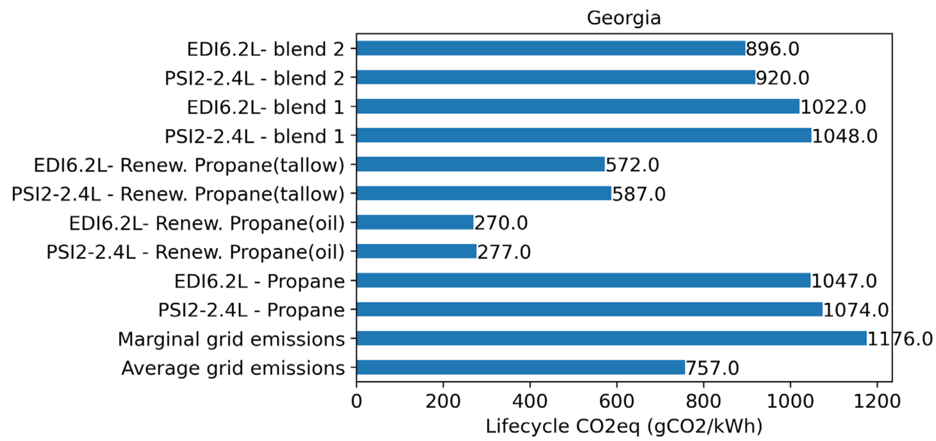
## Florida

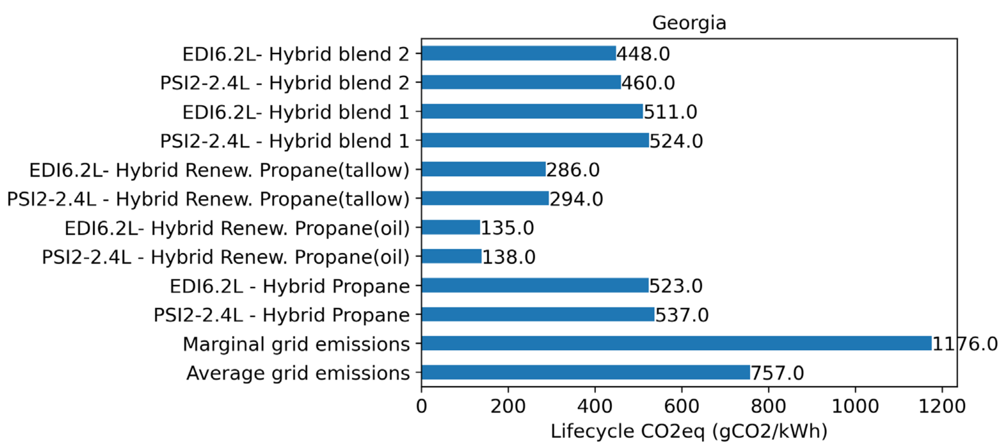

Florida
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
896.0
920.0
1022.0
1048.0
572.0
587.0
270.0
277.0
1047.0
1074.0
884.0
782.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)

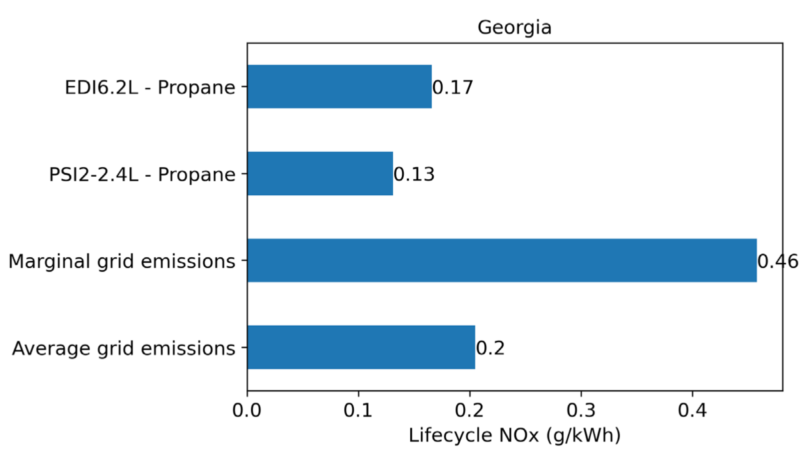

Florida
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
448.0
460.0
511.0
524.0
286.0
294.0
135.0
138.0
523.0
537.0
884.0
782.0
0
200
400
600
800
Lifecycle CO2eq (gCO2/kWh)


Florida
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.2
0.18
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
Lifecycle NOx (g/kWh)

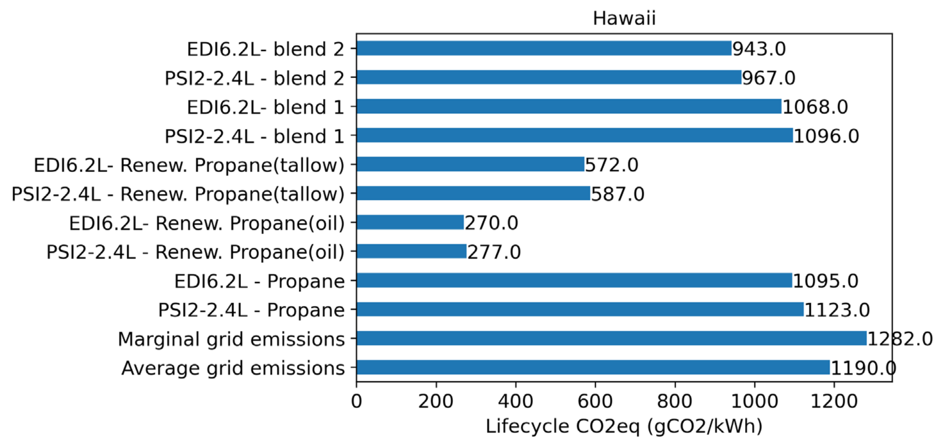
## Georgia


Georgia
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
896.0
920.0
1022.0
1048.0
572.0
587.0
270.0
277.0
1047.0
1074.0
1176.0
757.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)

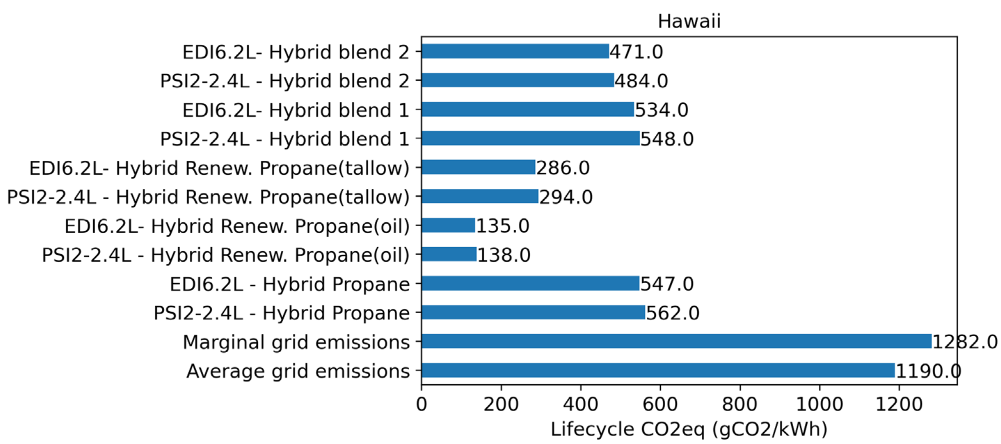

Georgia
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
448.0
460.0
511.0
524.0
286.0
294.0
135.0
138.0
523.0
537.0
1176.0
757.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)


Georgia
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.46
0.2
0.0
0.1
0.2
0.3
0.4
Lifecycle NOx (g/kWh)

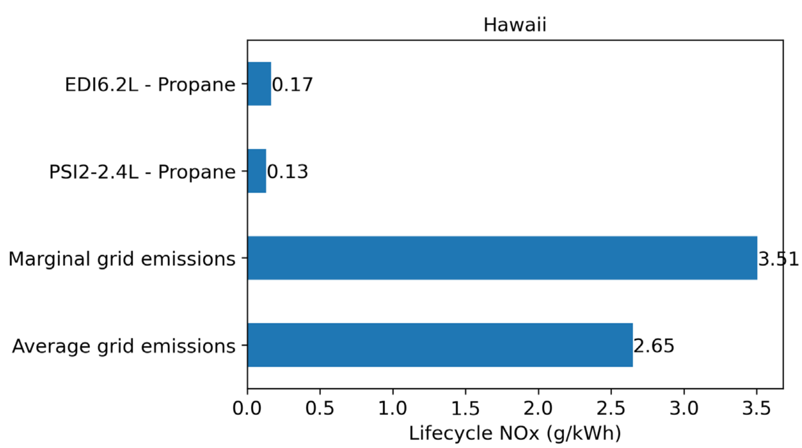
## Hawaii



Hawaii
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
943.0
967.0
1068.0
1096.0
572.0
587.0
270.0
277.0
1095.0
1123.0
1282.0
1190.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)

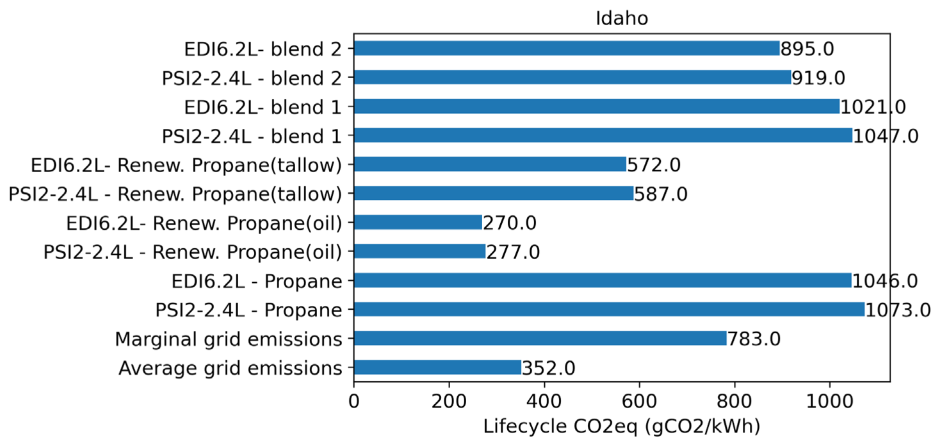



Hawaii
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
471.0
484.0
534.0
548.0
286.0
294.0
135.0
138.0
547.0
562.0
1282.0
1190.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)

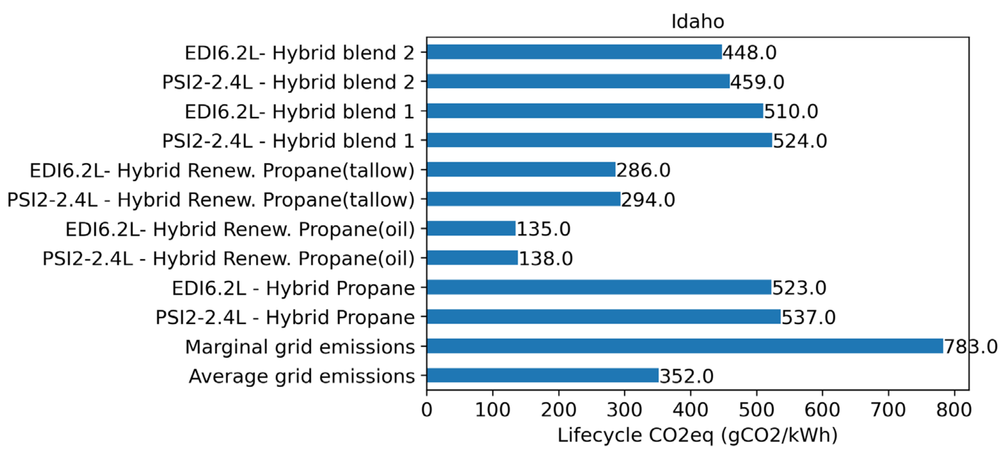



Hawaii
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
3.51
2.65
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Lifecycle NOx (g/kWh)

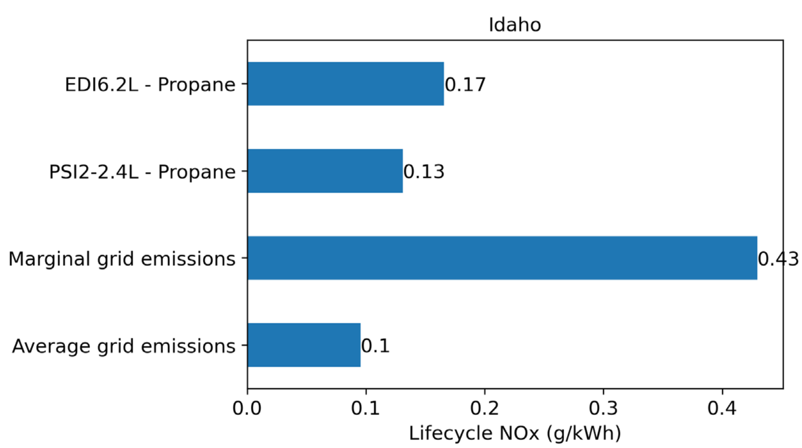
## Idaho



Idaho
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
895.0
919.0
1021.0
1047.0
572.0
587.0
270.0
277.0
1046.0
1073.0
783.0
352.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)

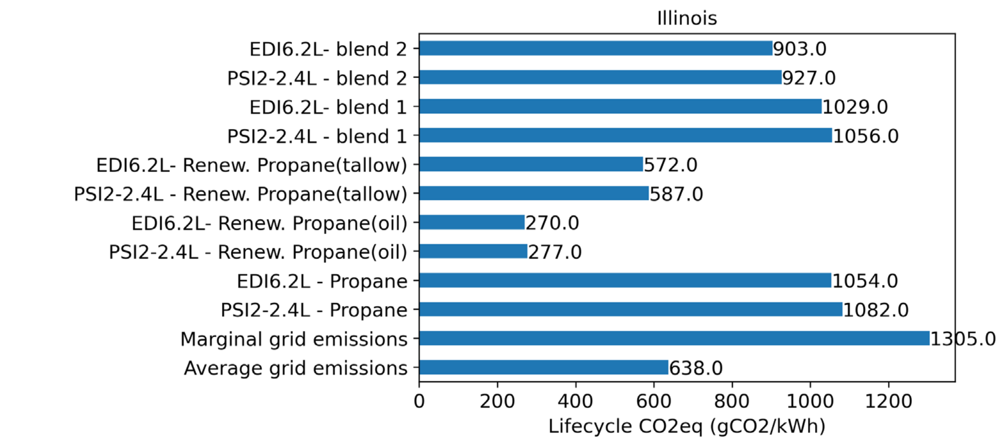



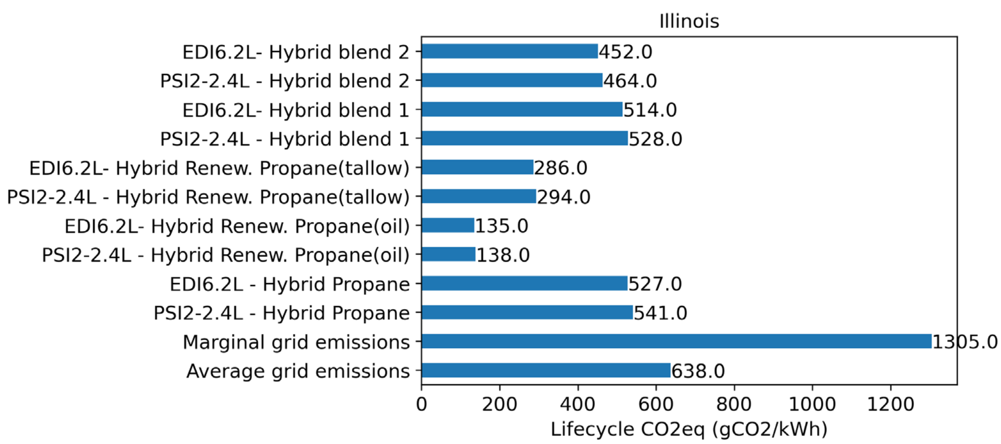
Idaho
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
448.0
459.0
510.0
524.0
286.0
294.0
135.0
138.0
523.0
537.0
783.0
352.0
0
100
200
300
400
500
600
700
800
Lifecycle CO2eq (gCO2/kWh)

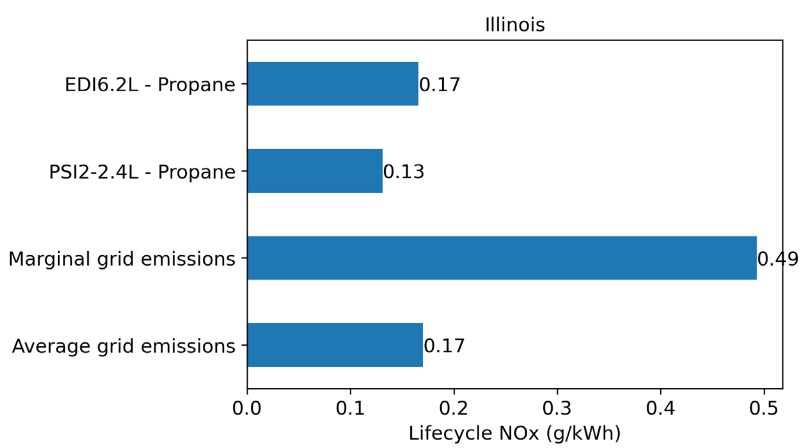



Idaho
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.43
0.1
0.0
0.1
0.2
0.3
0.4
Lifecycle NOx (g/kWh)

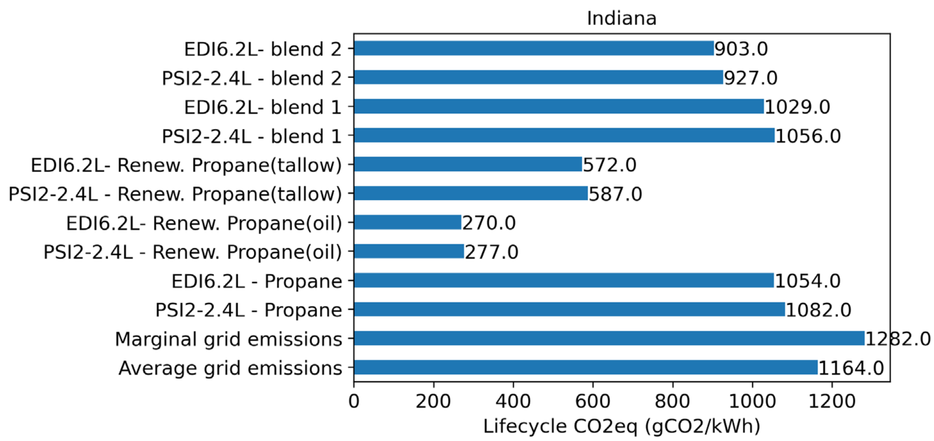
## Illinois

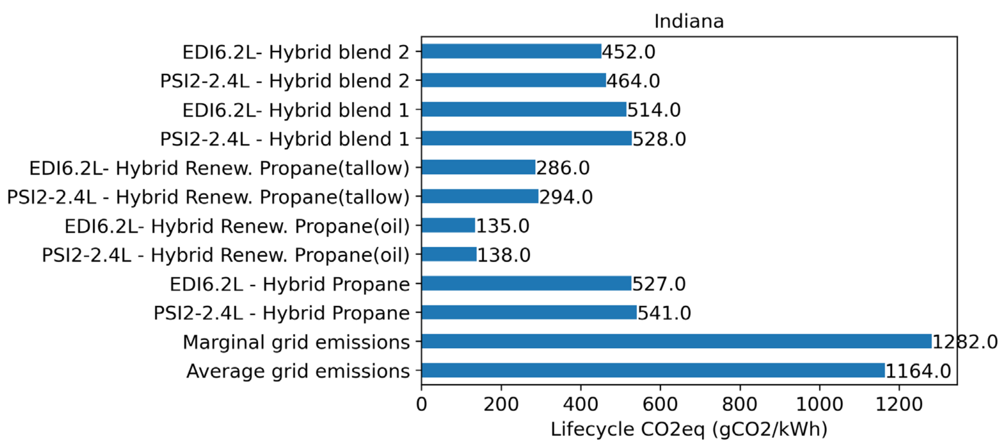

Illinois
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
903.0
927.0
1029.0
1056.0
572.0
587.0
270.0
277.0
1054.0
1082.0
1305.0
638.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)

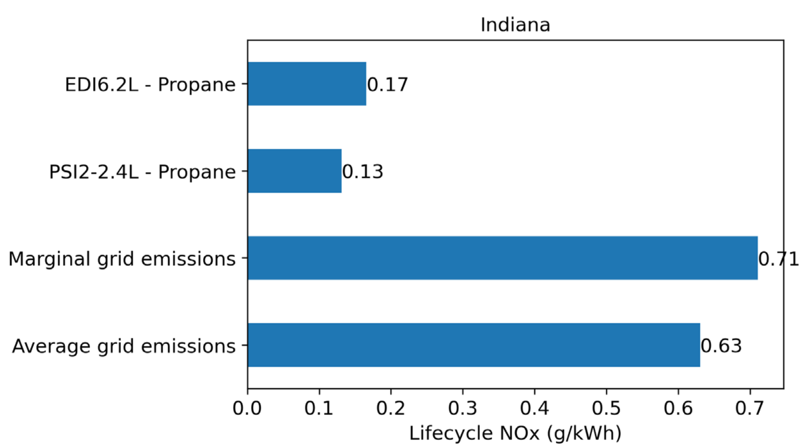

Illinois
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
452.0
464.0
514.0
528.0
286.0
294.0
135.0
138.0
527.0
541.0
1305.0
638.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)


Illinois
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.49
0.17
0.0
0.1
0.2
0.3
0.4
0.5
Lifecycle NOx (g/kWh)

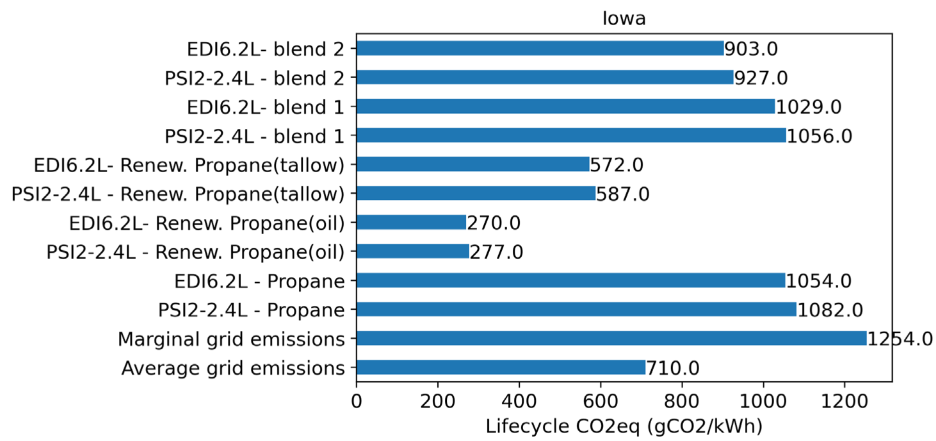
## Indiana

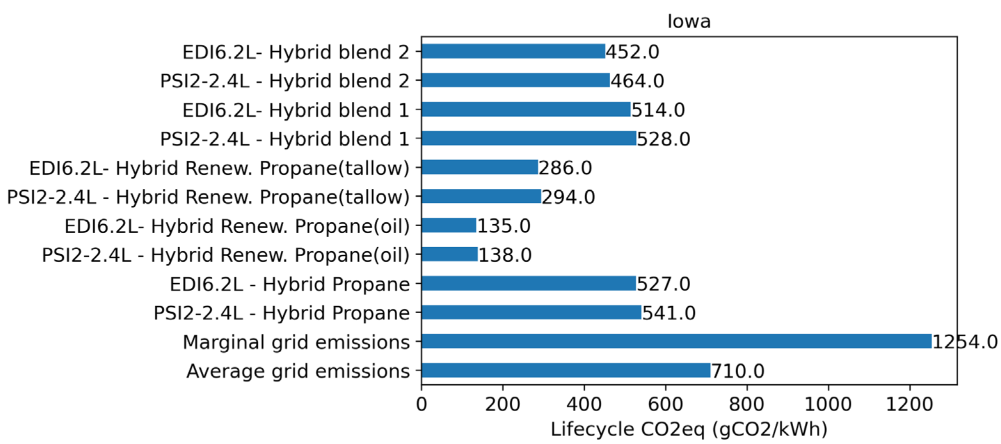

Indiana
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
903.0
927.0
1029.0
1056.0
572.0
587.0
270.0
277.0
1054.0
1082.0
1282.0
1164.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)

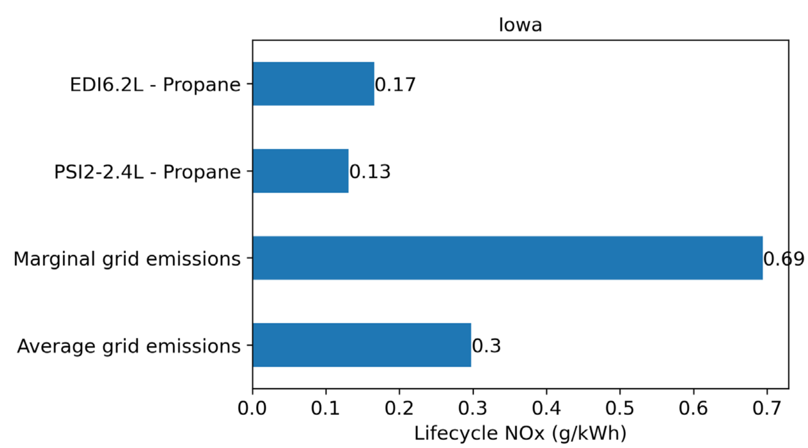

Indiana
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
452.0
464.0
514.0
528.0
286.0
294.0
135.0
138.0
527.0
541.0
1282.0
1164.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)


Indiana
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.71
0.63
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Lifecycle NOx (g/kWh)

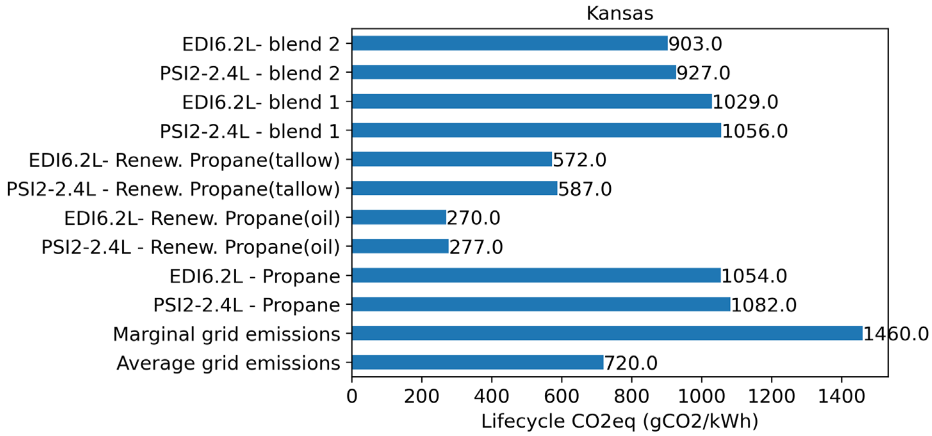
## Iowa

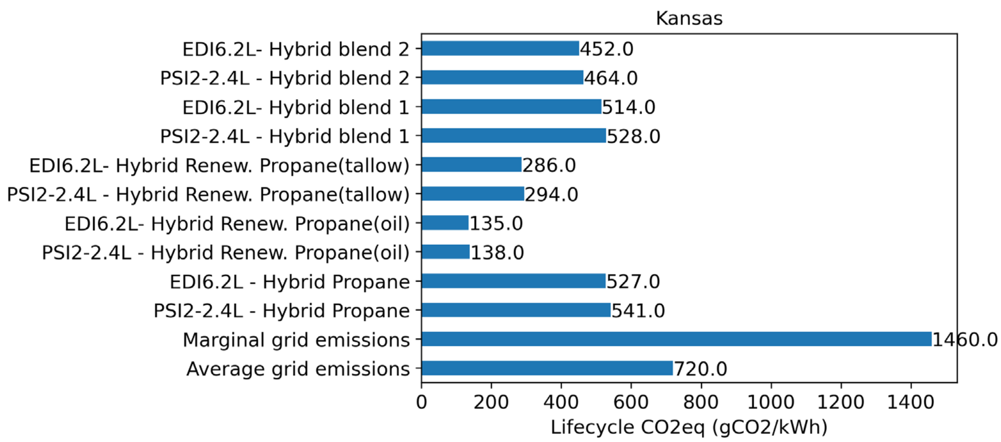

Iowa
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
903.0
927.0
1029.0
1056.0
572.0
587.0
270.0
277.0
1054.0
1082.0
1254.0
710.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)

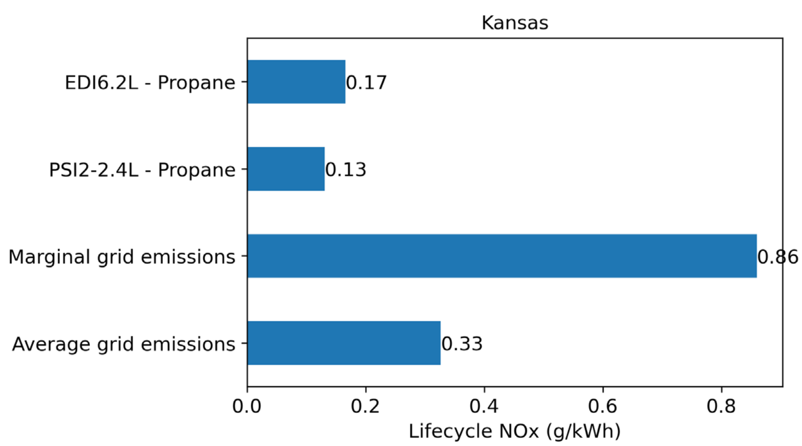

Iowa
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
452.0
464.0
514.0
528.0
286.0
294.0
135.0
138.0
527.0
541.0
1254.0
710.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)


Iowa
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.69
0.3
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Lifecycle NOx (g/kWh)

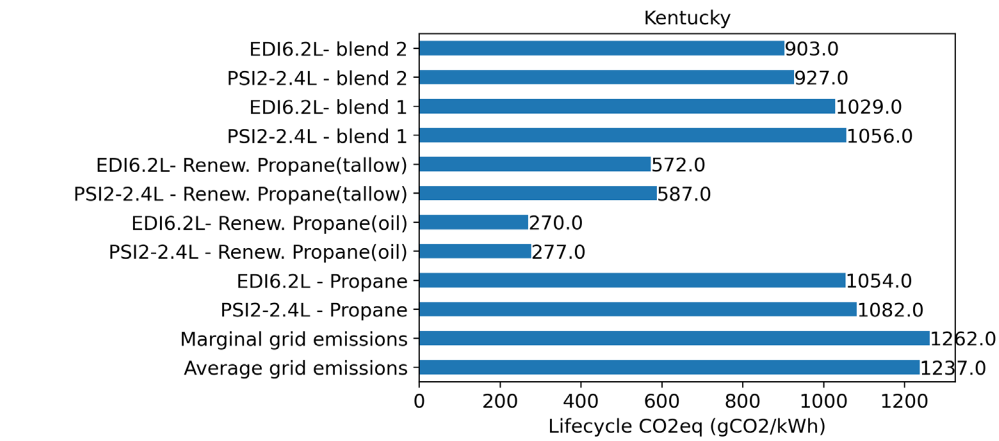
## Kansas

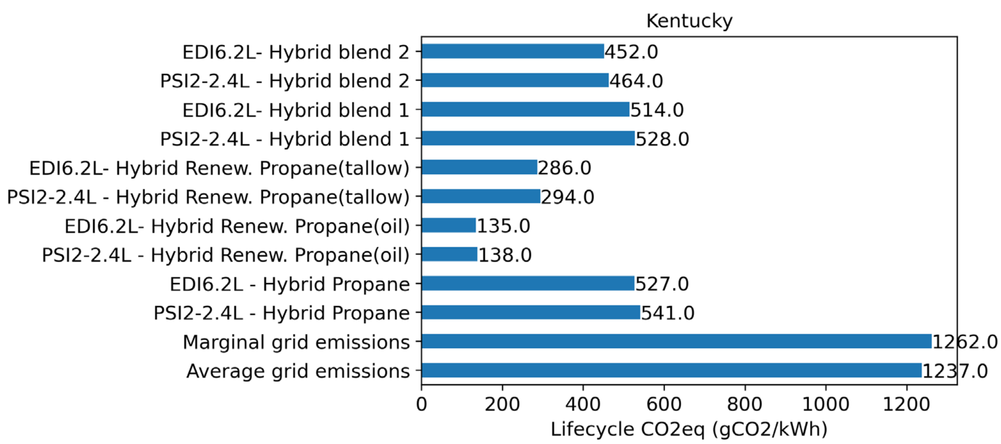

Kansas
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
903.0
927.0
1029.0
1056.0
572.0
587.0
270.0
277.0
1054.0
1082.0
1460.0
720.0
0
200
400
600
800
1000
1200
1400
Lifecycle CO2eq (gCO2/kWh)

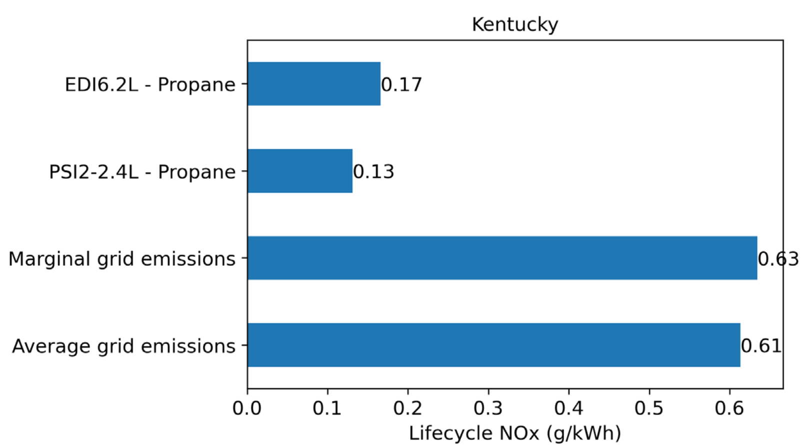

Kansas
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
452.0
464.0
514.0
528.0
286.0
294.0
135.0
138.0
527.0
541.0
1460.0
720.0
0
200
400
600
800
1000
1200
1400
Lifecycle CO2eq (gCO2/kWh)


Kansas
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.86
0.33
0.0
0.2
0.4
0.6
0.8
Lifecycle NOx (g/kWh)

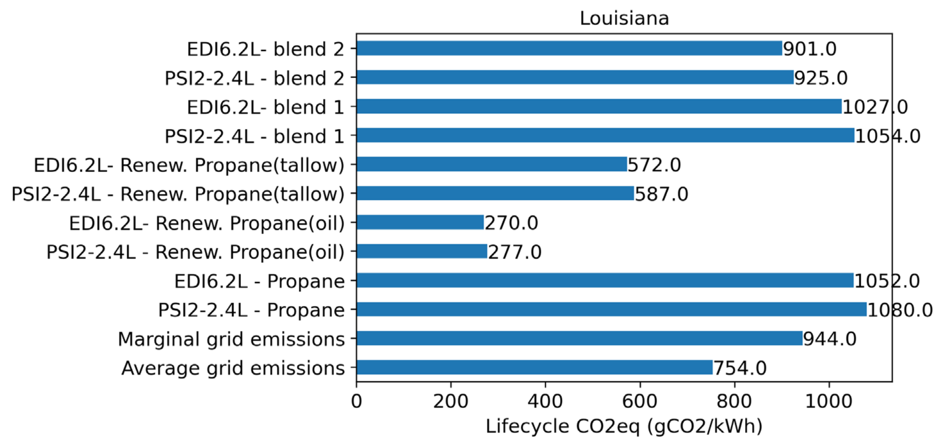
## Kentucky

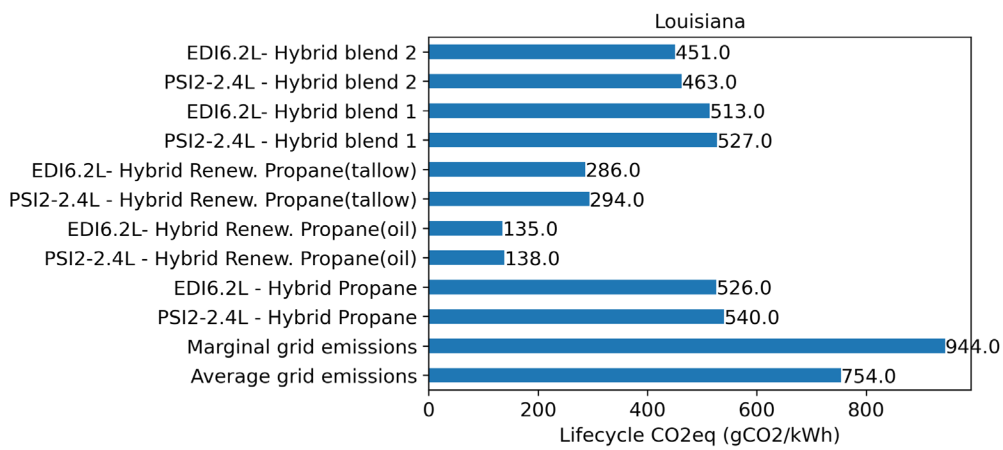

Kentucky
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
903.0
927.0
1029.0
1056.0
572.0
587.0
270.0
277.0
1054.0
1082.0
1262.0
1237.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)

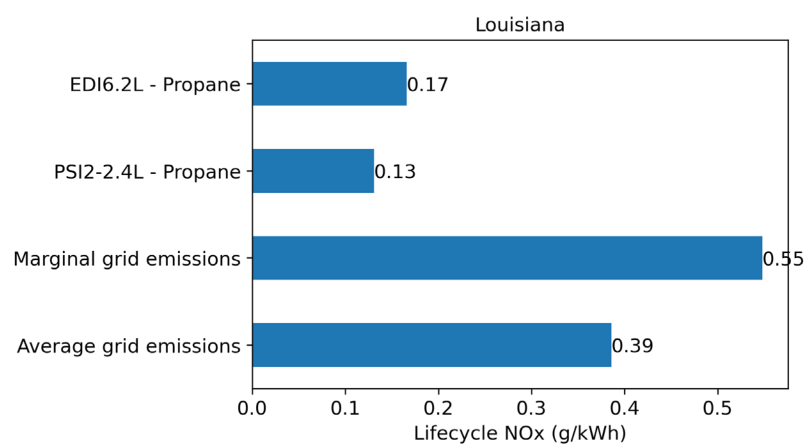

Kentucky
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
452.0
464.0
514.0
528.0
286.0
294.0
135.0
138.0
527.0
541.0
1262.0
1237.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)


Kentucky
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.63
0.61
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Lifecycle NOx (g/kWh)

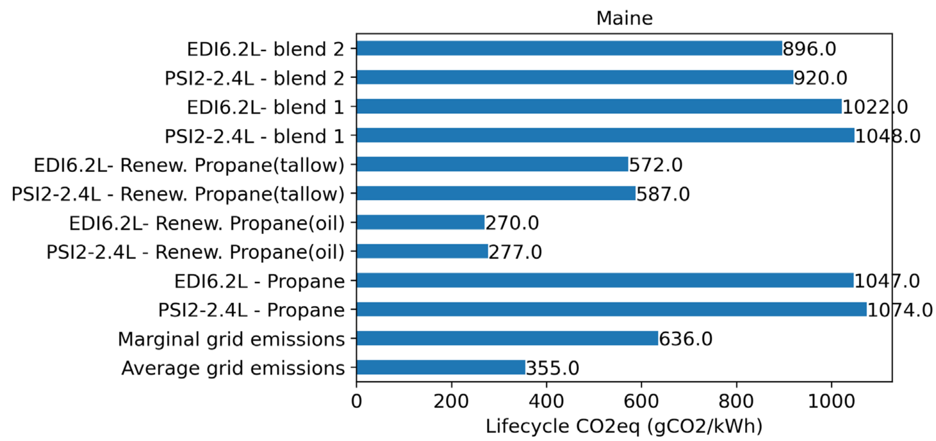
## Louisiana

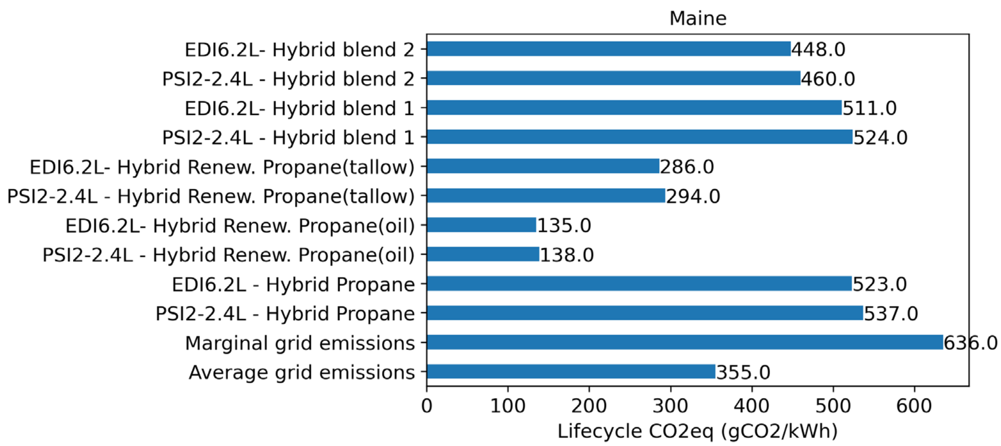

Louisiana
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
901.0
925.0
1027.0
1054.0
572.0
587.0
270.0
277.0
1052.0
1080.0
944.0
754.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)

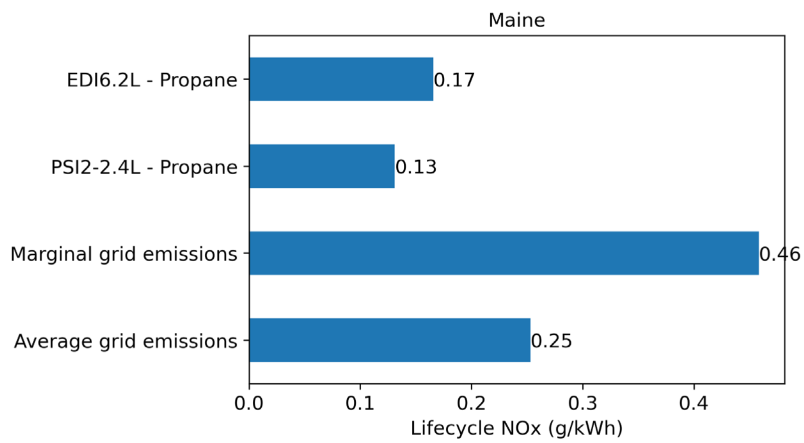

Louisiana
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
451.0
463.0
513.0
527.0
286.0
294.0
135.0
138.0
526.0
540.0
944.0
754.0
0
200
400
600
800
Lifecycle CO2eq (gCO2/kWh)


Louisiana
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.55
0.39
0.0
0.1
0.2
0.3
0.4
0.5
Lifecycle NOx (g/kWh)

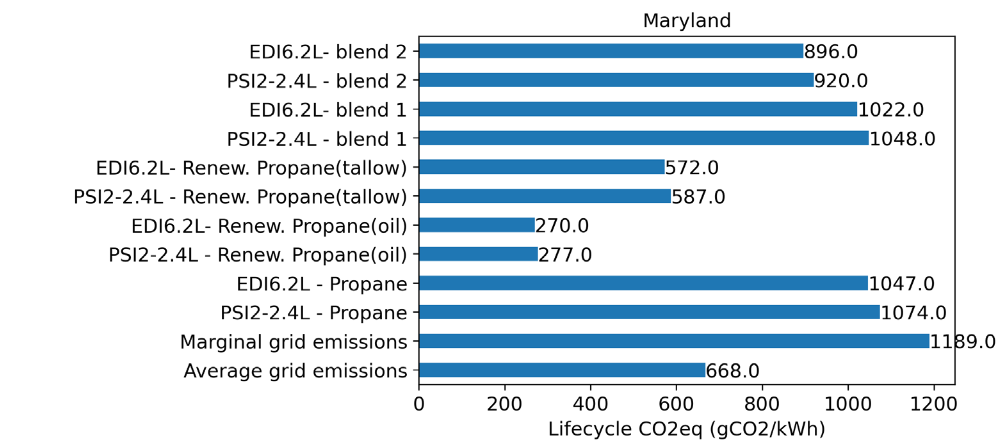
## Maine

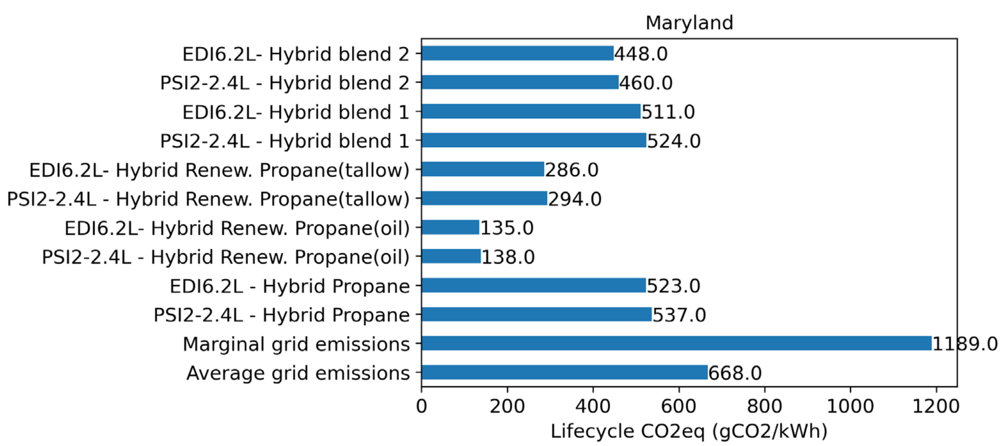

Maine
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
896.0
920.0
1022.0
1048.0
572.0
587.0
270.0
277.0
1047.0
1074.0
636.0
355.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)

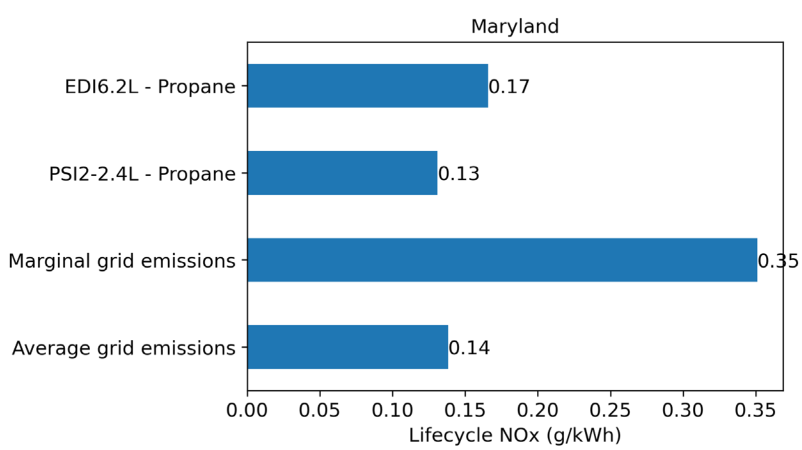

Maine
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
448.0
460.0
511.0
524.0
286.0
294.0
135.0
138.0
523.0
537.0
636.0
355.0
0
100
200
300
400
500
600
Lifecycle CO2eq (gCO2/kWh)


Maine
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.46
0.25
0.0
0.1
0.2
0.3
0.4
Lifecycle NOx (g/kWh)

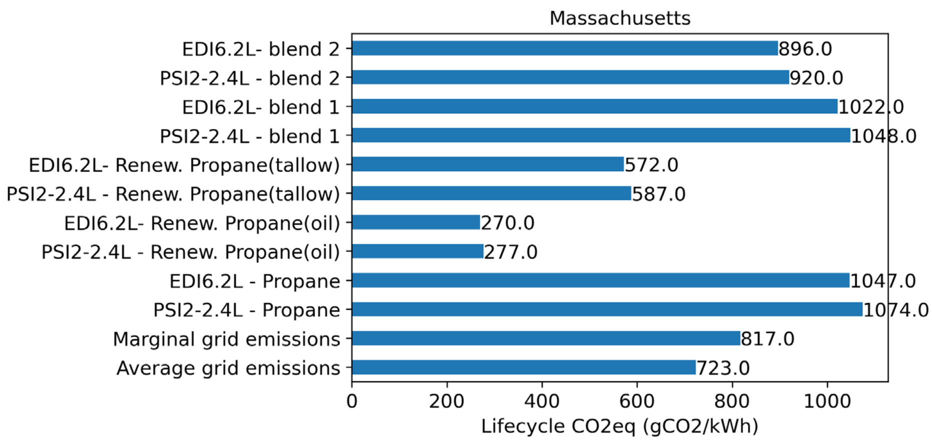
## Maryland

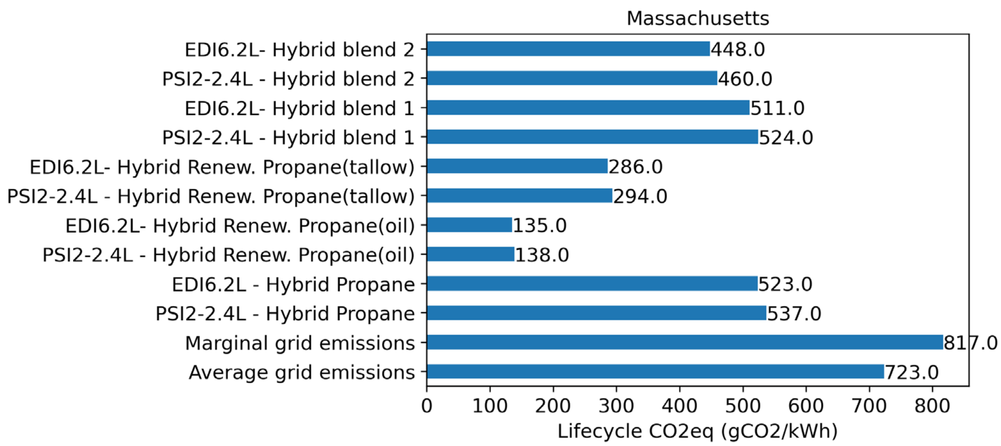

Maryland
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
896.0
920.0
1022.0
1048.0
572.0
587.0
270.0
277.0
1047.0
1074.0
1189.0
668.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)

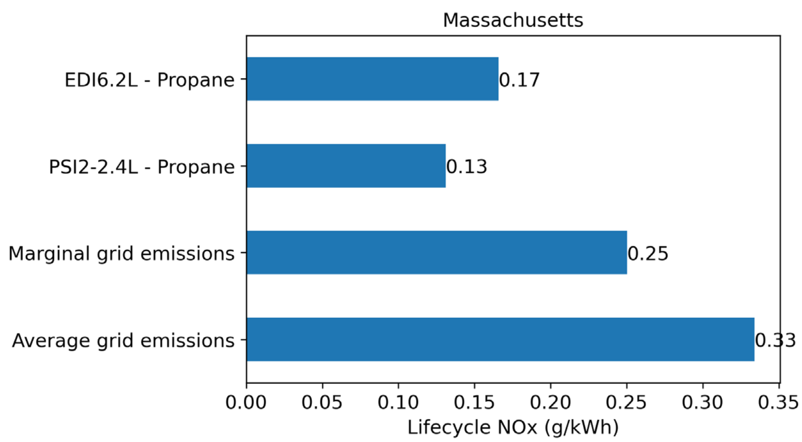

Maryland
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
448.0
460.0
511.0
524.0
286.0
294.0
135.0
138.0
523.0
537.0
1189.0
668.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)


Maryland
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.35
0.14
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Lifecycle NOx (g/kWh)

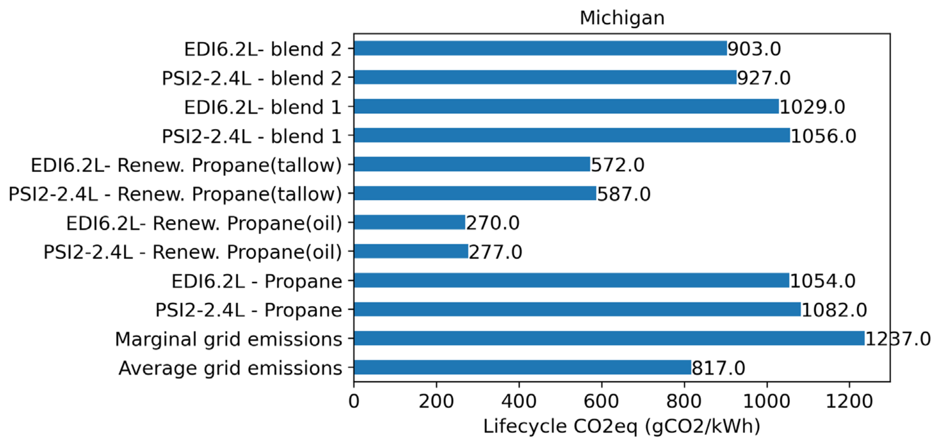
## Massachusetts

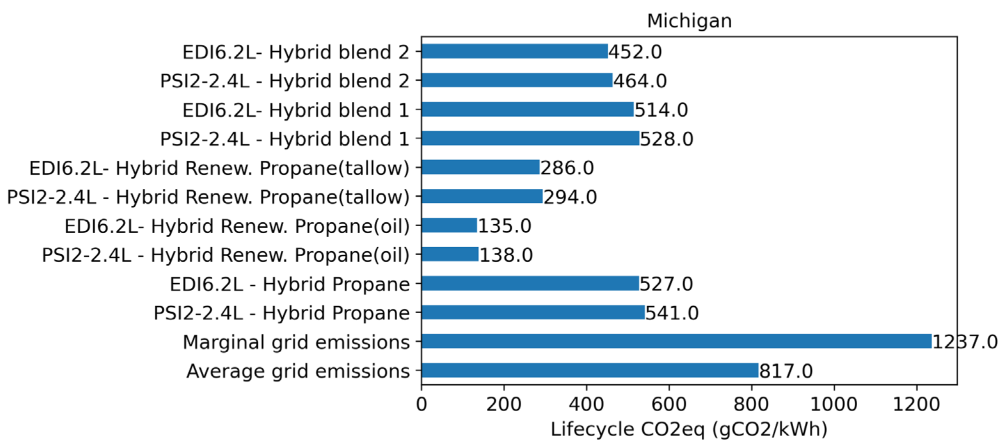


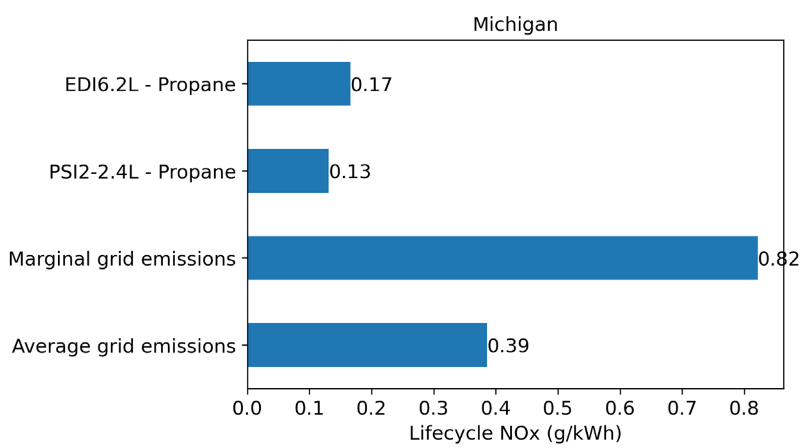



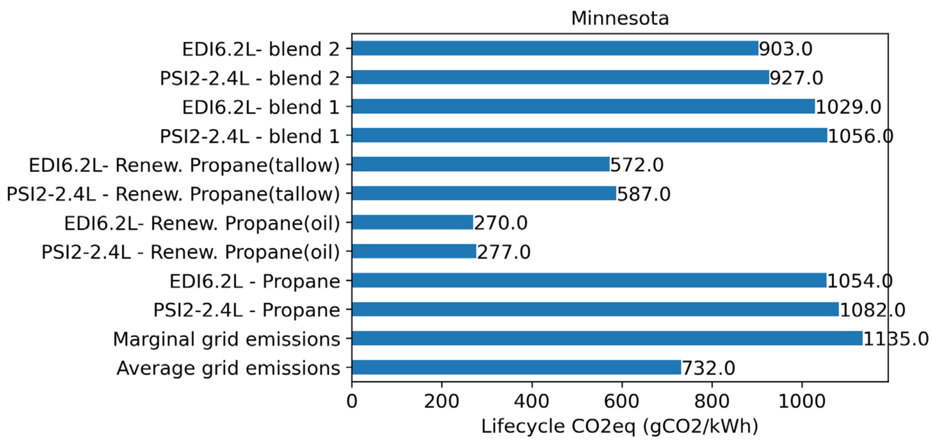
## Michigan

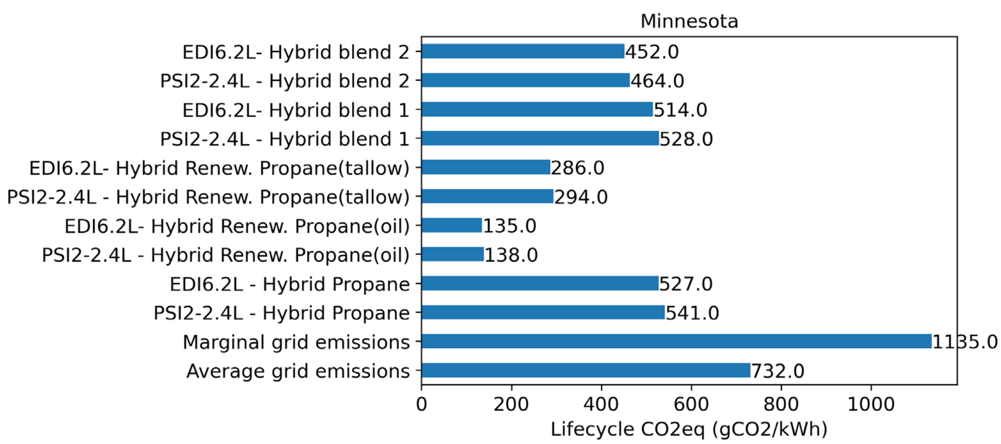

Michigan
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
903.0
927.0
1029.0
1056.0
572.0
587.0
270.0
277.0
1054.0
1082.0
1237.0
817.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)

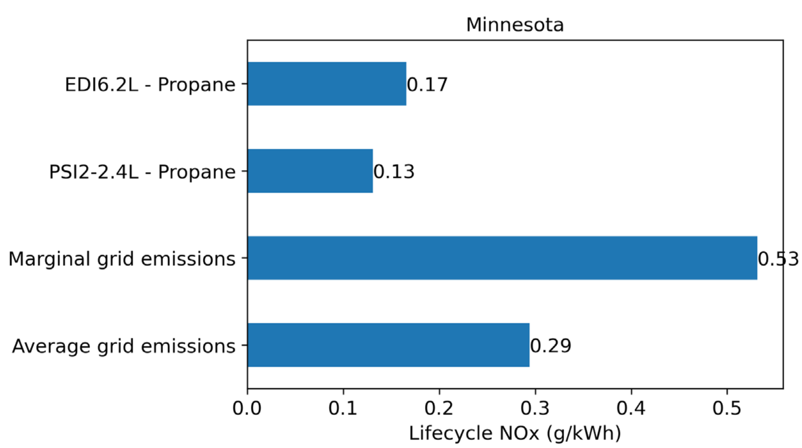

Michigan
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
452.0
464.0
514.0
528.0
286.0
294.0
135.0
138.0
527.0
541.0
1237.0
817.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)


Michigan
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.82
0.39
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Lifecycle NOx (g/kWh)

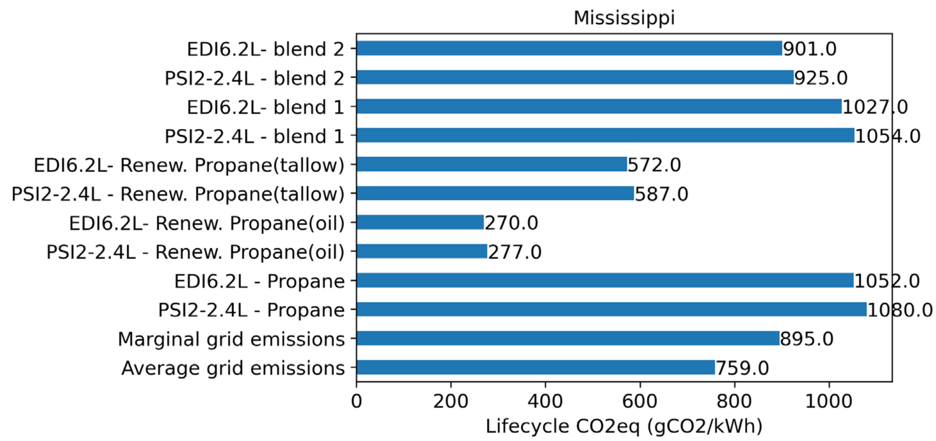
## Minnesota

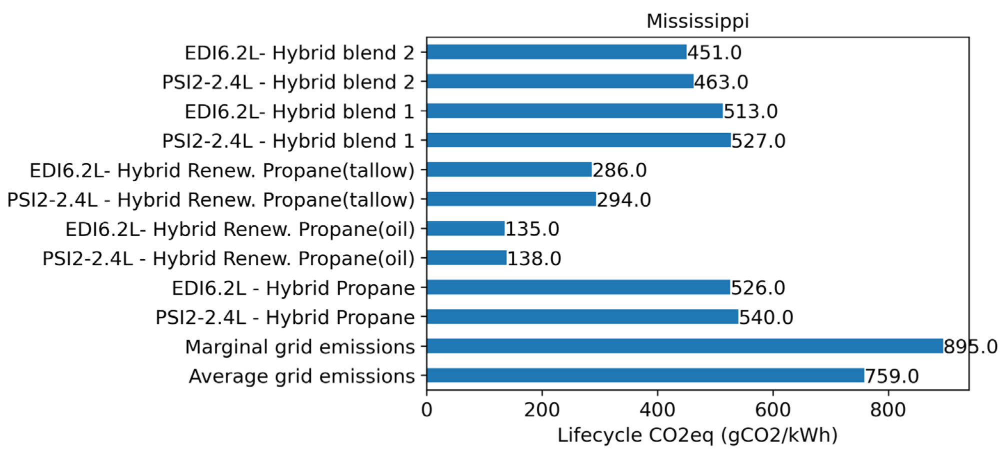

Minnesota
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
903.0
927.0
1029.0
1056.0
572.0
587.0
270.0
277.0
1054.0
1082.0
1135.0
732.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)

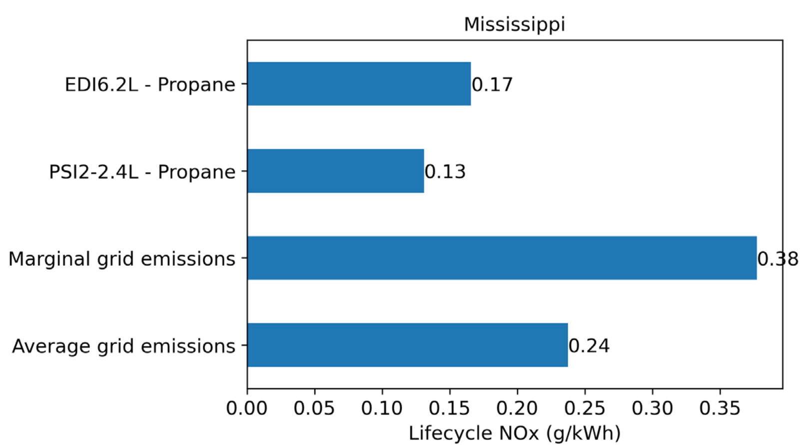

Minnesota
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
452.0
464.0
514.0
528.0
286.0
294.0
135.0
138.0
527.0
541.0
1135.0
732.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)


Minnesota
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.53
0.29
0.0
0.1
0.2
0.3
0.4
0.5
Lifecycle NOx (g/kWh)

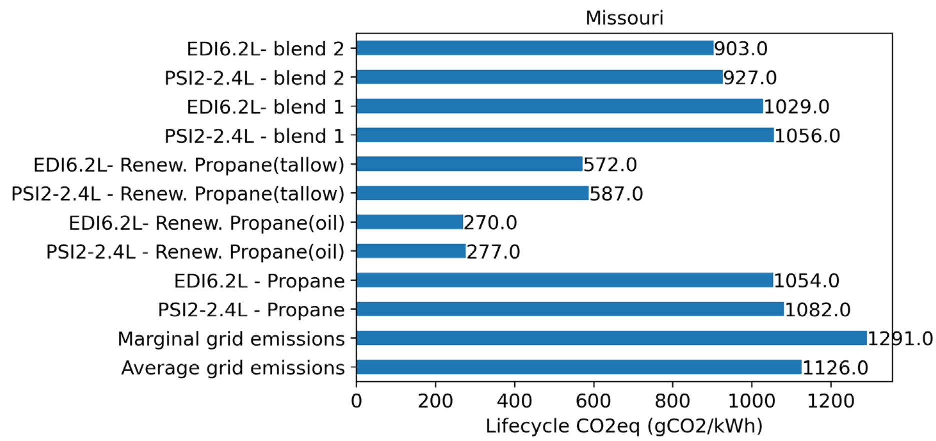
## Mississippi

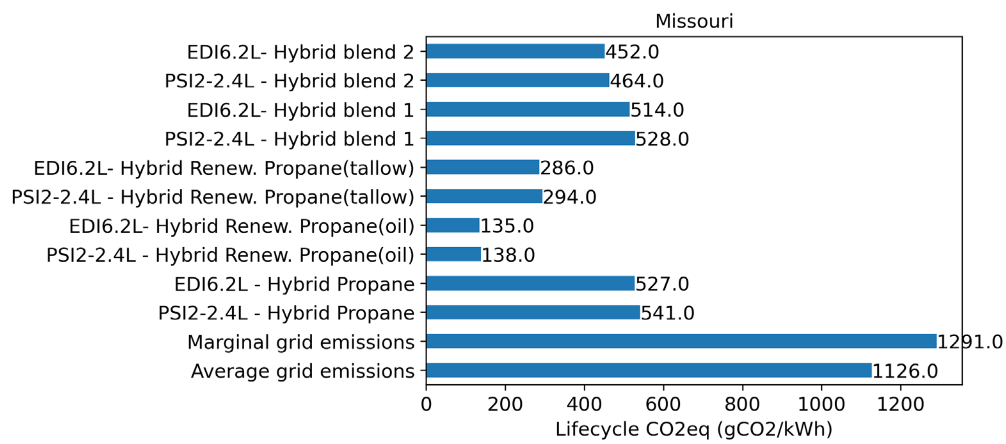


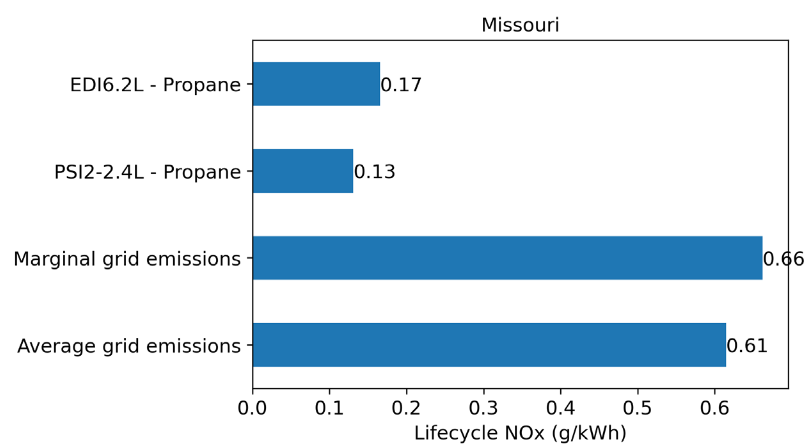



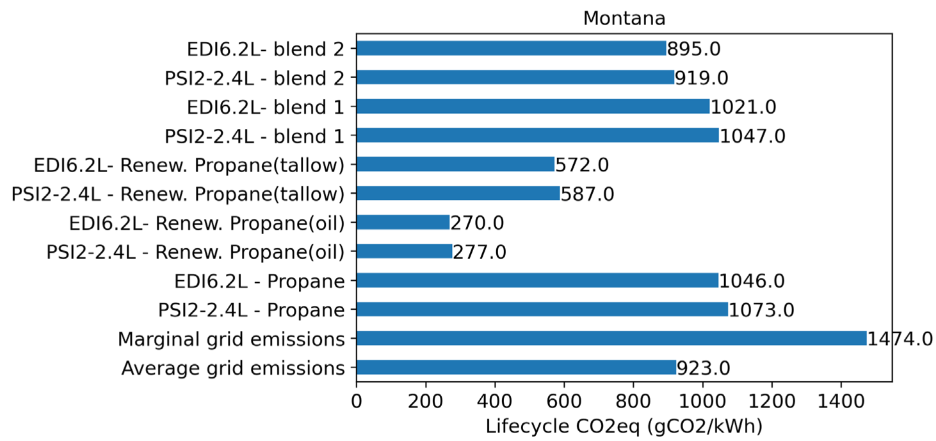
## Missouri

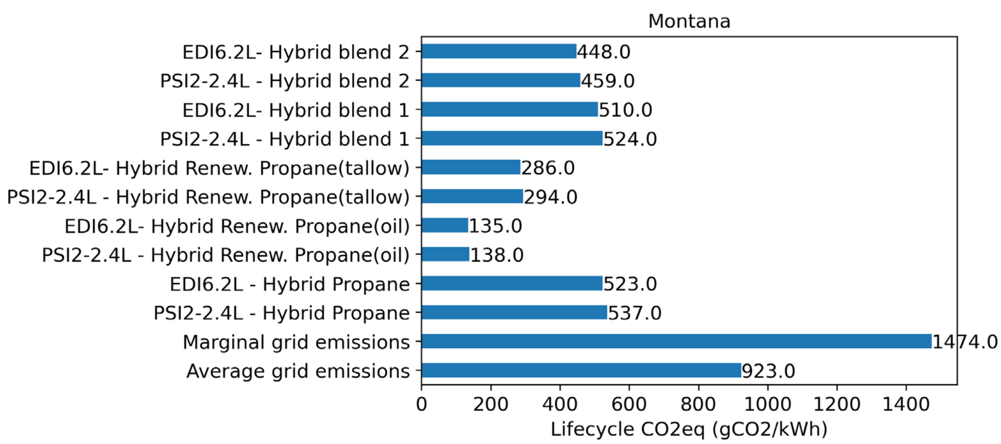

Missouri
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
903.0
927.0
1029.0
1056.0
572.0
587.0
270.0
277.0
1054.0
1082.0
1291.0
1126.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)

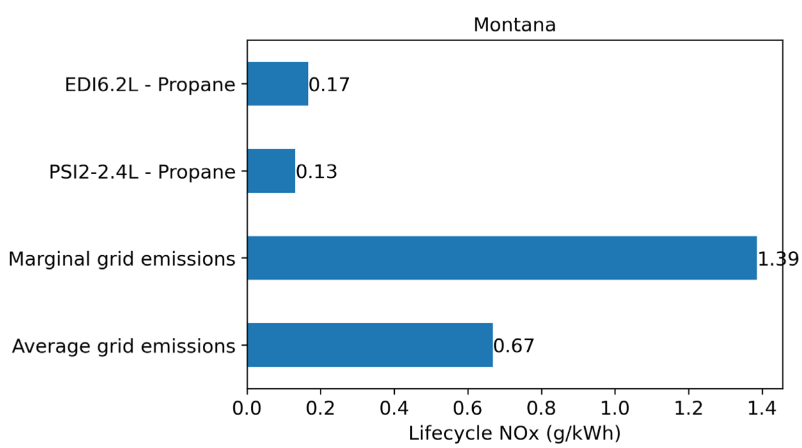

Missouri
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
452.0
464.0
514.0
528.0
286.0
294.0
135.0
138.0
527.0
541.0
1291.0
1126.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)


Missouri
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.66
0.61
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Lifecycle NOx (g/kWh)

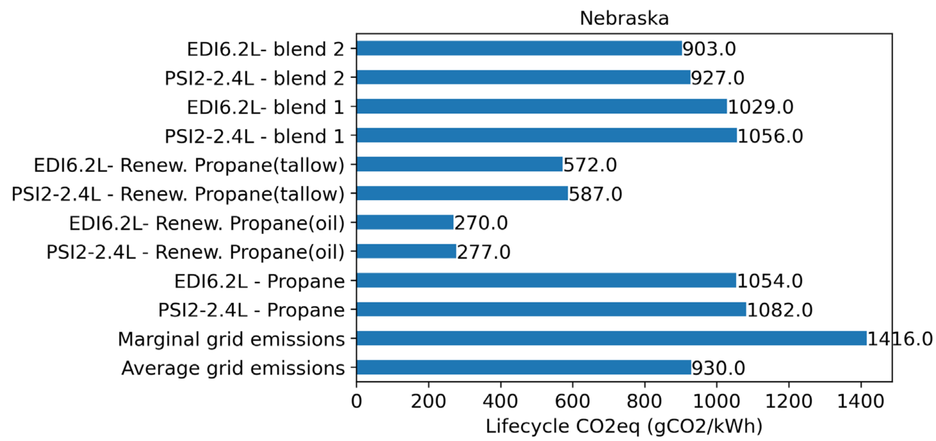
## Montana

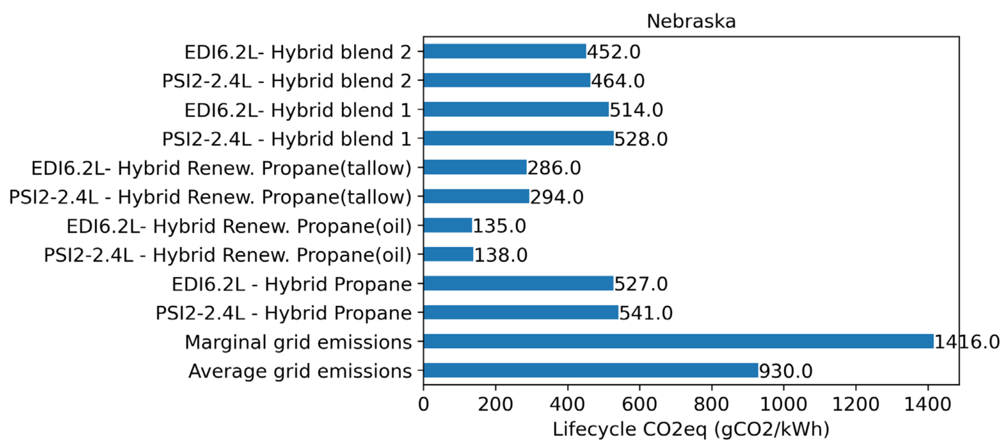

Montana
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
895.0
919.0
1021.0
1047.0
572.0
587.0
270.0
277.0
1046.0
1073.0
1474.0
923.0
0
200
400
600
800
1000
1200
1400
Lifecycle CO2eq (gCO2/kWh)

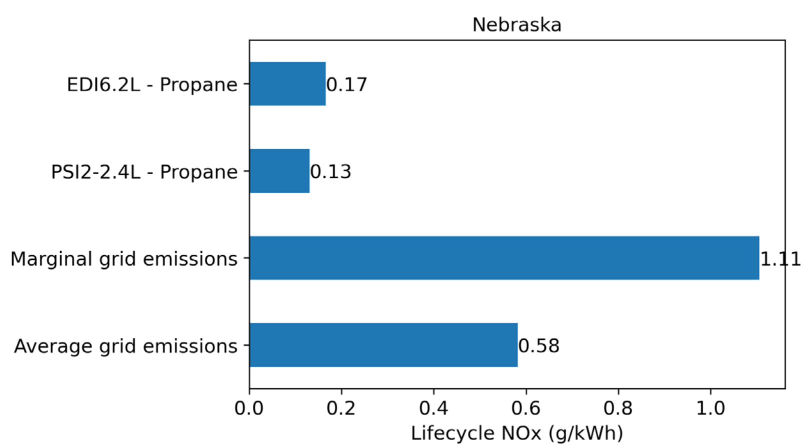

Montana
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
448.0
459.0
510.0
524.0
286.0
294.0
135.0
138.0
523.0
537.0
1474.0
923.0
0
200
400
600
800
1000
1200
1400
Lifecycle CO2eq (gCO2/kWh)


Montana
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
1.39
0.67
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Lifecycle NOx (g/kWh)

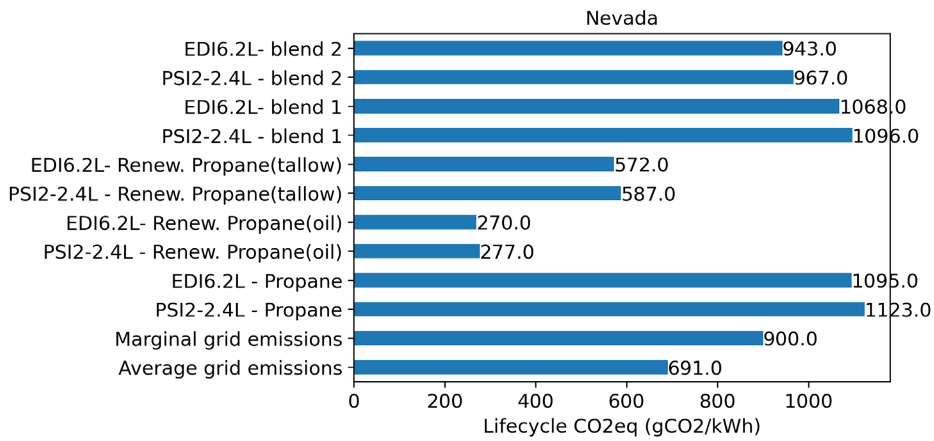
## Nebraska

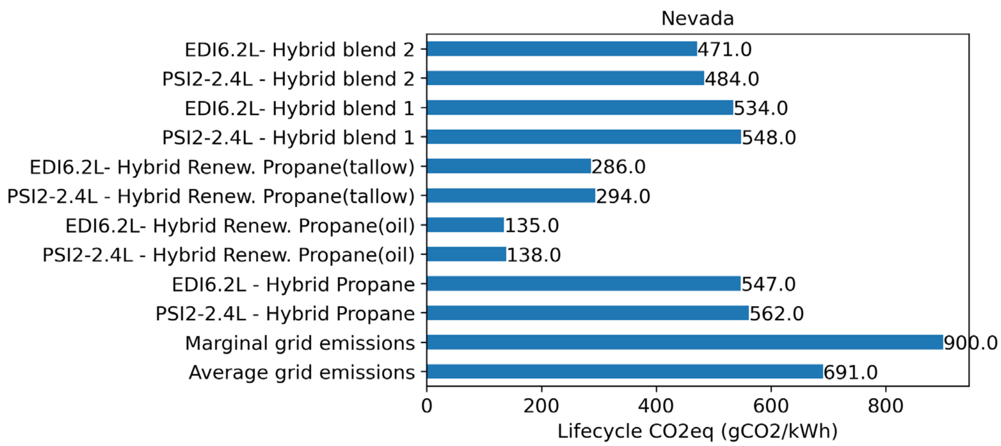

Nebraska
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
903.0
927.0
1029.0
1056.0
572.0
587.0
270.0
277.0
1054.0
1082.0
1416.0
930.0
0
200
400
600
800
1000
1200
1400
Lifecycle CO2eq (gCO2/kWh)

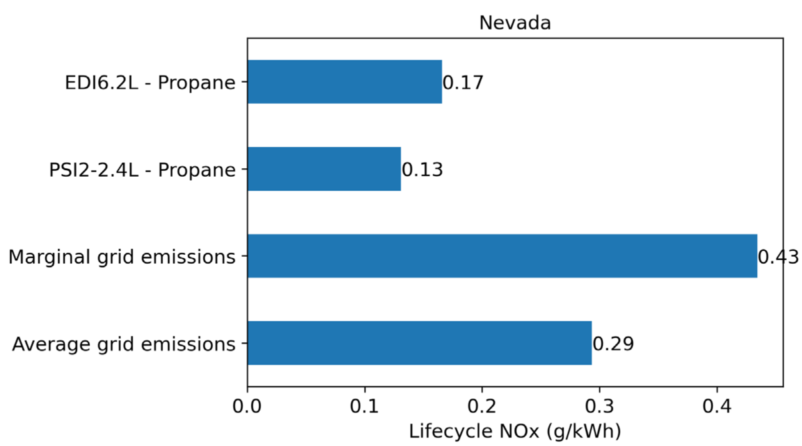

Nebraska
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
452.0
464.0
514.0
528.0
286.0
294.0
135.0
138.0
527.0
541.0
1416.0
930.0
0
200
400
600
800
1000
1200
1400
Lifecycle CO2eq (gCO2/kWh)


Nebraska
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
1.11
0.58
0.0
0.2
0.4
0.6
0.8
1.0
Lifecycle NOx (g/kWh)

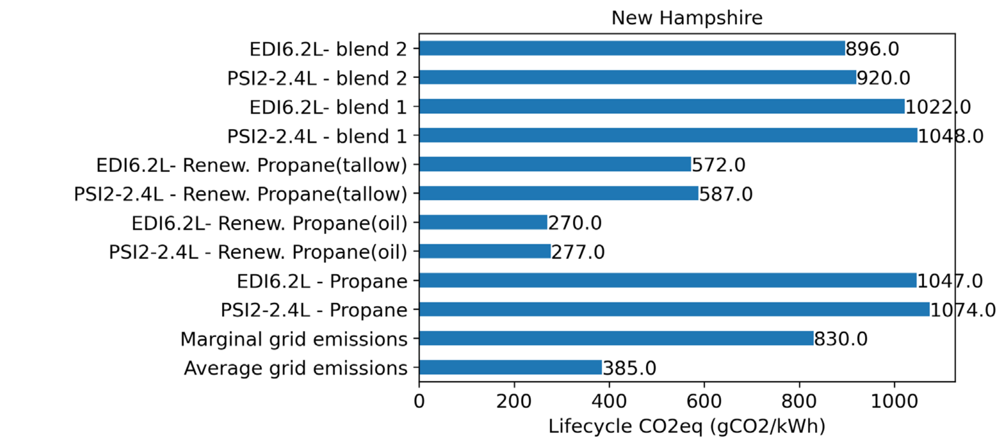
## Nevada

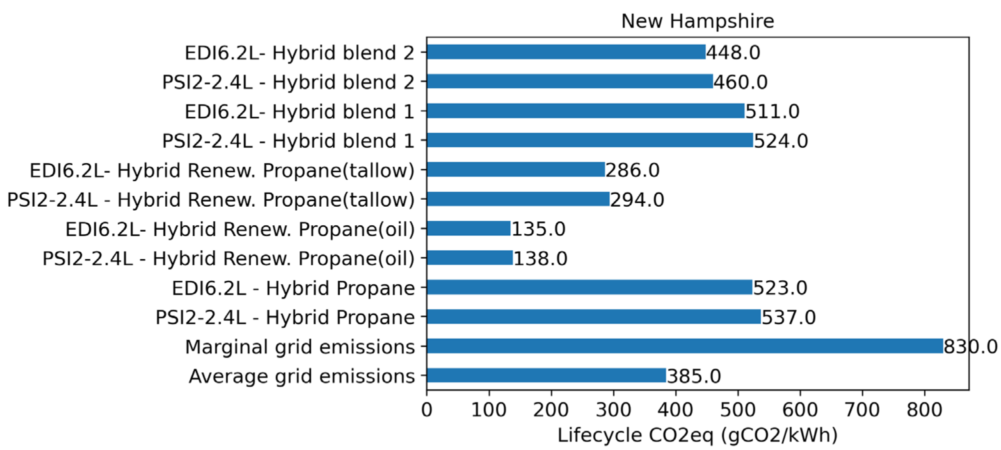

Nevada
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
943.0
967.0
1068.0
1096.0
572.0
587.0
270.0
277.0
1095.0
1123.0
900.0
691.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)

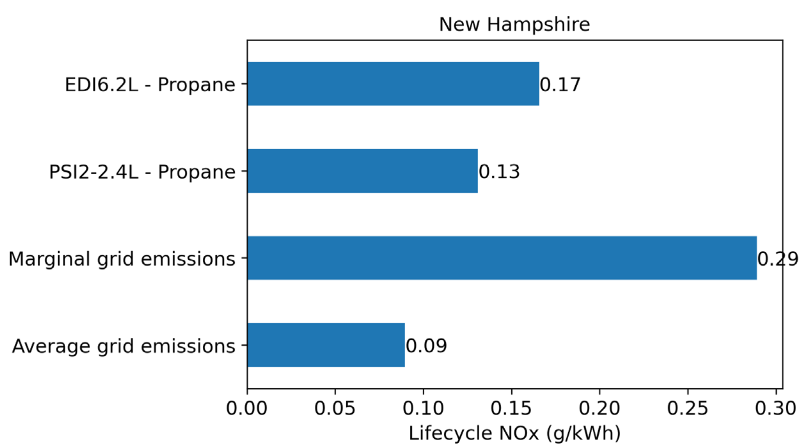

Nevada
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
471.0
484.0
534.0
548.0
286.0
294.0
135.0
138.0
547.0
562.0
900.0
691.0
0
200
400
600
800
Lifecycle CO2eq (gCO2/kWh)


Nevada
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.43
0.29
0.0
0.1
0.2
0.3
0.4
Lifecycle NOx (g/kWh)

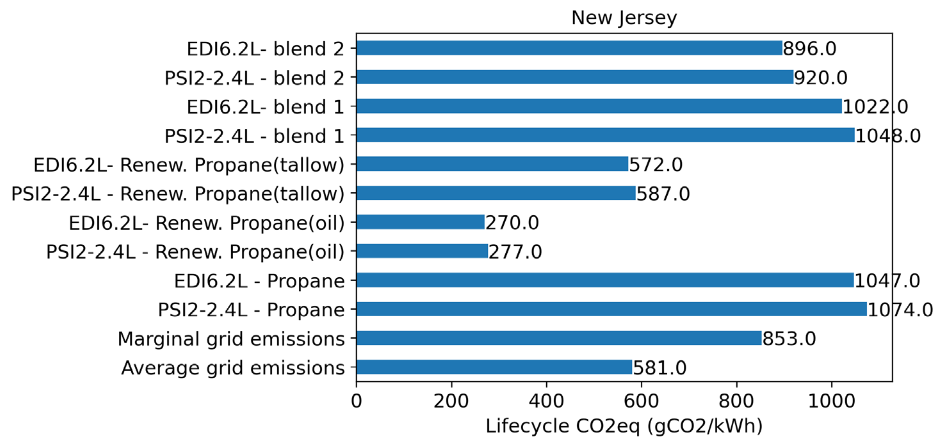
## New Hampshire

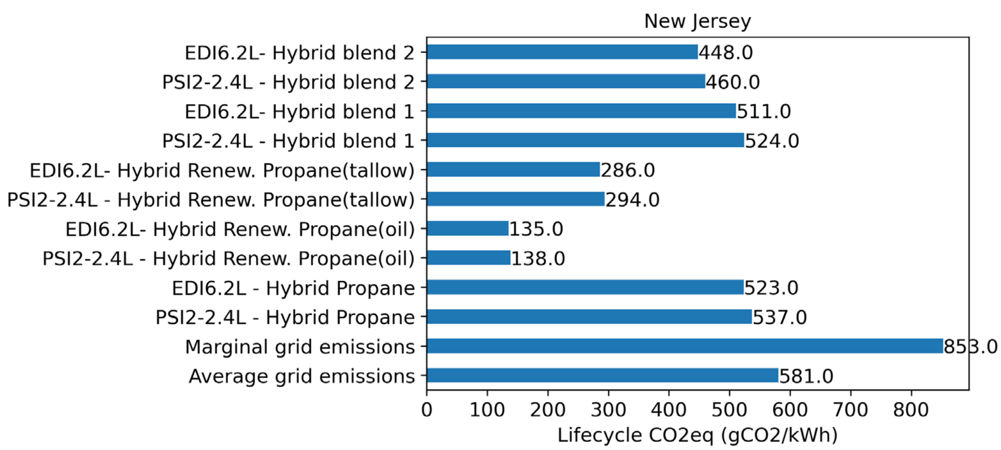


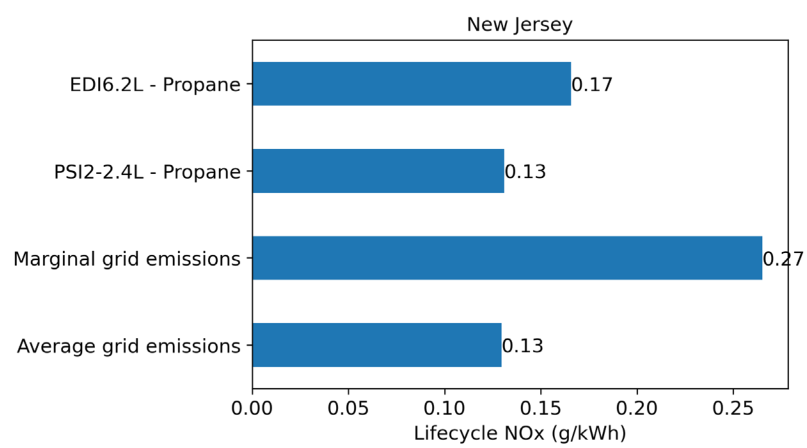



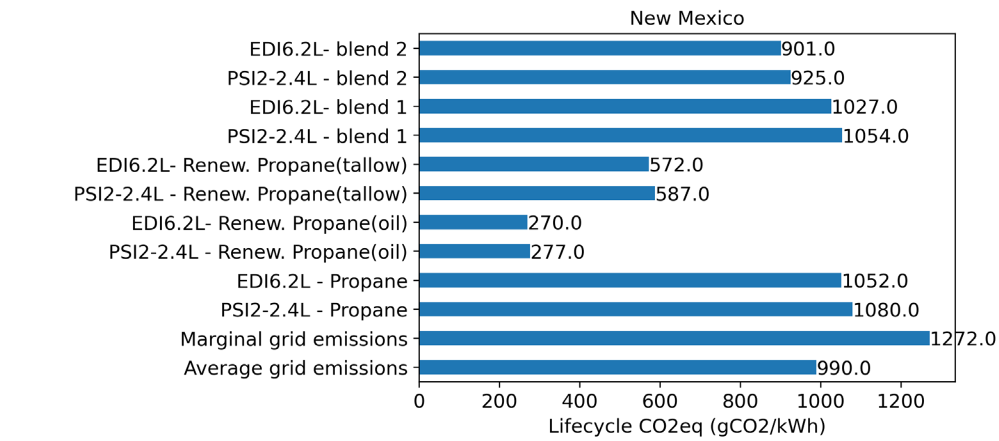
## New Jersey

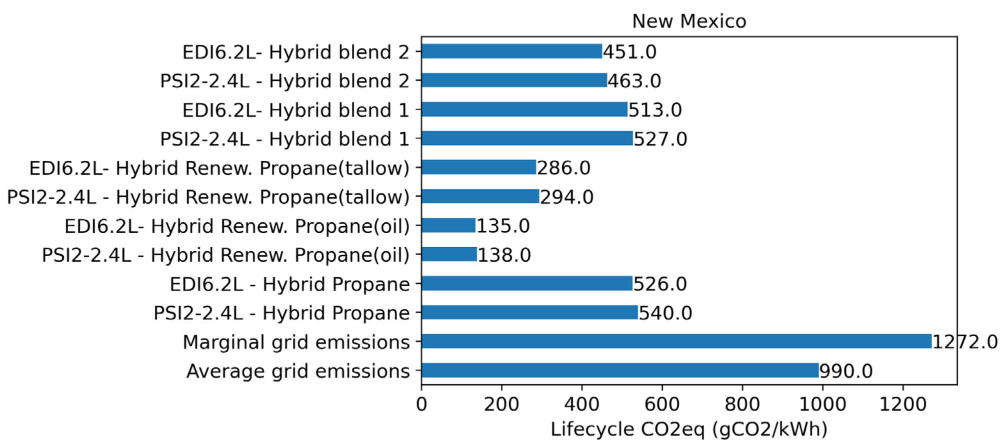

New Jersey
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
896.0
920.0
1022.0
1048.0
572.0
587.0
270.0
277.0
1047.0
1074.0
853.0
581.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)

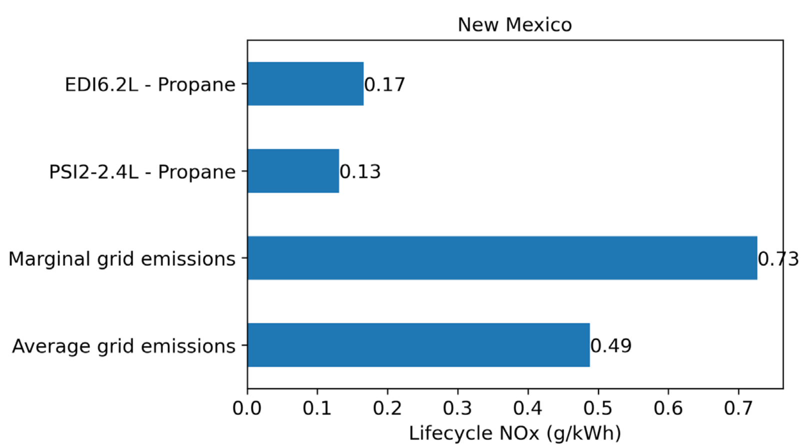

New Jersey
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
448.0
460.0
511.0
524.0
286.0
294.0
135.0
138.0
523.0
537.0
853.0
581.0
0
100
200
300
400
500
600
700
800
Lifecycle CO2eq (gCO2/kWh)


New Jersey
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.27
0.13
0.00
0.05
0.10
0.15
0.20
0.25
Lifecycle NOx (g/kWh)

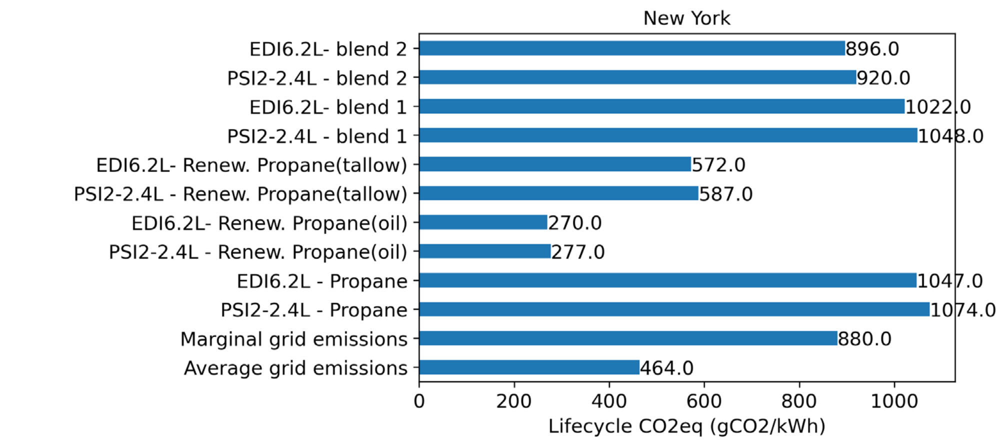
## New Mexico

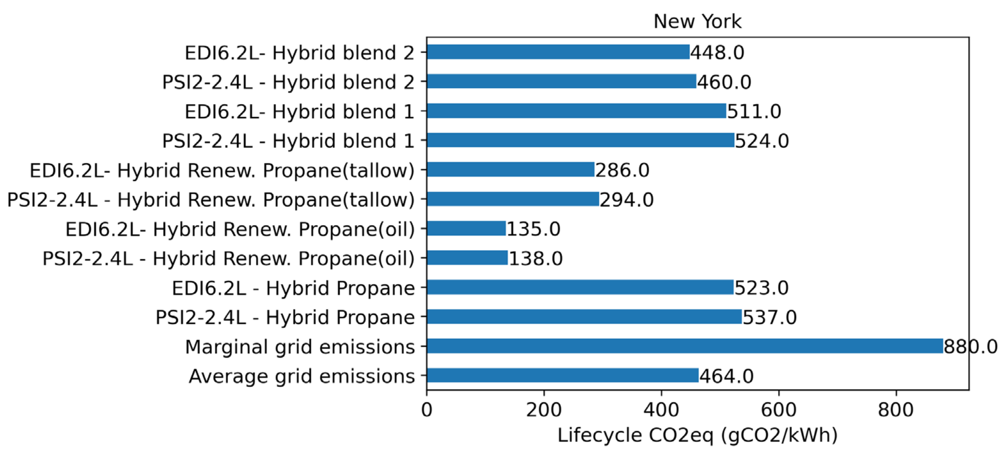

New Mexico
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
901.0
925.0
1027.0
1054.0
572.0
587.0
270.0
277.0
1052.0
1080.0
1272.0
990.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)

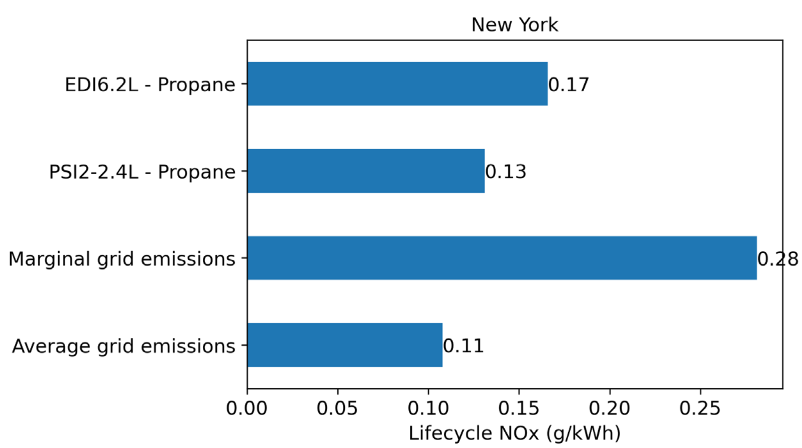

New Mexico
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
451.0
463.0
513.0
527.0
286.0
294.0
135.0
138.0
526.0
540.0
1272.0
990.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)


New Mexico
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.73
0.49
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Lifecycle NOx (g/kWh)

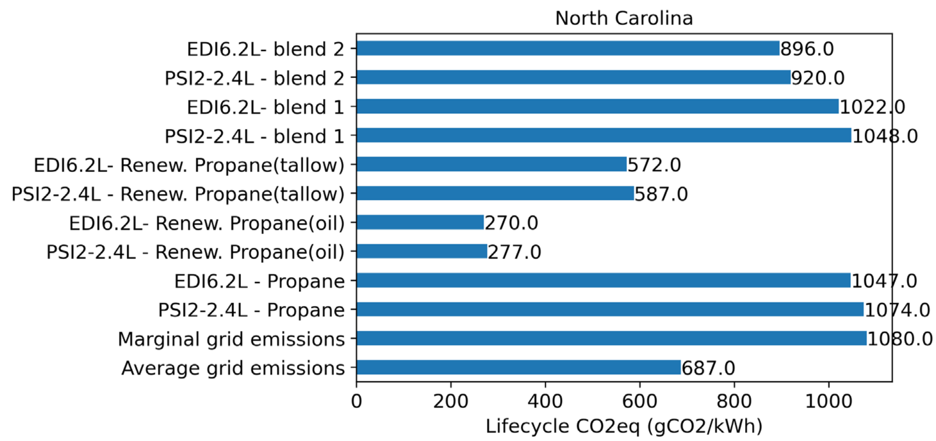
## New York

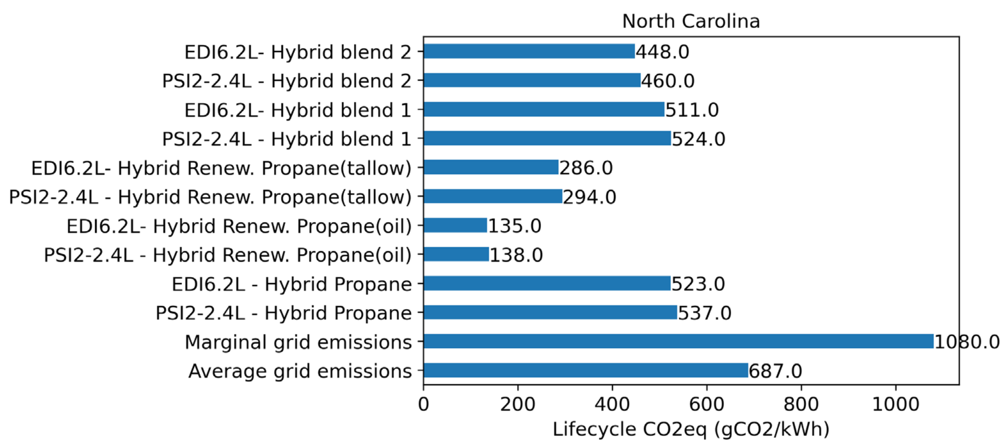

New York
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
896.0
920.0
1022.0
1048.0
572.0
587.0
270.0
277.0
1047.0
1074.0
880.0
464.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)

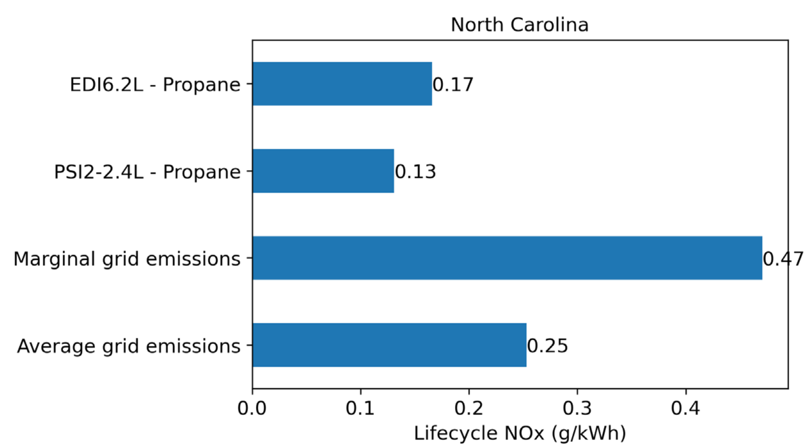

New York
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
448.0
460.0
511.0
524.0
286.0
294.0
135.0
138.0
523.0
537.0
880.0
464.0
0
200
400
600
800
Lifecycle CO2eq (gCO2/kWh)


New York
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.28
0.11
0.00
0.05
0.10
0.15
0.20
0.25
Lifecycle NOx (g/kWh)

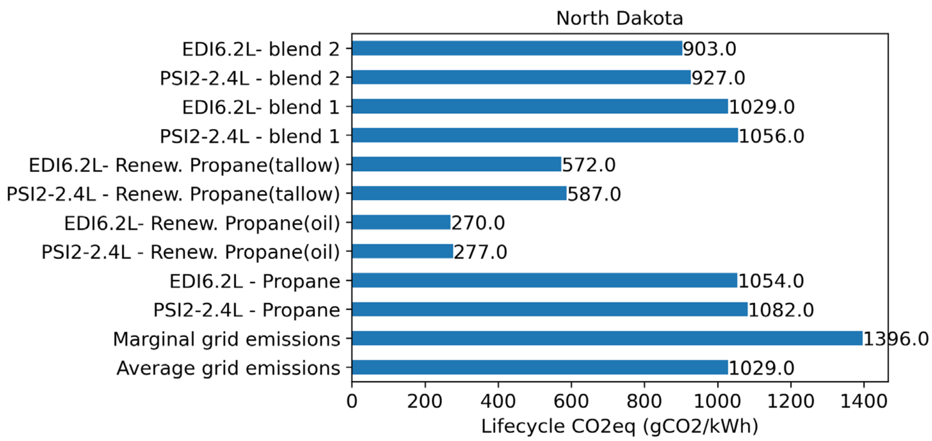
## North Carolina

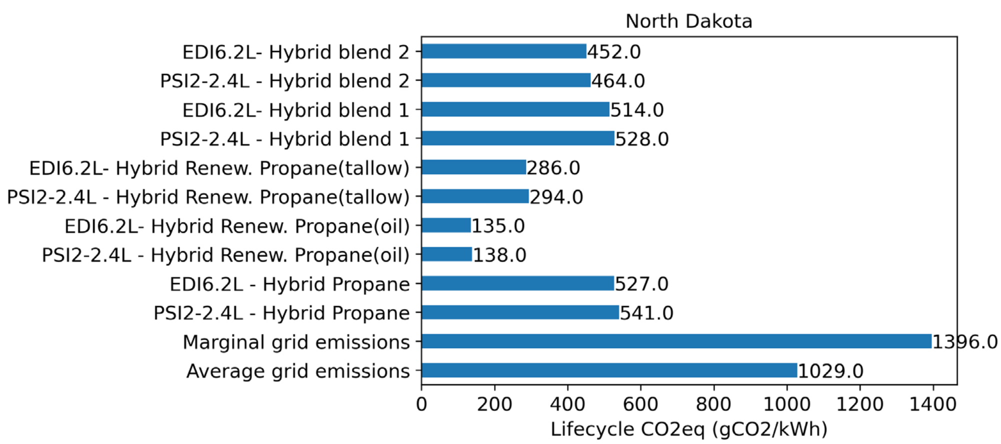


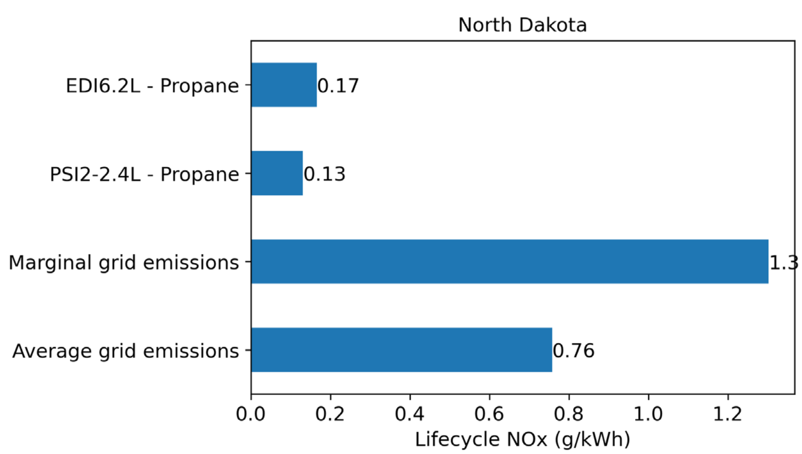



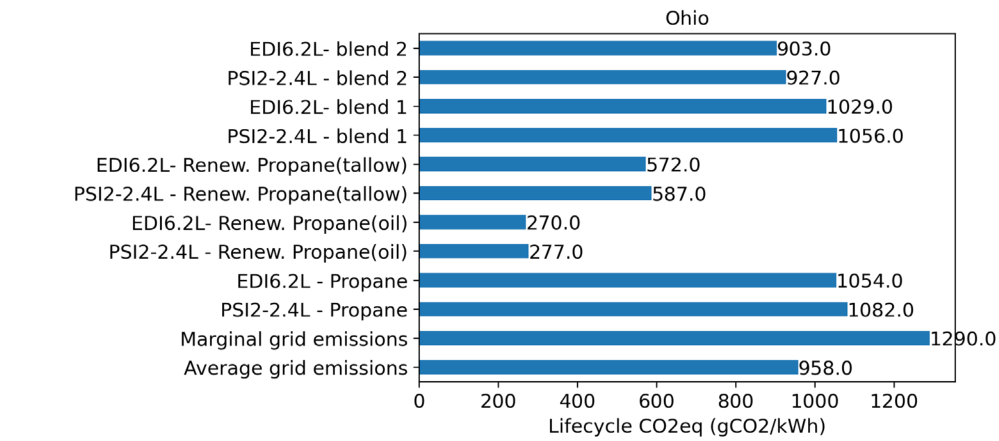
## North Dakota

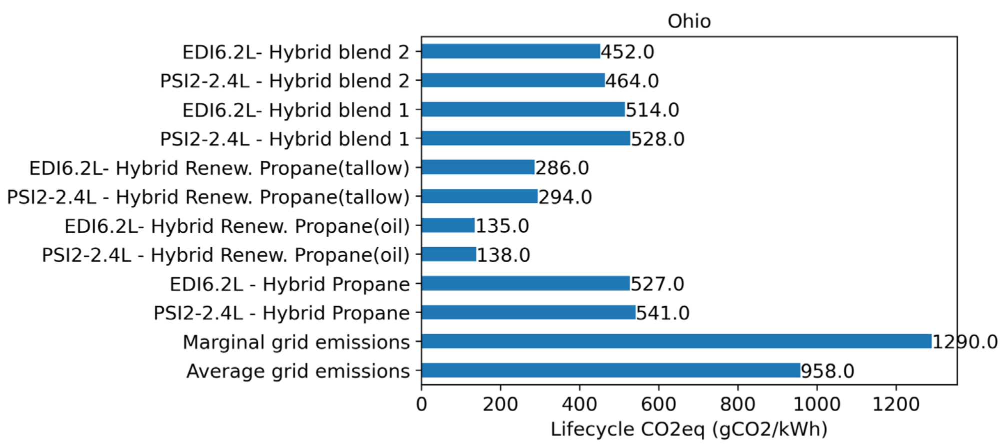


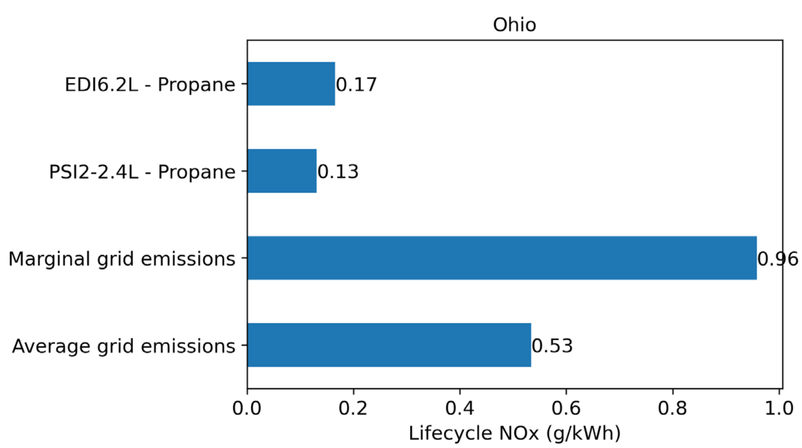



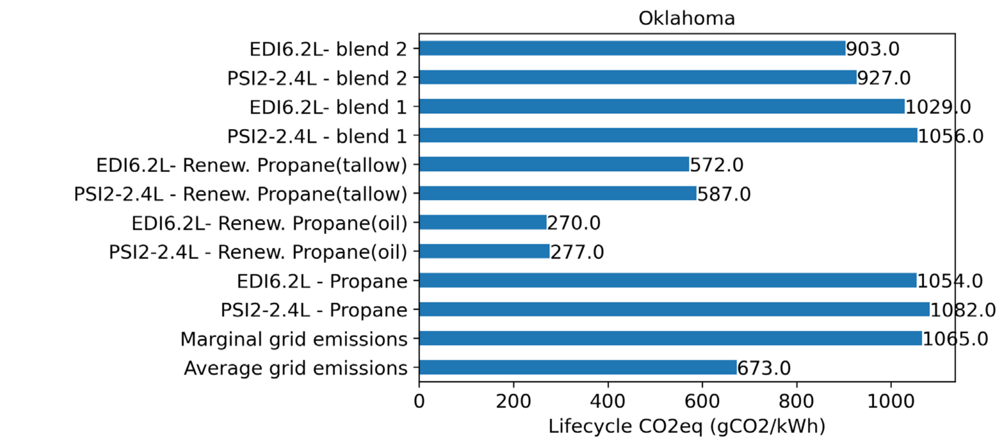
## Ohio

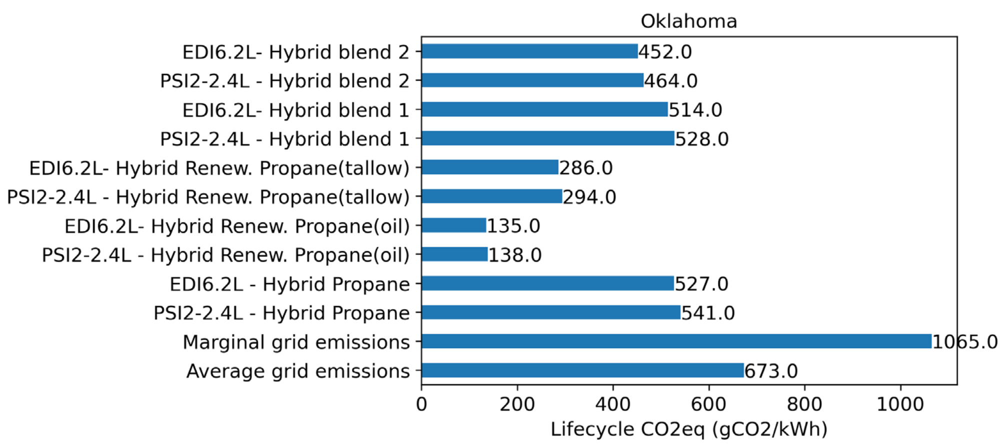

Ohio
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
903.0
927.0
1029.0
1056.0
572.0
587.0
270.0
277.0
1054.0
1082.0
1290.0
958.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)

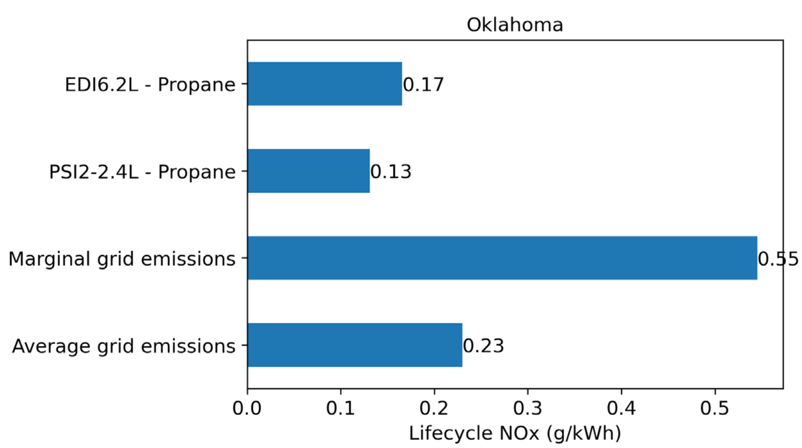

Ohio
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
452.0
464.0
514.0
528.0
286.0
294.0
135.0
138.0
527.0
541.0
1290.0
958.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)


Ohio
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.96
0.53
0.0
0.2
0.4
0.6
0.8
1.0
Lifecycle NOx (g/kWh)

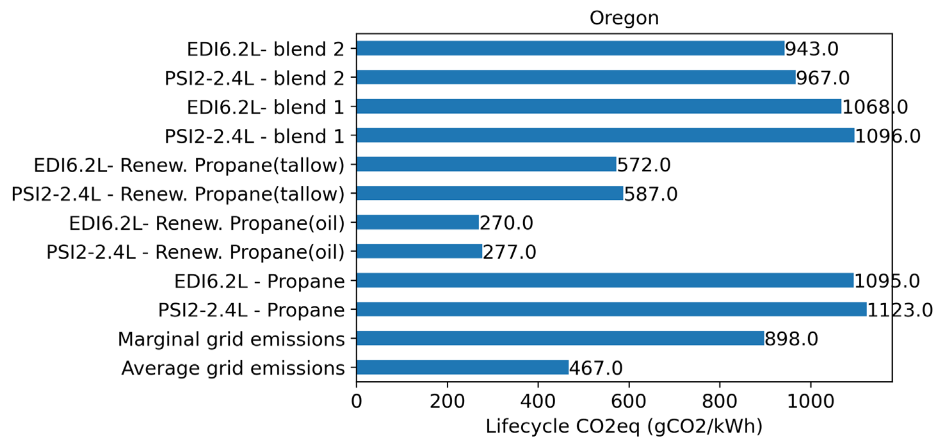
## Oklahoma

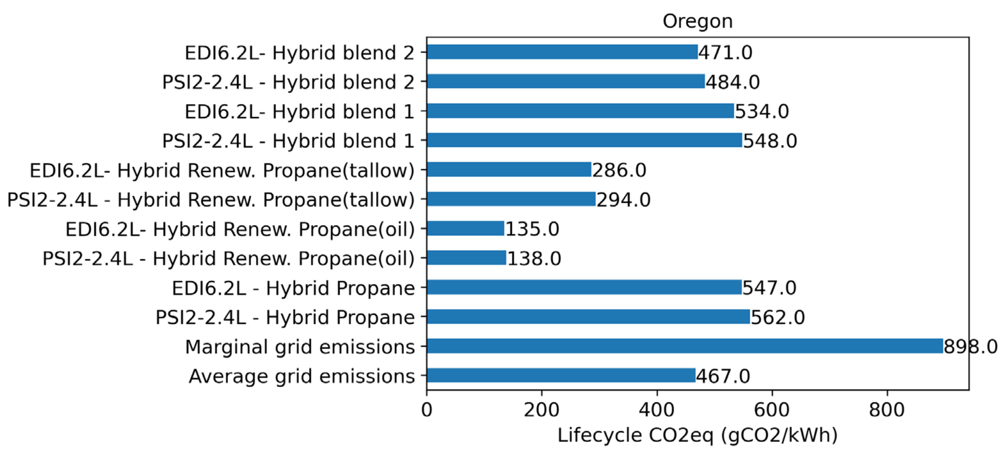

Oklahoma
EDI6.2L- blend 2
903.0
PSI2-2.4L - blend 2
927.0
EDI6.2L- blend 1
1029.0
PSI2-2.4L - blend 1
1056.0
EDI6.2L- Renew. Propane(tallow)
572.0
PSI2-2.4L - Renew. Propane(tallow)
587.0
EDI6.2L- Renew. Propane(oil)
270.0
PSI2-2.4L - Renew. Propane(oil)
277.0
EDI6.2L - Propane
1054.0
PSI2-2.4L - Propane
1082.0
Marginal grid emissions
1065.0
Average grid emissions
673.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)

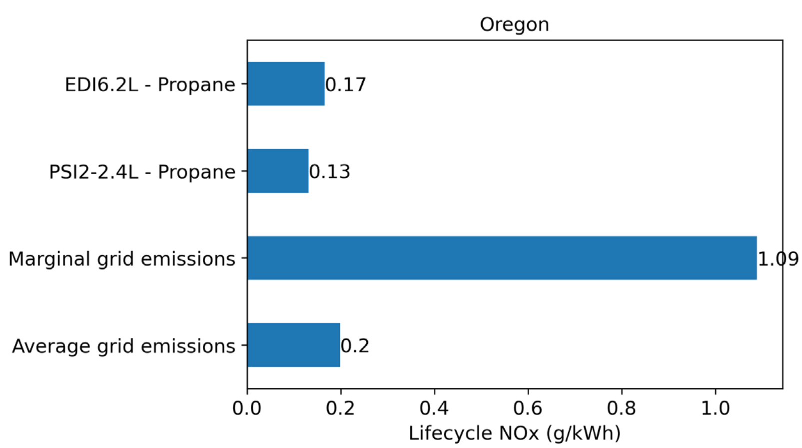

Oklahoma
EDI6.2L- Hybrid blend 2
452.0
PSI2-2.4L - Hybrid blend 2
464.0
EDI6.2L- Hybrid blend 1
514.0
PSI2-2.4L - Hybrid blend 1
528.0
EDI6.2L- Hybrid Renew. Propane(tallow)
286.0
PSI2-2.4L - Hybrid Renew. Propane(tallow)
294.0
EDI6.2L- Hybrid Renew. Propane(oil)
135.0
PSI2-2.4L - Hybrid Renew. Propane(oil)
138.0
EDI6.2L - Hybrid Propane
527.0
PSI2-2.4L - Hybrid Propane
541.0
Marginal grid emissions
1065.0
Average grid emissions
673.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)


Oklahoma
EDI6.2L - Propane
0.17
PSI2-2.4L - Propane
0.13
Marginal grid emissions
0.55
Average grid emissions
0.23
0.0
0.1
0.2
0.3
0.4
0.5
Lifecycle NOx (g/kWh)

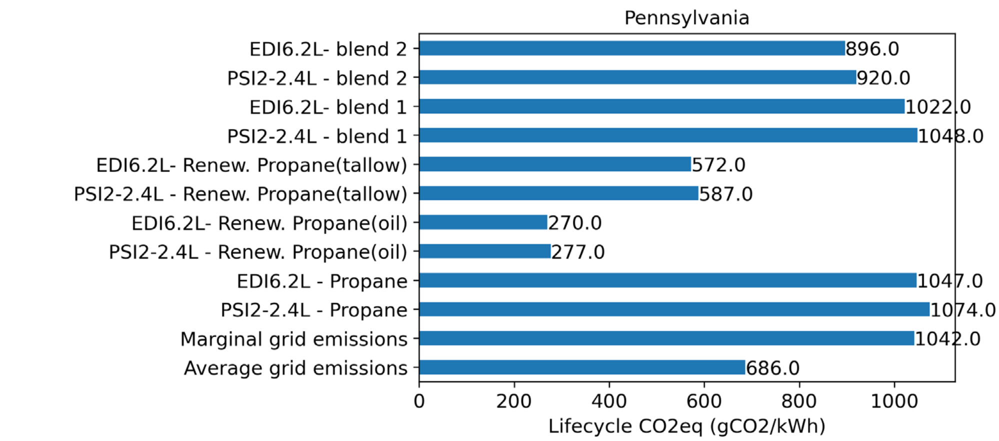
### Oregon

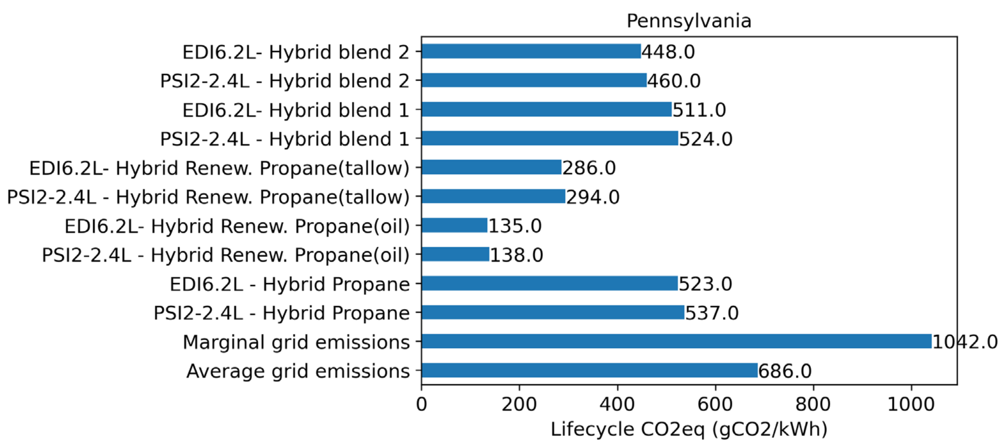

Oregon
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
943.0
967.0
1068.0
1096.0
572.0
587.0
270.0
277.0
1095.0
1123.0
898.0
467.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)

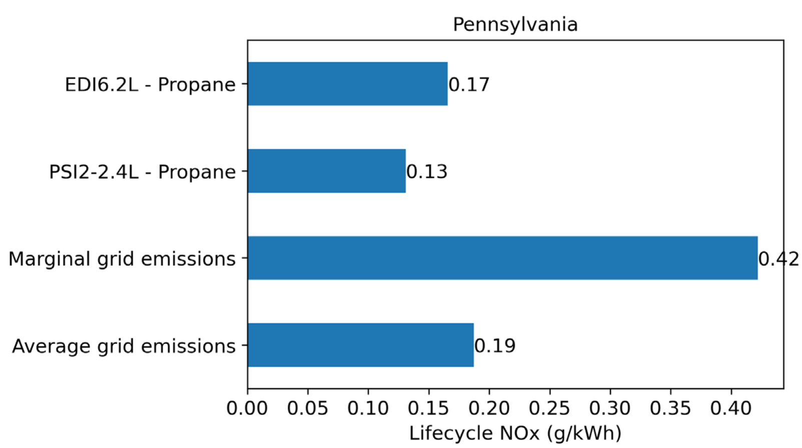

Oregon
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
471.0
484.0
534.0
548.0
286.0
294.0
135.0
138.0
547.0
562.0
898.0
467.0
0
200
400
600
800
Lifecycle CO2eq (gCO2/kWh)


Oregon
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
1.09
0.2
0.0
0.2
0.4
0.6
0.8
1.0
Lifecycle NOx (g/kWh)

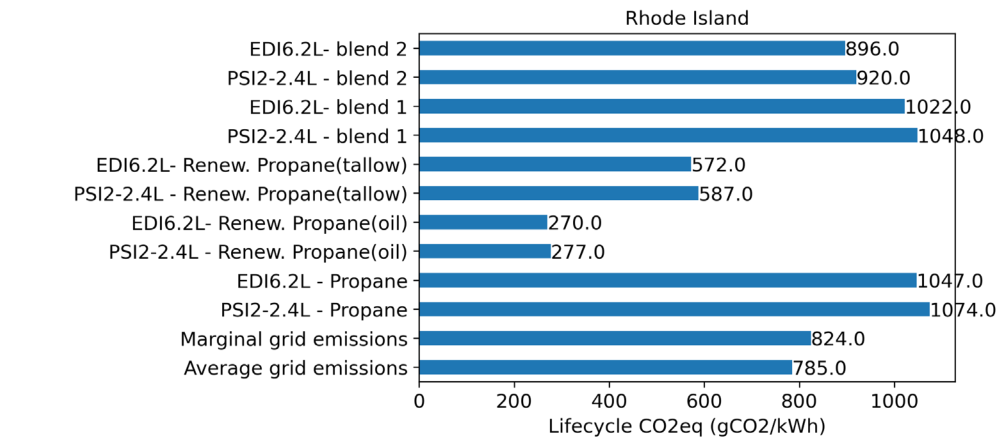
## Pennsylvania

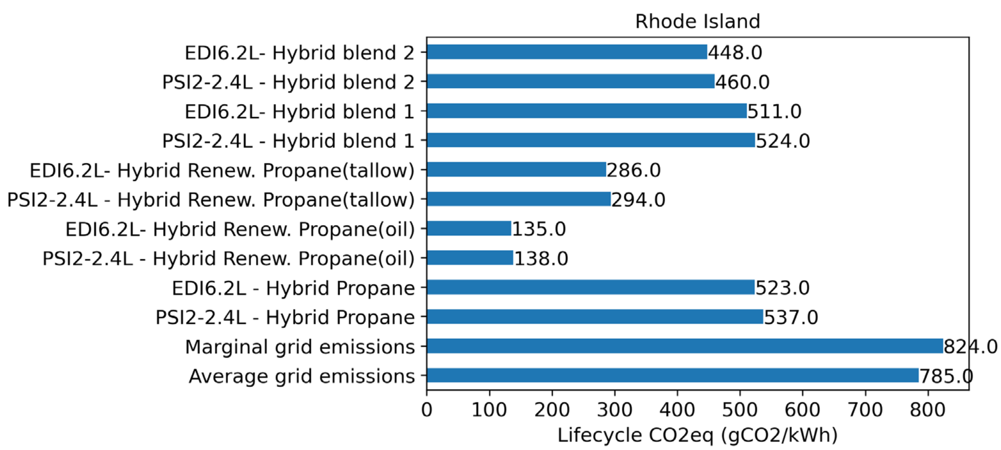


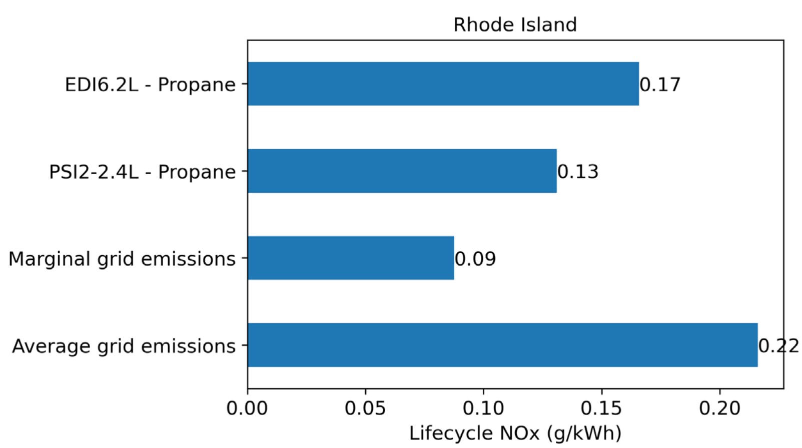



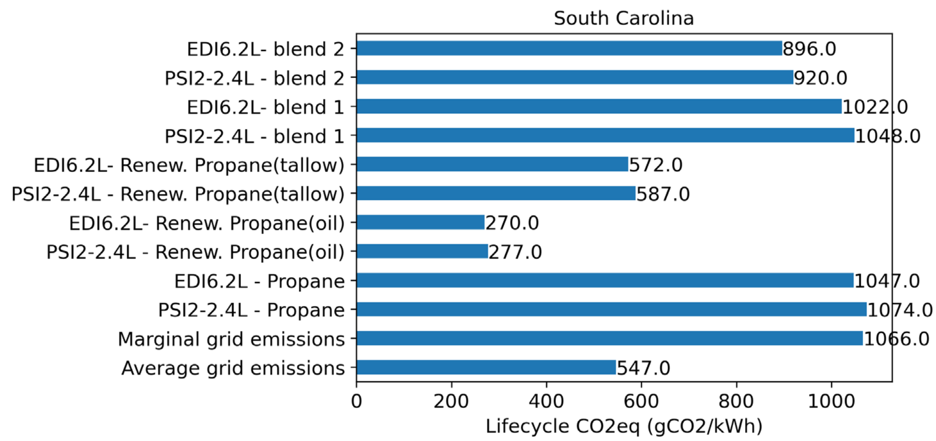
## Rhode Island

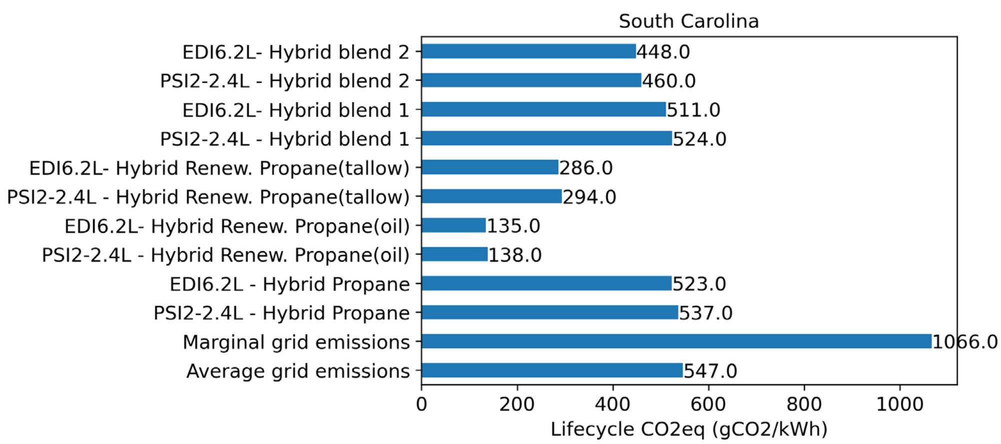


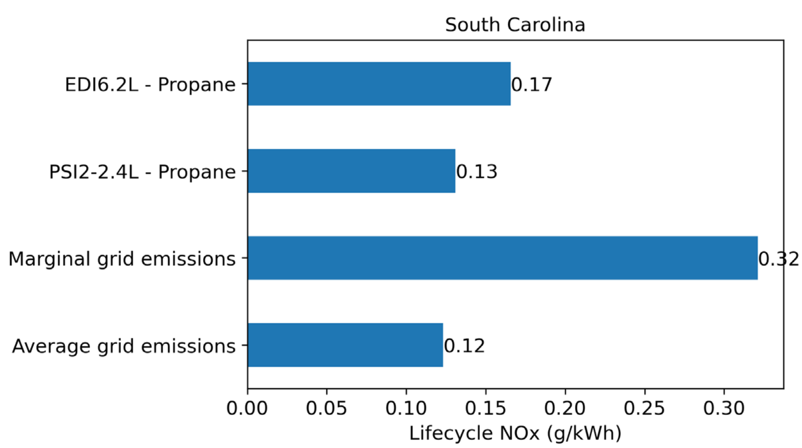



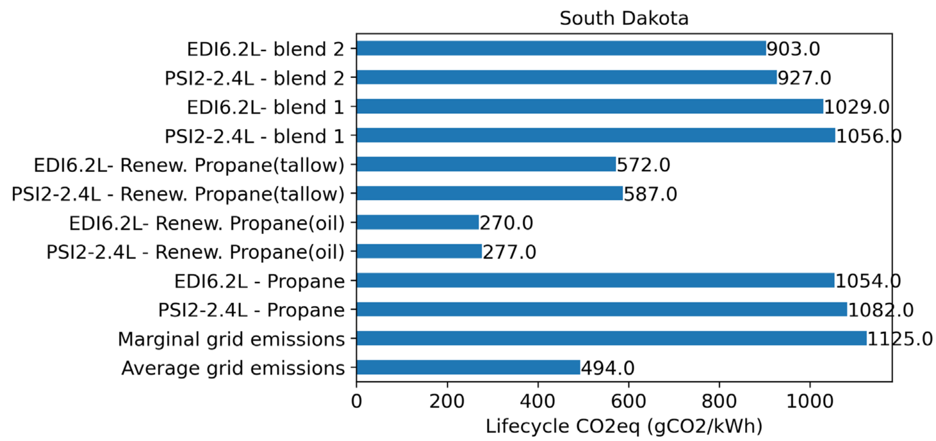
## South Carolina

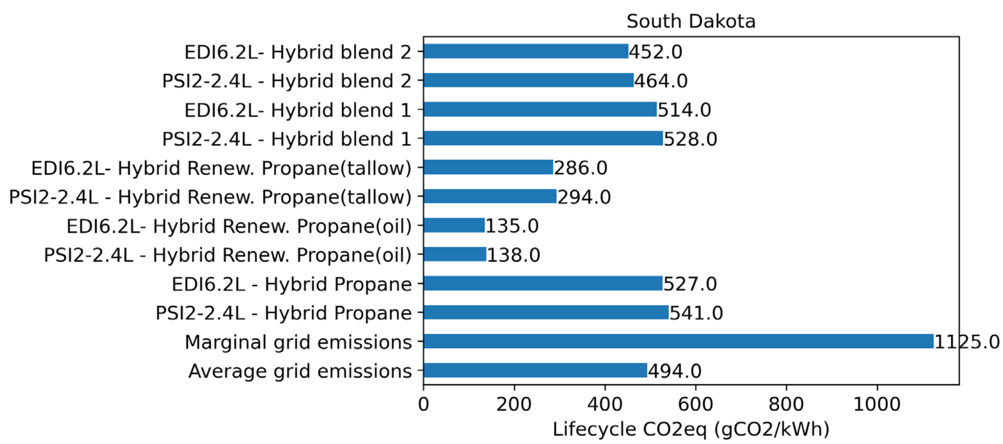


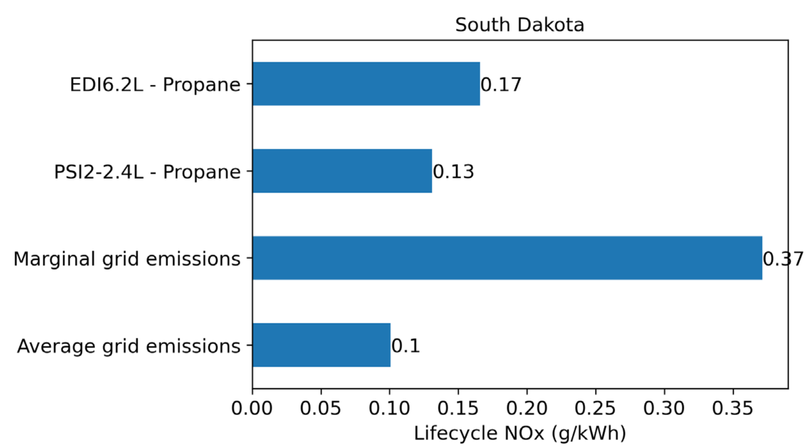



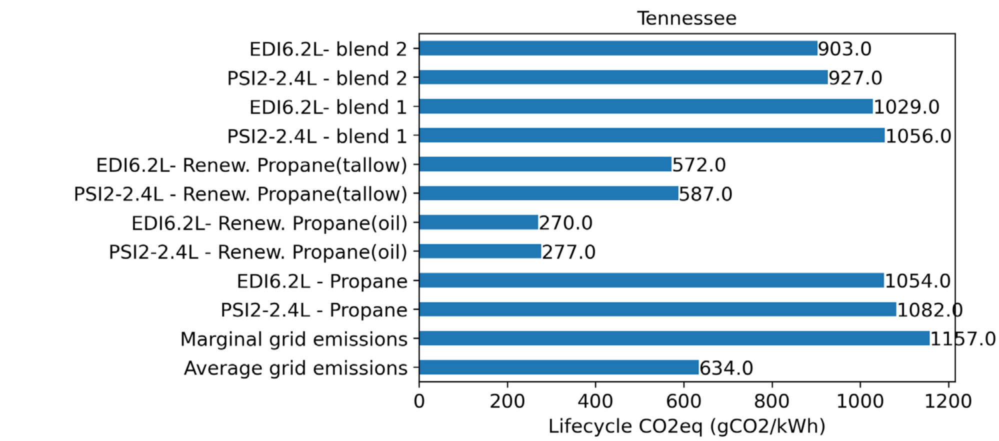
## South Dakota



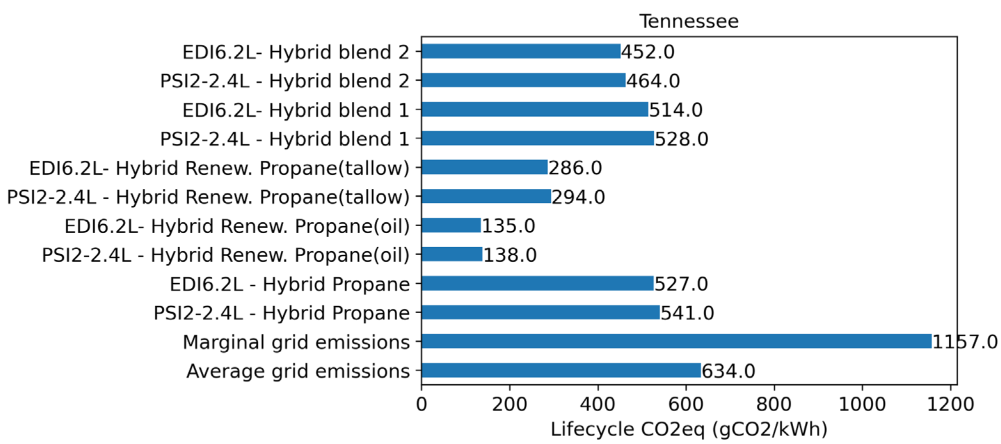



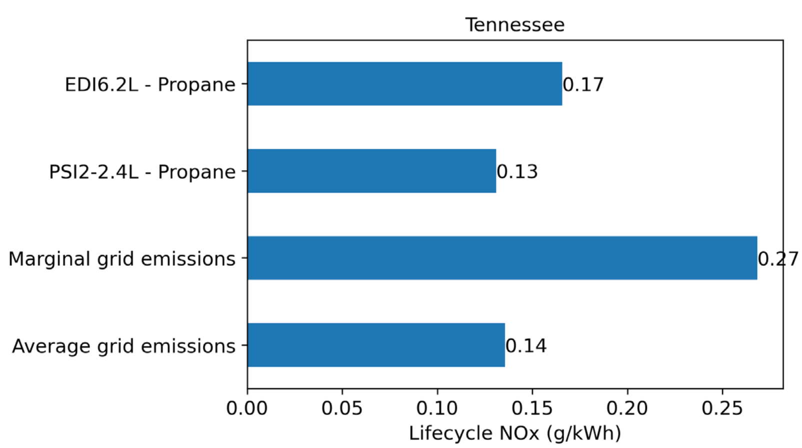
## Tennessee



Tennessee
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
903.0
927.0
1029.0
1056.0
572.0
587.0
270.0
277.0
1054.0
1082.0
1157.0
634.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)

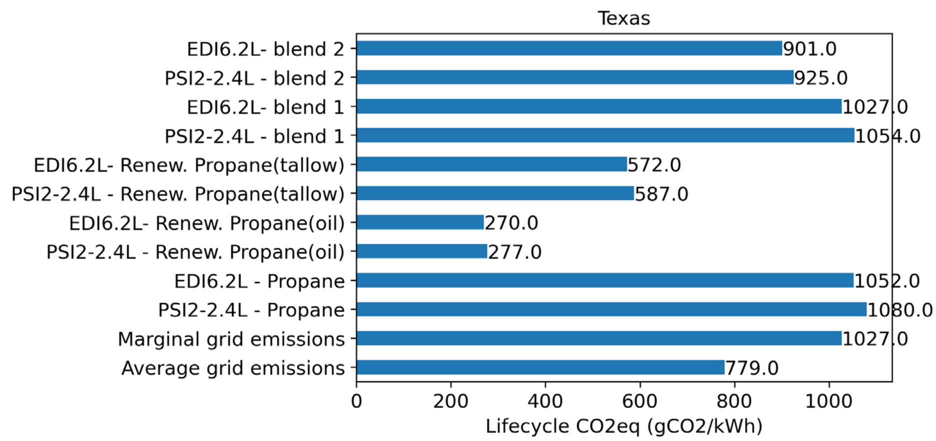



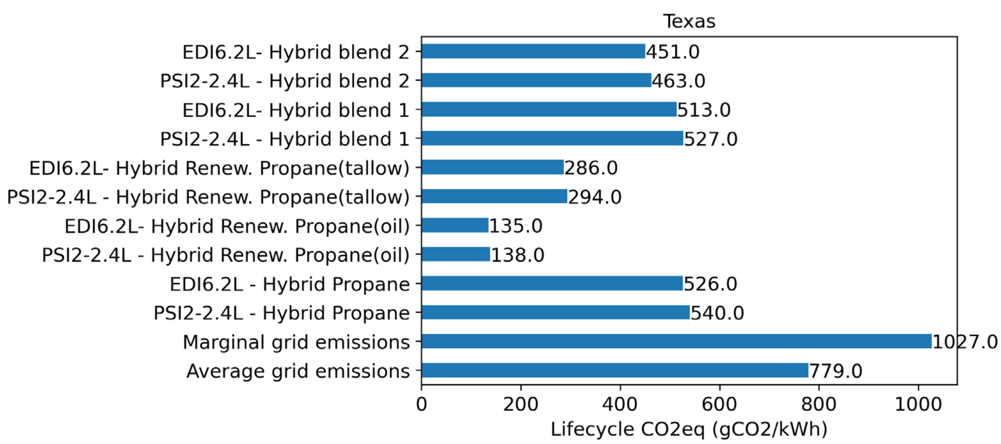
Tennessee
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
452.0
464.0
514.0
528.0
286.0
294.0
135.0
138.0
527.0
541.0
1157.0
634.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)

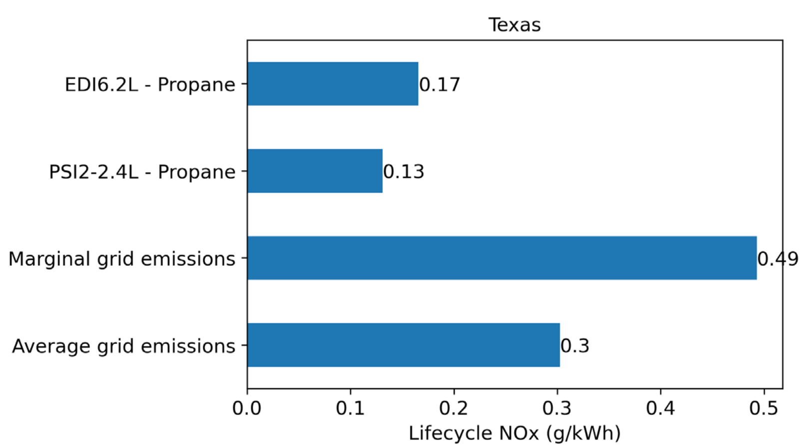



Tennessee
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.27
0.14
0.00
0.05
0.10
0.15
0.20
0.25
Lifecycle NOx (g/kWh)

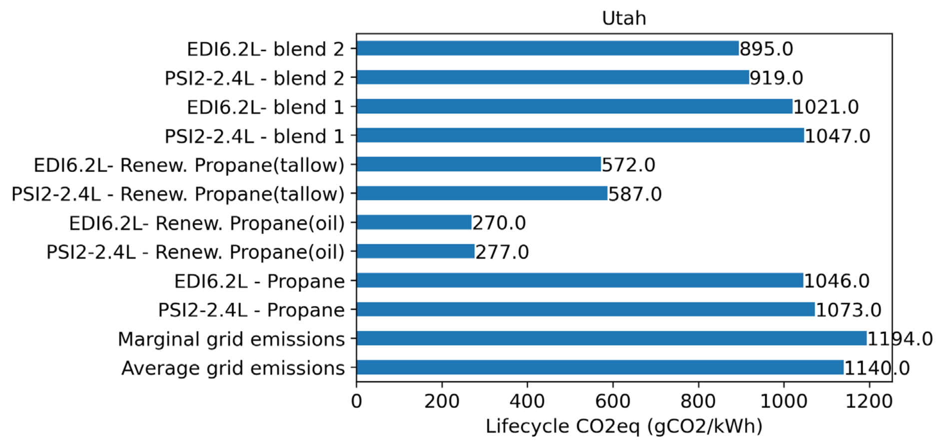
## Texas

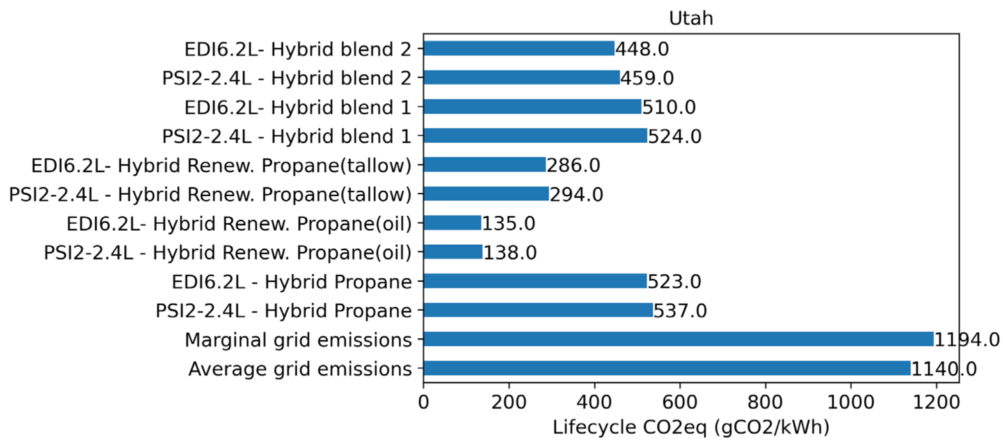

Texas
EDI6.2L- blend 2
901.0
PSI2-2.4L - blend 2
925.0
EDI6.2L- blend 1
1027.0
PSI2-2.4L - blend 1
1054.0
EDI6.2L- Renew. Propane(tallow)
572.0
PSI2-2.4L - Renew. Propane(tallow)
587.0
EDI6.2L- Renew. Propane(oil)
270.0
PSI2-2.4L - Renew. Propane(oil)
277.0
EDI6.2L - Propane
1052.0
PSI2-2.4L - Propane
1080.0
Marginal grid emissions
1027.0
Average grid emissions
779.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)

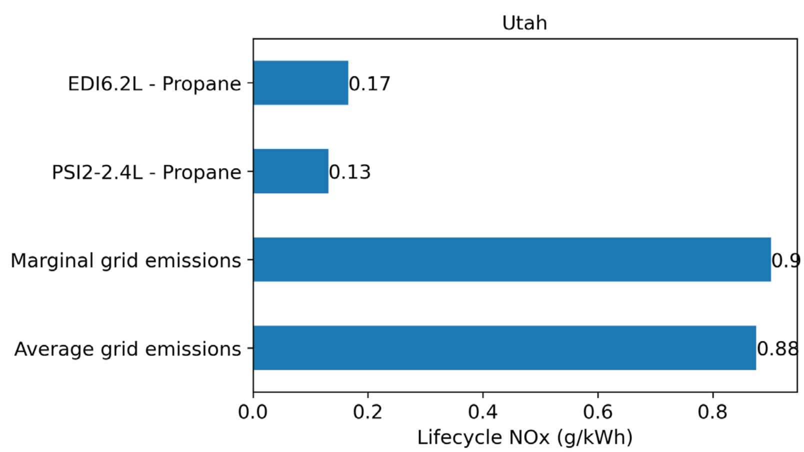

Texas
EDI6.2L- Hybrid blend 2
451.0
PSI2-2.4L - Hybrid blend 2
463.0
EDI6.2L- Hybrid blend 1
513.0
PSI2-2.4L - Hybrid blend 1
527.0
EDI6.2L- Hybrid Renew. Propane(tallow)
286.0
PSI2-2.4L - Hybrid Renew. Propane(tallow)
294.0
EDI6.2L- Hybrid Renew. Propane(oil)
135.0
PSI2-2.4L - Hybrid Renew. Propane(oil)
138.0
EDI6.2L - Hybrid Propane
526.0
PSI2-2.4L - Hybrid Propane
540.0
Marginal grid emissions
1027.0
Average grid emissions
779.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)


Texas
EDI6.2L - Propane
0.17
PSI2-2.4L - Propane
0.13
Marginal grid emissions
0.49
Average grid emissions
0.3
0.0
0.1
0.2
0.3
0.4
0.5
Lifecycle NOx (g/kWh)

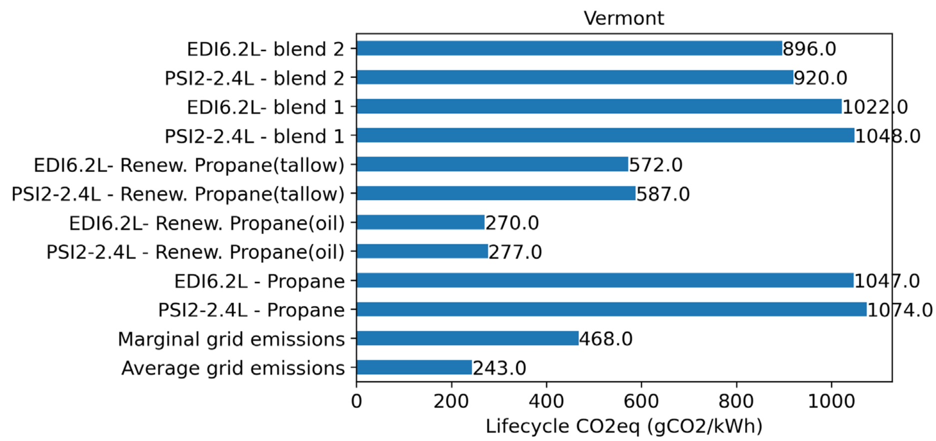
## Utah

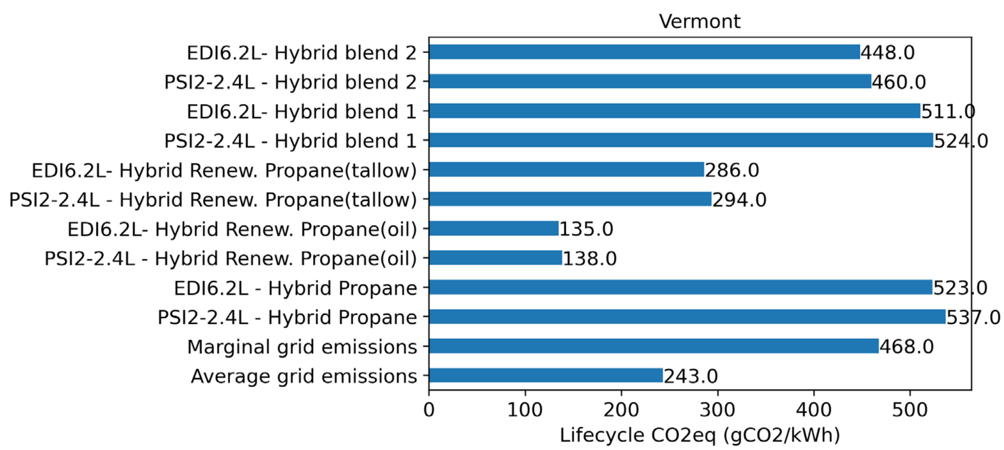

Utah
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
895.0
919.0
1021.0
1047.0
572.0
587.0
270.0
277.0
1046.0
1073.0
1194.0
1140.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)

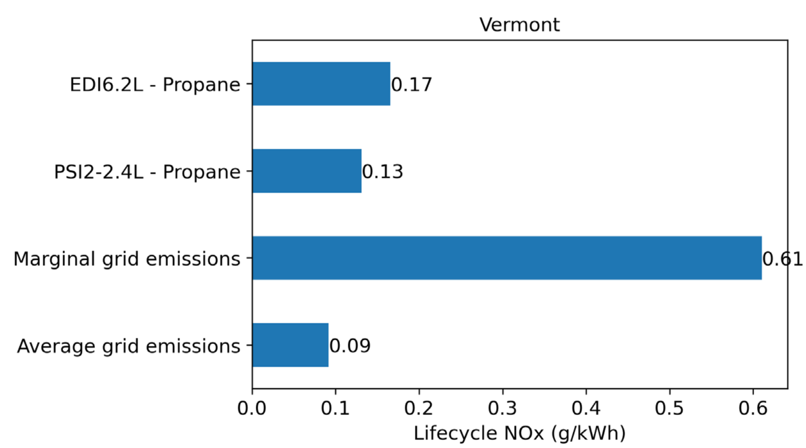

Utah
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
448.0
459.0
510.0
524.0
286.0
294.0
135.0
138.0
523.0
537.0
1194.0
1140.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)


Utah
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.9
0.88
0.0
0.2
0.4
0.6
0.8
Lifecycle NOx (g/kWh)

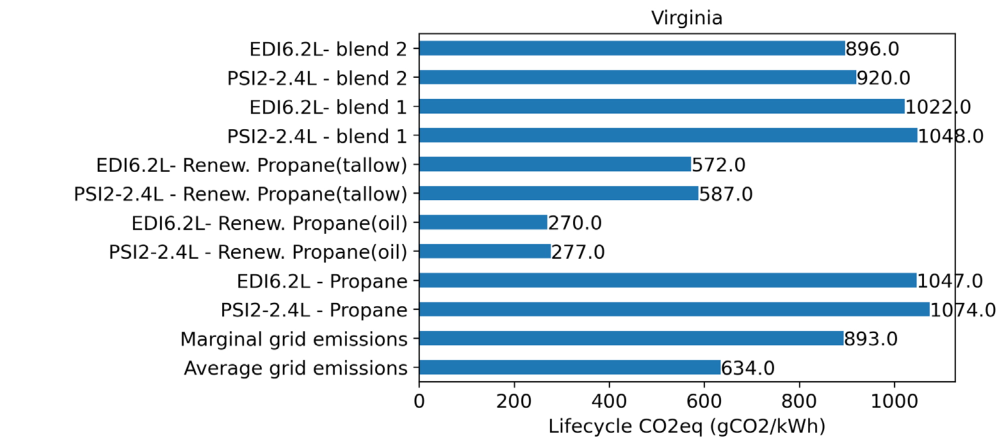
## Vermont


Vermont
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
896.0
920.0
1022.0
1048.0
572.0
587.0
270.0
277.0
1047.0
1074.0
468.0
243.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)

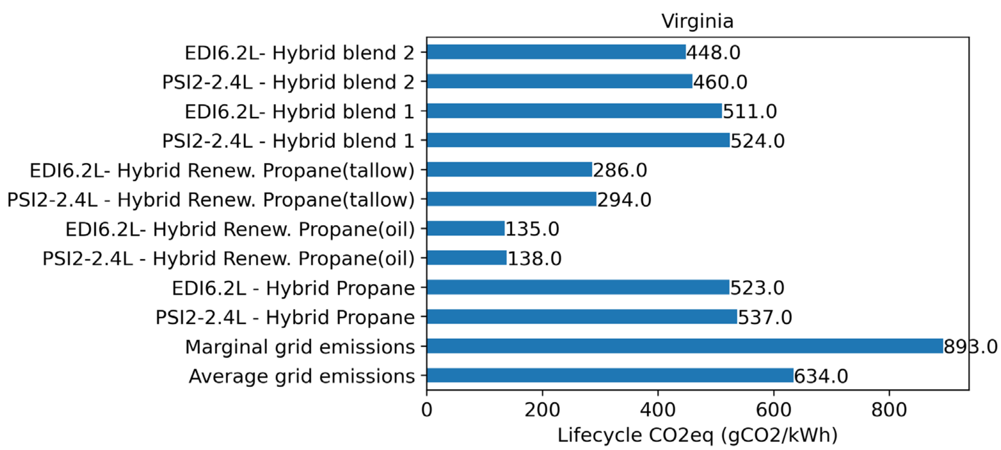

Vermont
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
448.0
460.0
511.0
524.0
286.0
294.0
135.0
138.0
523.0
537.0
468.0
243.0
0
100
200
300
400
500
Lifecycle CO2eq (gCO2/kWh)


Vermont
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.61
0.09
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Lifecycle NOx (g/kWh)

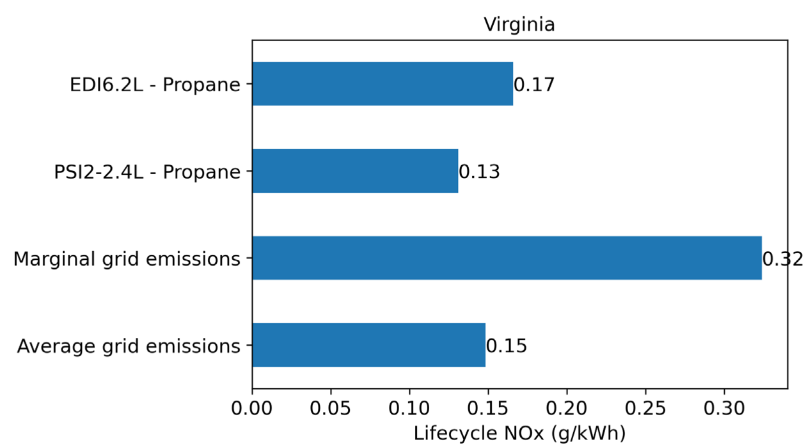
## Virginia



Virginia
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
896.0
920.0
1022.0
1048.0
572.0
587.0
270.0
277.0
1047.0
1074.0
893.0
634.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)

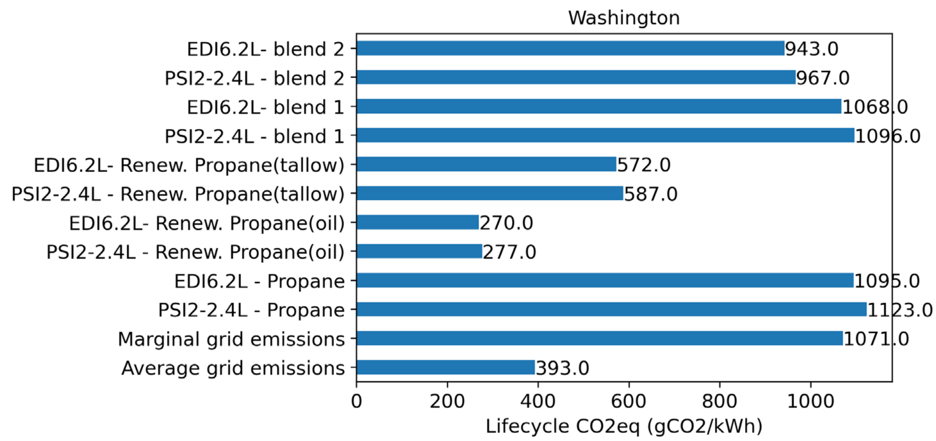



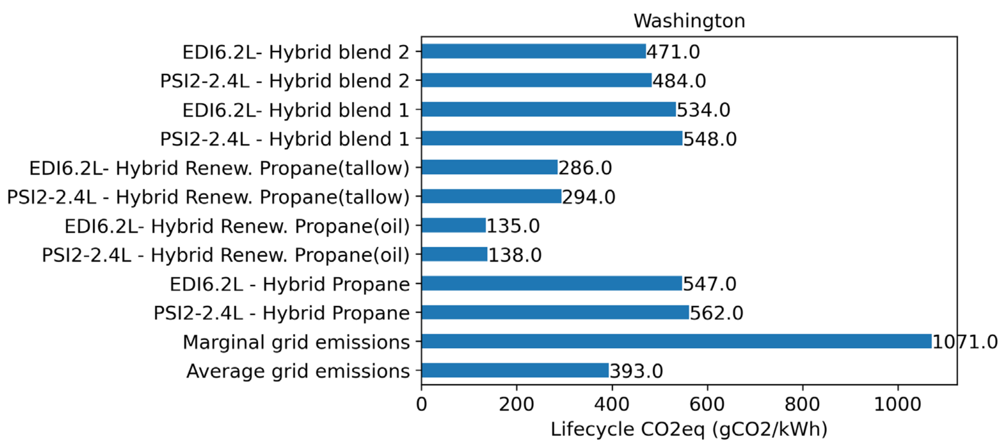
Virginia
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
448.0
460.0
511.0
524.0
286.0
294.0
135.0
138.0
523.0
537.0
893.0
634.0
0
200
400
600
800
Lifecycle CO2eq (gCO2/kWh)

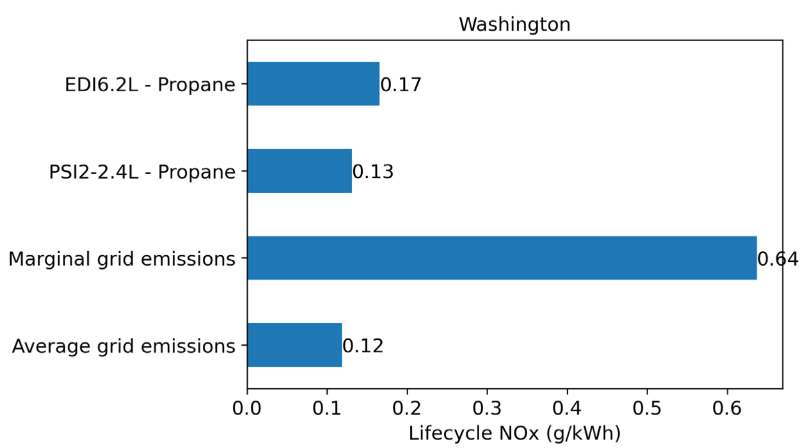



Virginia
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.32
0.15
0.00
0.05
0.10
0.15
0.20
0.25
0.30
Lifecycle NOx (g/kWh)

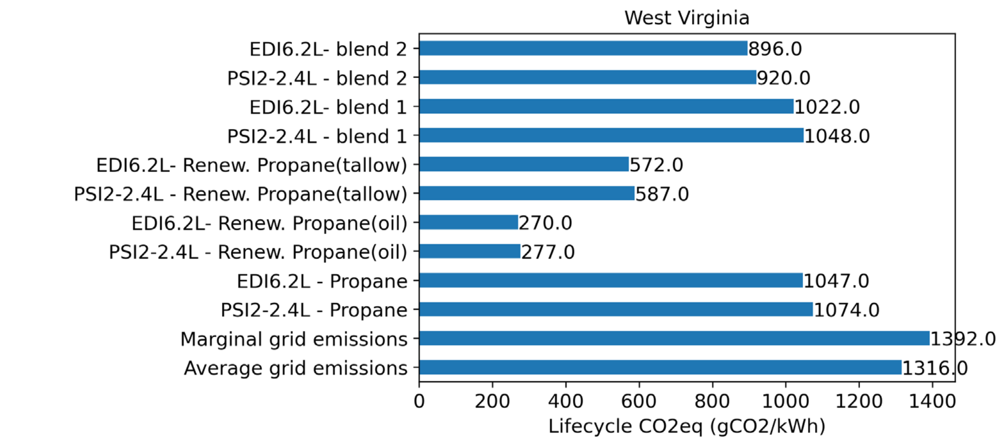
## Washington

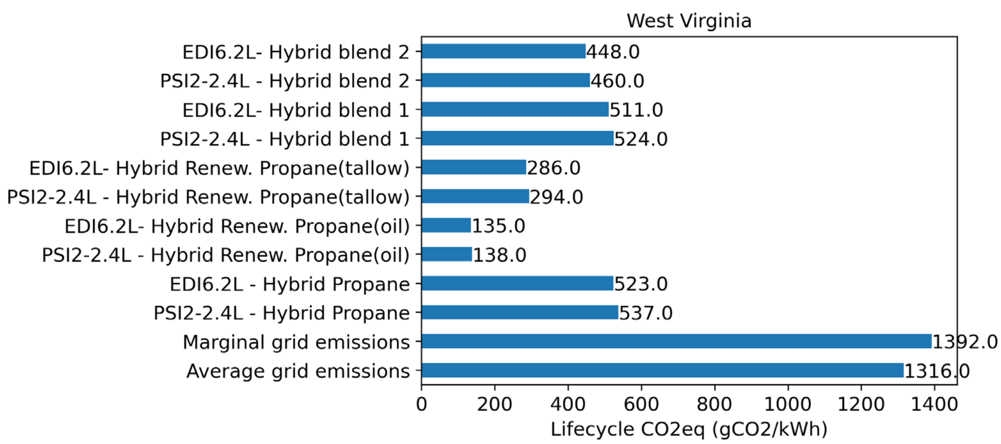

Washington
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
943.0
967.0
1068.0
1096.0
572.0
587.0
270.0
277.0
1095.0
1123.0
1071.0
393.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)

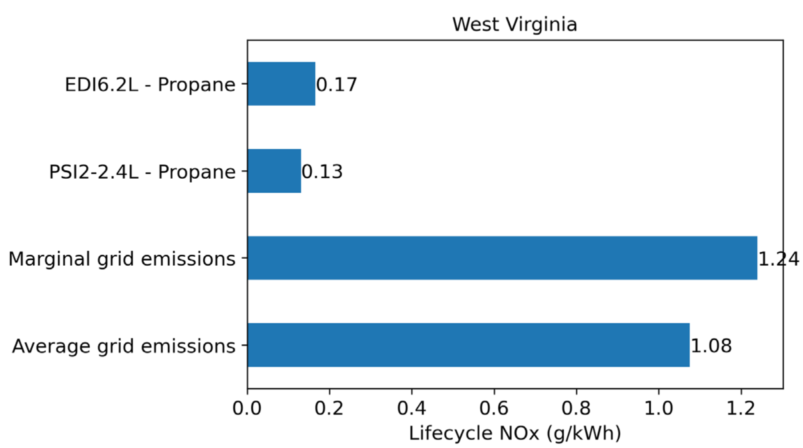

Washington
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
471.0
484.0
534.0
548.0
286.0
294.0
135.0
138.0
547.0
562.0
1071.0
393.0
0
200
400
600
800
1000
Lifecycle CO2eq (gCO2/kWh)


Washington
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.64
0.12
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Lifecycle NOx (g/kWh)

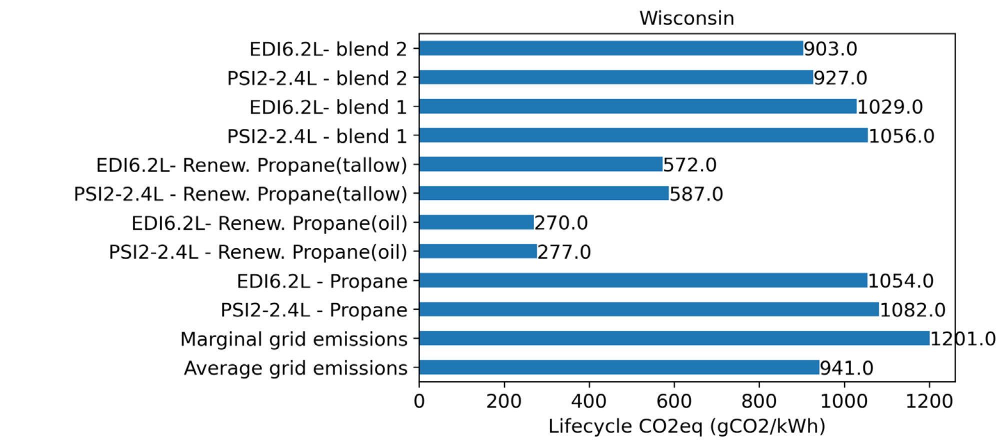
## West Virginia

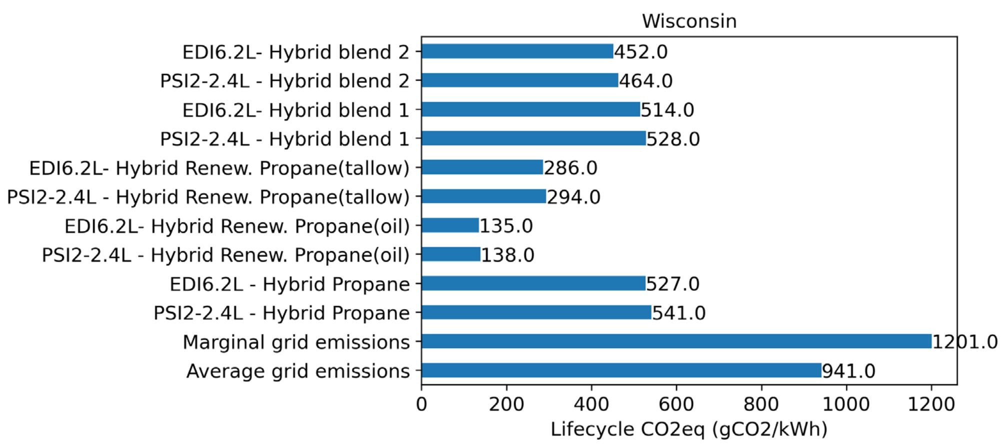


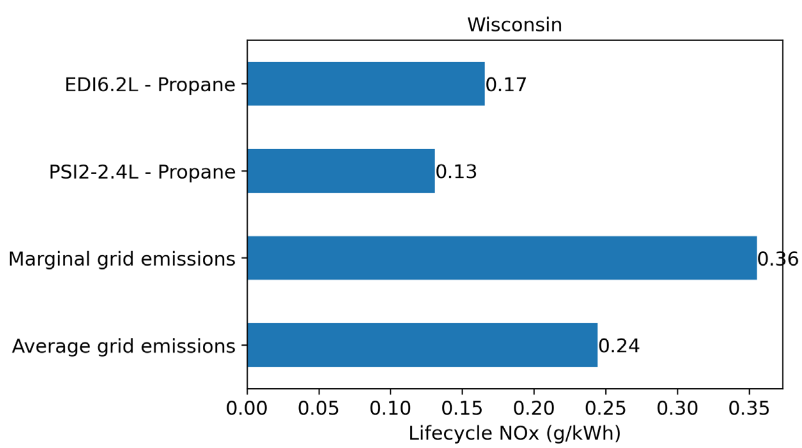



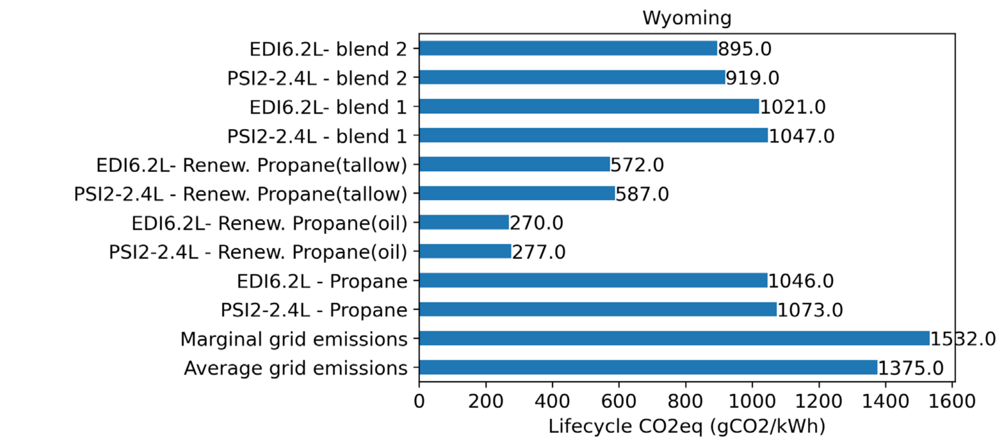
## Wisconsin

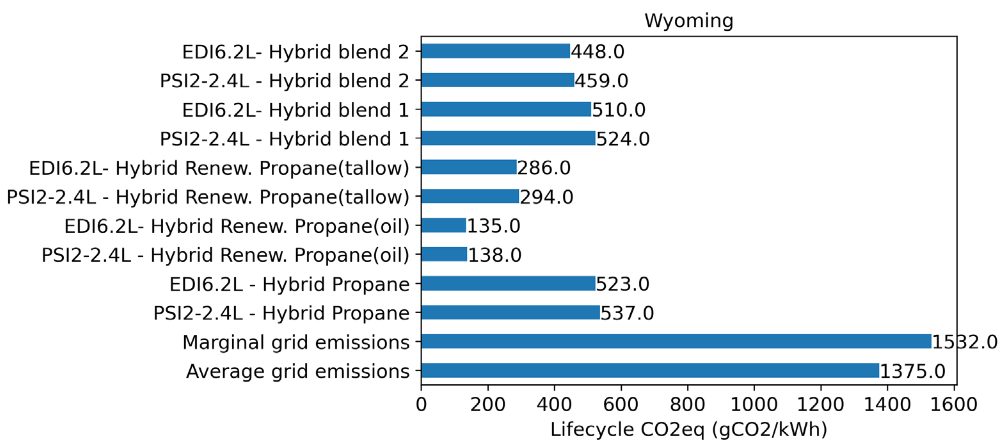

Wisconsin
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
903.0
927.0
1029.0
1056.0
572.0
587.0
270.0
277.0
1054.0
1082.0
1201.0
941.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)

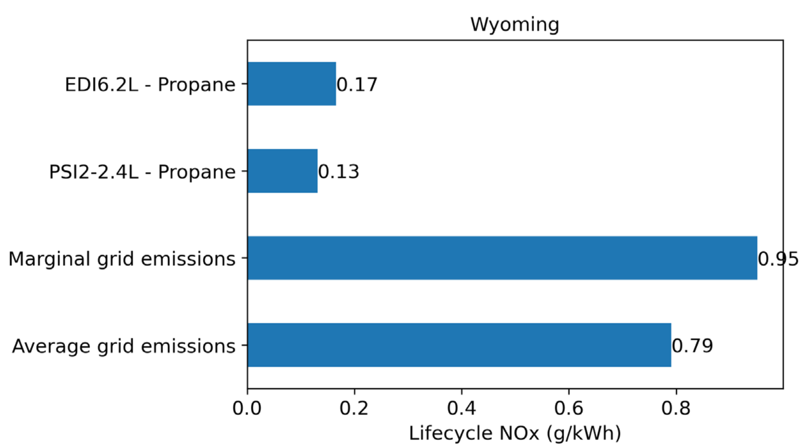

Wisconsin
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
452.0
464.0
514.0
528.0
286.0
294.0
135.0
138.0
527.0
541.0
1201.0
941.0
0
200
400
600
800
1000
1200
Lifecycle CO2eq (gCO2/kWh)


Wisconsin
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.36
0.24
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Lifecycle NOx (g/kWh)

## Wyoming


Wyoming
EDI6.2L- blend 2
PSI2-2.4L - blend 2
EDI6.2L- blend 1
PSI2-2.4L - blend 1
EDI6.2L- Renew. Propane(tallow)
PSI2-2.4L - Renew. Propane(tallow)
EDI6.2L- Renew. Propane(oil)
PSI2-2.4L - Renew. Propane(oil)
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
895.0
919.0
1021.0
1047.0
572.0
587.0
270.0
277.0
1046.0
1073.0
1532.0
1375.0
0
200
400
600
800
1000
1200
1400
1600
Lifecycle CO2eq (gCO2/kWh)


Wyoming
EDI6.2L- Hybrid blend 2
PSI2-2.4L - Hybrid blend 2
EDI6.2L- Hybrid blend 1
PSI2-2.4L - Hybrid blend 1
EDI6.2L- Hybrid Renew. Propane(tallow)
PSI2-2.4L - Hybrid Renew. Propane(tallow)
EDI6.2L- Hybrid Renew. Propane(oil)
PSI2-2.4L - Hybrid Renew. Propane(oil)
EDI6.2L - Hybrid Propane
PSI2-2.4L - Hybrid Propane
Marginal grid emissions
Average grid emissions
448.0
459.0
510.0
524.0
286.0
294.0
135.0
138.0
523.0
537.0
1532.0
1375.0
0
200
400
600
800
1000
1200
1400
1600
Lifecycle CO2eq (gCO2/kWh)


Wyoming
EDI6.2L - Propane
PSI2-2.4L - Propane
Marginal grid emissions
Average grid emissions
0.17
0.13
0.95
0.79
0.0
0.2
0.4
0.6
0.8
Lifecycle NOx (g/kWh)

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