EXECUTIVE SUMMARY

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GHG and Criteria Pollutant Emissions Analysis

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Introduction

Direct use of propane in buildings, transportation, and agriculture applications is a proven, cost-effective, and reliable approach to reducing greenhouse gas (GHG) and other emissions. Propane production and delivery is more efficient than electricity provided by the power grid, which is still dominated by fossil fuel power generation and includes large energy losses at the power plant and transmission lines. In the future, the direct use of propane will remain a sustainable strategy for reducing greenhouse gas and criteria pollutant emissions.

This study presents a comparative analysis of full-fuel-cycle GHG and criteria pollutant emissions for targeted applications in key propane markets, including buildings, agriculture, and transportation. Technology options selected for this analysis are listed below:

- Residential Applications
  - Space Heating: furnaces, boilers, heat pumps
  - Water Heating: conventional storage, tankless, heat pumps
  - Appliances: ranges, clothes dryers
- Commercial Applications
  - Space Heating: furnaces, boilers, heat pumps
  - Water Heating: conventional storage, tankless, heat pump
  - Combined Heat and Power (CHP): engine, microturbine, conventional electric grid
  - Power Generation: engine, conventional electric grid power
- Vehicles
  - Light Duty Trucks
  - School Buses
  - Bobtail Trucks
- Irrigation Engines
- Commercial Lawn Mowers
- Forklifts

Comparative emissions for each technology option are summarized in Table 1 through Table 15. Full-fuel-cycle emissions for each option are normalized with respect to the equivalent baseline propane technology to indicate the relative benefit of propane in comparison to other fuel options. Using this approach, baseline propane options are set to an emissions ratio of 1. Options with higher emissions than the baseline have ratios greater than 1, while those with lower emissions have ratios less than 1.

Key Findings

Propane technologies can provide significant source energy savings and reductions in GHG and criteria pollutants compared to other technologies across a wide range of applications. The following applications show the most potential for reducing full-fuel-cycle emissions through the use of propane technologies:

- **Residential and commercial water heating** are key markets where propane equipment offers marked energy and environmental benefits compared to electric resistance and oil water heaters.
  - **Propane water heaters** use less source energy and generate fewer GHG, NOx, and SOx emissions than conventional electric resistance water heaters.
  - Compared to electric heat pump water heaters, propane water heaters have comparable source energy and GHG emissions, with significant reductions in SOx.
  - Compared to oil water heaters, propane has lower GHG emissions and significantly reduces NOx emissions.

  - Based on this analysis, **a hybrid solar water heater with backup propane** tankless water heater could reduce source energy and emissions by more than half compared to the best available electric technology.
  - **Propane heat pump water heaters** are recent developments that offer potential for lower source energy and emissions.
- Compared to electric resistance heat for both residential and commercial space conditioning, **propane furnaces** can reduce source energy use and GHG emissions by up to 50%.
  - Propane options have significantly fewer SOx emissions than both electric furnace and electric heat pumps.
  - Compared to oil furnaces, propane reduces NOx emissions by as much as 79%.
  - New developments in **absorption heat pumps** show potential to achieve lower emissions than the best available electric heat pumps.
  - Electric heat pumps generate over three times more SOx emissions compared to baseline propane furnaces.
  - A **hybrid heat pump with propane furnace backup** shows potential for reducing source energy, GHG and NOx emissions, but SOx emissions would still be higher than conventional propane furnaces.
- **Propane residential clothes dryers** have significantly lower emissions and source energy use than electric dryers.
- **Propane cooking ranges** also reduce source energy use, GHG emissions, and SOx emissions compared to electric ranges, but to a lesser degree.
- **Propane mCHP** reduces source energy use and GHG emissions by almost half compared to equivalent electric grid power and electric water heating. Propane mCHP also reduces SOx emissions by almost 90% compared to the all-electric case,
- Without heat recovery, propane power generation does not have the source energy and emission benefits provided by mCHP; however, propane engines offered significant reduction in SOx emissions compared to electric grid power.
- **Propane vehicles** have several advantages for fleets, including economic benefits, reliable performance, onsite fueling, and reduced maintenance.
  - **Compared to diesel, LPG vehicles** have lower NOx emissions.
  - **LPG school buses** reduce NOx emissions by 5% to 15% compared to diesel. For Type C school buses, LPG have 6% fewer GHG emissions than diesel.
  - Use of **LPG Type A school buses in place of gasoline** reduces source energy use by 18%, along with 12% fewer GHG emissions, 15% fewer NOx emissions, and 37% SOx emissions.
  - Compared to gasoline, **LPG light-duty vehicles** reduce source energy use by 18%, along with 12% fewer GHG emissions, 5% fewer NOx emissions, and 37% SOx emissions.
- **Propane irrigation engines** have 8% lower GHG and 9% lower NOx emissions compared to diesel.
  - Compared to gasoline, propane irrigation engines reduce source energy use by 21%, along with 18% fewer GHG emissions, 20% fewer NOx emissions and 17% fewer SOx emissions
  - Electric irrigation engines have over three times higher SOx emissions than propane

- **Propane commercial lawn mowers** reduce source energy use by 20%, with 17% lower GHG, 19% lower NOx, and 16% lower SOx emissions compared to gasoline.
- **Propane forklifts** reduce source energy use and all emissions by about 15% to 19% compared to gasoline forklifts
    - Compared to diesel, propane has about 4% lower GHG and 6% lower NOx emissions
    - Electric forklifts have over four times higher SOx emissions than propane

Recommendations

- Hybrid configurations with propane backup show potential savings in source energy use and emissions compared to the best available conventional equipment for water heating or space conditioning. More detailed modeling of these configurations, supplemented by field data, is needed to quantify energy use and full-fuel-cycle emissions more accurately.
- Upstream and end use emission factors need to be validated for emerging technologies with potential for significant emission reductions, such as the gas engine-driven water heater (Ilios), Yanmar mCHP system, or the gas absorption heat pump (SMTI). This can be done using existing data or new data collected from field demonstrations or laboratory tests.
- The majority of emission factors used for vehicles and engine applications in this analysis were based on GREET® 2016 defaults. These defaults vary from SEEAT vehicle emission factors (based on GREET® 2015) and AFLEET 2016 emission factors, as shown in the Appendix table. GTI recommends a more detailed review of GREET® 2016 default assumptions to verify their appropriateness for these applications. Some default emission factors and the associated assumptions warrant further investigation, including:
    - NOx emission factor for LPG medium-duty vehicles is significantly higher than the default for school buses, although both use the same or similar engines
    - NOx emission factor for diesel light-duty vehicles is significantly higher than school bus and medium-duty vehicles
    - Analyses for commercial power generation, CHP, and irrigation engines were based on EPA non-road emission factors, pending more appropriate data for stationary engines
    - Some emission factors may need to be updated based on recent engine developments

Table 1 – Residential Water Heater Technologies Source Energy and Emissions

Residential Water Heating	Efficiency (EF)	Final Site (MMBtu)	Final Source (MMBtu)	Source Energy Ratio	Total CO2e (kg)	GHG Ratio	NOx Ratio	SOx Ratio
Solar Storage / Propane Backup								
Solar Storage (SEF 3) with Propane Storage (0.67 EF)	0.67	2.9	4.1	0.31	265	0.30	0.28	0.62
Standard Efficiency Storage								
Propane Storage (0.67 EF)	0.67	11.4	13.1	1.00	879	1.00	1.00	1.00
Electric Storage (0.85 EF)	0.85	9.0	27.2	2.07	1,637	1.86	1.35	9.27
Natural Gas Storage (0.67 EF)	0.67	11.4	12.4	0.95	761	0.87	0.76	0.53
Electric Heat Pump Storage (2.0 EF)	2.00	5.3	16.1	1.23	969	1.10	0.80	5.49
Best Available Storage								
Propane Storage (0.85 EF)	0.85	9.0	10.7	0.82	715	0.81	0.80	1.01
Electric Storage (0.95 EF)	0.95	8.0	24.3	1.85	1,464	1.67	1.21	8.29
Natural Gas Storage (0.85 EF)	0.85	9.0	10.3	0.78	629	0.72	0.62	0.65
Electric Heat Pump Storage (2.90 EF)	2.90	3.7	11.1	0.85	667	0.76	0.55	3.78
Standard Efficiency Tankless								
Propane tankless (0.90 EF)	0.90	8.4	9.9	0.75	659	0.75	0.74	0.82
Electric tankless (0.95 EF)	0.95	8.0	24.3	1.85	1,464	1.67	1.21	8.29
Natural Gas tankless (0.90 EF)	0.90	8.5	9.4	0.72	576	0.66	0.58	0.48
Best Available Tankless								
Propane tankless (0.95 EF)	0.95	8.0	9.4	0.72	629	0.72	0.71	0.79
Electric tankless (1.0 EF)	1.00	7.6	23.1	1.76	1,391	1.58	1.15	7.88
Natural Gas tankless (0.95 EF)	0.95	8.0	8.9	0.68	545	0.62	0.54	0.46

Notes:

1. Energy factors for residential water heater technologies based on DOE and Energy Star; storage tanks assumed less than 55 gallons
2. Analysis assumes SEF=3 with a propane storage tank energy factor of 0.67.
3. Solar heating systems include electrical pump and heater controller

Analysis assumes electric use equal to 5% the total heat delivered. .

4. Electric tankless water heaters (EF=0.95) were assumed to consume energy similar to electric storage water heaters
5. Water heating demand for all cases was 7.63 MMBtu based on energy models for an average 3 occupants. Piping losses assumed negligible.

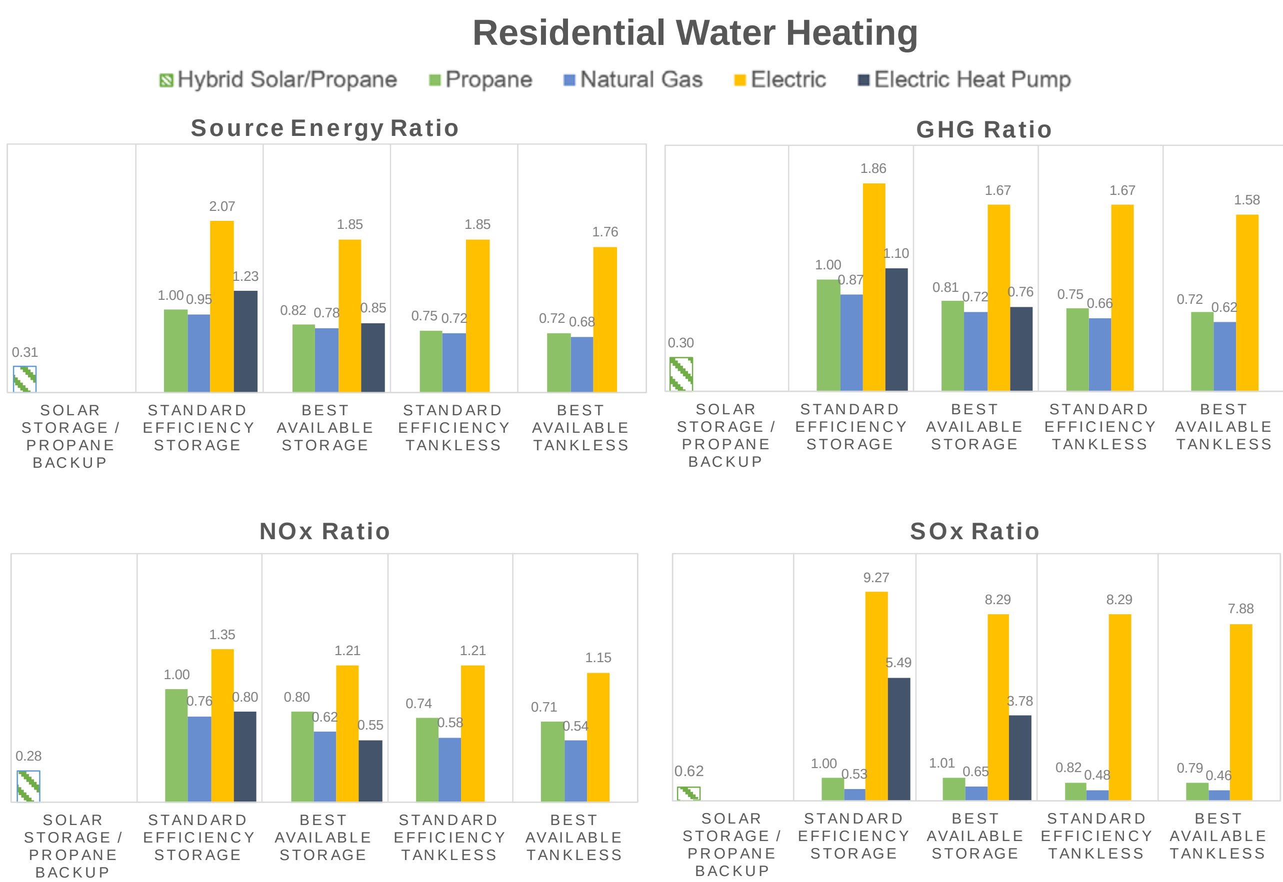

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Table 2 – Space Conditioning Technologies Source Energy and Emissions

Residential Space Conditioning	Efficiency	Final Site (MMbtu)	Final Source (MMbtu)	Source Energy Ratio	Total CO2e (kg)	Source Energy Ratio	GHG Ratio	NOx Ratio	SOx Ratio
Energy Star electric heat pump (16 SEER)	8.60 HSPF	30	91	1.18	5,501	1.18	1.08	0.83	3.00
Standard electric heat pump (10 SEER)	7.20 HSPF	36	108	1.39	6,489	1.39	1.28	0.98	3.53
Elec ASHP w propane backup	1.23 COP	47	83	1.07	5,250	1.07	1.03	0.93	1.80
Propane absorption heat pump (prototype)	1.40 COP	43	61	0.79	3,960	0.79	0.78	0.76	0.93
Propane furnace	0.96 AFUE	58	78	1.00	5,083	1.00	1.00	1.00	1.00
Oil furnace	0.96 AFUE	58	80	1.03	5,818	1.03	1.14	4.72	1.01
Electric furnace	1.00 AFUE	56	169	2.18	10,166	2.18	2.00	1.54	5.54
Natural Gas furnace	0.96 AFUE	58	75	0.96	4,547	0.96	0.89	0.80	0.79

Notes:

1. Energy use based on average 51.2 MMBtu annual heating load [Nexight, 2014]; includes HVAC blower energy and SEER 13 A/C;
2. ASHP efficiency can vary significantly with climate. This analysis is based on ASHRAE Climate Zone 4 temperature profiles (Nashville, TN).
3. Hybrid configuration assumes Energy Star electric ASHP serves 40% of heating load; propane furnace provides 60% with proportional energy use. This assumption based on published analysis of residential heating systems by Newport Partners, 2013. [Nexight 2104]
4. GAHP performance specifications based on prototype laboratory data.

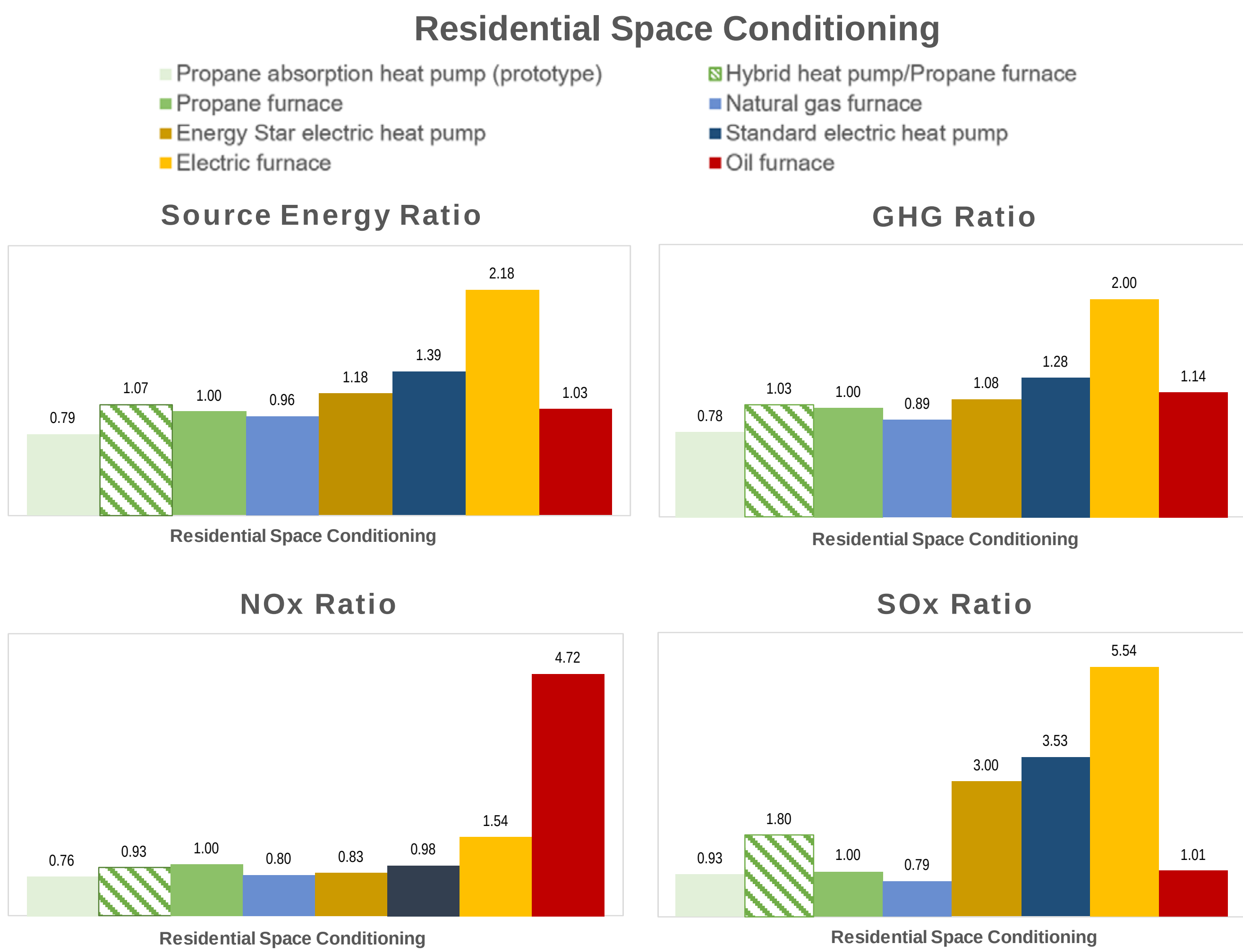

Table 3 – Residential Appliances Source Energy and Emissions

Residential Appliances	Final Site (MMbtu)	Final Source (MMbtu)	Total NOx (kg)	Total CO2e (kg)	Source Energy Ratio	GHG Ratio	NOx Ratio	SOx Ratio
Clothes Dryers								
Propane (EF 2.75)	3.77	4.74	0.40	313	1.00	1.00	1.00	1.00
Electric (EF 3.10)	2.97	8.99	0.52	541	1.90	1.73	1.30	5.74
Natural Gas (EF 2.75)	3.81	4.58	0.32	279	0.96	0.89	0.79	0.73
Cooking Ranges								
Propane	4.12	4.73	0.42	317	1.00	1.00	1.00	1.00
Electric	2.06	6.24	0.36	376	1.32	1.18	0.86	5.90
Natural Gas	4.10	4.47	0.32	274	0.94	0.86	0.76	0.53

Notes:

1. Annual fuel use for clothes dryers and cooking ranges based on GTI's Carbon Management Information Center SEEAT (http://seeatcalcbeta.gastechnology.org/HelpPages/EFHelp.htm) accessed December 2016.

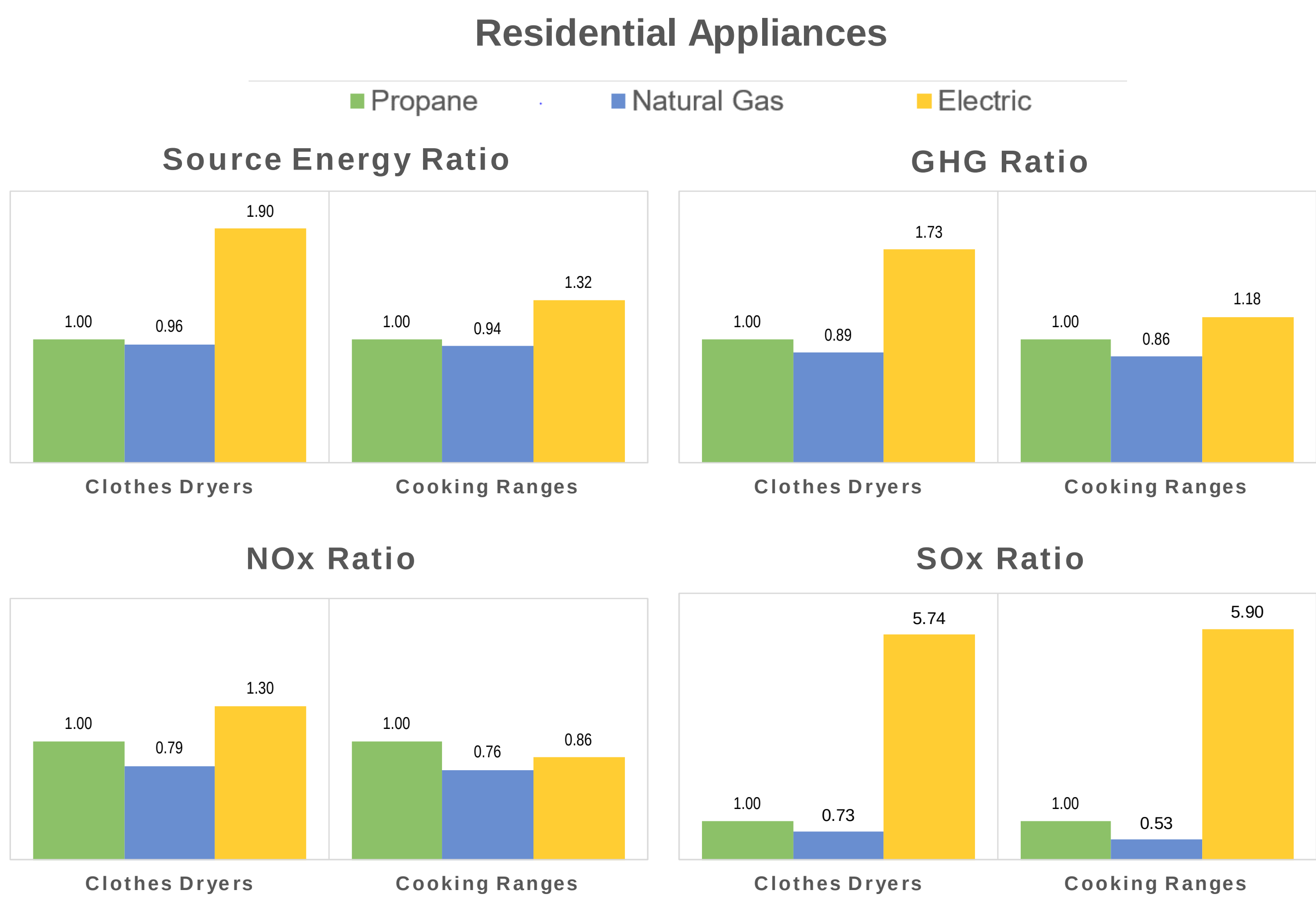

Table 4 – Commercial Water Heater Technologies Source Energy and Emissions

Commercial Water Heating	Efficiency (EF)	Final Site (MMbtu)	Final Source (MMbtu)	Source Energy Ratio	Total CO2e (kg)	GHG Ratio	NOx Ratio	SOx Ratio
Standard Efficiency Storage								
Propane Storage (0.86 EF)	0.86	59	68	1.00	4,549	1.00	1.00	1.00
Electric Storage (0.98 EF)	0.98	42	127	1.87	7,628	1.68	1.22	8.34
Natural Gas Storage (0.86 EF)	0.86	59	64	0.95	3,938	0.87	0.76	0.53
Fuel Oil Storage (0.78 EF)	0.78	65	77	1.14	5,900	1.30	5.93	1.12
Electric Heat Pump (HPWH) (2.0 EF)	2.00	20	61	0.89	3,656	0.80	0.58	4.00
Best Available Storage								
Propane Storage (0.95 EF)	0.95	49	59	0.86	3,904	0.86	0.84	1.06
Electric Storage (1.0 EF)	1.00	41	124	1.83	7,475	1.64	1.19	8.18
Natural Gas Storage (0.95 EF)	0.95	49	56	0.82	3,412	0.75	0.65	0.68
Fuel Oil Storage (0.82 EF)	0.82	57	67	0.99	5,138	1.13	5.17	0.98
Electric Heat Pump (HPWH) (2.40 EF)	2.40	17	51	0.75	3,047	0.67	0.49	3.33
Standard Efficiency Tankless (non-condensing)								
Propane tankless (0.85 EF)	0.85	48	56	0.82	3,732	0.82	0.82	0.90
Electric tankless (0.95 EF)	0.95	42	128	1.88	7,697	1.69	1.23	8.42
Natural Gas tankless (0.85 EF)	0.85	48	53	0.78	3,238	0.71	0.62	0.52
Best Available Tankless								
Propane Heat Pump (HPWH) (1.20 EF)	1.20	33	40	0.59	2,680	0.59	0.58	0.75
Propane tankless (0.95 EF)	0.95	43	50	0.74	3,343	0.73	0.73	0.82
Electric tankless (0.99 EF)	0.99	41	123	1.81	7,386	1.62	1.18	8.08
Natural Gas tankless (0.95 EF)	0.95	43	47	0.70	2,906	0.64	0.56	0.48

Notes:
1. Water heater energy use based on building energy model for 2000 s.f. Fast Food Restaurant, Nashville TN, selected from available SEEAT options with delivered energy (41 MMBtu) similar to CBECS 2003 average for water heating
2. Electric heat pump water heaters energy use extrapolated from residential models
3. Propane heat pump water heater assumed average COP=1.20 (Ilios) and electric use equivalent to best propane tankless

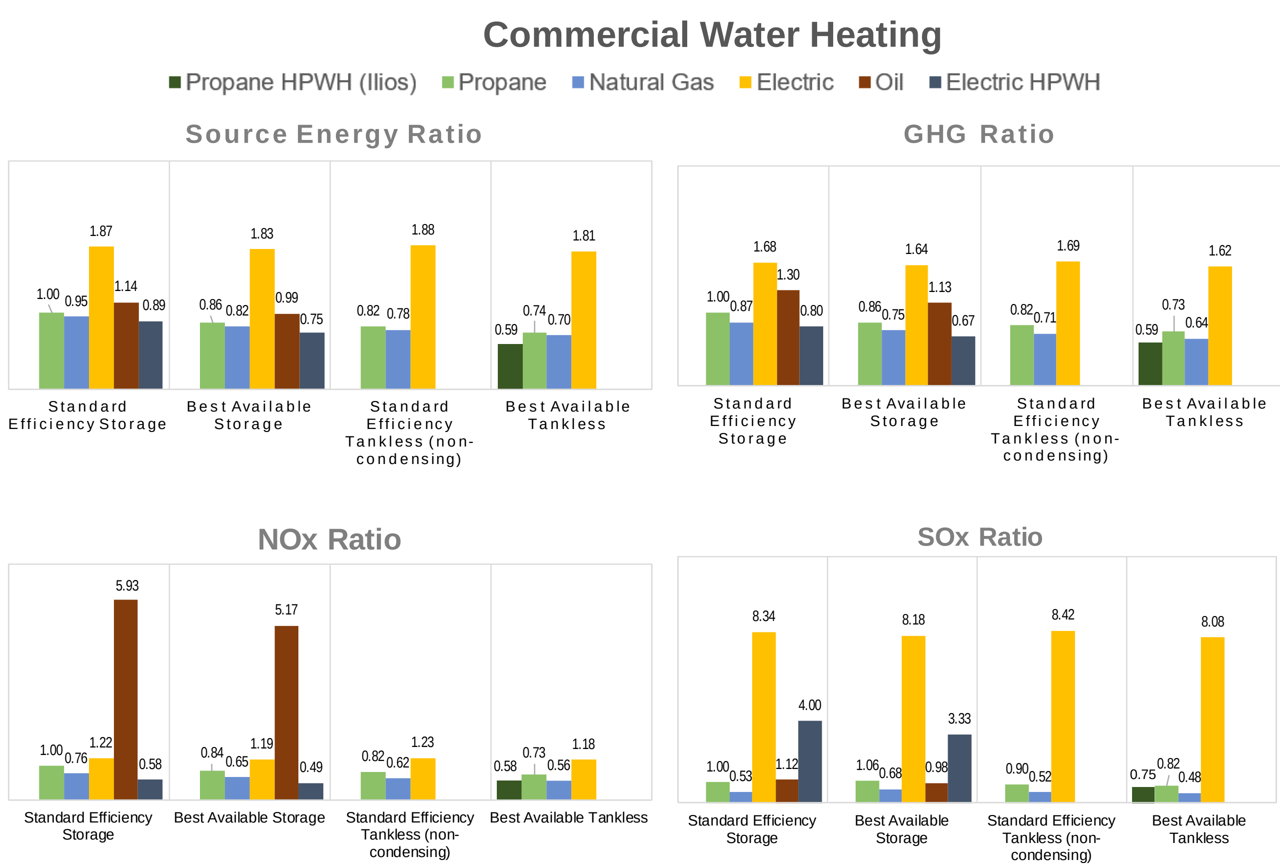

Table 5 – Commercial Space Conditioning Technologies Source Energy and Emissions

Commercial Space Conditioning	Efficiency (HSPF/ COP)	Final Site (MMBtu)	Final Source (MMBtu)	Source energy Ratio	Total CO2e (kg)	GHG Ratio	NOx Ratio	SOx Ratio
Best available Furnaces								
Propane furnace	0.99	585	919	0.88	58,876	0.88	0.87	0.95
Natural Gas furnace	0.99	585	892	0.86	54,184	0.81	0.73	0.85
Electric furnace	1.00	551	1,669	1.60	100,433	1.50	1.21	3.09
Oil furnace	0.98	587	940	0.90	65,296	0.98	3.42	0.95
Minimum Efficiency Furnaces								
Propane furnace	0.80	690	1,040	1.00	66,967	1.00	1.00	1.00
Natural Gas furnace	0.80	690	1,006	0.97	61,183	0.91	0.83	0.87
Electric furnace	0.98	559	1,695	1.63	101,995	1.52	1.23	3.13
Oil furnace	0.80	690	1,062	1.02	74,603	1.11	4.12	1.00

Notes:
Annual space conditioning for a Fast Food Restaurant, 2000 s.f., in Nashville,TN
Analysis for furnaces includes energy for heating, cooling (electric DX 13 EER), and HVAC blower.

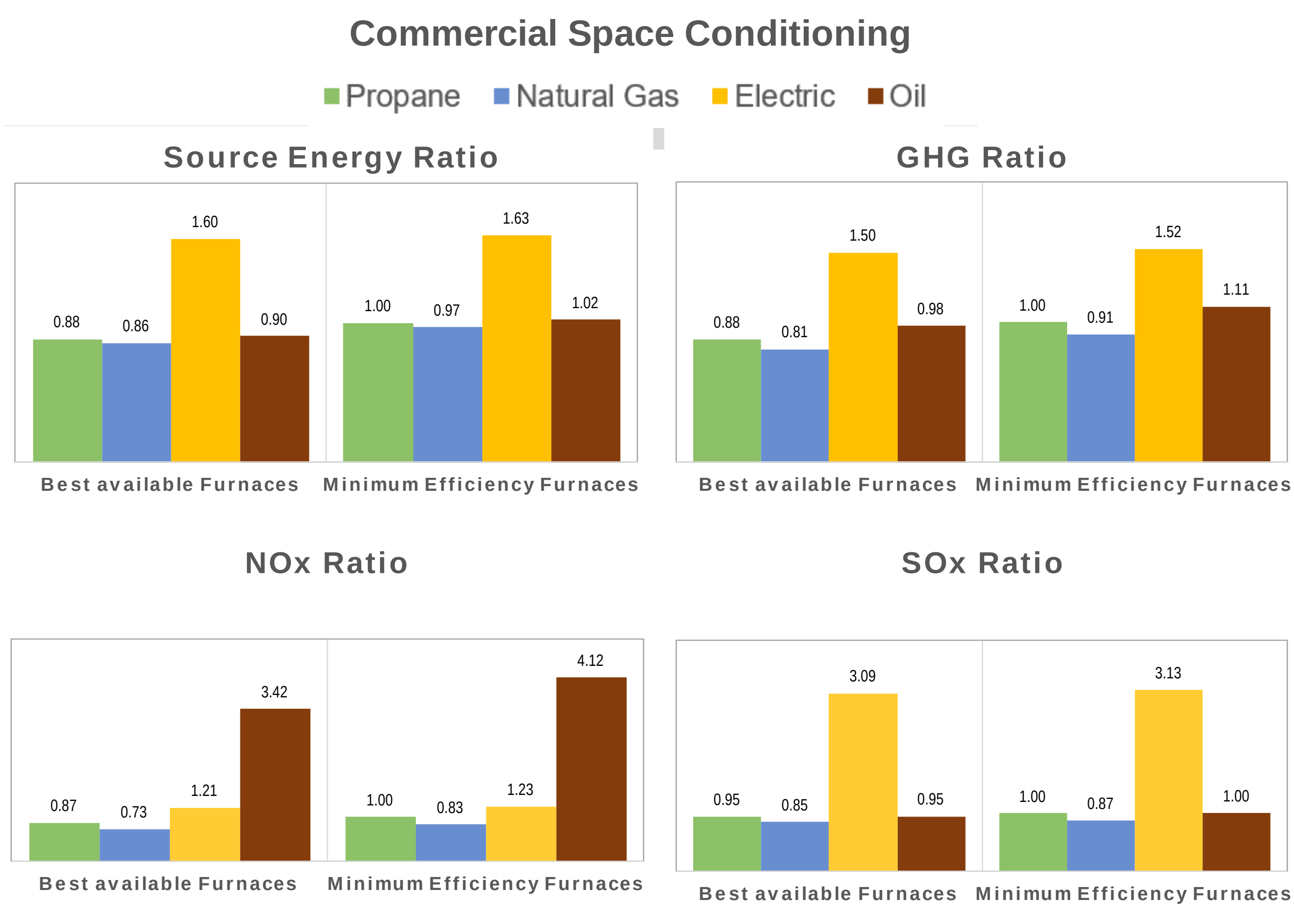

Table 6 – Commercial Heat Pump Technologies Source Energy and Emissions

Commercial Heat Pumps	Efficiency (HSPF/ COP)	Final Site (MMBtu)	Final Source (MMBtu)	Source energy Ratio	Total CO2e (kg)	GHG Ratio	NOx Ratio	SOx Ratio
Heat Pumps								
Energy Star electric ASHP (14 SEER)	8.40	341	1,034	1.19	62,208	1.08	0.80	4.18
Hybrid ASHP (8.4 HSPF) w/	0.00	243	677	0.78	40,982	0.71	0.54	2.62
Propane engine-driven heat pump	1.20	717	867	1.00	57,585	1.00	1.00	1.00
Standard electric ASHP (10 SEER)	7.20	427	1,295	1.49	77,894	1.35	1.00	5.23

Notes:
1. Ratios are based on the propane engine-driven heat pump (ICE NextAire™)
2. Annual space conditioning for a Fast Food Restaurant, 2000 s.f., in Nashville,TN
3. ASHP efficiency varies with climate; estimate based on ASHRAE Climate Zone 4 (Nashville, TN)
4. Hybird configuration assumes Energy Star (ASHP) serves 60% of load; backup propane furnace 40%.
with propane furnace backup system (80% TE) provides the remaining 60%.
5. Engine driven GHP with DOAS assumed average 1.2 COPgas

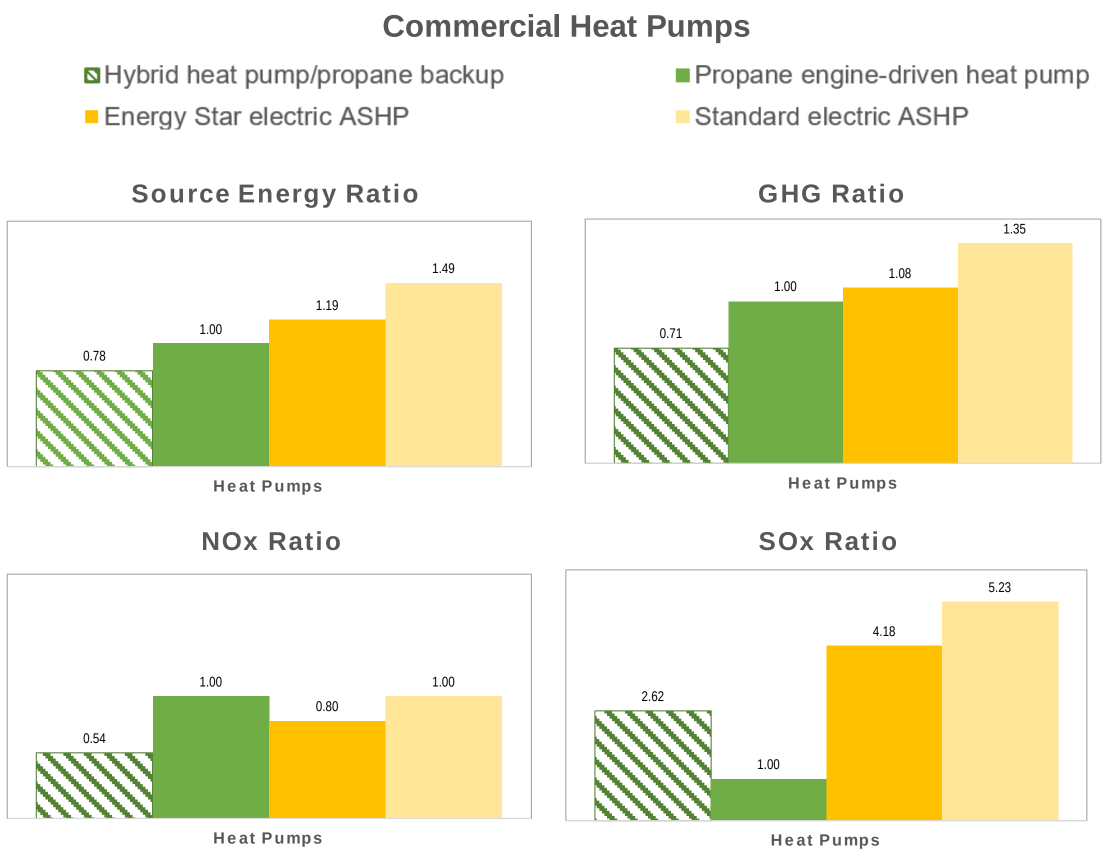

Table 7 – Micro-Combined Heat and Power Technologies Source Energy and Emissions

Micro-Combined Heat and Power	Electric Efficiency (%LHV)	Heat Recovery Efficiency (LHV))	Site Energy Use (MMBtu)	Source Energy Use (MMbtu)	Source Energy Ratio	Total CO2e (kg)	GHG Ratio	NOx Ratio	SOx Ratio
Engine mCHP (10 kW)									
Propane	32%	58%	338	389	1.00	22,937	1.00	1.00	1.00
Natural gas	30%	53%	323	352	0.90	21,527	0.94	1.15	0.51
Diesel	36%	56%	284	338	0.87	22,675	0.99	1.01	0.86
Equivalent All Electric System			263	798	2.05	48,013	2.09	2.11	9.38
MicroTurbine mCHP (30 kW)									
Propane	26%	50%	1,181	1,359	1.00	80,079	1.00	1.00	1.00
Natural gas	26%	50%	1,181	1,288	0.95	78,861	0.98	1.20	0.54
Diesel	26%	43%	1,181	1,406	1.03	94,190	1.18	1.20	1.03
Equivalent All Electric System			865	2,622	1.93	157,779	1.97	1.98	8.83

Notes:
1. Engine mCHP analysis assumes 3000 hrs operation at full load (10 kW); heat utilization:
2. Engine mCHP efficiency based on CP10WN (http://www.yanmar-es.com/uploads/files/CP10WN%20Spec%20Sheet.pdf);
Microturbine based on Capstone C30 (https://www.capstoneturbine.com/products/c30)
3. Microturbine mCHP analysis assumes 3000 hrs operation at full load (30 kW); heat utilization:
4. Grid energy use based on delivering same electric service (30,00 kWh) and same thermal output (183 MMbtu)
5. GHG emission factors for Propane and Diesel based on EPA NonRoad Vehicles;
all other emission factors used for natural gas and electric based on SEEAT

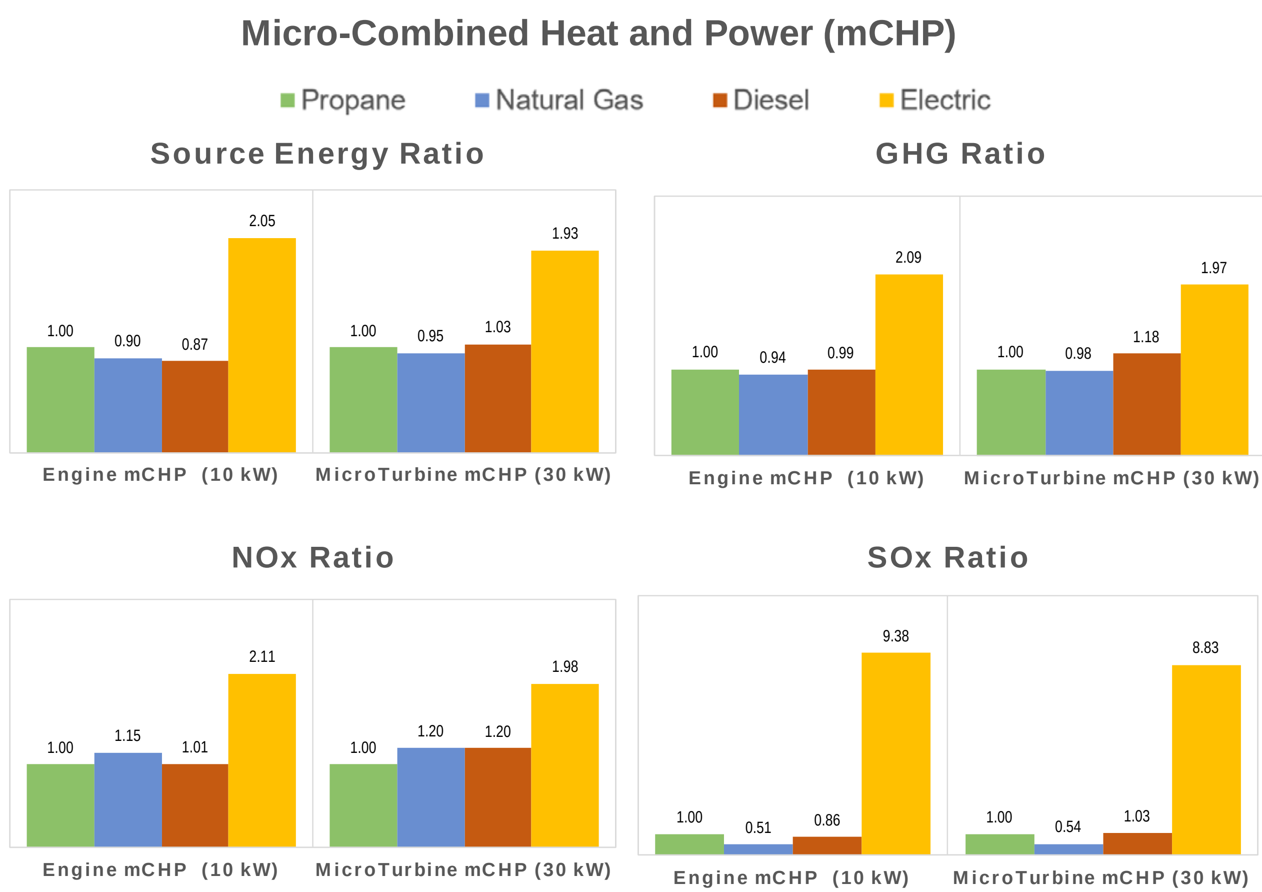

Table 8 – Commercial Power Generation (7 kW) Source Energy and Emissions

Commercial Power Generation	Final Site (MMBtu)	Final Source (MMBtu)	Source Energy Ratio	Total CO2e (kg)	GHG Ratio	NOx Ratio	SOx Ratio
Propane	11.04	12.7	1.00	749	1.00	1.00	1.00
Natural gas	13.42	14.6	1.15	896	1.20	1.46	0.66
Diesel	9.19	10.9	0.86	733	0.98	1.00	0.85
Grid Electricity	2.39	7.2	0.57	435	0.58	0.59	2.61

Notes:
1. Generators in the analysis are assumed to operate at full load (7 kW) for (hours per year) :100
2. Fuel use is based on full load specifications of representative generators:
3. Annual energy use for grid electricity is based on same energy service of the generators (700 kWh)
4. GHG emission factors for Propane and Diesel based on EPA NonRoad Vehicles;
all other emission factors used for natural gas and electric based on SEEAT

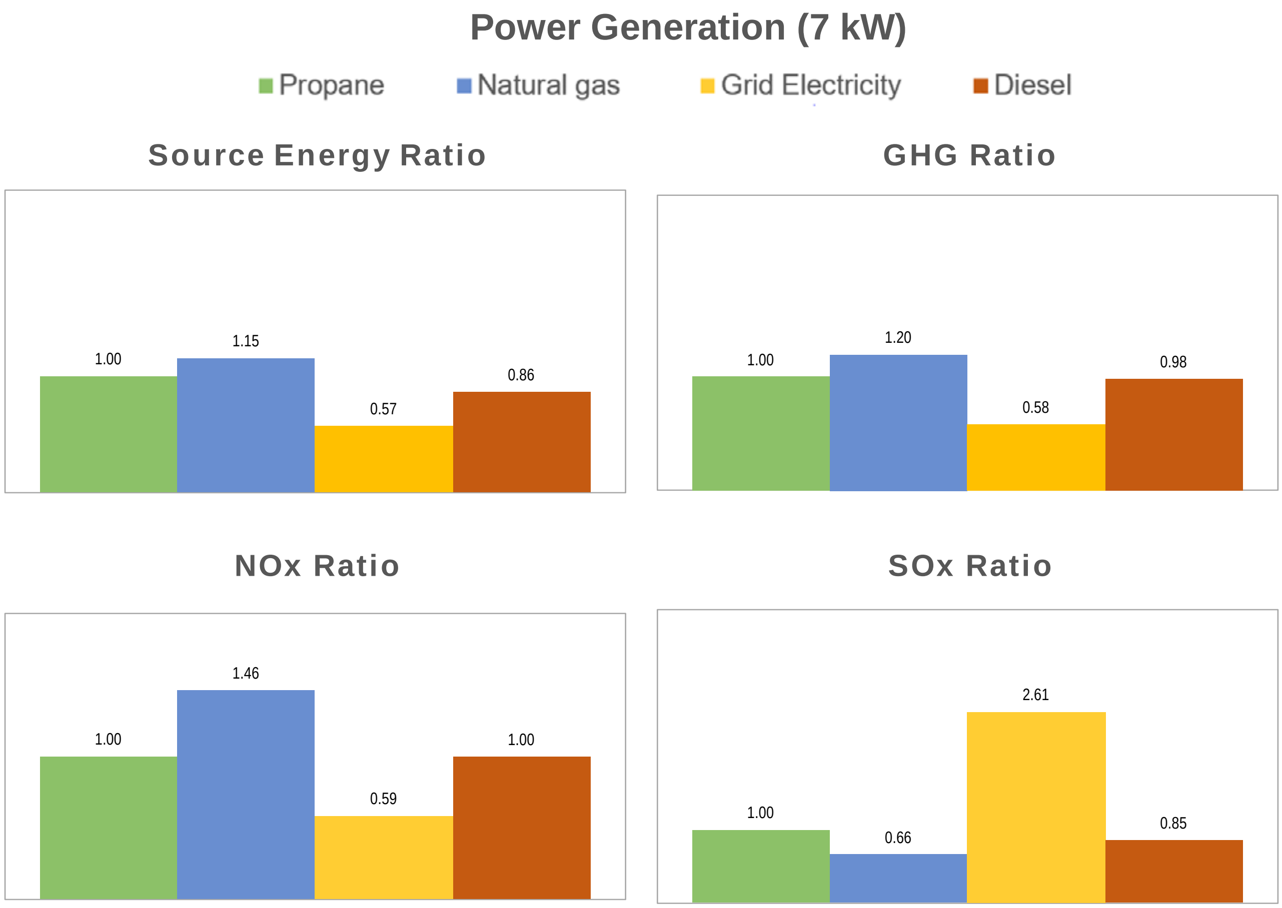

Table 9 – Commercial Power Generation (100 kW) Source Energy and Emissions

Commercial Power Generation	Final Source (MMBtu)	Final Source (MMBtu)	Source Energy Ratio	Total CO2e (kg)	GHG Ratio	NOx Ratio	SOx Ratio
Propane	1156.89	1330.4	1.00	78,416	1.00	1.00	1.00
Natural gas	1171.80	1277.3	0.96	78,218	1.00	1.22	0.55
Diesel	1002.87	1193.4	0.90	79,955	1.02	1.04	0.89
Grid Electricity	341.20	1033.8	0.78	62,203	0.79	0.80	3.56

Notes:

1. Generators in the analysis are assumed to operate at full load (100 kW) for (hours per year) :1000
2. Fuel use is based on full load specifications of representative generators:
   - Generac SG100 (8cyl 8.9L)
   - Generac SD100 (6cyl 6.7L)
3. Annual energy use for grid electricity is based on same energy service of the generators (700 kWh)
4. GHG emission factors for Propane and Diesel based on EPA NonRoad Vehicles;
   all other emission factors used for natural gas and electric based on SEEAT

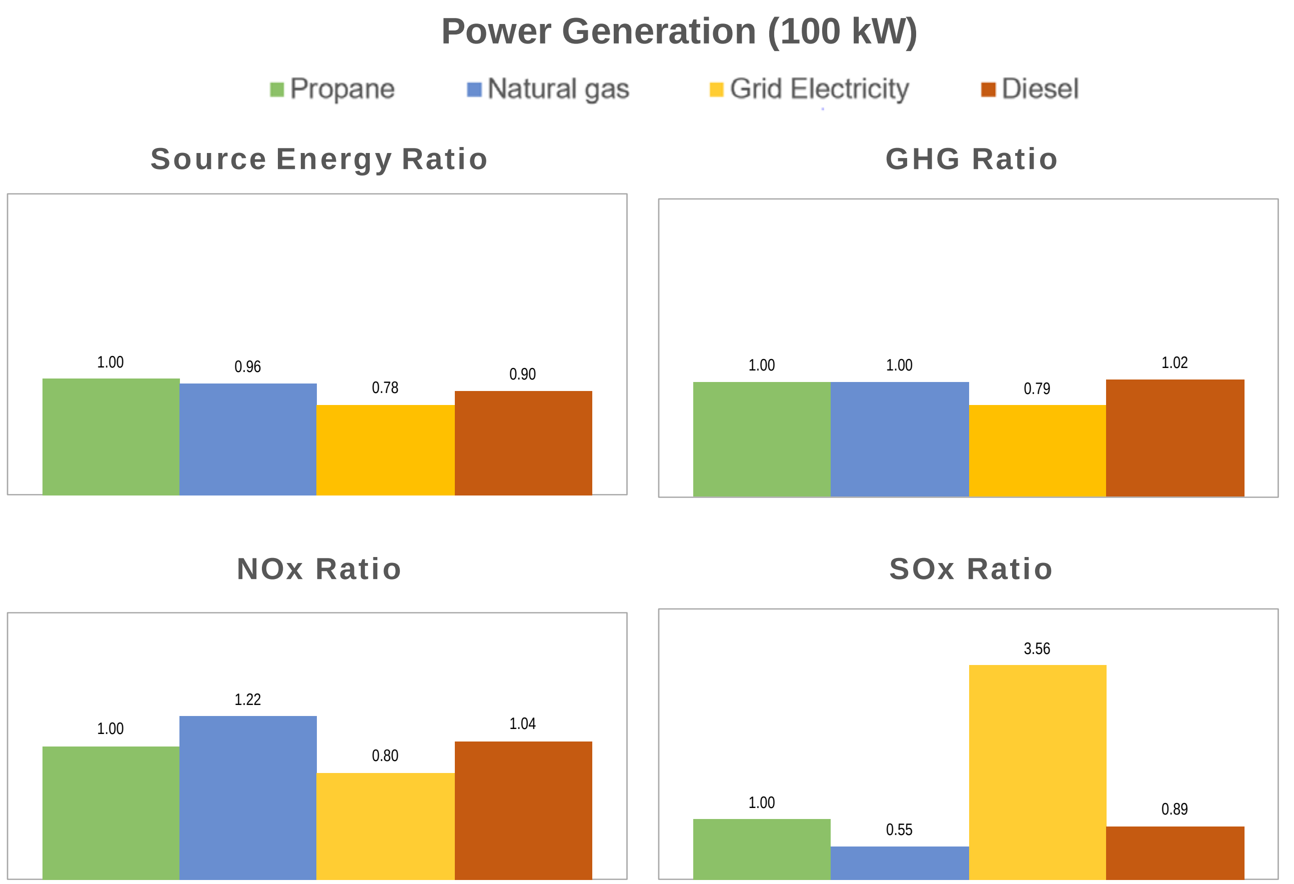

Table 10 – Light-Duty Vehicles Source Energy and Emissions

Light Duty Vehicles	Fuel Economy (miles/ gge)	Annual Fuel Use (gge)	Source Energy Use (MMBtu)	Source Energy Ratio	Total CO2e (kg)	GHG Ratio	NOx Ratio	SOx Ratio
Light Duty Trucks								
Propane	22.7	502	65	1.00	4,854	1.00	1.00	1.00
CNG	21.6	528	65	1.00	5,300	1.09	1.11	0.71
Diesel	27.2	419	56	0.87	4,692	0.97	1.57	0.66
Gasoline	22.7	502	79	1.21	5,518	1.14	1.06	1.58

Notes:
1. Vehicle Mileage and fuel economy based on AFLEET 2016
2. Emission factors based on GREET 2016 for Light-Duty Vehicles: Conventional and LS Diesel (Light Commercial Truck/LDT2), Gasoline emission factors from SI ICEV Car
Fuels: Spark ignited LPG and CNG; CIDI Low-Sulfur Diesel; CA reformulated gasoline
3. Source energy factors based on SEEAT
4. Assume Light Duty Trucks Average Annual Vehicle Miles Traveled: 11,400

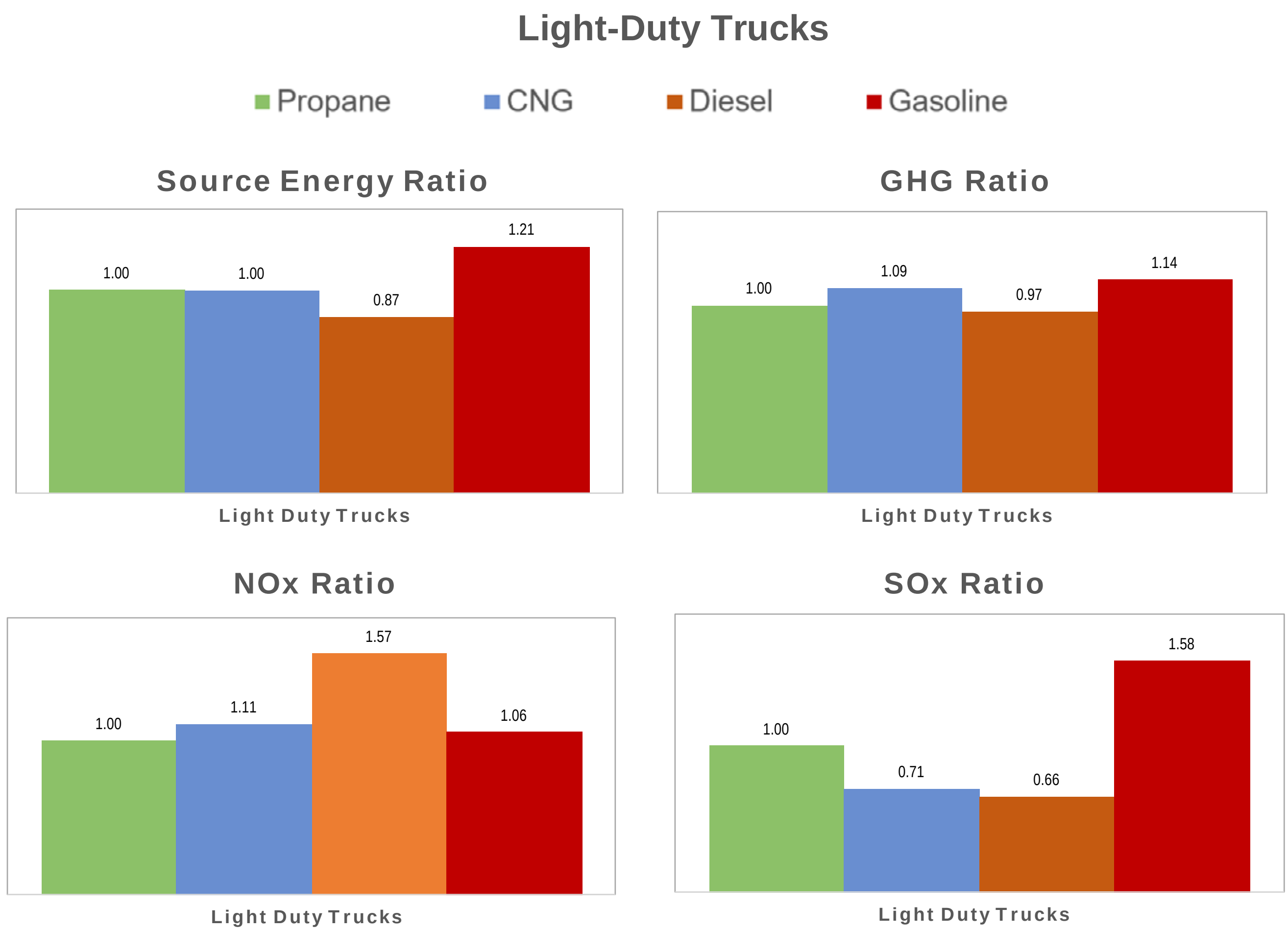

Table 11 – School Buses Source Energy and Emissions

Buses	Fuel Economy (miles/ gge)	Annual Fuel Use (gge)	Source Energy Use (MMbtu)	Source Energy Ratio	Total CO2e (kg)	GHG Ratio	NOx Ratio	SOx Ratio
Type A Buses								
Propane	14.5	1,034	133	1.00	10,032	1.00	1.00	1.00
CNG	13.8	1,087	133	1.00	10,910	1.09	1.06	0.71
Diesel	17.4	862	116	0.87	9,547	0.95	1.05	0.68
Gasoline	14.5	1,034	162	1.21	11,366	1.13	1.17	1.60
Type C Buses	**(miles/ gge)**							
Propane	6.3	2,392	309	1.00	23,199	1.00	1.00	1.00
CNG	5.7	2,632	322	1.04	26,414	1.14	1.11	0.74
Diesel	6.7	2,239	300	0.97	24,794	1.07	1.18	0.76
Gasoline	5.6	2,679	419	1.36	29,430	1.27	1.31	1.79

Notes:
1. Vehicle mileage and fuel economy based on AFLEET models (ANL 2016);
propane fuel economy for Type C buses (6.3 mpgge) based on recent industry data
2. Emission factors based on GREET 2016 for HD Bus: School, spark ignited LPG and CNG, and CIDI Low-Sulfur Diesel
Gasoline emission factors from SI ICEV Car CA Reformulated Gasoline
3. Source energy factors based on SEEAT
4. Assume Type A Buses Annual Miles 15,000
5. Assume Type C Buses Annual Miles 15,000

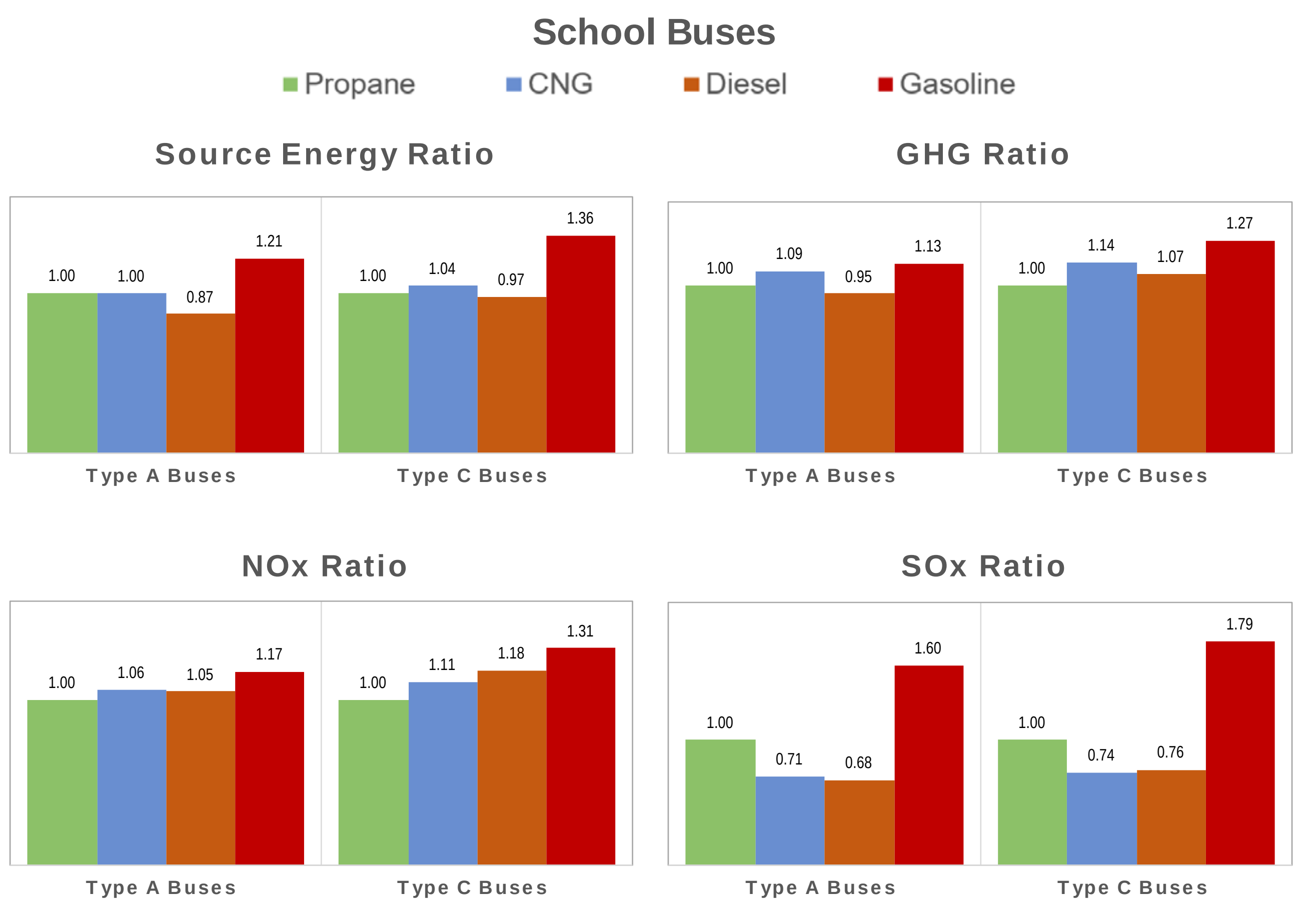

Table 12 – Medium-Duty Vehicles Source Energy and Emissions

Medium-Duty Trucks	Annual Fuel Use (gge)	Fuel Economy (miles/ gge)	Site Energy Use (MMBtu)	Source Energy Ratio	Total CO2e (kg)	GHG Ratio	NOx Ratio	SOx Ratio
Bobtail Trucks								
Propane	3,190	6.3	358	1.00	30,861	1.00	1.00	1.00
Diesel	3,125	6.4	351	1.02	34,751	1.13	1.04	0.80

Notes:
1. Bobtail Trucks mileage and diesel fuel efficiency (6.4 mpgge) based on AFLEET models (ANL 2013a) for a Combination Short-Haul Truck;
2. Propane fuel economy (6.3 mpgge) from recent industry data on new liquid propane injection (LPI) engines
3. Assume 20,000 Annual Miles

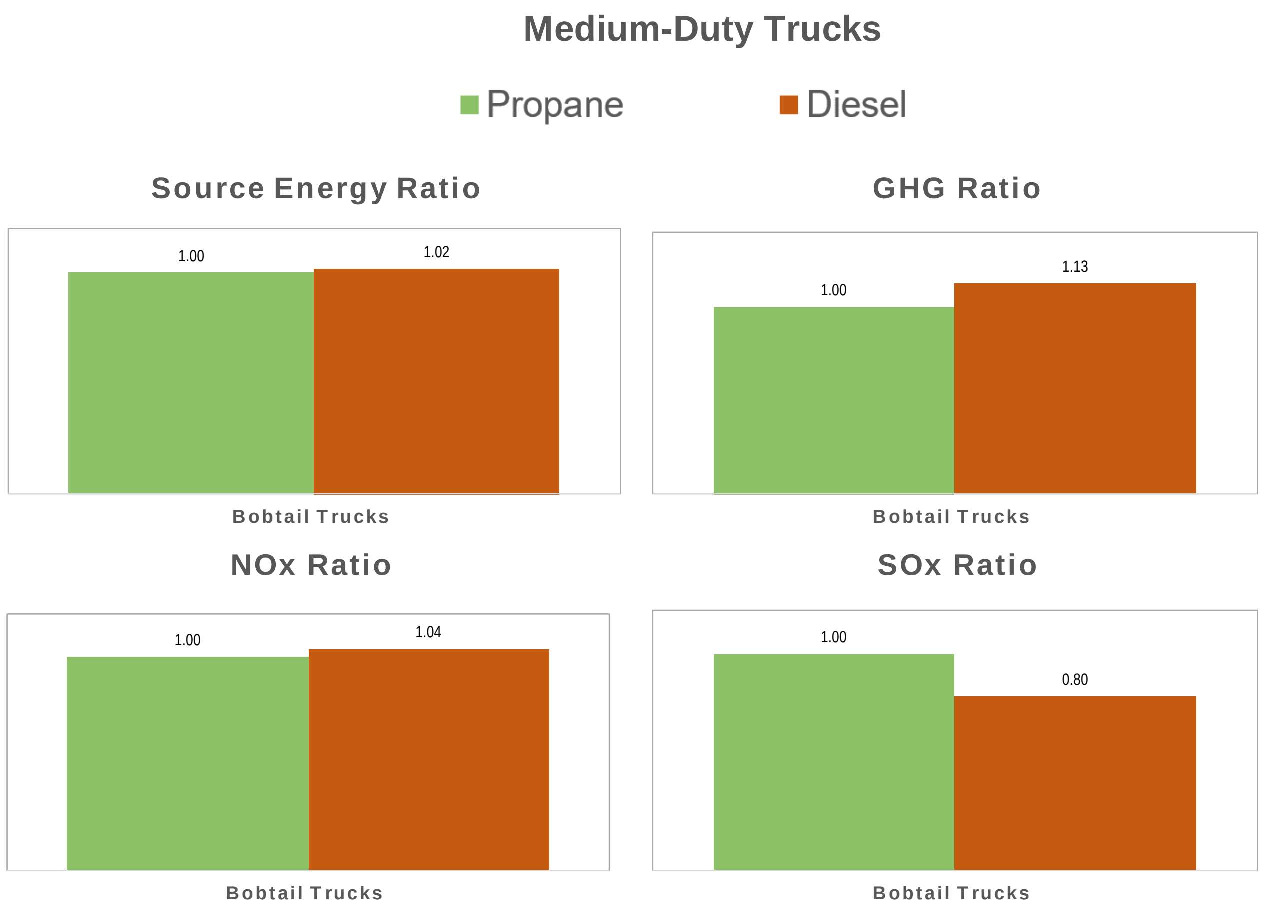

Table 13 – Irrigation Engines Source Energy and Emissions

Irrigation Engines	Annual Fuel Use (gge)	Site Energy Use MMBtu	Source Energy Use MMbtu	Source Energy Ratio	Total CO2e (kg)	GHG Ratio	NOx Ratio	SOx Ratio
Propane	8,811	989	1,137	1.00	67,005	1.00	1.00	1.00
Gasoline	9,195	1,032	1,439	1.27	81,626	1.22	1.24	1.20
Diesel	8,130	912	1,085	0.95	72,723	1.09	1.10	0.95
Electric	2,676	300	910	0.80	54,743	0.82	0.82	3.66

Notes:
1. Irrigation engines 5.7L displacement, 100 hp, operate fully loaded 1039 hrs/yr (Propane's Advantage 2009)
2. Irrigation relative fuel consumption based on University of Florida performance standards
3. Electric GHG emission factors from SEEAT, other fuels based on EPA NonRoad Vehicles. NOx and SOx emission factors based on SEEAT

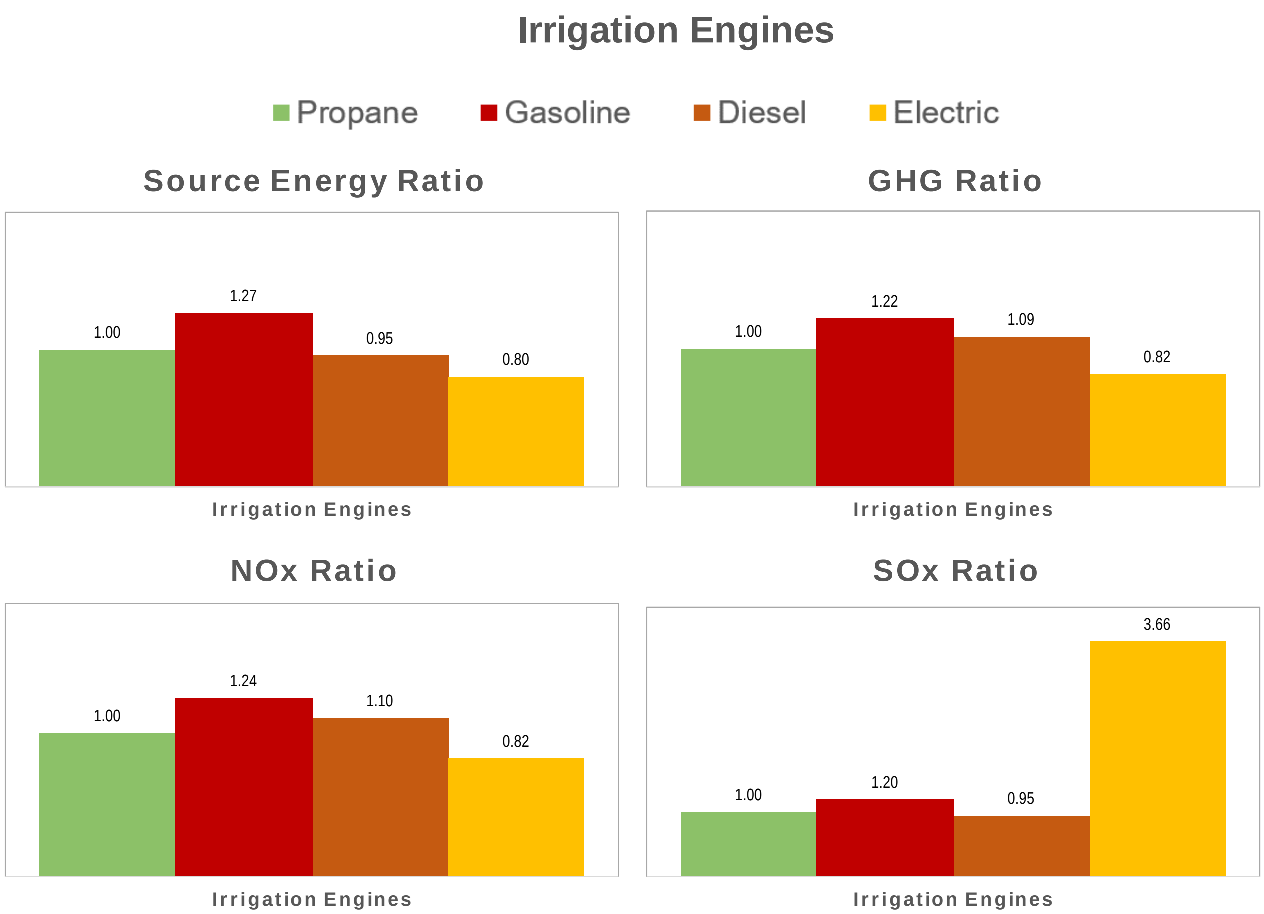

Table 14 – Commercial Lawn Mowers Source Energy and Emissions

Lawn Mowers	Annual Fuel Use (gge)	Site Energy Use MMBtu	Source Energy Use MMbtu	Source Energy Ratio	Total CO2e (kg)	GHG Ratio	NOx Ratio	SOx Ratio
Propane	750	84	97	1.00	5,700	1.00	1.00	1.00
Gasoline	773	87	121	1.25	6,858	1.20	1.23	1.19

Notes:
1. Lawn mower fuel use based on Kholer EFI mowers: Propane 1.32 gal/hr, Gasoline 1.03 gal/hr [Nexight Group, 2014]
2. Based on 750 hours/year
3. Gasoline and LPG GHG emission factors based on EPA NonRoad Vehicles; all other factors based on SEEAT

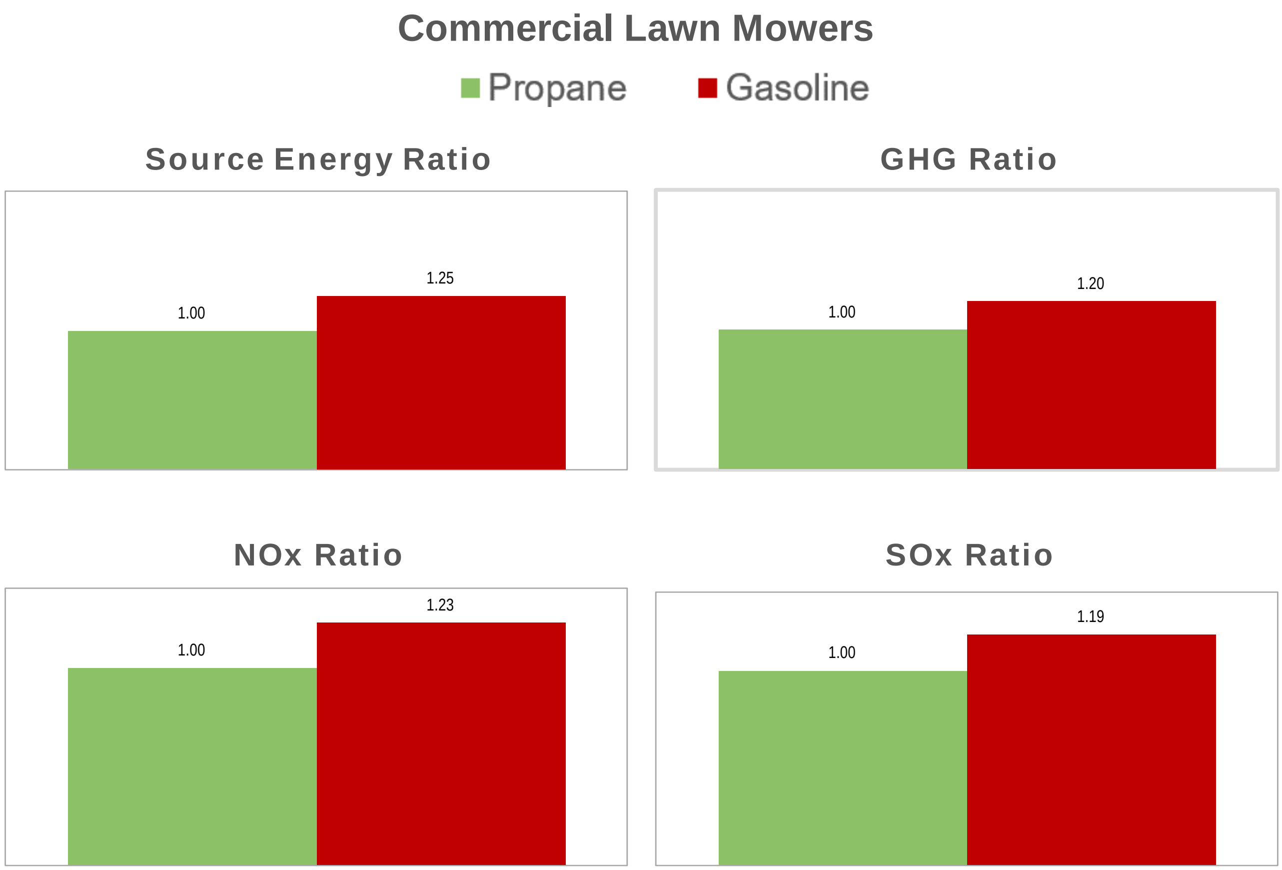

Table 15 – Forklifts Source Energy and Emissions

Forklifts	Average Annual Fuel Use (gge) [1]	Site Energy Use (MMBtu)	Source Energy Use (MMBtu)	Source Energy Ratio	Total CO2e (kg)	GHG Ratio	NOx Ratio	SOx Ratio
Propane	737	82.7	95.1	1.00	5,603	1.00	1.00	1.00
Gasoline	749	84.0	117.1	1.23	6,646	1.19	1.21	1.17
Diesel	651	73.0	86.9	0.91	5,819	1.04	1.06	0.91
Electric	252	28.3	85.6	0.90	5,152	0.92	0.93	4.12
CNG	763	85.6	93.3	0.98	6,274	1.12	0.79	0.51

Notes:
1. Average annual fuel use for propane forklifts of 973 gallons (Delucchi 2001)
2. Assume 2/3 total forklift energy use for driving; 1/3 for lifting
3. Relative efficiency for each fuel based on AFLEET model. (ANL 2013a)
4. Forklift fuel efficiency for lifting based on Delucchi 2001; electric forklift efficiency assumed 64% (ANL 2008).
5. GHG emission factors for LPG, Diesel and Gasoline based on EPA NonRoad Vehicles; NOx, SOx and emission factors for CNG and electric from SEEA