ALTERNATIVE FUELS COALITION OF CONNECTICUT

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Public Comment – T. Michael Morrissey

Governor's Council on Climate Change (GC3) Meeting
November 13, 2015
2:00 PM – 4:00 PM
Office of Higher Education,
Board Room, 1st floor
61 Woodland Street, Hartford

Good Afternoon Councilers: My name is Mike Morrissey and I serve as State Director to the National Propane Gas Association. I have served in this elected capacity since 1993. Today I represent AFCC a small adhoc group of busninesses who are committed to the future development of propane markets in our state. Our Chairman, David Gable, owner of Hocon gas, CT's largest independent marketer of propane, has authorized me to comment before you today.

We are greatful your council has decided so early on in it's existance, to focus on the environmental inpact of the Transportation Sector and its potential ability to contribute to Climate Change goals in our state. Although today's meeting has focused on Electric Vehicles, there are other vehicles in our state which are poised to make a favorable contribution to our environment, provided they are equipped with a source of energy to do so.

As per your own data, 40% of all of CT's Greenhouse Gas Emmissions are caused by the Transporation Sector. Of this 40%, 44% of these emmisions are the result of Light and Heavy Duty vehicles. **Electricity for these vehicles, does not work**. However, there are other alternate fuels which do and need to be recognized today if this sector of tranportation is going to do their part, to **"Clean up their Act"**.

I was in Washington DC earlier this year with the CLEAN CITIES PEOPLE and someone mentioned at our conference, “there was no **Silver Bullett** when it comes to Alternative Fuels. Instead, there are a bunch of **Silver Bee Bees”** which collectively, are available today to get the job done.

One of these **Silver Bee Bees** is propane, more commonly refered today as ***Autogas.*** You might be interested in knowing some of the following facts about Autogas;

- Autogas is the third leading transporation fuel in the world and the number one Alternative Fuel. Over 23 million vehicles operate on it today.
- Almost all the propane brought to market in America, is produced right here and we have lots of it.
- Autogas is not an experimental fuel, it has a proven existance and has been used in the transportation sector for almost 100 years
- Unlike natural gas, propane because of its portability, is available to everyone every where in CT.
- Propane infrasturcture and dispensing systems costs are a fraction of the cost of natural gas and because of this, is much better suited especially to small and medium size fleet vehicles.

Autogas is already playing an important role in our state. The Cities of Shelton and Torrington are on their third year of operations on this fuel. Collectively, both Cities operate a 110 vehicles on autogas. Two months ago, the City of Boston deployed 86 new autogas school buses. **Peter Crossan, Fleet Manager for Boston Public Schools** was a guest speaker at the Altwheels conference in October of this year. Peter in his opening comments to our group stated, Boston choose this direction; “**primarly for environmental reasons and the economic advantage associated with it, was an added benefit to my City**”.

Currently, over 500,000 school kids on over 7000 autogas powered vehicles, are bused daily in our nation. Blue Bird bus, a leading manufacturer of propane buses, estimates 50-60 % of all their production in five years, will feature propane. Over the last month, Waterbury and South Windor have issued RFP’s for propane autogas bused and we believe there are more communities looking to do the same.

As your Council goes forward, we encourage you to give more attention to propane. Our fuel works and is ideally suited for Light, Medium and some Heavy Duty vehicles. We are here to help, please give us an opportunity to do our job.

LINKS TO SUPPORTING REFERENCES

1. COMPARATIVE ANALYSIS OF GREENHOUSE GAS EMISSIONS - 2014
2. PROPANE MARKET OUTLOOK - 2013

Sponsored by:
PROPANE education & research COUNCIL

A COMPARATIVE ANALYSIS OF GREENHOUSE GAS EMISSIONS FROM PROPANE AND COMPETING ENERGY OPTIONS

Prepared by:
NEXIGHT GROUP
ENERGETICS
A Subsidiary of VSE Corporation

2014

Acknowledgements

This report was sponsored by the Propane Education & Research Council (PERC) and prepared under the direction of Greg Kerr, Director of Research and Development at PERC. Ross Brindle, Jared Kosters, and Lindsay Pack of Nexight Group and Matt Antes, C.W. Gillespie, and Beth Zotter of Energetics Incorporated prepared this report.

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Executive Summary

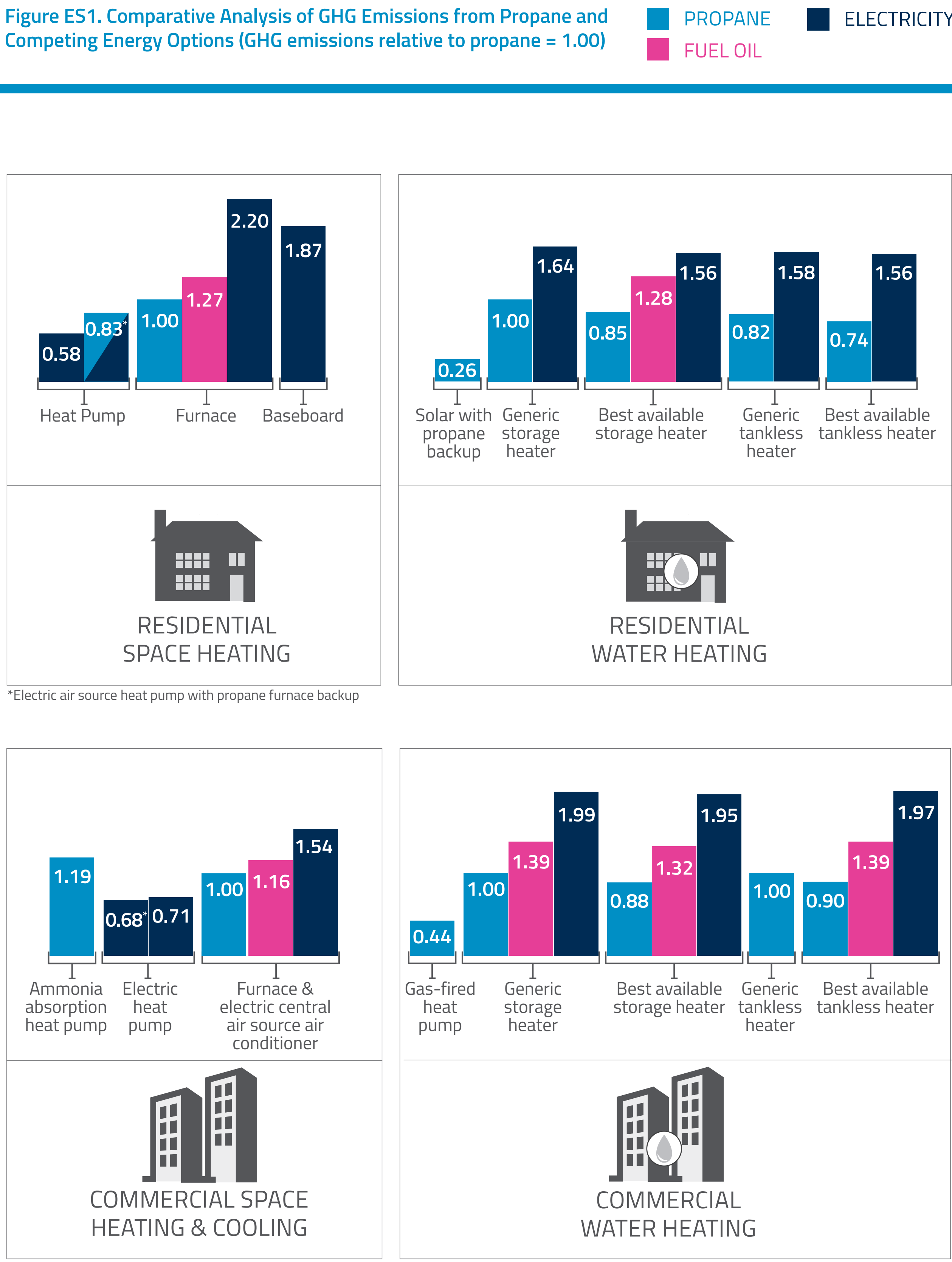
Energy production and use generates greenhouse gas (GHG) emissions that can contribute to climate change. While government and business leaders as well as consumers are increasingly concerned with climate change, they also understand that energy plays an essential role in daily life. As a result, many leaders are currently seeking ways to reduce GHG emissions while also promoting economic development and consumer choice, and many consumers are taking more of an active role in determining their personal energy mix. In order to make informed choices in this area, these decision-makers require unbiased, credible information about available energy options.

This study aims to provide both leaders and consumers with the type of information they need by quantifying the greenhouse gas emissions produced by the use of propane and other energy sources in 14 selected applications important to the U.S. propane industry. These applications cover the major propane markets: residential buildings, commercial buildings, off-road applications, on-road vehicles, and agricultural applications. The study's methodology considers not only emissions generated at the point of use but also all upstream emissions produced during the extraction, production, and transportation of each energy source. Because equipment efficiency plays an important role in the amount of energy required to perform a useful task, such as heating a home, the study's methodology also considers efficiency, which can vary significantly depending on the energy source used.

The results of this study show that propane is a low-carbon fuel source that produces fewer greenhouse gas emissions than many competing energy options in a wide range of applications. Propane's chemistry—its molecular structure—provides it with relatively low carbon content compared to liquid fuels like diesel and gasoline and compared to electricity, much of which is generated from coal in the United States. As a result, propane is a favorable energy option across the market areas featured in this study, as demonstrated by the graphs in Figure ES1.

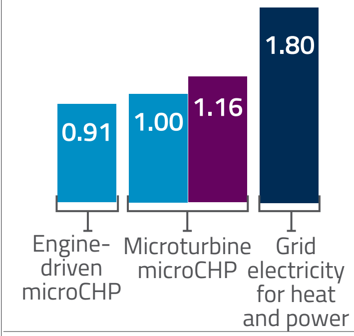
Energy choice is a complex issue. Greenhouse gas emissions are just one of the many factors that decision-makers must consider when weighing their energy options; factors such as cost, performance, reliability, and safety also play a significant role. As leaders and consumers grow increasingly aware of the potential impact of their energy choices, their access to sound information about their options will grow increasingly critical as well. The results of this study offer new insights that can aid decision-makers considering propane as a low-carbon energy source.

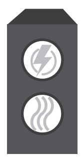
Figure ES1. Comparative Analysis of GHG Emissions from Propane and Competing Energy Options (GHG emissions relative to propane = 1.00)



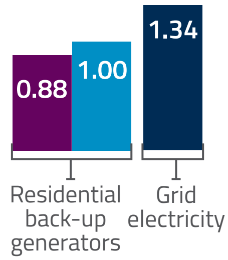
*High-efficiency electric heat pump

PROPANE
NATURAL GAS
ELECTRICITY
GASOLINE
DIESEL
FUEL OIL
E85

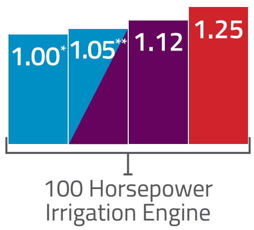


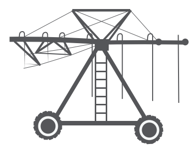


COMBINED HEAT & POWER



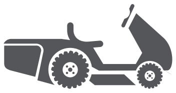
GENERATORS



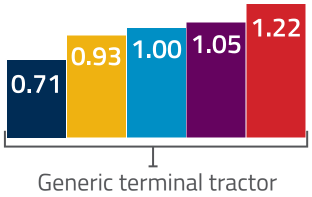


IRRIGATION ENGINES

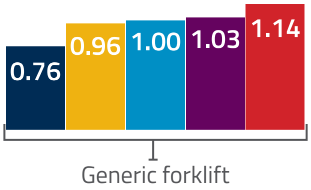
*Propane irrigation engine
**Propane and diesel dual fuel irrigation engine

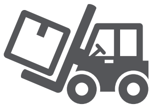


MOWERS



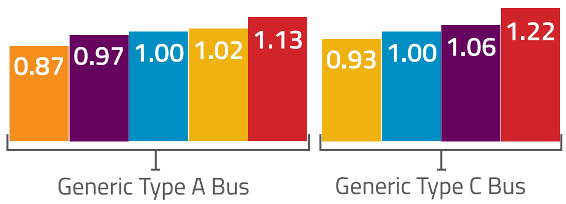
TERMINAL TRACTORS

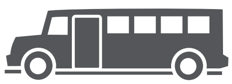




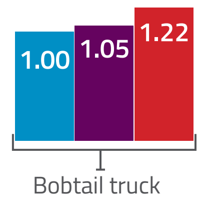
FORKLIFTS

PROPANE ELECTRICITY DIESEL E85
NATURAL GAS GASOLINE FUEL OIL

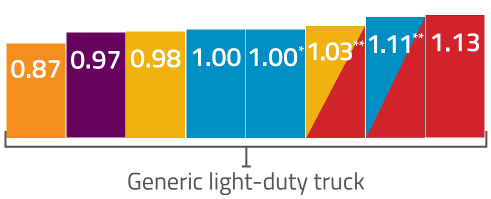


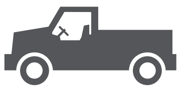


TYPE A/C
BUSES



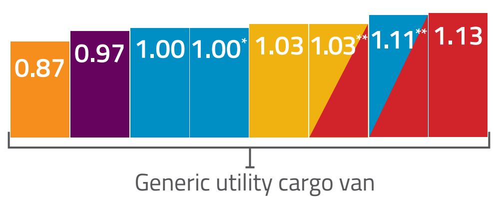
BOBTAIL
TRUCKS





LIGHT-DUTY
TRUCKS

*Light-duty truck with propane conversion kit
**Gasoline bi-fuel light-duty truck



UTILITY
CARGO VANS

*Utility cargo van with propane conversion kit
**Gasoline bi-fuel utility cargo van

Purpose of this Report

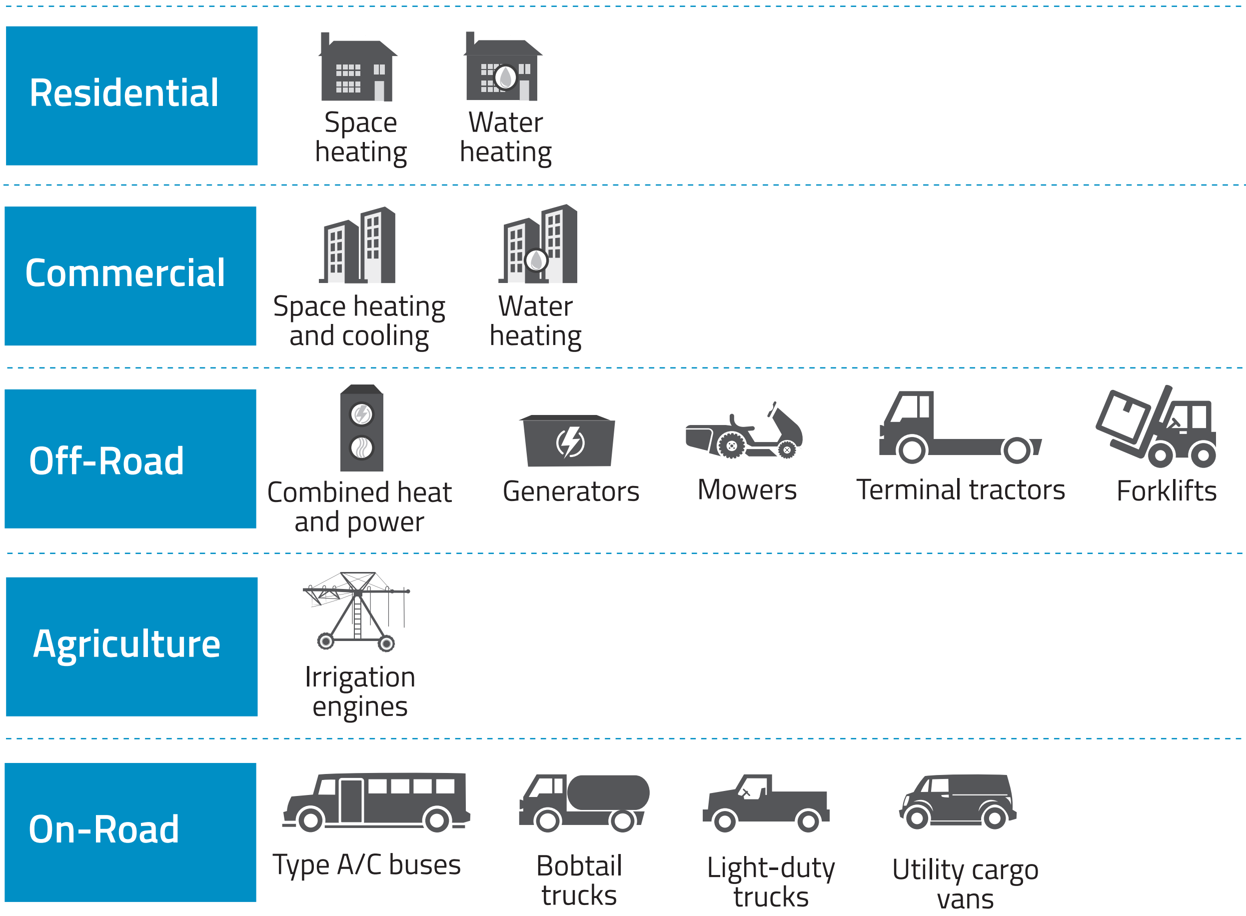
Energy production and use generates greenhouse gas (GHG) emissions that can contribute to climate change. Government and business leaders are increasingly concerned with climate change but also understand that energy plays an essential role in our daily lives. Public and private sector decision-makers are therefore seeking ways to reduce GHG emissions while also promoting economic development and consumer choice.

The purpose of this study is to quantify the GHG emissions associated with the production and use of propane and other fuels in 14 selected applications of importance to the U.S. propane industry. These applications address a range of major propane markets, including residential buildings, commercial buildings, off-road vehicles, on-road applications, and agricultural applications (see Figure 1).

This study builds on previous GHG analyses commissioned by PERC, the most recent of which was published in 2009. Since then, the propane industry has witnessed the following significant changes and developments:

- In 2009, approximately 60% of domestic propane was produced from natural gas production, with the remainder being produced during petroleum refining. With the rapid development of shale gas resources in recent years, this ratio has shifted; now more than 70% of domestic propane originates from natural gas production, which is a change that affects the carbon intensity of propane (ICF International 2013).
- Since 2009, many new propane-fueled products have been successfully commercialized, including several engine-based products that were not included in the previous study.
- The full fuel cycle model used to estimate upstream emissions—the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (GREET) published by Argonne National Laboratory—has been updated several times since the previous study, most recently in October 2013 (ANL 2013b).

Figure 1. Selected Applications Included in this Report



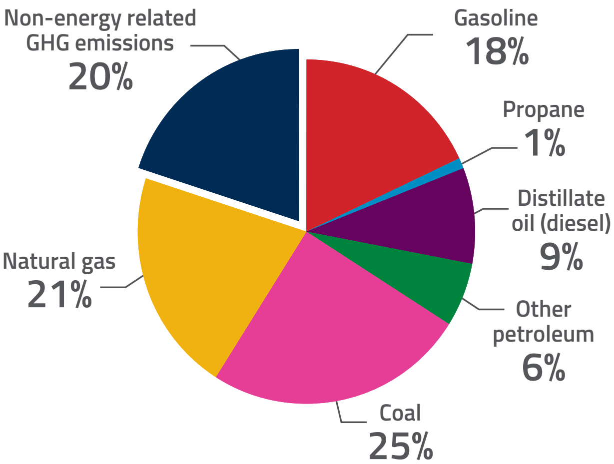
About Greenhouse Gases and Climate Change

Greenhouse gases affect the earth's climate by trapping heat from the sun. While these gases keep the earth at a temperature suitable for human life, elevated levels of greenhouse gases in the atmosphere cause global warming. Scientists have concluded that increasing concentrations of greenhouse gases emitted by human activity are contributing to changes in the earth's climate (IPCC 2013) that are threatening ecosystems and public health (EPA 2013). If greenhouse gas (GHG) emissions continue to increase, climate change is predicted to continue and accelerate significantly (USGCRP 2009).

Greenhouse gases are emitted from several sources, but 80% of the emissions from human activity can be attributed to the combustion of fossil fuels for energy. Figure 2 shows the sources of greenhouse gases emitted from human activity in the United States by energy and non-energy sources (EPA 2014).[1] The majority of these GHG emissions are carbon dioxide (CO_2), but other gases represent a significant share of the total.

After energy use, the remaining balance of GHG emissions from human activity is from industrial processes that emit CO_2 directly (e.g., cement kilns), methane (e.g., landfills and natural gas leaks), nitrous oxide (e.g., agricultural fertilizer), and fluorine-containing halogenated substances (e.g., hydrofluorocarbons [HFCs], perfluorocarbons [PFCs], and sulfur hexafluoride [SF6] from refrigerants and industrial processes).

Figure 2. Source of U.S. GHG Emissions (2012)
(Total: 6,301 million metric tons CO_2e)



The global warming impact of these other gases is typically quantified in terms of its "global warming potential" (GWP) or the relative impact of how much heat is trapped by the gas compared to CO_2. Methane gas, for example, is 28 times more potent than

[1]Energy-related emissions shown in the figure are emitted as CO_2 from fossil fuel combustion.

CO_2 at warming the atmosphere, so total methane emissions are multiplied by a GWP of 28 to express emissions in terms of "CO_2 equivalent." The results in this analysis are all expressed in terms of CO_2 equivalent (CO_2e).

The three greenhouse gases of primary concern for the purposes of this study are CO_2, methane, and nitrous oxide, because they are associated with fuel production and use. Other greenhouse gases are not included in this analysis because they are not significantly related to the production or use of the fuels evaluated.

Greenhouse Gases and Criteria Air Pollutants

When considering emissions from fuel combustion, it is useful to distinguish between criteria air pollutants, which have been regulated by the EPA since 1970, and GHG emissions. While criteria pollutants are relatively short-lived and cause regional environmental problems such as smog and acid rain, they are not the primary gases contributing to climate change. In contrast, GHG emissions remain in the atmosphere for decades to centuries and cause global effects (IPCC 2001b).[2] Other important differences between criteria pollutants and GHG emissions are summarized in Table 1.

Although GHG emissions and criteria pollutants are both products of combustion reactions, CO_2—the most significant greenhouse gas—is the unavoidable product of the chemical conversion of carbon-based fuels into energy. Criteria pollutants such as ozone and particulate matter are the byproducts of undesired processes including fuel leaks, incomplete combustion, and secondary chemical reactions, among others. Criteria pollutants can often be mitigated by pollution control equipment and operational and maintenance practices. In contrast, CO_2 emissions can only be reduced by improving fuel efficiency or by switching to a fuel with a lower carbon content, such as propane.[3]

Table 1. Important Differences between Greenhouse Gases and Criteria Air Pollutants

	GREENHOUSE GASES	CRITERIA POLLUTANTS
EXAMPLES	Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_20)	Ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), particulates (PM10, PM2.5)
CAUSE OF EMISSIONS	Carbon dioxide is the principal product of fuel combustion	Fuel leak, undesired byproduct of combustion, or secondary reactions
QUANTITY RELEASED	Depends on the carbon content of fuel and amount of fuel used	Sensitive to many factors, such as side reactions or leaks
SCALE OF IMPACT	Global	Local or regional
LIFETIME IN ATMOSPHERE	Decades to centuries	Days to months

Upstream vs. End-Use GHG Emissions

This analysis takes a lifecycle approach to estimating the greenhouse gases emitted

[2] The greenhouse gases described in this report refer to "well-mixed" GHGs, meaning that the lifetimes of these gases are long enough to be thoroughly mixed in the lower atmosphere. Some GHGs are short-lived, but they are not included in this study because they are minor contributors to global warming from the fuels and applications examined in this analysis.

[3]Carbon capture and storage (CCS) technologies can also be employed to reduce CO_2 emissions released to the atmosphere. Although CCS is being considered for large point sources such as power plants and industrial facilities, it is not considered for the types of applications examined in this study.

by different energy and technology combinations. A lifecycle approach accounts for not only the emissions generated when using energy at the point of use (e.g., heating a building, driving a vehicle), but also the emissions generated in all processes used to extract, process, and transport the energy to its point of use.

The GHG accounting begins where the raw feedstock is extracted from the well or mine and ends where the fuel is consumed to power a vehicle, appliance, or other product. This report refers to emissions released at the point of final use as "end-use emissions" and refers to those emissions that occur along the delivery pathway as "upstream emissions."

GHG Emissions from Fuel Production (Upstream Emissions)

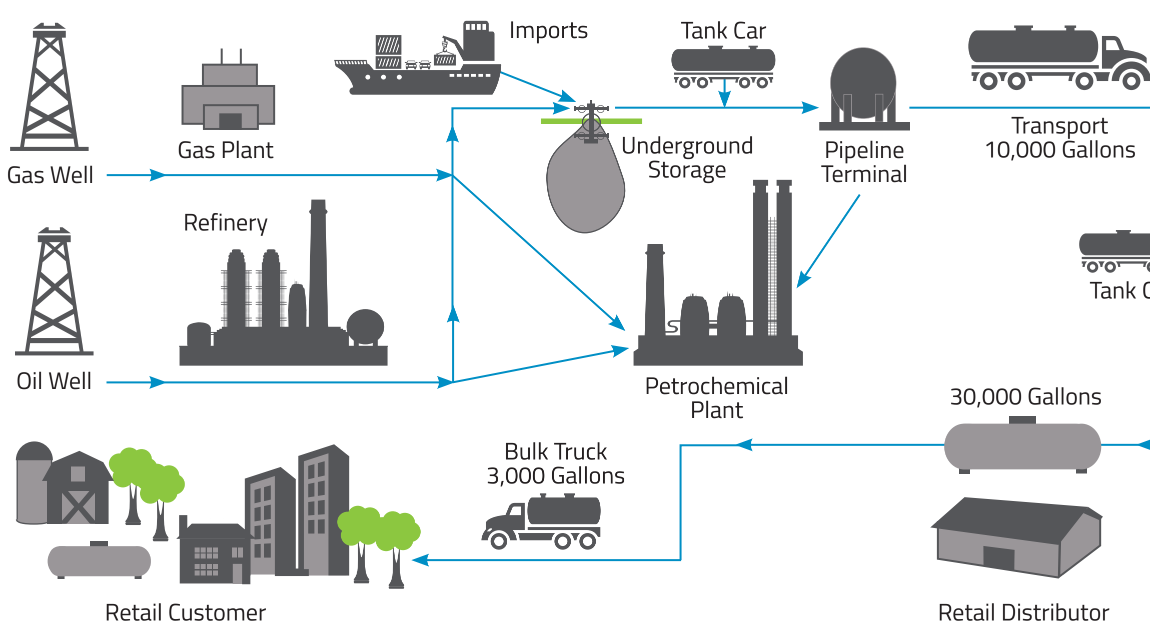
Upstream emissions as defined in this analysis are the sum of all emissions resulting from the recovery, processing, and transport of fuel from the point of extraction to the point of delivery to the end user.

Including upstream emissions in an analytical comparison of different energy sources has a significant impact on results. For example, a GHG comparison of end-use emissions would give the false impression that electricity, with zero end-use emissions, is an energy source with no GHG emissions. This approach fails to account for the substantial release of emissions by the combustion of fossil fuels to generate electricity.

Just as fossil-based power plants are responsible for GHG emissions associated with electricity use, GHG emissions are also emitted in the extraction, production, and transportation of fuels such as gasoline and propane before they are used by consumers. To illustrate the types of processes that are included in an upstream emissions analysis, Figure 3 shows the numerous processes involved in the production and distribution of propane from its two principal sources: natural gas processing and petroleum refining (EIA 2012).

Greenhouse gases are emitted from upstream processes as a result of combustion for the heat and energy that is required during the

Figure 3. Upstream Supply Chain for Propane



Source: Energy Information Administration production and delivery of fuels. But energy use is not the only source of upstream emissions; other production processes also release greenhouse gases. For example, growing crops for ethanol production requires the application of nitrogen fertilizer, which causes the formation of nitrous oxide, while natural gas production and processing releases fugitive methane emissions. GHG emissions from these processes have been quantified by the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model developed by Argonne National Laboratory on behalf of the U.S. Department of Energy, which is a valuable tool for comparative lifecycle analyses of fuel systems.

GHG Emissions from Fuel Combustion (End-Use Emissions)

The principal greenhouse gas emitted during fuel combustion is CO_2, though very small amounts of methane and nitrous oxide are also emitted during combustion.

The carbon content of a fuel determines how much CO_2 will be released when the carbon in the fuel is burned and oxidized. Lighter hydrocarbons, such as propane, have fewer carbon atoms per molecule than heavier fuels, such as diesel. Heavier fuels tend to emit more CO_2 per unit of chemical energy. This trend is evident in Table 4 of the Methodology section, which outlines the range of different fuels in terms of mass of CO_2 released per unit of energy.

The carbon content of a fuel is only one part of the end-use emissions equation. The amount of fuel consumed plays an equally important role. Diesel has a higher carbon content than gasoline, but since diesel engines are generally more fuel efficient than spark-ignition engines, a diesel-fuel technology may still produce less CO_2 than a gasoline technology that requires more fuel to do the same amount of work. To compare GHG emissions from different fuels, the technologies and fuel efficiencies of each specific application must be considered.

Greenhouse Gas Emissions from the Use of Propane and Natural Gas

When released into the air, propane is considered to be a part of the volatile organic compounds (VOC) class. These compounds have a short atmospheric lifetime and a small direct impact on climate (IPCC 2001a). Although precipitation and chemical reactions remove VOC from the atmosphere, some reactions convert VOC into other compounds, such as organic aerosols, methane, and ozone, which do influence climate. The largest source of VOC emissions by far is natural vegetation (IPCC 2001a), and the overall impact of all energy-associated VOC on global temperature is very small (IPCC 2013).

Natural gas (methane) generates fewer CO_2 emissions per Btu than propane, but unlike propane, natural gas is a powerful greenhouse gas. When released into the air, natural gas is slow to break down and produces a global warming effect 28 times that of CO_2.[4] Furthermore, new research suggests that methane leaks from the North American natural gas infrastructure are higher than previously estimated (Brandt et al. 2014).

[4]Based on GWPs provided in the IPCC's Fifth Assessment Report (AR5).

Methodology

This section describes the general methodology used to prepare this report. Application-specific assumptions are provided with their respective applications in the Summary of Findings section of this report.

Basis for Comparison of Emissions by Application

This study quantifies lifecycle greenhouse gas (GHG) emissions for fourteen different applications that use propane as a fuel source. The applications in the analysis represent a diverse set of market segments that include well-established propane-fueled products, such as forklifts, and emerging propane applications, such as the propane-fueled light-duty truck or the propane-fueled heat pump for commercial heating and cooling.

Each propane application was compared to systems using other fuels for the same application. For each application, competing technologies were evaluated based on an equivalent unit of energy service, such as hours of operation, miles traveled, or heat delivered.

For some fuels, such as electricity, energy efficiency differences from propane are the result of two different technology designs. For other fuels, there are only slight differences in technology design. To ensure a consistent basis for comparison, the highest available energy efficiency for each technology was used whenever possible. Where application-specific data was not available, the relative efficiencies of the fuel systems under comparison were based on the efficiencies reported for similar technologies.

Upstream Emissions Analysis

Upstream emissions as defined in this analysis are the sum of all emissions resulting from the recovery, processing, and transport of fuel from the point of extraction to the point of delivery to the end user. These emissions are quantified by the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (GREET) model, which was used to estimate the upstream portion of the lifecycle greenhouse gas (GHG) emissions of each application evaluated in this study.

The emission factors used in this study to calculate upstream emissions are shown in Table 2, which outlines the amount of each gas (in grams) released upstream for each unit of energy (in million Btu)[5] of fuel consumed. The amounts reported for each individual gas were obtained using the GREET model. The values shown for carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are the output of the "Well-to-Pump" table in the GREET model spreadsheet using the input parameters described below. The total CO_2 equivalent (CO_2e) shown in the right-hand column of Table 2 is calculated as the sum of each greenhouse gas after it has been multiplied by its global warming potential. The global warming potentials used in this analysis for CH_4 and N_2O reflect the most up-to-date values as reported by the IPCC for a 100-year timescale: 28 for CH_4 and 265 for N_2O (IPCC 2013).

Table 2. Upstream Emissions Factors (grams per million Btu)[6]

	CO_2	CH_4	N_2O	TOTAL CO_2 EQUIVALENT
ETHANOL (E85)	-14,409	113	41.0	-387
NATURAL GAS	6,995	317	1.34	16,228
PROPANE	12,867	188	0.26	18,204
GASOLINE	16,010	118	3.95	20,368
COMPRESSED NATURAL GAS	10,985	324	1.40	20,429
DIESEL	18,727	118	0.31	22,104
FUEL OIL	18,727	118	0.31	22,104
ELECTRICITY	182,897	317	2.84	192,523

For each application evaluated in this analysis, the total energy use (in million Btu) was multiplied by the upstream emissions factor for that energy source (in grams of CO_2e per million Btu). Accordingly, the upstream emissions factor and the energy efficiency of the end-use technology were both important in determining the total upstream emissions resulting from an application.

The GREET model is a convenient tool for upstream emissions analysis in part because it allows users to modify input parameters to test hypotheses and answer specific research questions. The values for each of the three greenhouse gases shown in Table 2 are the output of the GREET model, run under defined process parameters. These parameters include the type, fractional share, and efficiency of power plants used to generate electricity; market shares of different fuel formulations; fuel feedstock shares and refining efficiencies; and fuel transportation mode, distance, and mode share.

In order to reflect the most current market landscape and to evaluate the use of standard pressure natural gas as an application fuel, the default values in the GREET model were modified for several user-defined input parameters. Specifically, the share of natural gas feedstock used for propane production was changed from a default value of 65% to the present market share of 70% in North America (ICF International 2013).[7]

Second, because the GREET model was designed for transportation fuel analysis, the only natural gas fuels listed in the

[5]Based on lower heating values (LHV).
[6]End-use emissions are based on the lower heating value, density, and weight ratio of carbon atoms per unit volume of each fuel provided in the GREET model software. All carbon is assumed to be released as CO_2.
[7]Based on most current industry data. Propane is produced from both natural gas and petroleum sources. The natural gas share of propane supply has increased due to the expansion of shale gas, and ICF International currently represents more than 70% of total propane production. The upstream emissions attributed to propane depend on the relative contribution of these two sources to overall propane supply. In the GREET model, propane produced from crude oil refining has higher GHG emissions than propane produced from natural gas processing.

model's well-to-pump output table are liquefied or compressed natural gas (LNG or CNG). However, the scope of this analysis includes standard pressure (i.e., pipeline delivered) natural gas in several non-vehicle applications. As a proxy for upstream emissions of uncompressed natural gas, the parameter value for natural gas compression efficiency was set to 100%. All other input parameters in GREET were left unchanged from the model's default values.

End-Use Emissions Analysis

For each technology and fuel combination evaluated in this analysis, end-use emissions were determined by calculating the CO_2 emissions resulting from fuel combustion at the point of technology end use.

First, an equivalent level of energy service was chosen as a basis for comparison for each application (e.g., 10,000 miles per year for a light-duty truck). The estimated energy efficiencies of each technology were then used to calculate the total energy required to provide the energy service to the end user. Whenever possible, the highest reported energy efficiency was selected for each technology from published data. When appropriate, systems losses (such as heat loss through ducts in residential space heating) were also included in the calculation of total end-use energy consumption.

Many of the technologies evaluated in this analysis are subject to well-defined and regulated standards for energy efficiency. Standards such as annual fuel utilization efficiency (AFUE), energy factor (EF), solar energy factor (SEF), heating season performance factor (HSPF), coefficient of performance (COP), and energy efficiency rating (EER) were used to evaluate building energy applications such as space heating, air conditioning, and water heating.

Most of the vehicle applications examined in this analysis include propane-fueled technologies that have either recently emerged on the market or are in sectors not regulated by fuel efficiency standards. As a result, it was not possible to obtain standardized fuel efficiency values for many of these new technologies, especially on a basis that would allow a valid comparison to conventional vehicles. However, the AFLEET model developed by Argonne National Laboratory (as a module of GREET) is designed to help fleet managers assess alternative-fuel vehicle options.[9] Because the model uses fuel efficiency values that are specific to each vehicle weight class and fuel type, and because it is frequently updated with data reflecting new advances in alternative fuel technologies, it was deemed the most appropriate source for comparing alternative fuel vehicles in this analysis. As a result, the default fuel efficiency values used by AFLEET Tool 2013 ("Background Data" sheet) were used to calculate vehicle fuel consumption for all of the vehicle applications evaluated as part of this study.

In many cases, the data sources used for this analysis were specific to the application under evaluation. Technology-specific data was obtained from published test results, vendor-supplied specifications, government studies, and other sources. Please refer to the Summary of Findings section for the

[9] AFLEET is a decision-making model developed by Argonne National Laboratory to help fleet managers evaluate the costs, benefits, and life-cycle GHG impacts of their vehicle purchasing decisions. Source: https://greet.es.anl.gov/afleet

assumptions and methodologies used for individual applications. The List of References includes a complete list of sources.

The fuel specifications used in the GREET model were used to calculate both the energy consumption and CO_2 emissions for technology end-use. For applications in which conversion from volumetric units (gallons or cubic feet) was required, the default energy contents[10] in the GREET model (sheet "Fuel Specs") were used to convert volumetric fuel consumption to total energy consumption in mmBTU. Total end-use energy consumption was then multiplied by the CO_2 emissions factor for the fuel being used.

In addition to being the source for fuel energy content, the GREET model was also used to obtain CO_2 emissions factors. The CO_2 emissions factors were calculated from the lower heating value, density, and carbon content of the fuel (also in sheet "Fuel Specs"). Although combustion can produce other compounds containing carbon (such as VOC, CO, and particulates), these products are typically short-lived and are oxidized to CO_2. For the purposes of this analysis, all of the carbon in each fuel is assumed to be converted to CO_2 during end-use,[11] and is shown in Table 3.

Table 3. CO_2 Released per Btu[12]

FUEL TYPE	KG CO_2 PER MILLION BTU
NATURAL GAS	59.41
PROPANE	68.06
ETHANOL (E85)	75.19
GASOLINE	76.71
DIESEL	78.20
FUEL OIL	85.08

[10]Based on lower heating values

[11]Although small amounts of CH_4 and N_2O are released during combustion of fuel during end use, this analysis does not quantify end use emissions for these two gases. Emissions levels are specific to variable combustion conditions such as temperature, and there is insufficient data to accurately estimate emissions of CH_4 and N_2O for many of the different technologies in this report. However, since they are very small contributors to end-use GHG emissions for most technologies, this is not expected to significantly influence the outcome of this analysis. For comparison, end-use emissions in the GREET model show that CH_4 and N_2O together represent 21% of upstream GHG emissions for a gasoline vehicle, but less than 1% of all end-use GHG emissions.

[12]End-use emissions are based on the lower heating value, density, and weight ratio of carbon atoms per unit volume of each fuel which were provided in the GREET model software. All carbon is assumed to be released as CO_2.

Summary of Findings

This section presents a summary of this study's findings, organized by application area. For each application area, the study provides a brief description of the application followed by two-page sections providing the following information:

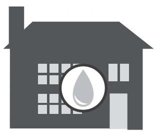
1. A brief description of the application, including important technologies used to meet the application's needs
2. A data table that presents this study's results, including:
    - The major technology classes investigated with this study
    - The fuels analyzed for each technology class
    - Total greenhouse gas emissions, indexed to the GHG emissions for a reference case of a selected technology class using propane
    - The energy use for the basis for analysis as defined for each application
    - Upstream, end-use, and total greenhouse gas emissions for each technology and fuel
3. A detailed list of assumptions used to arrive at the results

Readers are cautioned from comparing total values for energy use and GHG emissions across applications, as the basis for analysis can vary significantly from one application to the next and greatly affect the total energy use and emissions results. However, the comparative emissions results (i.e., the indexed results) may be compared across applications to assess the magnitude of differences of GHG emissions by fuel type and technology class.

Application Overview

Residential Space Heating

Homes are most commonly heated by either a centralized system that moves warm air through ducts (or hot water through pipes), while others have separate heating units (usually electric) distributed throughout the home. Furnaces can be gas-fired (natural gas or propane), oil-fired, or electric. Approximately 8.4 million U.S. households rely on propane for home heating (EIA 2013).[13]



Residential Water Heating

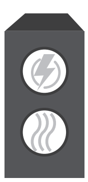
Residential water heaters include both tank storage units as well as instantaneous ("tankless") water heaters. Both types of water heaters can be gas-fueled or electric. Fuel oil and solar power are also used for storage tank water heating. Approximately 4.5 million U.S. households use propane for water heating purposes (EIA 2013).[14]

Commercial Space Heating and Cooling

Heat pumps provide both heating and cooling in commercial buildings, combining the functions of furnaces and air conditioners into a single unit. Most furnaces are fueled by gas or oil (EIA 2003), while nearly all commercial buildings use electricity for cooling (EIA 2003). Nearly 80 percent of commercial buildings with packaged heat pumps use electricity as the energy source for heating (EIA 2003), and nearly 100 percent use electricity for cooling, although interest in propane- and natural gas-fueled engines for cooling is growing (EIA 2003).

Commercial Water Heating

The majority of commercial buildings use a centralized water heating system to provide hot water to tenants. More than half of commercial buildings use electricity as an energy source for heating water, while slightly less than half of buildings use natural gas or propane (EIA 2003).

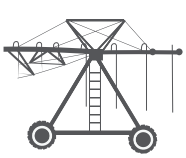


Combined Heat and Power

Combined heat and power (CHP) generates both electricity and useful heat from a single fuel source. Power plants use cogeneration to recapture heat and boost efficiency, and in some cases provide thermal energy to nearby homes, which is known as district heating. MicroCHP does this at a smaller scale, allowing homes and offices to generate heat and power closer to the point of use, reducing energy losses associated with electricity transmission and distribution from the electrical grid.

Generators

Generators are used as a primary source of electricity or as a backup energy source when power cannot be distributed by a utility provider. These units range in capacity from a few kilowatts to several hundred kilowatts depending on the application.



Irrigation Engines

More than 150,000 farms in the United States rely on approximately 570,000 irrigation pumps to deliver water from reservoirs, lakes, streams, and wells for crop production (USDA 2010). The majority of irrigation pumps operate using electric motors and diesel fuel. The smallest pumps are often operated by electric motors, while higher capacity wells tend to be operated by diesel, natural gas, and propane engines.

[13] Based on main and secondary heating equipment.
[14] Based on main and secondary water heating equipment.

Mowers

Turfgrass and lawncare management in the United States is a $62 billion industry (Haydu et al 2006) with more than 40 million acres (Milesi et al 2005) of residential lawns, sports fields, golf courses, parks, roadsides, and public and commercial land. While commercial mowers have historically been fueled by gasoline or diesel, small engine technology advancements, alternative fuel technologies, and the need for low-emission equipment to comply with Ozone Action Days in some parts of the country have allowed propane-fueled mowers to successfully enter the market.

Terminal Tractors

Terminal tractors are slow-moving, heavy-duty vehicles that are capable of towing freight weighing more than 50 tons. These vehicles operate continuously and, due to emissions regulations at some freight yards (California Environmental Protection Agency 2005), some yard operators are seeking alternative fuel options such as propane for their tractors.

Forklifts

Forklifts use fuel for both vehicle propulsion and load lifting work. Indoor air quality concerns restrict the use of diesel and gasoline for heavy-duty jobs; electric forklifts are normally used for light-duty jobs, while propane can be used for both.

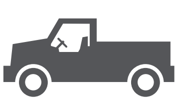
Type A/C Buses

Type A buses are used as small school buses and light transit shuttle buses, and are constructed by placing bus bodies on the chassis of cutaway vans. Type C buses hold approximately twice the capacity as Type A buses, and are the most common bus types for school districts across the United States. Although diesel currently fuels the majority of school buses in the United States, several studies have raised concerns about high levels of exposure to diesel exhaust, which has been recognized by the World Health Organization as a known human carcinogen (WHO 2012). Many fleet owners have replaced their diesel buses with alternative fuels such as propane and compressed natural gas to reduce emissions and realize other benefits.

Bobtail Trucks

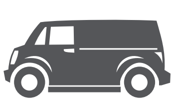
Bobtail trucks are often used to transport fuel (up to 6,000 gallons) and are considered the “workhorse” of the propane industry for delivering fuel. While most bobtails run on diesel, Freightliner Custom Chassis has manufactured a propane-fueled delivery that uses an advanced liquid propane injection (LPI) system that provides more power and fuel efficiency than conventional vapor injection systems.

Light-Duty Trucks



Light-duty trucks, such as the Ford F-250 or Chevrolet Silverado, constitute nearly one-third of the U.S. vehicle fleet (DOT 2010). While gasoline fuels the majority of light-duty trucks in the United States, ethanol (E85) and propane have gained greater use in recent years.

Utility Cargo Vans



Utility cargo vans, such as the Ford E-Series, are commonly used for light-duty cargo transport and ambulance services. Several models can now be purchased to run on alternative fuels, while older models can be retrofitted.

Residential Space Heating

Homes are most commonly heated by a centralized system that moves warm air through ducts, such as a furnace or heat pump, a centralized system that uses a boiler to heat water and move it through pipes and radiators, such as radiant floor heating, or by separate heating units (usually electric) distributed throughout the home. This analysis focuses on the following residential space heating technologies:

- **Furnaces**, which can be gas-fired, oil-fired, or electric; most gas furnaces can be fueled by either natural gas or propane.
- **Heat pumps** use electricity to move heat from outdoor air into the home and rely on a backup source such as electrical resistance when they cannot gather enough heat from the air; as a result, they are more efficient than electric radiators and can deliver more Btus of heat energy than they consume using electricity.
- **Hybrid systems**, which combine electric-powered heat pumps with gas-fueled furnaces, and can be favorable if electric heat pumps struggle to meet heating demand, or if users prefer to use electric heat pumps for cooling and furnaces for heating.

PROPANE | FUEL OIL | ELECTRICITY

		GHG Index	Energy Use (mmBTU per unit per year)	Annual Life Cycle GHG Emissions per unit (kg CO_2 equivalent per unit per year) (= upstream; = end-use)
HEAT PUMP	Electric air source heat pump (ASHP)	0.58	15.8	3,050; 3,050 total
HEAT PUMP	Electric air source heat pump (ASHP) with propane furnace backup	0.83	43.1	1,890; 2,500; 4,390 total
FURNACE	Propane furnace	1.00	61.3	1,110; 4,170; 5,280 total
FURNACE	Fuel oil furnace	1.27	62.4	1,380; 5,310; 6,690 total
FURNACE	Electric furnace	2.20	60.3	11,600; 11,600 total
BASEBOARD	Electric baseboard/ wall vent	1.87	51.3	9,870; 9,870 total

Because boilers have the same range of energy efficiencies as furnaces, they were not added to this analysis. Similarly, a number of different electric resistance heating units can be used to heat rooms, but because they all convert nearly 100 percent of electricity into useful heat, their emissions impact will be similar to electric baseboard heating. In addition, this analysis does not cover cooling because gas- or oil-fired technologies that provide cooling to residential homes are not commercially relevant and electric cooling would provide the same energy use to cool a residential space for all of the technologies included in this analysis.

Assumptions

1. All technologies are assumed to deliver an equivalent energy service, which for this application is 51.2 mmBTU of space heating. The total annual energy consumption used for residential space heating is based on the most recent Residential Energy Consumption Survey (RECS) data by the U.S. Energy Information Administration of homes that used propane for space heating purposes. After factoring for the average annual fuel utilization efficiency (AFUE) for a propane furnace of 98.5 and estimated duct losses, a typical home receives 51.2 mmBTU of delivered heat energy. This value has been used as the baseline in the analysis for space heat delivered in a typical year (EIA 2013).
2. According to DOE, the average duct system uses "R-4" insulation which has 15% leakage on each side (supply and return), totaling 30%. In new construction, a duct efficiency of 100% is possible if construction is done in a manner that leaves no hidden leakage paths. Therefore, it is assumed that there is a 15% efficiency loss split between the supply and return of a duct system. This thermal efficiency has been applied to the all furnaces, heat pumps, and air conditioning systems in the analysis. The energy efficiency of a furnace or boiler is designated by its annual fuel utilization efficiency (AFUE), which is the ratio of heat output of the furnace or boiler compared to the total energy consumed by a furnace or boiler (DOE EERE 2004a).
3. The following AFUE values for generic commercial space heating technologies are based on the highest reported values in the AHRI Directory of Certified Product Performance (AHRI 2012):
    a. Furnaces: fuel oil = 96.7; propane = 98.5
4. Typical AFUE values for electric furnaces are not provided by AHRI. According to Energy Star, the AFUE of electric furnaces ranges from 95–100. An AFUE of 100 was assumed for the electric furnace based on the upper end of the range (DOE 2012).
5. The energy efficiency of a heat pump is designated by its heating season performance factor (HSPF), which is the ratio of heat delivered in Btu to the electricity consumed in watt-hours. This efficiency standard was selected to measure energy use in this analysis of commercial heat pumps, though it is designated for temperature profiles of Climate Region IV, and generally varies significantly with climate (Fairey et al 2004).
6. The following HSPF value for an electric air source heat pump is based on the highest reported values in the AHRI Directory of Certified Product Performance (AHRI 2012):
    a. Air source Heat Pump (HSPF): electric = 13.
7. The electric air source heat pump (ASHP) with propane furnace backup is assumed to handle 40% of the heating load with the backup system handling the remaining 60%. This assumption coincides with a ratio used in a separate analysis of residential heating systems (Newport Partners 2013).

Residential Water Heating

Residential water heaters include both tank storage units and instantaneous ("tankless") water heaters. This analysis includes both types of water heaters:

- **Storage water heaters** keep a constantly available supply of hot water and can be gas-fueled (propane or natural gas), electric, fuel oil, or solar power (solar water heaters frequently use electricity to pump water through the collector, and solar water heating systems almost always require a conventional heater as a backup for cloudy days [EERE 2012]).
- **Tankless water heaters** heat water as it is supplied to the end user units and can be gas-fueled (propane or natural gas) or electric.

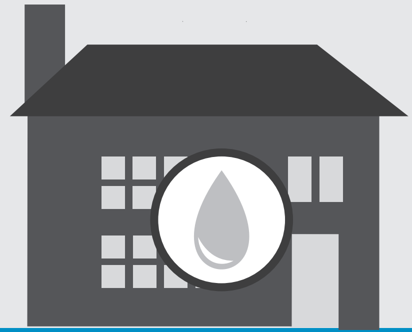
PROPANE | FUEL OIL | ELECTRICITY

		GHG Index	Energy Use (mmBTU per unit per year)	Annual Life Cycle GHG Emissions per unit (kg CO_2 equivalent per unit per year): upstream	end-use	total
SOLAR	Solar storage tank, propane backup	0.26	3.84[1]	157	227	385 total
GENERIC STORAGE	Generic propane storage tank	1.00	16.9	307	1,150	1,450 total
GENERIC STORAGE	Generic electric storage tank	1.64	12.4	2,390		2,390 total
BEST AVAILABLE STORAGE	Best available propane storage tank	0.85	14.4	262	979	1,240 total
BEST AVAILABLE STORAGE	Best available fuel oil storage tank[2]	1.28	17.4	384	1,480	1,860 total
BEST AVAILABLE STORAGE	Best available electric storage tank	1.56	11.8	2,270		2,270 total
GENERIC TANKLESS	Generic propane tankless	0.82	13.9	253	945	1,200 total
GENERIC TANKLESS	Generic electric tankless	1.58	11.9	2,290		2,290 total
BEST AVAILABLE TANKLESS	Best available propane tankless	0.74	12.4	226	845	1,070 total
BEST AVAILABLE TANKLESS	Best available electric tankless	1.56	11.8	2,270		2,270 total

[1]The energy use accounts for only the consumption of fuel from the propane storage tank, and the electrical energy required to circulate heat-transfer fluids.

[2]Typical ranges of energy factors for generic fuel oil storage tank water heaters are not provided by Energy Star. According to the AHRI Directory of Certified Product Performance, the highest reported energy factor is 0.68. Since this energy factor is already at its highest level, fuel oil has not been included in the analysis of generic storage tank water heaters (AHRI 2012).

Heat pump water heaters use electricity to move heat rather than to generate heat directly. They are more efficient than electric water heaters, but very few are commercially available. Therefore, electric heat pumps have been omitted from the study.



Assumptions

1. The energy efficiency of a water heater is designated by its energy factor (EF), which is the ratio of the heat delivered (as hot water) to the energy consumed.
2. All technologies are assumed to deliver an equivalent energy service, which for this application is 10 mmBTU of hot water. The total annual energy consumption used for residential water heating is based on the most recent data for homes that use electricity for water heating, reported in the U.S. Energy Information Administration's Residential Energy Consumption Survey (RECS). After applying the energy factors of generic storage tank and tankless water heaters while accounting for the number of homes by fuel type, and applying the estimated efficiency losses of 15% due to piping, a typical home receives approximately 10 mmBTU of delivered hot water. This value has been used as the baseline in the analysis for hot water delivered in a typical year (EIA 2013).
3. It is assumed that 15% of energy is lost to piping in residential homes (City of Santa Monica 2010).
4. Energy factors for residential storage tank and tankless water heater technologies
(Factors for generic models are based on values reported in an independent study by Energy Star [Global Energy Partners 2005] and factors for best-available models are based on highest reported values in the AHRI Directory of Certified Product Performance [AHRI 2012].)

	Electric	Propane
Generic tankless water heaters	0.99	0.85
Generic storage tank water heaters	0.95	0.70
Best-available tankless water heaters	1.00	0.95
Best-available storage tank water heaters	1.00	0.85

5. Solar energy factors (SEF) range from 1.0 to 11 with 2 or 3 as the most common. A SEF of 3 has been used in this analysis with a propane storage tank energy factor of 0.70 (EERE 2012).
6. According to a study of 88 solar heating systems by the Energy Savings Trust, all systems in the trial used an electric pump to circulate the solar heat-transfer fluid to and from the solar collector. The majority of these systems used power from the electrical grid to run the pump and heater controller, ranging from 1–23% of the total heat energy delivered (10 kWh to 180 kWh per year in total) with a median value of 5%. It is assumed that the solar storage tank system with propane backup uses power from the electrical grid equal to 5% of the total heat delivered by the storage tank (The Energy Savings Trust 2011).

Commercial Space Heating and Cooling

The most common type of heating and cooling equipment used in commercial buildings combines a furnace for heating in cold weather with residential-type central air conditioners for cooling in warm weather. Heat pumps use electricity to move heat rather than to generate electricity and are capable of providing both heating and cooling without the need for two separate devices. These systems place refrigerants with low boiling points under high pressures so that they absorb heat at a high rate, enabling the heat pump to pull heat from both a fuel source and room temperature air to deliver more energy than is consumed by the system.

PROPANE
ELECTRICITY
FUEL OIL

		GHG Index	Energy Use (mmBTU per unit per year)		Annual Life Cycle GHG Emissions per unit (kg CO_2 equivalent per unit per year) (= upstream; = end-use)
			Heating	Cooling	
AMMONIA ABSORPTION	Propane-fueled ammonia absorption heat pump	1.19	329	705	18,800; 70,400 — 89,200 total
ELECTRIC	High-efficiency electric heat pump	0.68	132	133	51,000 — 51,000 total
ELECTRIC	Generic electric heat pump	0.71	141	135	53,100 — 53,100 total
FURNACE & ELECTRIC CENTRAL AIR SOURCE AIR CONDITIONER	Propane furnace & electric central air source air conditioner	1.00	566	135	36,300; 38,500 — 74,800 total
FURNACE & ELECTRIC CENTRAL AIR SOURCE AIR CONDITIONER	Fuel oil furnace & electric central air source air conditioner	1.16	567	135	38,500; 48,200 — 86,700 total
FURNACE & ELECTRIC CENTRAL AIR SOURCE AIR CONDITIONER	Electric furnace & electric central air source air conditioner	1.54	465	135	115,000 — 115,000 total

This analysis includes the following types of commercial space heating and cooling systems:

- **Absorption heat pumps**, which use the heat from a gas burner to operate an ammonia-water absorption cycle.
- **Electric heat pumps**
- **Furnace and electric central air source air conditioner systems**

Assumptions

1. All technologies are assumed to deliver an equivalent energy service, which for this application is 442 mmBTU of space heating, and 454 mmBTU of space cooling (heat removal). These values were calculated by applying the thermal efficiency of a generic propane furnace (82.2%) including duct losses (5%) for space heating, and applying the cooling efficiency of an electric central air source air conditioner (12.1 EER) including duct losses for space cooling, to average heating and cooling energy use for commercial buildings surveyed by the EIA. (EIA 2003).
2. Thermal efficiencies for commercial furnace technologies (Based on the highest reported values in the AHRI Directory of Certified Product Performance [AHRI 2012])

	Fuel Oil	Propane
Furnaces	82.0%	82.2%

3. The energy efficiency of a heat pump is designated by coefficient of performance (COP), or energy efficiency ratio (EER). COP is may often exceed a value of 1 as it is defined as the ratio of heating provided to the heat equivalent of energy consumed (e.g., electricity, natural gas, propane). The EER is the ratio of cooling in Btus to the energy consumed in watt-hours.
4. Energy efficiencies for commercial electric heat pumps (Based on the highest reported values in the AHRI Directory of Certified Product Performance [AHRI 2012])

Heating coefficient of performance (COP)	3.52
Cooling energy efficiency ratio (EER)	12.3

5. There are no apparent federal standards for the thermal efficiency of commercial electric furnaces. It is assumed that the thermal efficiency of commercial electric furnaces is 100%.
6. The furnaces analyzed in this study are assumed to use a water-cooled or evaporative-cooled electric air conditioner, and are based on current federal standards with cooling capacities of 65,000–135,000 Btu/hr. The cooling efficiency (EER) of the electric air conditioner is 12.1 (EERE 2012).
7. The propane and natural gas commercial heat pumps in the analysis are based on manufacturer specifications of the Fulton Reversible Air Source Ammonia Absorption Heat Pump IVS-095-AR (Fulton 2012).
8. According to a study by LBNL, duct leakage flows were measured on 10 large commercial duct systems at operating conditions: three had less than 5% leakage, and seven had substantial leakage ranging from 9 to 26% percent). The average duct efficiency for both heating and cooling for all technologies is therefore assumed to be 95% (Wray, Diamond, and Sherman 2005).

Commercial Water Heating

Commercial water heaters include storage tank units, instantaneous ("tankless") units, and heat pumps. Most non-mall commercial buildings use centralized water heating systems, while some buildings require more than one water heating unit to adequately provide hot water to their tenants.

PROPANE | ELECTRICITY | FUEL OIL

Category	Technology	GHG Index	Energy Use (mmBTU per unit per year)	Annual Life Cycle GHG Emissions per unit (kg CO_2 equivalent per unit per year) (= upstream; = end-use)
HEAT PUMP	Propane-fueled heat pump[1]	0.44	31.8	579 upstream; 2,160 end-use; 2,740 total
GENERIC STORAGE	Generic propane storage tank	1.00	73.0	1,330 upstream; 4,970 end-use; 6,300 total
GENERIC STORAGE	Generic fuel oil storage tank	1.39	81.8	1,810 upstream; 6,960 end-use; 8,770 total
GENERIC STORAGE	Generic electric storage tank	1.99	65.1	12,500 upstream; 12,500 total
BEST AVAILABLE STORAGE	Best available propane storage tank	0.88	64.5	1,170 upstream; 4,390 end-use; 5,560 total
BEST AVAILABLE STORAGE	Best available fuel oil storage tank	1.32	77.8	1,720 upstream; 6,620 end-use; 8,340 total
BEST AVAILABLE STORAGE	Best available electric storage tank	1.95	63.8	12,300 upstream; 12,300 total
GENERIC TANKLESS	Generic propane tankless	1.00	72.9	1,330 upstream; 4,960 end-use; 6,290 total
BEST AVAILABLE TANKLESS	Best available propane tankless	0.90	65.8	1,200 upstream; 4,480 end-use; 5,680 total
BEST AVAILABLE TANKLESS	Best available fuel oil tankless[2]	1.39	81.8	1,810 upstream; 6,960 end-use; 8,770 total
BEST AVAILABLE TANKLESS	Best available electric tankless	1.97	64.5	12,400 upstream; 12,400 total

[1]Although heat pump water heaters may be used for tankless water heating, there were no commercial tankless heat pump models listed in the AHRI Directory of Certified Product Performance; the propane and natural gas commercial tankless heat pumps in the analysis are based on manufacturer specifications of the Ilios High Efficiency Water Heater (Ilios Dynamics).

[2]The AHRI Directory of Certified Product Performance only reported one fuel oil tankless water heater. Therefore, this technology is analyzed only for best-available models.

This analysis includes the following technologies[3]:

- **Air-source heat pumps**,[4] which can run on electricity or gas, have the ability to extract a significant amount of heat from the outside air to heat water to help offset the high initial purchase price of the unit.
- **Storage water heaters** and **tankless water heaters**, which can both run on propane, natural gas, fuel oil, and electricity.

Assumptions

1. Many commercial buildings with more than one water heating unit have centralized water heating equipment while the rest have a distributed system or a combination of both, meaning it is possible to have more than one water heating unit per building. To adjust for the number of water heating units per building, it is assumed that there are 1.5 water heaters per commercial building. The results presented in this application therefore represent the energy and emissions from more than a single water heater (EIA 2003).
2. All technologies are assumed to deliver an equivalent energy service, which for this application is 64 mmBTU of water heating. The total annual energy consumption used for water heating per commercial building is based on the most recent Commercial Buildings Energy Consumption Survey (CBECS) data by the U.S. Energy Information Administration (EIA 2003). After factoring in the assumption that each commercial building uses 1.5 water heaters, and using an average EF of 0.80, the estimated annual energy consumption is 64 mmBTU per commercial building for water heating purposes (EIA 2003).
3. The energy efficiency of a hot water heater is designated by its energy factor (EF) or coefficient of performance (COP). The EF is the ratio of heat delivered (as hot water) to the energy consumed (e.g., electricity, natural gas, propane, or oil). COP is designated for heat pump systems, and may often exceed a value of 1 as it is defined as the ratio of heating provided to the heat equivalent of energy consumed (e.g., electricity, natural gas, propane).
4.

Energy factors for generic commercial storage tank water heater technologies (Based on the average and highest reported values in the AHRI Directory of Certified Product Performance, and are applied to the analysis of generic and best-available models [AHRI 2012].)			
	Electric	Fuel Oil	Propane
Generic storage tank water heaters	0.98	0.78	0.87
Best available storage tank water heaters	1.00	0.82	0.99
Energy factors for commercial tankless water heater technologies (Based on the average and highest reported values in the AHRI Directory of Certified Product Performance, and are applied to the analysis of generic and best-available models, respectively [AHRI 2012].)			
	Electric	Fuel Oil	Propane
Generic tankless water heater	---	---	0.88
Best-available tankless water heaters	0.99	0.78	0.97

5. Typical ranges of energy factors for tankless electric water heaters are not provided by the AHRI Directory of Certified Product Performance. According to Energy Star, the highest reported energy factor of electric tankless water heaters is 0.99, and has been applied to the analysis of best-available models (Global Energy Partners 2005).

[3]Some commercial water heaters common in hotels are equipped with separate recirculation loop systems to quickly deliver hot water to individual dwelling units. Due to the lack of data available on pipe losses which are assumed to be dependent on the size of the system, recirculation loop systems have not been included in this analysis.
[4]While electricity may be used for heat pumps in commercial water heating, these units did not appear in the AHRI Directory of Certified Product Performance. They were not included in the analysis due to a lack of reliable information.

Combined Heat and Power

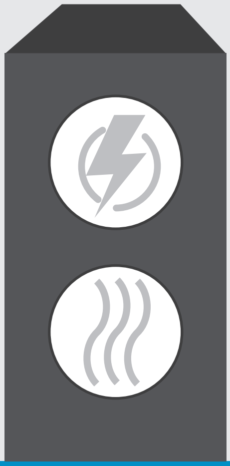
Combined heat and power (CHP) units generate electricity and efficiently capture and use of waste heat. Also known as “district heating,” power plants may use CHP to save energy by redirecting the heat emitted from electricity generation and providing it to nearby homes and buildings for space and water heating. Micro-combined heat and power (microCHP) is a small-scale version of power plant cogeneration that generates heat and power closer to its point of use, resulting in fewer losses of energy that are inherent in the transmission and distribution of electricity from power plants and utility substations. MicroCHP units may be used in combination with renewable energy sources, such as wind and solar, or in conjunction with the electrical grid to provide users with a backup option in the event of electrical grid failure. Some regulations in the U.S. allow owners of microCHP units to sell excess generated electricity back to the national grid.

PROPANE ■ DIESEL ■ ELECTRICITY

		GHG Index	Energy Use (mmBTU per unit per year)	Annual Life Cycle GHG Emissions per unit (kg CO_2 equivalent per unit per year) (■ = upstream; ■ = end-use)
ENGINE-DRIVEN MICROCHP	10 kW propane engine-driven microCHP	0.91	862	15,700 58,600 — 74,300 total
MICROTURBINE MICROCHP	Generic propane microturbine	1.00	948	17,300 64,500 — 81,800 total
	Generic diesel microturbine	1.16	948	20,900 74,100 — 95,100 total
GRID-SUPPLIED ELECTRICITY	Commercial electric furnace and tankless water heater	1.80	2,410	147,000 — 147,000 total

This analysis focuses on the following technologies:

- **MicroCHP units**, which are typically defined as CHP units that generate less than 50 kW and uses different types of electricity generation technologies, such as internal combustion engines, fuel cells, and microturbines.
- A **commercial electric furnace and tankless water heater**; a combination that relies on grid-supplied electricity to provide heat and power for larger-scale applications.



Assumptions

1. According to the Biomass Energy Centre, a typical CHP system powered by an internal combustion engine or gas microturbine has a heat to electrical output ratio of 2:1 (Forestry Commission n.d.).
2. The microCHP technologies and grid-supplied electrical systems are assumed to deliver an equivalent energy service in both heat and power. The heat delivery is based on the combined energy service for commercial space heating and water heating, which is equal to 505 mmBTU per commercial building (see previous applications: Commercial Space Heating and Cooling, and Commercial Water Heating). After applying the heat to electrical output ratio of 2:1 for a typical microCHP system, all applications are assumed to deliver an additional 253 mmBTU of electrical power output (EIA 2003).
3. The total CHP efficiency of the 10 kW engine-driven microCHP unit is based on the propane-fueled Yanmar CP10WN model, which is equal to 88% (Yanmar 2012).
4. The total CHP efficiencies of the generic microturbine-powered CHP units are assumed to be 80% based on a claim from Capstone that CHP units may achieve total efficiencies in excess of 80% (Capstone 2009).
5. The electricity application is assumed to deliver the equivalent energy service for heat using high efficiency commercial appliances for both space heating (furnace) and water heating (tankless water heater). The combined efficiency of these systems is assumed to be 99%.

Generators

Generators are used in residential, commercial, and industrial sectors as a primary, backup (“standby”), or portable source of electricity. These units contain a combustion engine that drives an electrical generator to produce power ranging from a few kilowatts to several hundred kilowatts.

Primary generators are used in areas where the consumer does not purchase power from a utility provider, either because the consumer is not connected to the power grid or because he or she requires greater reliability than the utility provider can provide. Standby, mobile, and portable generators, have a range of uses, including emergency backup power, construction, and recreation.

■ PROPANE ■ ELECTRICITY ■ DIESEL

		GHG Index	Energy Use (mmBTU per unit per year)	Annual Life Cycle GHG Emissions per unit (kg CO_2 equivalent per unit per year) (■ = upstream; ■ = end-use)
RESIDENTIAL BACK-UP GENERATOR	7–15 kW diesel generator	0.88	6.97	154 / 545 — 699 total
	7–15 kW propane generator	1.00	9.20	167 / 626 — 793 total
GRID-SUPPLIED ELECTRICITY	Electricity[1]	1.34	5.51	1,060 — 1,060 total

[1]The efficiency of utility power generation and transmission is assumed to be 10,500 BTU/kWh, which represents average values for the national grid (DOE EERE 2004b).

This analysis focuses on the following generators:

- **Standby power generators**, which provide emergency or backup power for homes, office buildings, hospitals, factories, telecommunication centers, and other critical operations.
- **Grid-supplied electricity**, which is generated by power plants, transmitted to regional electrical substations, and finally distributed to consumers.

Assumptions

1. The propane and diesel generators in the analysis are assumed to operate for 50 hours per year.
2. End-use energy consumption data is based on reported fuel use in vendor specifications of representative generators. The annual energy use for each respective fuel type is based on the average energy consumption between the two generator power supply capacities. Representative generators are:
   a. Propane
      i. Generac CorePower 7 kW (Generac 2013a)
      ii. Generac Guardian 14 kW (Generac 2013b)
   b. Diesel
      i. Kubota GL7000 7 kW (Kubota 2014)
      ii. Generac Protector 30 kW (Diesel) (Generac 2013c)
3. Annual energy use for grid-supplied electricity is based on delivering the same energy service of the propane generators in the analysis. The average delivered energy service between the 7 kW and 14 kW propane generator models is equal to 525 kWh.

Irrigation Engines

Irrigation pumps deliver water from reservoirs, lakes, streams, and wells to fields at essential times to ensure productive crop harvests. Most irrigation pumps are centrifugal, driven by an engine connected to the drive shaft. The smallest pumps are often operated by electric motors, while higher capacity wells tend to be operated by diesel, natural gas, and propane engines.

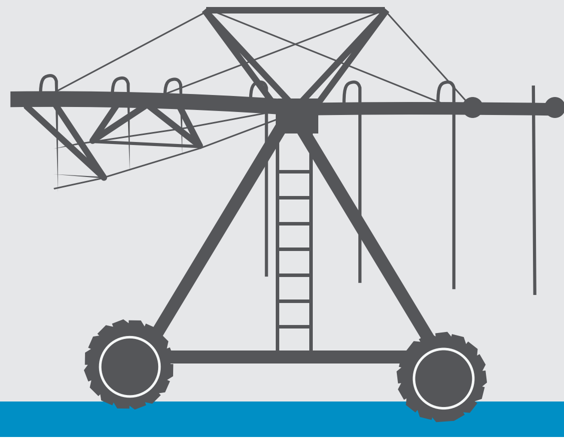
The energy required to run a pump is measured in terms of fuel consumption or electric power use of the engine driving the shaft. Most irrigation pumps range in size from 30 to 300 horsepower and operate at a steady speed and load for many hours, often 24–48 hours nonstop. The effectiveness in converting fuel or electricity to mechanical power to drive the irrigation pump varies based on the

PROPANE DIESEL GASOLINE

100 HORSEPOWER IRRIGATION ENGINE	GHG Index	Energy Use (mmBTU per unit per year)	Annual Life Cycle GHG Emissions per unit (kg CO_2 equivalent per unit per year) (= upstream; = end-use)
Propane irrigation engine	1.00	945	17,200 upstream; 64,300 end-use; 81,500 total
Propane and diesel dual fuel irrigation engine	1.05	927	18,500 upstream; 67,400 end-use; 86,000 total
Diesel irrigation engine	1.12	910	20,100 upstream; 71,200 end-use; 91,300 total
Gasoline irrigation engine	1.25	1,050	21,400 upstream; 80,700 end-use; 102,000 total

type of engine, operating conditions, engine load, and maintenance. Operating an irrigation pump at speeds outside of its optimal range can increase engine load, drastically decreasing engine performance and increasing fuel consumption.

This analysis compares properly loaded and maintained standard 100-horsepower 5.7L **irrigation engines**.



Assumptions

1. Fuel consumption of irrigation engines is calculated using power unit performance standards reported by the University of Florida that represent the effectiveness in converting fuel to mechanical power. These standards allow the effects of loading on the engine to be compared between fuels. The performance standards used are based on fully loaded irrigation power units with respect to each fuel type using direct pump drives with 100% efficiency, and pump efficiencies of 75% (Boman 2002).
2. All engines are assumed to be 5.7L of displacement with 100 horsepower.
3. According to propane industry estimates, irrigation engines operate for 1039 hours per year on average. All engines in this analysis are assumed to operate the same number of hours (Propane's Advantage 2009).

Mowers

Commercial mowers are used on a daily basis to maintain the health and appearance of residential lawns, sports fields, golf courses, parks, roadsides, and other public and commercial lands. Due to the vast amount of lawns and turfgrass in the United States requiring this level of care, mowing contributes significantly to criteria pollutant emissions to the point where many cities have banned the use of gasoline-fueled commercial mowers before 1 p.m. on Ozone Action Days. As a result, smaller and cleaner commercial mowers are highly desirable and sometimes mandated by law.

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GASOLINE

		GHG Index	Energy Use (mmBTU per unit per year)	Annual Life Cycle GHG Emissions per unit (kg CO_2 equivalent per unit per year) (■ = upstream; ■ = end-use)
GENERIC MOWER	Generic propane mower	1.00	84.1	1,530 / 5,720 — 7,250 total
	Generic gasoline mower	1.20	89.7	1,830 / 6,880 — 8,710 total

Propane-fueled mowers deliver propane from tanks mounted on the mower to the engine through a clean, closed fuel system. As a result, fewer burned hydrocarbons enter the crankcase oil, which extends oil life, reduces maintenance needs, and improves overall system efficiency. This analysis, which compares **propane-fueled mowers** and **gasoline-fueled mowers**, demonstrates propane's additional potential to reduce greenhouse gas emissions when used to power commercial mowers.

Assumptions

1. Fuel consumption values are based on estimates provided by Kohler Engines for electronic fuel injection (EFI) mowers that run on propane or gasoline. The engines are assumed to have the same displacement and mower: Gasoline = 1.03 gallons/hour; Propane = 1.32 gallons/hour (Kohler Engines 2013).
2. According to the Austin Parks and Recreation Department, mowers used by the city operate for approximately 750 hours per year, which is the equivalent of operating for 25 hours per week and 30 weeks per year (Texas Alternative Fuel Fleet Pilot Program 2011).

Terminal Tractors

Terminal tractors are vehicles specifically designed to move trailers within or about freight operation yards, such as rail and marine intermodal terminals. Also known as yard trucks, jockeys, spotting tractors, port tractors, shunt trucks, and utility tractor rigs, these heavy-duty vehicles have maximum speeds of less than 30 miles per hour and are capable of towing freight in excess of 50 tons.

Freight operations yards often operate continuously at all times, resulting in heavy fuel consumption by terminal tractors. As more freight yards must comply with emerging emissions laws (CARB 2005), demand has increased for alternative fuel options to meet new regulations.

PROPANE
NATURAL GAS
ELECTRICITY
DIESEL
GASOLINE

GENERIC TERMINAL TRACTOR	GHG Index	Energy Use (mmBTU per unit per year)	Annual Life Cycle GHG Emissions per unit (kg CO_2 equivalent per unit per year) (upstream; end-use)
Electric terminal tractor	0.71	125	24,100 upstream; 24,100 total
Compressed natural gas terminal tractor	0.93	393	8,030 upstream; 23,400 end-use; 31,400 total
Propane terminal tractor	1.00	393	7,160 upstream; 26,800 end-use; 33,900 total
Diesel terminal tractor	1.05	354	7,820 upstream; 27,700 end-use; 35,500 total
Gasoline terminal tractor	1.22	425	8,650 upstream; 32,600 end-use; 41,200 total

State-of-the-art propane-fueled terminal tractors with advanced liquid propane injection (LPI) engines offer comparable fuel consumption rates as conventional fuels while significantly reducing greenhouse gas emissions. This analysis compares **terminal tractors** that use a wide range of energy sources.

Assumptions

1. Because there was little data available giving metrics of appropriate terminal tractor energy efficiencies (e.g. tons of freight moved per gallon), total energy use for propane tractors was assumed to be 5,000 gallons per year. Total energy consumption of tractors using other fuels was determined using relative fuel efficiency values.
2. According to a conservative estimate by PERC and Tug Technologies, propane-fueled ground service equipment uses an average 5,000 gallons of propane per year (Propane Diesel Injection 2009).
3. Relative fuel efficiencies used are based on those in the AFLEET model for vehicles with an equivalent weight rating. The ratio of the fuel economy of each vehicle type (in miles per gasoline gallon equivalent) relative to a gasoline-fueled vehicle are as follows: CNG = 1.08; diesel = 1.20; electric = 3.4; gasoline = 1.0; propane = 1.08 (ANL 2013a).
4. The relatively high efficiency of large propane engines reported by the AFLEET model for combination short-haul tractor-trailers is attributed to a recent case study data suggesting that new liquid propane injection (LPI) engines have similar fuel efficiencies to diesel engines (ANL 2013a).

Forklifts

Forklifts are used to engage, lift, and transfer palletized loads in warehousing, manufacturing, materials handling, and construction applications. They are rated into one of six classes: Classes 1–3 are electric-motor driven and Classes 4–6 are driven by internal combustion engines. More than 670,000 propane-fueled forklifts currently operate in the United States (ITA 2006).

Unlike most vehicles, forklifts use fuel not only for vehicle propulsion (with typical maximum speeds of 10–15 mph) but also for load lifting work. Propane fuels a wide variety of forklifts; other common energy sources include electricity, compressed natural gas, gasoline, and diesel.

PROPANE · NATURAL GAS · ELECTRICITY · DIESEL · GASOLINE

GENERIC FORKLIFT	GHG Index	Energy Use (mmBTU per unit per year)	Annual Life Cycle GHG Emissions per unit (kg CO_2 equivalent per unit per year) (upstream; end-use)
Electric forklift	0.76	28.3	5,440; 5,440 total
Compressed natural gas forklift	0.96	85.6	1,750; 5,080; 6,830 total
Propane forklift	1.00	82.7	1,500; 5,630; 7,130 total
Diesel forklift	1.03	73.0	1,610; 5,710; 7,320 total
Gasoline forklift	1.14	84.0	1,710; 6,440; 8,150 total

Forklift fuel choice may depend on load size and air quality concerns. For example, electric forklifts are normally used for light-duty jobs while diesel forklifts are typically used for heavy-duty loads and are restricted to outdoor use for air quality reasons. Propane forklifts, on the other hand, are used for both light- and heavy-duty applications and approved for both indoor and outdoor use. This analysis compares **forklifts** powered by these and other energy sources.

Assumptions

1. Average fuel use of 973 gallons of propane per year is based on market data provided by Delucchi, which cites 400,000 forklifts using 389 million gallons of propane (Delucchi 2001).
2. The analysis used the assumption by Delucchi that two-thirds of forklift energy use goes to vehicle propulsion and one-third goes to lifting (Delucchi 2001).
3. For forklifts powered by fuels other than propane, the relative efficiencies of lifting and propulsion compared to a propane-fueled system were used to estimate the fuel consumption of those vehicles.
4. Relative fuel efficiencies used are based on those in the AFLEET model for forklifts with a similar gross vehicle weight rating to vehicles. The ratio of the fuel economy of each vehicle type (in miles per gasoline gallon equivalent) relative to a gasoline-fueled vehicle are as follows: CNG = 0.95; diesel = 1.20; electric = 3.4; gasoline = 1.0; propane = 1.0 (ANL 2013a).
5. Thermal engine efficiencies were used to calculate fuel use for equivalent lifting work in Btu. Forklift engine thermal efficiencies used were those used by Delucchi: propane and CNG = 28.0%; gasoline = 26.7%; diesel = 28.5% (Delucchi 2001).
6. According to ANL, the thermal efficiency of electric forklifts is 64% (ANL 2008).

Type A/C Buses

“Type A” buses, also known as mini-buses or shuttle buses, are the smallest classification of buses capable of transporting up to about 40 passengers. The construction of Type A buses uses a bus body placed on the chassis of a cutaway van. These vehicles have medium-duty engines and are capable of running on most fuel types. New dedicated propane Type A buses, such as the Thomas Built Saf-T-Liner C2, are using liquid propane injection (LPI) systems, which are far more effective than vapor injection systems in terms of power, durability, and fuel economy.

Capable of transporting twice as many passengers as a Type A bus, Type C buses are a bus body mounted on top of a medium-duty truck chassis. Also known as “conventional-style” buses, Type C buses continue to be the most common bus type for school districts across the United States.

PROPANE · NATURAL GAS · E85 · DIESEL · GASOLINE

		GHG Index	Energy Use (mmBTU per unit per year)	Annual Life Cycle GHG Emissions per unit (kg CO_2 equivalent per unit per year): upstream	end-use	total
GENERIC LIGHT COMMERCIAL TRUCK: SHUTTLE/ PARATRANSIT VAN (TYPE A BUS)	E85 Type A bus	0.87	160	12,000	(62.0)	12,000 total
	Diesel Type A bus	0.97	133	2,950	10,400	13,400 total
	Propane Type A bus	1.00	160	2,910	10,900	13,800 total
	Compressed natural gas Type A bus	1.02	177	3,620	10,500	14,200 total
	Gasoline Type A bus	1.13	160	3,260	12,300	15,500 total
GENERIC SCHOOL BUS (TYPE C BUS)	Compressed natural gas Type C bus	0.93	464	9,490	27,600	37,100 total
	Propane Type C bus	1.00	464	8,450	31,600	40,100 total
	Diesel Type C bus	1.06	422	9,330	33,000	42,300 total
	Gasoline Type C bus	1.22	505	10,330	38,700	49,000 total

While diesel fuel is the most common fuel type used in Type A and C buses, many fleet owners have replaced their buses with alternative fuel buses in response to concerns echoed by the World Health Organization that diesel engine exhaust is a known human carcinogen (IARC 2012). This analysis compares **Type A buses** and **Type C buses** that run on a range of fuels.

Assumptions

1. Each vehicle was assumed to travel 20,000 miles per year.
2. Relative fuel efficiencies used are based on those in the AFLEET model for vehicles with the same vehicle weight rating as a Type A bus. The fuel economies of each vehicle type (in miles per gasoline gallon equivalent) are as follows: CNG = 13.1; diesel = 17.4; E85 = 14.5; gasoline = 14.5; propane = 14.5 (ANL 2013a).
3. Relative fuel efficiencies used are based on those in the AFLEET model for vehicles with the same vehicle weight rating as a Type C bus. The fuel economies of each vehicle type (in miles per gasoline gallon equivalent) are as follows: CNG = 5.0; diesel = 5.5; gasoline = 4.6; propane = 5.0 (ANL 2013a).
4. The relatively high efficiency of large propane engines reported by the AFLEET model for Type C buses is attributed to a recent case study data suggesting that new liquid propane injection (LPI) engines have similar fuel efficiencies to diesel engines (ANL 2013a).

Bobtail Trucks

There are two types of fuel delivery trucks: large semi-trailer trucks, and small bulk delivery trucks, known as "bobtails." Bobtail trucks are designed to transport up to 6,000 gallons of fuel, and are generally considered the workhorse of the propane industry for delivering fuel. Although most bobtail trucks operate on diesel, Freightliner Custom Chassis has manufactured a new dedicated propane-fueled delivery truck that runs on an 8.0L engine and uses new liquid propane injection (LPI) systems that are far more effective than vapor injection systems in terms of power, durability, and fuel economy. This analysis compares **bobtail trucks** that use a range of fuel types.

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DIESEL

		GHG Index	Energy Use (mmBTU per unit per year)	Annual Life Cycle GHG Emissions per unit (kg CO_2 equivalent per unit per year) (= upstream; = end-use)
BOBTAIL TRUCK	Propane bobtail truck	1.00	537	9,780; 36,600; 46,400 total
	Diesel bobtail truck	1.05	484	10,700; 37,800; 48,500 total
	Gasoline bobtail truck	1.22	580	11,800; 44,500; 56,300 total

Assumptions

1. Each vehicle was assumed to travel 20,000 miles per year.
2. Relative fuel efficiencies used are based on those in the AFLEET model for vehicles with the same vehicle weight rating as a combination short-haul tractor-trailer. The fuel economies of each vehicle type (in miles per gasoline gallon equivalent) are as follows: diesel = 4.8; gasoline = 4.0; propane = 4.3 (ANL 2013a).
3. The relatively high efficiency of large propane engines reported by the AFLEET model for combination short-haul tractor-trailers is attributed to a recent case study data suggesting that new liquid propane injection (LPI) engines have similar fuel efficiencies to diesel engines (ANL 2013a).

Light-Duty Trucks

Light duty trucks constitute a significant portion of the U.S. vehicle fleet. While gasoline fuels the majority of light-duty trucks in the United States, the use of ethanol (E85) and propane has increased in recent years.

The alternative fuel vehicle manufacturer ROUSH CleanTech has developed a dedicated propane light-duty vehicle that directly replaces the original equipment manufacturer (OEM) gasoline injection system with a liquid propane injection (LPI) system. In addition, manufacturers such as Prins, Technocarb, and ICOM offer gasoline-to-propane conversion kits and bi-fuel conversion kits, which allow the vehicle to start on gasoline fuel and immediately switch to propane autogas. This analysis compares **light-duty trucks** that use a range of fuels.

PROPANE · NATURAL GAS · E85 · DIESEL · GASOLINE

GENERIC LIGHT-DUTY PASSENGER TRUCK (6,001–8,500 LBS GVWR)

	GHG Index	Energy Use (mmBTU per unit per year)	Annual Life Cycle GHG Emissions per unit (kg CO_2 equivalent per unit per year) (upstream; end-use)
E85 light-duty truck	0.87	65.6	(25.4); 4,930; 4,910 total
Diesel light-duty truck	0.97	54.8	1,210; 4,280; 5,490 total
Compressed natural gas light-duty truck	0.98	69.1	1,410; 4,110; 5,520 total
Propane light-duty truck	1.00	65.6	1,190; 4,460; 5,660 total
Light-duty truck with propane conversion kit	1.00	65.7	1,200; 4,470; 5,670 total
Compressed natural gas and gasoline bi-fuel light-duty truck	1.03	72.4	1,480; 4,370; 5,850 total
Propane and gasoline bi-fuel light-duty truck	1.11	72.4	1,330; 4,960; 6,290 total
Gasoline light-duty truck	1.13	65.6	1,340; 5,030; 6,370 total

Assumptions

1. Each vehicle was assumed to travel 10,000 miles per year.
2. Relative fuel efficiencies used are based on those in the AFLEET model for vehicles with the same vehicle weight rating as a light-duty pickup truck. The fuel economies of each vehicle type (in miles per gasoline gallon equivalent) are as follows: CNG = 16.8; diesel = 21.2; E85 = 17.7; gasoline = 17.7; propane = 17.7 (ANL 2013a).
3. The bi-fuel vehicles in the analysis are assumed to be converted from gasoline vehicle models. The base fuel economies are assumed to be the same as gasoline vehicles.
4. According to an NREL study of propane autogas conversion kits, vehicles experience a volumetric fuel economy reduction of 27% when converting from gasoline, which was consistent with the energy content difference between fuels. This loss has been applied to the analysis of the gasoline-to-propane converted vehicle (Bass 1993).
5. The Prins [Bi-fuel] Vapor Sequential Injection System starts on gasoline and immediately switches to autogas. Depending on the number of starting cycles, as much as 10 percent of total fuel consumption may be gasoline, or as little as 2 percent if the vehicle is driven primarily on the highway. For the purposes of the analysis, the total consumption of gasoline is 6% (PERC 2012).
6. According to a study by the International Energy Agency (IEA), bi-fuel gasoline-CNG vehicle experience a 5-10% loss of efficiency while running on CNG. It is assumed that the CNG and LPG bi-fuel conversions of gasoline vehicles will experience a 6% loss in fuel economy while running on CNG or LPG, respectively. Because CNG is a compressed gas, the bi-fuel analysis assumes that the volume of CNG fuel consumed is based on gasoline gallon equivalents. The volume of propane fuel consumed is based on the equivalent energy content as gasoline gallons (IEA 2010).

Utility Cargo Vans

Utility cargo vans are often used by businesses to make deliveries, are converted for ambulance services, and serve as the chassis for Type A buses. These vehicles typically operate on gasoline or diesel fuel, although some manufacturers are offering alternative fuel options such as E85, compressed natural gas, and propane.

The alternative fuel manufacturer ROUSH CleanTech offers a propane-fueled conversion retrofit system for the Ford E-350 on model years 2012 or newer. Manufacturers such as Prins, Technocarb, and ICOM offer gasoline-to-propane conversion kits as well as bi-fuel conversion kits, which allow the vehicle to start on gasoline fuel and immediately switch to propane autogas. This analysis compares **utility cargo vans** that use a range of fuels.

PROPANE / NATURAL GAS / E85 / DIESEL / GASOLINE

GENERIC UTILITY CARGO VAN	GHG Index	Energy Use (mmBTU per unit per year)	Annual Life Cycle GHG Emissions per unit (kg CO_2 equivalent per unit per year): upstream	end-use	total
E85 utility cargo van	0.87	116	(44.9)	8,730	8,680 total
Diesel utility cargo van	0.97	96.7	2,140	7,570	9,700 total
Propane utility cargo van	1.00	116	2,110	7,900	10,000 total
Utility cargo van with propane conversion kit[1]	1.00	116	2,120	7,920	10,000 total
Compressed natural gas utility cargo van	1.03	129	2,640	7,660	10,300 total
Compressed natural gas and gasoline bi-fuel utility cargo van	1.03	128	2,620	7,740	10,400 total
Propane and gasoline bi-fuel utility cargo van	1.11	128	2,350	8,790	11,100 total
Gasoline utility cargo van	1.13	116	2,360	8,910	11,300 total

[1]The propane vehicle with conversion kit is based on converting a gasoline vehicle to run on propane. Numbers appear similar to the indexed dedicated propane vehicle due to rounding.

Assumptions

1. Each vehicle was assumed to travel 10,000 miles per year.
2. Relative fuel efficiencies used are based on those in the AFLEET model for vehicles with the same vehicle weight rating as a utility cargo van. The fuel economies of each vehicle type (in miles per gasoline gallon equivalent) are as follows: CNG = 9; diesel = 12; E85 = 10; gasoline = 10; propane = 10 (ANL 2013a).
3. The bi-fuel vehicles in the analysis are assumed to be converted from gasoline vehicle models. The base fuel economies are assumed to be the same as gasoline vehicles.
4. According to an NREL study of propane autogas conversion kits, vehicles experience a volumetric fuel economy reduction of 27% when converting from gasoline, which was consistent with the energy content difference between fuels. This loss has been applied to the analysis of the gasoline-to-propane converted vehicle (NREL 1993).
5. The Prins [Bi-fuel] Vapor Sequential Injection System starts on gasoline and immediately switches to autogas. Depending on the number of starting cycles, as much as 10 percent of total fuel consumption may be gasoline, or as little as 2 percent if the vehicle is driven primarily on the highway. For the purposes of the analysis, the total consumption of gasoline is 6% (Hofmann 2012).
6. According to a study by the International Energy Agency (IEA), bi-fuel gasoline-CNG vehicle experience a 5-10% loss of efficiency while running on CNG. It is assumed that the CNG and LPG bi-fuel conversions of gasoline vehicles will experience a 6% loss in fuel economy while running on CNG or LPG, respectively. Because CNG is a compressed gas, the bi-fuel analysis assumes that the volume of CNG fuel consumed is based on gasoline gallon equivalents. The volume of propane fuel consumed is based on the equivalent energy content as gasoline gallons (IEA 2010).

Appendix A. List of References

ANL (Argonne National Laboratory), Center for Transportation Research. 2008. *Full Fuel-Cycle Comparison of Forklift Propulsion Systems*. UChicago Argonne, LLC.

———. 2013a. *Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool 2013*. UChicago Argonne, LLC.

———. 2013b. *The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model 2013*. UChicago Argonne, LLC.

AHRI (Air-Conditioning, Heating, and Refrigeration Institute). 2012. "Directory of Certified Product Performance." http://www.ahridirectory.org/ahridirectory/pages/home.aspx.

Bass, E. A. 1993. *Evaluation of Aftermarket LPG Conversion Kits in Light-Duty Vehicle Applications: Final Report*. Golden, Colorado: National Renewable Energy Laboratory. http://www.nrel.gov/docs/legosti/old/5462.pdf.

Boman, Brian J. 2002. *Water and Florida citrus: Use, Regulation, Irrigation, Systems, and Management*. Institute of Food and Agricultural Sciences, University of Florida.

Brandt A. R., G. A. Heath, E. A. Kort, F. O'Sullivan, G. Pétron, S. M. Jordaan et al. 2014. "Methane Leaks from North American Natural Gas Systems." Science 343, no, 6172 (February). http://www.sciencemag.org/content/343/6172/733.

Capstone Turbine Corporation. 2009. "Capstone Corporate Brochure." http://www.capstoneturbine.com/_docs/Capstone%20Corporate%20Brochure_hires.pdf.

CARB (California Environmental Protection Agency, Air Resources Board). 2005. *Final Regulation Order: Regulation For Mobile Cargo Handling Equipment At Ports and Intermodal Rail Yards*. California Code of Regulations, Title 13, § 2479. http://www.arb.ca.gov/regact/cargo2005/cargo2005.htm.

City of Santa Monica, Office of Sustainability and the Environment. 2010. *Green Building: Guidelines for Design*. Accessed February 2014. http://www.smgov.net/Departments/OSE/Categories/Green_Building/Guidelines/Water_Systems/Hot_Water_Heat_Loss.aspx.

Delucchi, Mark. 2001. "A Lifecycle Emissions Analysis: Urban Air Pollutants and Greenhouse-Gases from Petroleum, Natural Gas, LPG, and Other Fuels for Highway Vehicles, Forklifts, and Household Heating in the U.S." World Resource Review 13, No. 1.

DOE EERE (U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy), Building Technologies Program. 2004a. Better Duct Systems for Home Heating and Cooling. http://www.nrel.gov/docs/fy05osti/30506.pdf.

DOE EERE (U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy). 2004b. Energy Use, Loss and Opportunities Analysis: U.S. Manufacturing & Mining. https://www1.eere.energy.gov/manufacturing/intensiveprocesses/pdfs/energy_use_loss_opportunities_analysis.pdf.

DOE EERE (U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy). 2012a. *Energy Conservation Program for Certain Industrial Equipment: Energy Conservation Standards and Test Procedures for Commercial Heating, Air-Conditioning, and Water-Heating Equipment; Final Rule*. 77 Fed. Reg. 28928. http://www.regulations.gov/#!documentDetail;D=EERE-2011-BT-STD-0029-0038

———. 2012b. "Estimating the Cost and Energy Efficiency of a Solar Water Heater." Accessed February 2014. http://energy.gov/energysaver/articles/estimating-cost-and-energy-efficiency-solar-water-heater.

———. 2012c. "Furnaces and Boilers." Accessed February 2014. http://energy.gov/energysaver/articles/furnaces-and-boilers.

———. 2012d. "Solar Water Heaters." Accessed February 2014. http://energy.gov/energysaver/articles/solar-water-heaters.

DOT (U.S. Department of Transportation), Research and Innovative Technology Administration. 2010. "Table 1-22. Number of Trucks by Weight." *National Transportation Statistics*. http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/index.html.

———. 2013. "Table 1-11. Number of U.S. Aircraft, Vehicles, Vessels, and Other Conveyances." *National Transportation Statistics*. http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/index.html.

EIA (U.S. Energy Information Administration). 2006a. "Table B26. Space Heating Energy Sources, Number of Buildings for Non-Mall Buildings, 2003." *2003 Commercial Buildings Energy Consumption Survey Data*. http://www.eia.gov/consumption/commercial/data/2003/.

———. 2006b. “Table B30. Cooling Energy Sources, Number of Building and Floorspace for Non-Mall Buildings, 2003.” *2003 Commercial Buildings Energy Consumption Survey Data*. http://www.eia.gov/consumption/commercial/data/2003/.

———. 2006c. “Table B31. Water-Heating Energy Sources, Number of Buildings for Non-Mall Buildings, 2003.” 2003 *Commercial Buildings Energy Consumption Survey Data*. http://www.eia.gov/consumption/commercial/data/2003/.

———.2006d. “Table B42. Water-Heating Equipment, Number of Buildings and Floorspace for Non-Mall Buildings, 2003.” *2003 Commercial Buildings Energy Consumption Survey Data*. http://www.eia.gov/consumption/commercial/data/2003/.

———. 2006e. “Table C1A. Total Energy Consumption by Major Fuel for All Buildings, 2003.” *2003 Commercial Buildings Energy Consumption Survey Data*. http://www.eia.gov/consumption/commercial/data/2003/.

———. 2006f. “Table E1A. Major Fuel Consumption (Btu) by End Use for All Buildings, 2003.” *2003 Commercial Buildings Energy Consumption Survey Data*. http://www.eia.gov/consumption/commercial/data/2003/.

———. 2012. “Propane Explained: Delivery and Storage of Propane.” Accessed February 2014. http://www.eia.gov/energyexplained/index.cfm?page=propane_delivery.

———. 2013a. “Table CE4.1. Household Site End-Use Consumption by Fuel in the U.S., Totals, 2009.” *2009 Residential Energy Consumption Survey Data*. http://www.eia.gov/consumption/residential/data/2009/.

———. 2013b. “Table HC6.1. Space Heating in U.S. Homes, by Housing Unit Type, 2009.” *2009 Residential Energy Consumption Survey Data*. http://www.eia.gov/consumption/residential/data/2009/.

———. 2013c. “Table HC8.1. Water Heating in U.S. Homes, by Housing Unit Type, 2009.” *2009 Residential Energy Consumption Survey Data*. http://www.eia.gov/consumption/residential/data/2009/.

The Energy Savings Trust. 2011. *Here Comes the Sun: A Field Trial of Solar Water Heating Systems*. London: Energy Savings Trust. http://www.energysavingtrust.org.uk/content/download/29047/348320/version/3/file/Here+comes+the+sun+-+solar+hot+water+report.pdf.

EPA (U.S. Environmental Protection Agency). 2013. “Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act.” Accessed February 2014. http://www.epa.gov/climatechange/endangerment/.

EPA (U.S. Environmental Protection Agency), Office of Air and Radiation. 2014. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2012*. Washington DC: U.S. Environmental Protection Agency. http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html.

Fairey, Philip, Danny Parker, Bruce Wilcox, and Mathew Lombardi. 2004. "Climate Impacts on Heating Seasonal Performance Factor (HSPF) and Seasonal Energy Efficiency Ratio (SEER) for Air Source Heat Pumps." *ASHRAE Transactions*. Atlanta, Georgia: American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. http://www.fsec.ucf.edu/en/publications/html/FSEC-PF-413-04/.

Forestry Commission, Biomass Energy Centre. n.d. "Information Sheet No. 4: Combined heat and power (CHP)." http://www.biomassenergycentre.org.uk/pls/portal/docs/PAGE/RESOURCES/REF_LIB_RES/PUBLICATIONS/4.%20CHP%20V5.1%209-2009%20DRAFT.PDF.

Fulton Heating Solutions, Inc. 2012. "Fulton Invictus Hydronic Heating and Cooling Systems with Gas Absorption Heat Pumps." http://www.fulton.com/downloader.php?doc_id=626.

Generac Power Systems, Inc. 2013a. "CorePower system Residential Standby Generators Air-Cooled Gas Engine." http://gens.lccdn.com/generaccorporate/media/library/content/all-products/generators/home-generators/corepower-series/0186720sby-q-corepower.pdf?ext=.pdf.

———. 2013b. "Guardian Series Standby Generators Air-Cooled Gas Engine." http://gens.lccdn.com/generaccorporate/media/library/content/all-products/generators/home-generators/guardian-series/0197990sby-g-2013-14-20kw-hsb.pdf?ext=.pdf.

———. 2013c. "Protector Series Standby Generators Diesel Engine." http://gens.lccdn.com/generaccorporate/media/library/content/all-products/generators/home-generators/protector-series/0k4730-d-export-protector.pdf?ext=.pdf.

Global Energy Partners, LLC. 2005. Electric Tankless Water Heating: Competitive Assessment. Lafayette, CA: Global Energy Partners, LLC, http://www.energystar.gov/products/specs/sites/products/files/ElectricTanklessCompetitiveAssessment.pdf

Haydu, John J., Alan W. Hodges, and Charles R. Hall. 2006. *Economic Impacts of the Turfgrass and Lawncare Industry in the United States*. Gainesville, Florida: University of Florida Institute of Food and Agricultural Services. http://edis.ifas.ufl.edu/fe632.

IARC (International Agency for Research on Cancer), World Health Organization. 2012. "IARC: Diesel Engine Exhaust Carcinogenic." June 12. http://www.iarc.fr/en/media-centre/pr/2012/pdfs/pr213_E.pdf.

ICF International, Inc. 2013. 2013 Propane Market Outlook: *Assessment of Key Market Trends, Threats, and Opportunities Facing the Propane Industry Through 2020*. Prepared for the Propane Education & Research Council (PERC). http://www.icfi.com/insights/reports/2013/propane-market-outlook-2013.

IEA (International Energy Agency), Energy Technology Systems Analysis Programme. 2010. *Automotive LPG and Natural Gas Engines*. http://www.iea-etsap.org/web/e-techds/pdf/t03_lpg-ch4_eng-gs-gct-ad.pdf.

Ilios Dynamics. n.d. "Ilios High Efficiency Water Heater." http://www.iliosdynamics.com/Collateral/Documents/Ilios/IliosDataSheet-AirSource.pdf.

IPCC (Intergovernmental Panel on Climate Change). 2001a. *Atmospheric Chemistry and Greenhouse Gases. Climate Change 2001: The Scientific Basis*. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. New York: Cambridge University Press. http://www.grida.no/publications/other/ipcc_tar/.

———. 2001b. Radiative Forcing of Climate Change. *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. New York: Cambridge University Press. http://www.grida.no/publications/other/ipcc_tar/.

———. 2013. Anthropogenic and Natural Radiative Forcing. *Climate Change 2013: The Physical Science Basis*. Working Group I contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. New York: Cambridge University Press. http://www.ipcc.ch/report/ar5/wg1/.

ITA (Industrial Truck Association). 2006. Information purchased by the Propane Education & Research Council (PERC).

Kohler Engines. 2013. "Kohler Command PRO Propane EFI: For the Landscape Professional." PowerPoint presentation.

Kubota Engine America Corporation. 2014. "GL 7000 Kubota GL Series." Accessed February 2014. http://www.kubotaengine.com/products/generators/gl-series/gl7000.

Milesi, C., C.D. Elvidge, J.B. Dietz, B.T. Tuttle, R.R. Nemani, and S.W. Running. 2005. *A Strategy for Mapping and Modeling the Ecological Effects of U.S. Lawns*. http://www.isprs.org/proceedings/xxxvi/8-w27/milesi.pdf.

Newport Partners LLC. 2013. *Performance Comparison of Residential Heating Systems: Energy, Economics, Emissions, and Comfort*. Prepared for the Propane Education & Research Council. http://www.buildwithpropane.com/html/files/HeatingSystemsAnalysis.pdf.

"Propane-Diesel Injection ... Where We Go From Here." 2009. *Butane-Propane News*. May. http://www.bpnews.com/archives/2009-05/Diesel_Injection.pdf.

PERC (Propane Education & Research Council). 2012. "Converting Vehicles to Propane Autogas, Part 4: Troubleshooting Four Current Autogas Fuel Systems." http://www.autogasusa.org/uploadedFiles/Fuel/Resources/RRC_Autogas_Webinars/Troubleshooting.pdf.

"Propane's Advantage in Fueling Irrigation Engines." 2009. *Butane-Propane News*. February. http://www.bpnews.com/archives/2009-02/AG_Engine.pdf.
Resource Dynamics Corporation. 1999. Industrial Applications for Micropower: A Market Assessment. Prepared for U.S. Department of Energy, Office of Industrial Technologies. http://www1.eere.energy.gov/manufacturing/distributedenergy/pdfs/micropower_market_assessment.pdf.

Texas Alternative Fuel Fleet Pilot Program. 2011. "Austin Parks and Recreation Department Unveils New Alternative Fuel Lawn Mowers." May 3. http://blogs.rrc.state.tx.us/TPF/?p=2419.

USDA (U.S. Department of Agriculture). 2010. *Farm and Ranch Irrigation Survey (2008): 2007 Census of Agriculture*. Vol. 3, Special Studies, Part I. http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/Farm_and_Ranch_Irrigation_Survey/fris08.pdf.

USGCRP (U.S. Global Change Research Program). 2009. *Global Climate Change Impacts in the United States*. New York: Cambridge University Press. http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf.

Wray, Craig P., Richard C. Diamond, and Max H. Sherman. 2005. *Rationale For Measuring Duct Leakage Flows in Large Commercial Buildings*. Berkeley, California: Lawrence Berkeley National Laboratory. http://epb.lbl.gov/homepages/Rick_Diamond/docs/lbnl58252-aivc.pdf.

Yanmar America Corporation. 2012. "CP10WN." http://us.yanmar.com/media/ext/uploaded/a2c54b24-d93b-447b-aa69-04d2fecb482e/mCHP-SpecSheet-CP10WN.pdf.

Appendix B. Sensitivity Analysis

A sensitivity analysis was conducted to identify the relative influence of key variables and assumptions on the GHG emissions results reported in this study. Each sensitivity scenario examines a base case, low case, and high case. The base case represents the variables used to produce the results of this study. The low and high cases are perturbations on the base case variables to determine how much the results change as a result. Sensitivities were conducted on variables relevant to both upstream emissions factors and end-use emissions results.

The results of this sensitivity analysis show that while individual variables and assumptions do affect the total energy use and GHG emissions values reported in this study, the relative GHG emissions values (i.e., the indexed values with propane = 1.00) do not significantly change in response to changes in assumed values. In most cases, changes in assumed values for thermal efficiency, fuel efficiency, and other variables affect all fuels equally, resulting in no change in the GHG index values. For those variables that do affect different fuel types differently, such differences are very small (less than 1%) and do not materially alter the study's findings.

Upstream Emissions Factors

The upstream sensitivity analysis focused on two key variables: global warming potentials (GWPs) and the proportion of propane sourced from natural gas and crude oil feedstocks. These variables are defined in this study as follows:

- **Global warming potential** — The GWP base case uses IPCC AR5 global warming potential values, and the sensitivity analysis examines the GWPs used in the 2009 version of this report (low case), and the GWPs with climate-carbon feedback in IPCC AR5 (high case). Climate-carbon feedback is a mechanism in which certain global warming processes trigger one another to intensify or weaken the overall impact of climate change.
- **Source of Propane Supply** — To test the influence of the propane source on upstream GHG emissions factors, the base case scenario of 70% propane sourced from natural gas and 30% sourced from crude oil was changed to 65% natural gas (low case) and 75% natural gas (high case).

Table B1. CO_2 Released per Btu

	ALL FUELS	PROPANE
VARIABLE	Global warming potentials	Source of propane supply
LOW CASE	IPCC AR4 GWPs: CO_2=1; CH_4=25; N_2O=298	65% Natural Gas 35% Crude Oil
BASE CASE	IPCC AR5 GWPs: CO_2=1; CH_4=28; N_2O=265	70% Natural Gas 30% Crude Oil
HIGH CASE	IPCC AR5 (with climate-carbon warming feedback) GWPs: CO_2=1; CH_4=34; N_2O=298	75% Natural Gas 25% Crude Oil

Sensitivity of Global Warming Potentials

When testing GWP values against the base case, the upstream emissions factors for gasoline and diesel show the smallest change in total GHG emissions, while E85 and natural gas show the largest change. Compared to the base case, the IPCC AR4 GWPs weaken methane (CH_4) potentials and intensify nitrous oxide (N_2O) potentials, while the IPCC AR5 climate-carbon feedback GWPs intensify both CH_4 and N_2O potentials. Diesel and gasoline have the lowest levels of upstream methane of the fuels considered in this study and emit very small amounts of upstream N_2O and therefore are less sensitive to changes in the GWPs.

The sensitivity analysis shows that varying GWPs does not significantly alter total GHG emissions for all applications in the study with respect to the indices to propane technologies, ranging from a 0.01 to 0.05 point difference in index scores.

Sensitivity of Propane Feedstock Ratio

When the share of propane refined by natural gas feedstock is increased (high case), both N_2O and CO_2 emissions decrease, while CH_4 emissions increase. The resulting change in upstream CO_2e emissions is only a 1.8% decrease with when increasing the share of natural gas feedstock by 5 percentage points, which translates to a decrease in total lifecycle GHG emissions of only 0.4%.

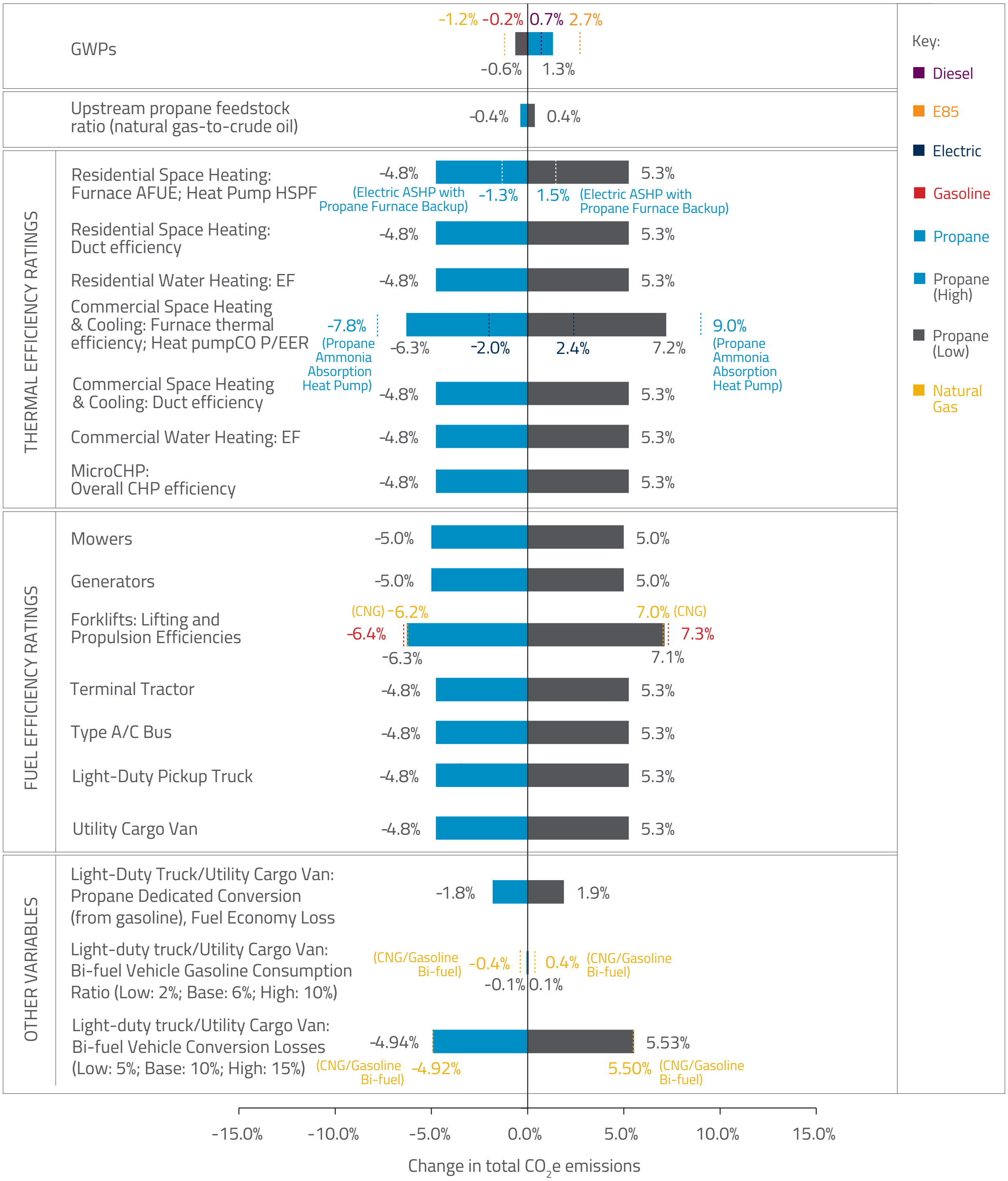
Upon examination of the indices of across all technologies, this only results in a difference of 0.01 index points or less.

Sensitivity of Efficiency and Other Variables

A sensitivity analysis was also applied to thermal efficiencies, fuel economies, and other key variables in this study to understand the impact of these variables on total lifecycle GHG emissions for each technology. In general, a ±5% change was applied to the efficiencies of each technology. For other applications, the low and high cases reflected the range of values that were provided by the source materials. While each fuel experiences a different change in emissions relative to its base value in the analysis, many fuels experience the same percent change in emissions. Other technologies may experience a different percent change due to using more than one efficiency variable, or using different load ratios of energy use between fuels or functions of the technology.

The results of the sensitivity analysis reveal that system efficiencies have the largest impact on the total lifecycle emissions for each technology in the analysis. This reaffirms the methodology used in this study to use a consistent approach for incorporating energy efficiencies (i.e., using the highest-reported efficiencies) available from source materials, and to present multiple system efficiencies when possible by providing lower efficiencies of "generic" systems, and higher efficiencies of "best-available" systems.

Figure B1. Sensitivity Analysis of Key Variables



Appendix C. List of Acronyms

AC	air conditioning
ASHP	air source heat pump
ASHRAE	(formerly known as) American Society of Heating, Refrigerating, and Air Conditioning
AHRI	Air Conditioning, Heating, and Refrigeration Institute
AFUE	annual fuel utilization efficiency
Btu	British thermal units
CAS	central air source
CO	carbon monoxide
CO_2	carbon dioxide
COP	coefficient of performance
CH_4	methane
CHP	combined heat and power
CBECS	Commercial Buildings Energy Conssumption Survey
CNG	compressed natural gas
DOE	Department of Energy
EERE	Energy Efficiency and Renewable Energy
EER	energy efficiency ratio
EF	energy factor
EFI	electronic fuel injection
EIA	Energy Information Administration
EPA	Environmental Protection Agency
E85	ethanol
GM	General Motors
GWP	global warming potential
GHG	greenhouse gas
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
GVWR	gross vehicle weight rating
hp	horsepower
HFC	hydroflurocarbons
HSPF	Heating Seasonal Performance Factor
ITA	Industrial Truck Association
IPCC	Intergovernmental Panel on Climate Change
kg	kilograms
lb	pound
LPG	liquefied petroleum gas
LPI	liquid propane injection
mmBTU	million British thermal units
NO_2	nitrogen dioxide
N_2O	nitrous oxide
NREL	National Renewable Energy Laboratory
O_3	ozone
Pb	lead

PFC perfluorocarbons

RECS Residential Energy Consumption Survey

SEER Seasonal Energy Efficiency Ratio

SEF solar energy factor

SO_2 sulfur dioxide

SF_6 sulfur hexaflouride

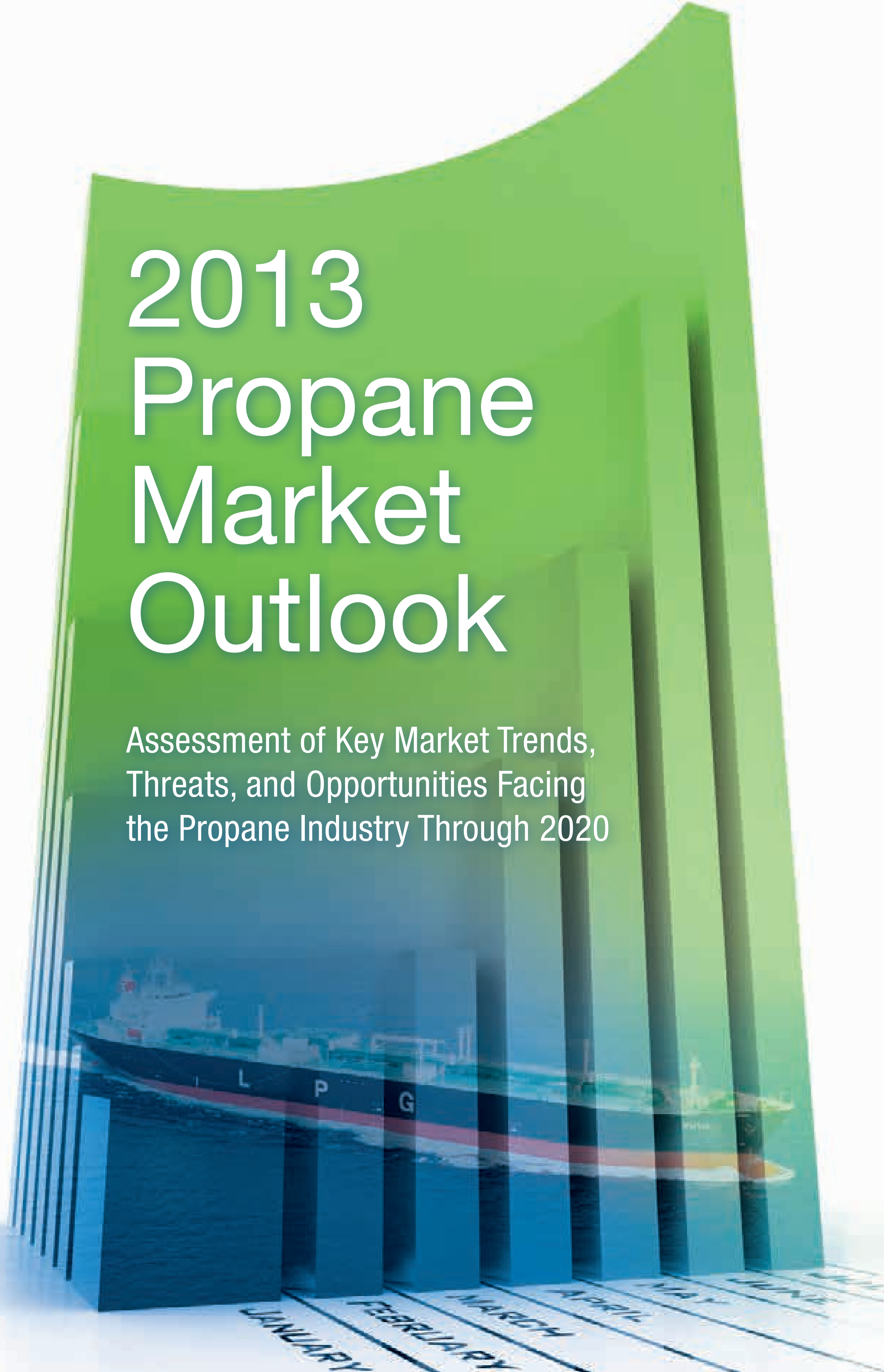
USGCRP U.S. Global Change Research Program

VOC volatile organic compounds

ICF INTERNATIONAL

2013 Propane Market Outlook

Assessment of Key Market Trends, Threats, and Opportunities Facing the Propane Industry Through 2020



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Propane Market Outlook at a Glance

- Total consumer propane sales declined by more than 17 percent between 2009 and 2012, including 3.3 percent in 2011 and 10 to 12 percent in 2012. The declines in 2011 and 2012 were due primarily to much warmer than normal weather, as well as the impact of higher propane prices and continuing efficiency trends. Sales are expected to rebound in 2013 with a return to more typical temperatures.
- Since 2010, propane prices have fallen substantially relative to other transportation fuels. The average price difference between major market marker prices for gasoline (New York Harbor gasoline price) and propane (Mt. Belvieu propane price) has increased by more than $0.76 per gallon, from $0.37 per gallon in 2010 to $1.12 per gallon in 2012.
- Propane prices are expected to remain very competitive with gasoline, diesel fuel, and distillate fuel oil as propane supply continues to increase.
- Markets for internal combustion engines offer long term potential for large growth in propane sales, as clean propane applications including commercial lawn mowers, irrigation pumps, and propane vehicles become more widely available.
- The residential new construction market remains depressed, with new housing starts slowly rebounding from their 2009 lows.
- Fuel oil conversions in the Northeast may offer the highest growth potential in the residential and commercial sectors.
- Targeting existing propane customers to maximize household propane applications may be the most efficient way to offset continuing declines in fuel use per customer.
- Sales are projected to grow slowly from 2013/2014 to 2020 due to a rebound in the economy and introduction of new propane applications, particularly propane vehicles and other engine applications.
- Taking advantage of the opportunities and minimizing the challenges that lie ahead will require concerted action by the industry as a whole, including investments in new technologies and participation in the national energy conversation.

1 Introduction

In the last ten years, propane markets have been transformed by the combined effects of volatile energy prices, swings in economic outlook, advancements in propane and competitive technologies, improvements in energy efficiency, and changes in propane supply. While many of these factors have resulted in increased challenges for propane marketers, they have also created new opportunities for the industry. Adapting to these changes and taking advantage of the opportunities will be one of the defining challenges for the propane industry in the next decade.

In this report, ICF evaluates the major market factors driving propane demand, and reviews the outlook for propane markets through 2020.

Outlook for Propane Supply and Infrastructure

The U.S. shale gas revolution is having a profound impact on propane supply and transportation infrastructure. The growth in natural gas liquids production from shale gas and tight sands resources is rapidly increasing propane production. The propane industry recently reached two major milestones due to the growth in propane supply:

- The U.S. became a net exporter of propane, and
- Domestic propane production from natural gas liquids (NGLs) exceeded consumer propane demand for the first time.

The growth in propane supply is projected to continue, and the U.S. is expected to be a major propane supplier to international markets in the future.

Much of the growth in propane supply is expected to occur in the Marcellus shale play in the Northeastern U.S., where ICF anticipates as much as 1.8 billion gallons of propane production per year by 2020, and the Bakken shale play in North Dakota, where ICF projects as much as 2 billion gallons of propane production per year by 2020. Supply growth in these and other shale regions is resulting in a major shift in propane supply and transportation patterns as well as infrastructure requirements.

Changes in Propane Pricing Relationships

The growth in propane supply is changing fundamental energy price relationships; propane prices have fallen substantially relative to gasoline, diesel fuel, and home heating oil prices. As a result, propane has become more competitive in the markets where propane competes against these fuels. While propane prices relative to crude oil are expected to rebound from 2012 levels as new infrastructure, including new export capacity, is brought on-line, ICF expects propane prices relative to crude oil to remain well below historical averages for the foreseeable future. At the same time, domestic propane prices will not fully delink from oil prices, and competition against electricity and natural gas in traditional propane markets will remain very challenging.

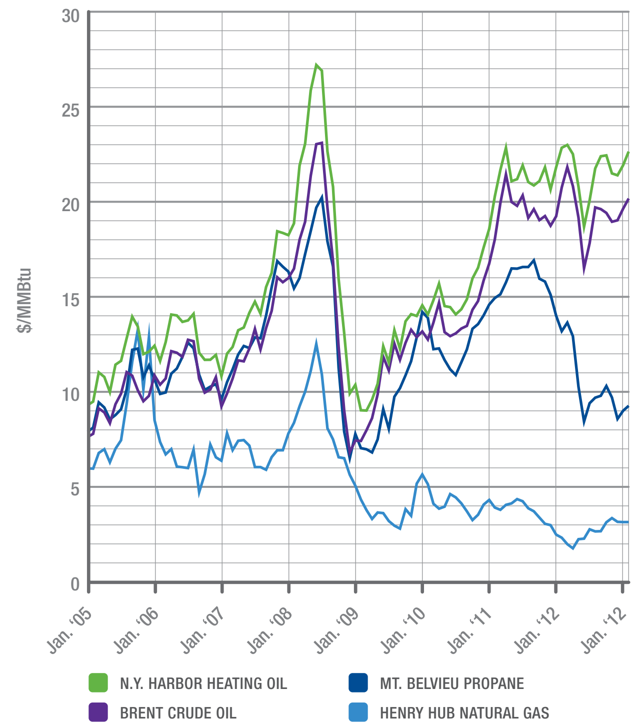
Outlook for Propane Demand

After peaking in 2003, nationwide consumer propane (odorized propane) demand fell by more than 10 percent through 2006. Although propane demand rebounded in 2007 and 2008 due to colder weather, propane consumption continued to decline in 2009, 2010, 2011, and 2012. (See Figure B)

The collapse of the new housing market and loss of residential market share to electricity in many regions, combined with decreases in fuel use per customer resulting from efficiency upgrades in homes and equipment, contributed to a decline in residential propane sales. The recession also reduced demand in the industrial and commercial sectors, which have yet to fully recover. The impact of these factors has been magnified by increases in retail propane prices, which peaked in 2011.

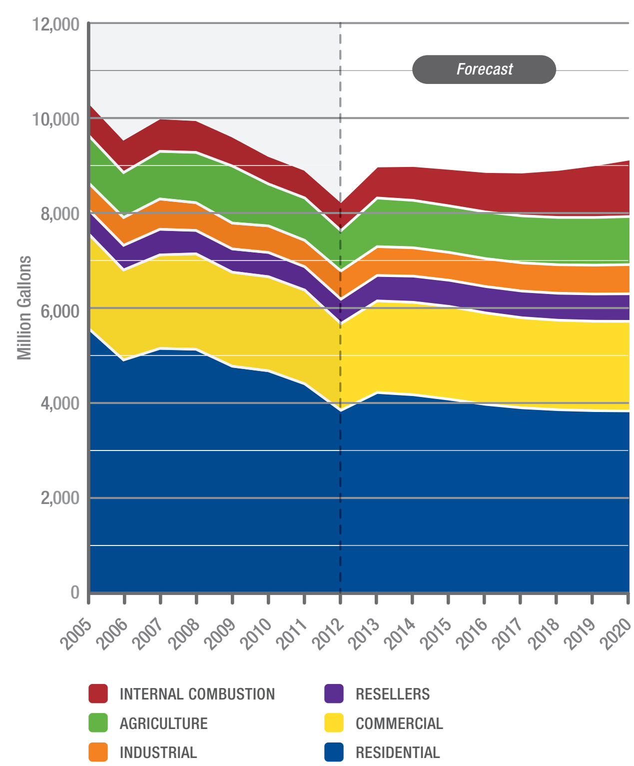
Consumer propane demand fell by 3.3 percent in 2011 relative to 2010. The decline was due to much warmer than normal temperatures during the fourth quarter of the year, as well as a continuation of load loss due to higher prices and improvements in energy efficiency in the residential and commercial sectors. 2012 was even warmer than 2011, leading to an additional decline in consumption of 10 to 12 percent.

Fig. A **Historical Spot Prices**



Source: EIA

Fig. B **Near-Term Odorized Propane Consumption Forecast**



Looking beyond 2012, the outlook is more optimistic. If weather returns closer to normal, propane sales should increase substantially in 2013. With normal temperatures, propane sales are projected to start to grow slowly in 2013/2014, and to continue to grow through 2020. The pace of growth will depend on development of and growth in the propane engine fuel markets. Aggressive growth in engine fuel applications will be necessary to offset continuing declines in the residential sector and other traditional propane markets.

Comparison with Previous Forecasts

This report is the third in a series of Propane Market Outlooks (PMO), which started in 2009. The previous versions of the PMO are available on the PERC Website at http://www.propanecouncil.org/about/market-metrics-initiative/. While the key drivers of propane demand have been relatively consistent across all of the versions of the PMO, the outlook for propane demand growth has changed over time. The current demand forecast is less optimistic than the 2010 forecast. The rebound in the economy and in the housing market has been slower than projected. In addition, oil and propane prices have been higher than expected, resulting in decreased demand relative to previous forecasts.

However, recent developments have improved the outlook for propane use in internal combustion engines. These developments include the availability of new emissions-certified engines, widening spreads between propane and conventional fuel prices, and the growing acceptance of propane vehicles by commercial vehicle fleet operators. With crude oil, gasoline, and diesel fuel prices projected to remain high to the end of the decade, propane's price advantage should help drive continuing growth in the engine fuel segment. ICF is projecting propane vehicle sales to increase from fewer than 5,000 in 2011 to more than 40,000 per year by 2020, with the potential for much higher growth depending on national energy policy and the rate at which the propane industry choses to develop propane refueling infrastructure and promote propane vehicle sales.

2 Critical Energy Market Trends

The U.S. propane industry is facing several fundamental changes in energy markets over the next few years. Growth in propane supply, volatile energy prices, evolving energy and environmental policies and regulations, and increased competition with electricity will all have major impacts on propane's competitive position.

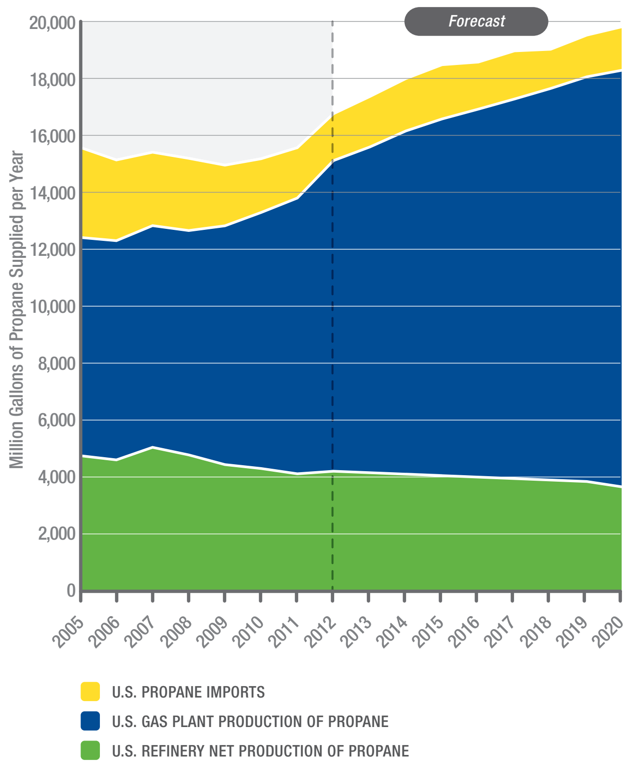
2.1 Changes in Propane Supply

In recent years, a sea-change has taken place in North American propane supply. Three years ago, the propane market relied on imports to meet domestic demand. Today, domestic production exceeds demand, with exports rising as quickly as capacity will allow.

Between 2005 and 2011, U.S. production of propane from natural gas processing plants and refineries grew from 12.4 billion gallons to 13.8 billion gallons (See Figure C). The primary driver of this expanding supply has been the growth in propane production from domestic natural gas liquids, which increased from 7.7 billion gallons in 2005 (the lowest level since 1991) to 9.7 billion gallons in 2011. In 2012, the U.S. produced about 15 billion gallons of propane, including almost 11 billion gallons of propane from natural gas liquids.

This dramatic increase in production from gas processing plants has had a powerful impact on America's propane balance of trade. In 2005 the U.S. imported more than 20 percent of its total propane supply, including nearly 1.2 billion gallons of propane from outside North America, and an additional 2 billion gallons from Canada. By 2011, imports from outside North America declined to just over 300 million gallons, while imports from Canada declined to 1.5 billion gallons. However, the

Fig. C U.S. Historical and Forecasted Propane Supply



Sources: EIA, U.S. Department of Commerce, ICF

U.S. also exported 1.9 billion gallons, and became a net exporter of propane. In 2012, exports of propane grew substantially to about 2.6 billion gallons, leading to net exports of almost 1.0 billion gallons.

The changing supply picture has flipped propane's perceived place in the fuels basket. Long seen as a crude oil derivative, with the same supply security issues as other petroleum products, more than 70 percent of total U.S. propane supply now comes from domestic natural gas liquids production. In 2012, propane produced in the U.S. from domestic natural gas liquids and crude oil resources exceeded total consumer propane demand. Imports from outside the U.S. and Canada made up only about one percent of total supply, and about 11 percent of propane was produced in U.S. refineries from non-U.S. or Canadian crude oil. The U.S. exported about 15 percent of total propane supply.

ICF projects that these trends will continue. The outlook for refinery-supplied propane remains negative due to additional refinery shutdowns, the reorientation of others to focus on diesel and distillate production, and continued refinery emphasis on producing propylene instead of propane. ICF is projecting North American production of propane in association with natural gas liquids to increase from 13.4 billion gallons per year in 2012 to 15.6 billion gallons a year in 2015 and 18.1 billion gallons per year by 2020.

This increasingly positive outlook for domestic propane supply is primarily due to the continuing development of shale gas and unconventional oil resources. The increase in propane production from natural gas liquids has also accelerated due to the shift in resource development activity from dry natural gas resources to wet gas and liquids resources.

Most of the new propane production is expected to go to markets other than U.S. consumer demand. As propane prices have fallen, petrochemical industry demand for propane has increased. The petrochemical industry is planning to significantly expand propane use in the future. Recently announced plans for new propane to propylene petrochemical facilities suggest that, by 2018, propane consumption in new facilities could increase petrochemical propane demand by an additional 2.3 billion gallons per year.

In addition, midstream companies, including Enterprise, Targa, Vitol, Phillips 66, and others have proposed development of new export capacity to meet demand in international markets with higher propane prices. The list on the following page shows some of the recently announced propane/butane export terminals, which, if all commissioned, would increase propane export nameplate capacity from 2.9 billion gallons per year in 2012 to as much as 16.8 billion gallons per year by 2018.

While today, most U.S. propane exports go to markets in Central and South America, much of the new capacity is slated to available by 2015, when the Panama Canal expansion project is scheduled for completion, allowing Gulf Coast terminals easier access to the Asian market.

Despite the growth in petrochemical propane demand, propane exports are expected to continue to increase

Existing and Publicly Announced Planned Propane Dehydrogenation Plants

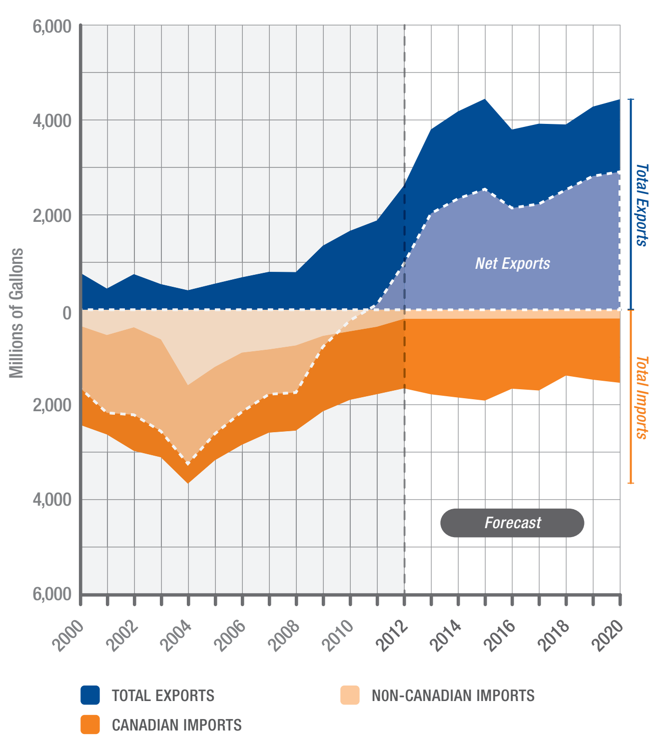
Company	Output Volume (tons/yr)	Propane Consumption (Mil. Gal./yr.)	Location	Start-up Year
PetroLogistics	640,000	460	Houston, TX	2010
PetroLogistics	640,000	460	Houston, TX	2014
Dow Chemical	750,000	540	Freeport, TX	2015
Enterprise	685,000	490	Chambers Co., TX	2015
C3 Petrochemicals	N/A	N/A	Alvin, TX	2015
Williams	500,000	360	Edmonton, AB	2016
Formosa Plastics	800,000	570	Point Comfort, TX	2016
Dow Chemical	550,000	380	TX/LA	2018
Total	**4.6 million**	**3,260**		

Existing and Proposed LPG Export Terminals

Company	LPG Export Capacity (Mil. Gal./yr.)	Location	Start-up Year
IN OPERATION ON JAN. 1. 2013			
Enterprise	2,076	Houston Ship Channel, TX	
Targa	756	Galena Park, TX	
Other	29	Miami, Norfolk, NY, Seattle, LA	
Total in Operations in 01/2013	**2,851**		
PROPOSED			
Enteprise	1,750	Houston Ship Channel, TX	2013 Q1
Targa	1,850	Galena Park, TX	2013 Q3
Vitol	1,500	Beaumont, TX	2014 Q4
Phillips 66*	6,500	Baytown, TX	2014
Sunoco Logistics	600	Marcus Hook, PA	2014 Q3
Pembina Pipeline Co.	600	Prince Rupert, BC (Canada)	2015 Q3
Occidental	1,150	Corpus Christi, TX	2017
Total Proposed	**13,950**		
Total in Operation + Proposed	**16,800**		**By 2017**

* Project unlikely to proceed.

Fig. D U.S. Propane Export Projection to 2020



Sources: U.S. Department of Commerce, ICF

for the next few years. Figure D at left shows both historical and projected propane import/export balance. Exports are expected to increase to more than 4 billion gallons per year by 2015, before stabilizing as new petrochemical demand offsets growth in propane production. The net balance is the result of shifting domestic propane production, as well as historical and projected demand from consumer and industrial markets. Imports from Canada will remain relatively stable as Canadian production of propane stabilizes after several years of decline. The U.S. will continue to import marginal quantities of propane from other countries into specific markets, including New England due to occasional supply shortfalls.

2.2 Energy Prices

World Oil Prices

Oil prices represent one of the greatest areas of uncertainty affecting the outlook for propane. Oil prices increased rapidly from 2001 to 2008, driving up propane prices and reducing propane's competitiveness in many markets. Although negative economic conditions reduced oil demand and caused prices to fall back to 2005 levels during 2009, crude oil prices moved back above $100 per barrel in 2011. Long term international demand for oil is expected to continue to increase, maintaining upward pressure on oil and petroleum product prices, as well as propane prices.

World oil prices are also expected to remain highly volatile. Much of the recent increase in crude oil prices has been the result of a significant risk premium added to market prices due to political instability in the Middle East and North Africa. Further instability in these regions likely would result in even higher oil prices and potentially dramatic price spikes.

In the past, propane prices have been very closely linked to oil prices in both domestic and international markets. This relationship is changing, but not disappearing, due to the growth in domestic propane supply. In 2012, high propane inventories due to warm winter weather, combined with growth in propane supply and constraints on propane export capacity pushed propane prices down to historically low levels relative to crude oil. As propane export capacity catches up to supply, domestic propane prices are expected to rebound. However, the change from an importer to an exporter of propane has shifted the fundamental relationship between domestic propane and crude oil prices.

In the future, we anticipate the ***ceiling*** on domestic propane prices will be set at the world price of propane ***minus*** transportation costs to international markets, rather than the world price of propane ***plus*** transportation costs that set the ***floor*** on domestic propane prices during the periods when the U.S. was a major propane importer. In addition, the growth in U.S. exports, as well as growth in other international sources of propane is likely to put downward pressure on international propane prices relative to crude oil.

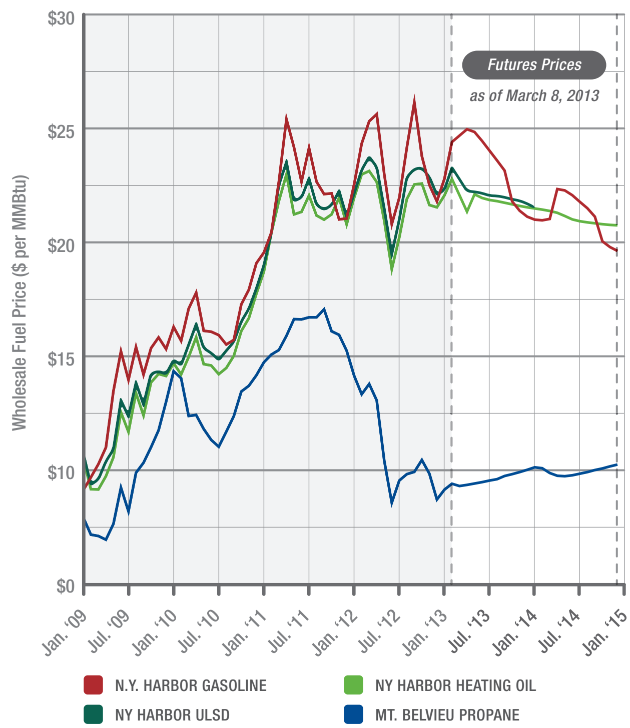
Petroleum Product Prices

Oil price volatility has carried over to petroleum product prices, including gasoline, heating oil, and ultra low sulfur diesel (ULSD).

While the price relationship between propane and crude tends to change from month to month, average 2012 propane spot prices at Mt. Belvieu[1] were 43 percent below the Brent[2] crude oil price when measured in dollars per MMbtu. This represents a significant decline relative to 2010, when propane prices were only 8 percent below the cost of Brent crude oil on a dollar per MMBtu basis. The impact on propane price of rapidly expanding supply and a declining consumer market, particularly due to the 2011/2012 "non-winter," was pronounced.[3] Propane prices declined from $1.56 per gallon in September 2011 to below $0.80 per gallon in July of 2012 before rebounding to between $0.80 and $1.00 per gallon during the second half of the year.

At the same time, the price of distillate fuel oil generally has been increasing relative to crude oil. The change in the relative fuel prices of both propane and distillate is a major shift away from the historic norms for both fuels.

Fig. E **Propane, Heating Oil, ULSD, and Gasoline Wholesale Prices**



Sources: EIA, NYMEX

1 Mt. Belvieu is the largest propane storage facility in the U.S., and prices at Mt. Belvieu are generally accepted as the market price for propane. Regional propane prices will differ from Mt. Belvieu based on transportation costs and transportation constraints.

2 The price of Brent crude is currently considered a marker price for world crude oil. Prices of other crude oils, including WTI (West Texas Intermediate) are generally linked to world crude oil prices based on transportation cost differences and differences in crude oil quality. In the past, WTI has been a marker price for crude. However, in the past two to three years, transportation infrastructure constraints have suppressed WTI prices relative to Brent and other crude oil prices.

3 During the 2011/2012 winter, the U.S. experienced 16% fewer heating degree days than during a "normal" winter.

The underlying trends in distillate fuel oil prices are determined by the international market. The economic slowdown reduced distillate demand and prices in the short term; however, international distillate demand is expected to grow, pushed higher by policies and taxes promoting the use of diesel. At the same time, the cost of distillate production is expected to increase due to tightening international environmental standards on sulfur content and changes in the international crude oil supply mix.

In addition, growth in worldwide propane supply is expected to exceed growth in non-petrochemical propane demand as major processing facilities come online in Qatar and other propane producing countries. These shifts in supply and demand indicate that distillate prices are likely to continue to remain high relative to propane prices over the next few years. As a result, propane is expected to remain very competitive with both diesel fuel and distillate fuel oil in U.S. markets.

In 2012, Mt. Belvieu propane prices averaged 43 percent of the price of Brent crude oil on a dollar per MMBtu basis, down from 8 percent below Brent in 2010 and 18 percent below Brent in 2011. During the same period, No. 2 Heating Oil maintained a relatively consistent premium of about 10 percent above Brent. This shift resulted in an increase in the wholesale price of fuel oil relative to propane of about $8.30 per MMBtu, or about $0.76 per gallon of propane.

This market shift is reflected in the current futures markets for both propane and fuel oil. The NYMEX futures market currently indicates that the participants in the market expect propane prices to rebound slowly relative to crude oil, while the price of distillate fuel oil is expected to continue to increase relative to crude oil. Overall, the futures market indicates a market expectation that the differential between wholesale fuel oil and wholesale propane prices is expected to remain at historical highs through 2014.

This shift has also affected the relationship between propane and gasoline prices. Since 2010, the average price difference between major market marker prices for gasoline (New York Harbor gasoline price) and propane (Mt. Belvieu propane price) has increased by more than $0.76 per gallon, from $0.37 per gallon in 2010 to $1.12 per gallon in 2012.

At today's prices, propane is extremely attractive relative to gasoline and diesel fuel in many engine fuel applications. ICF projects the difference between the prices of gasoline and diesel fuel and propane prices to decline slowly over time relative to today's levels, as markets continue to adjust to the growth in supply, leading to a continuation of the attractive economics for propane engine fuel applications for the foreseeable future.

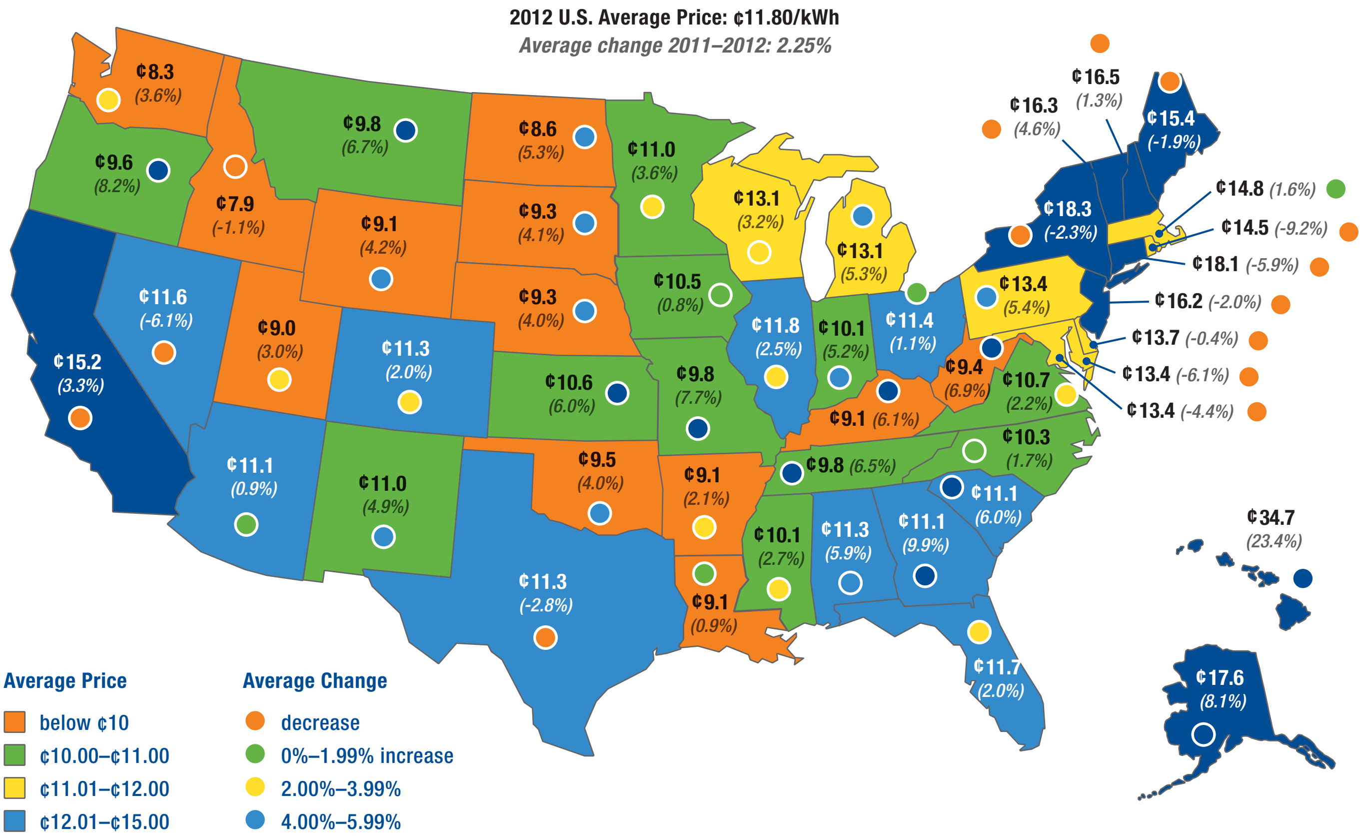
Electricity Prices

In most residential and commercial markets, competition with electricity will continue to be a major challenge to growth in propane sales. Over the past 10 years, propane prices have increased relative to electricity prices in most geographic markets. However, electricity prices have also increased, dramatically in some areas.

Electricity prices vary widely by region depending on market structure, generation types, and capacity constraints. The characteristics of electricity production lead to retail electricity prices that are generally more stable than those of other fuels. Hence, when energy prices are increasing, prices of other fuels can be expected to increase faster than electricity prices.

LPG Carrier Yuyo, photo courtesy of JX-Shipping of Tokyo, Japan

Fig.
F **2012 U.S. Residential Average Price *(and change from 2011)* per Kilowatthour**



Source: US DOE EIA (2012 Data are Preliminary)

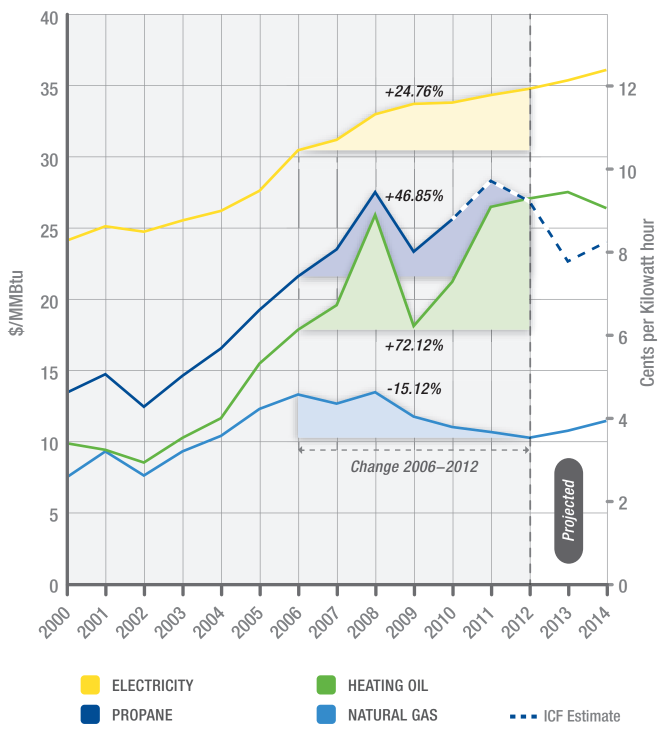
The price of electricity also varies widely by specific location. State average prices reflect the major factors driving prices in the state, but tend to be representative of the prices charged by utilities serving the major urban areas with the majority of electricity customers. Electricity prices in rural and suburban areas can diverge substantially from these state averages. Within a specific state, some markets are likely to see electricity prices as much as 40 percent higher or lower than the state average, with the higher prices often set by small municipal utilities that serve areas with a high concentration of propane customers. As a result, propane can be competitive with electricity in many communities even in states with relatively low average electricity prices.

Electricity prices are expected to rise slowly from their current levels in many states. However, ICF does not expect to see significant near-term improvement in the relationship between propane and electricity prices in any major market, and the softness in natural gas prices is beginning to translate into lower electricity prices in certain higher-cost markets such as New England and the Northeastern United States. In the longer term, increases in power generation investmestments related to implementation of emissions regulations is expected to lead to a slow increase in future electricity prices, but no fundamental impact on the competitive cost relationship between propane and electricity should be expected before 2020.

Near Term Residential Energy Price Outlook

The Energy Information Administration's (EIA) short-term residential energy price forecast, from January 2013, projects fuel oil prices to continue increasing from current levels through the end of 2013. While the EIA no longer projects residential propane prices, ICF estimates a steady decline from the peak prices in 2011. The EIA expects residential natural gas prices to rebound slightly from the lows of 2012, while electricity prices increase slowly (see Figure G).

Fig. G U.S. Average Residential Prices



2.3

Competition with Electricity and Other Fuels

Propane's share of the residential space heating market has been falling since 2007. Much of the loss in propane market share in the residential sector in recent years is attributable to competition with conventional electric heat pumps. This competition is expected to intensify over time for several reasons. Technology improvements are reducing heat pumps' traditional shortcomings. New generation heat pumps are much more efficient than older units. In addition to improved operating characteristics at low temperatures, the heat output from new heat pumps has increased, improving the comfort they deliver. Equipment reliability and lifespan also have been improved. As heat pump technology continues to advance, it will remain a growing threat to the propane heating market.

Geothermal heat pumps (GHPs) represent a growing competitive challenge to propane in some key regional heating markets where conventional heat pumps traditionally have not been able to compete effectively with propane. GHPs are designed to maintain high operating efficiency even when outside temperatures drop below 20 degrees Fahrenheit, which allows the technology to be competitive in colder environments where the conventional heat pump is unable to operate economically.

Until recently, market adoption of GHP technology was limited by the very high cost of installation. However, GHPs are now being aggressively marketed as a "green" technology and are currently eligible for a 30 percent income tax credit on the full installation cost. The U.S. Department of Agriculture also provides funding for rural electric cooperatives to install ground loops for GHP systems, with the costs recovered through a utility rate surcharge to the customer. These incentives have provided a significant boost to GHP installations in the past few years, and are expected to stimulate additional growth in GHP installations in the future.

The map in Figure H shows the fuel type with the largest increase in market share between 2009 and 2011 for each county. Overall, electricity's share of the home heating market has been increasing rapidly, particularly in the South, but also in some northern states. The share of homes heated with wood has also been increasing in the last few years, particularly in New England and the upper Midwest. Many of these homes switched from propane and fuel oil to wood due to increased fuel prices. ICF believes that most of the homes that switched to wood from propane can heat with either energy source and can switch back to propane if consumers tire of using wood or if propane prices moderate.

Propane gained market share in 1,128, or 36% of U.S. counties between 2009 and 2011. Much of the growth in market share occurred in counties where fuel oil market share declined. However, in a surprising number of counties (see map in Figure I), propane increased market share at the same time that natural gas market share was declining. In these counties, the propane market was increasing due to new housing growth and conversions from other fuels, while the natural gas system was not expanding, or was losing share to electricity.

This trend is unlikely to continue as natural gas utilities, often supported by natural gas regulators and consumer advocates, use lower natural gas prices to justify expansion of natural gas distribution systems to additional consumers.

Fig.
H Fuel with Largest Market Share Gains between 2009 and 2011

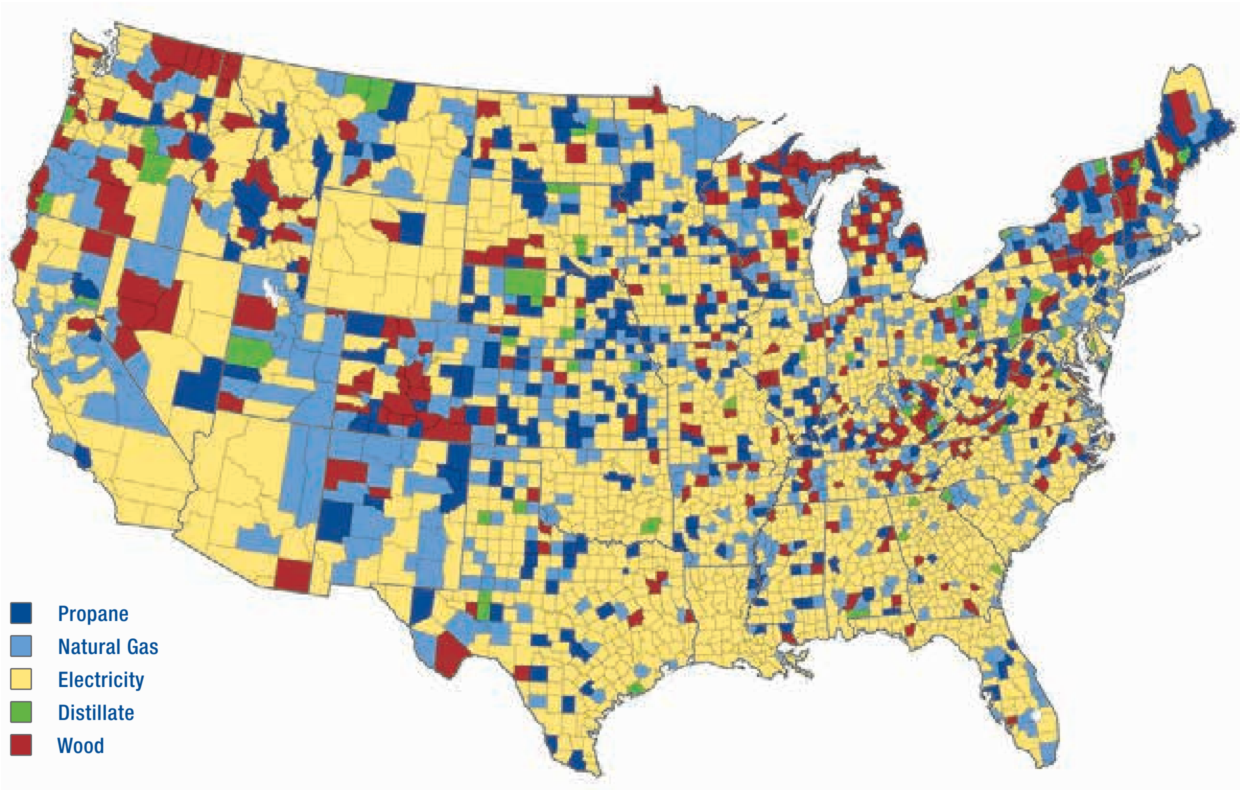


Fig.
I Fuel with Largest Market Share Losses between 2009 and 2011 in Counties where Propane Gained Market Share

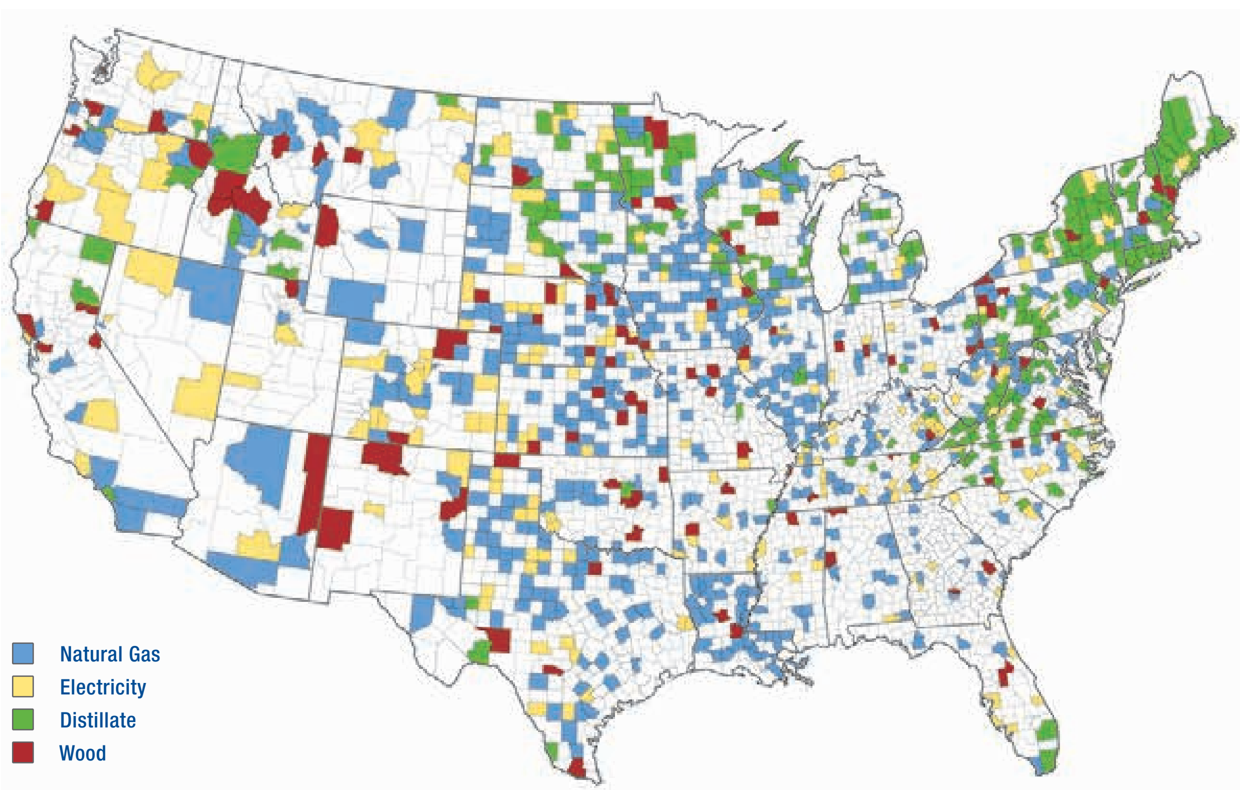
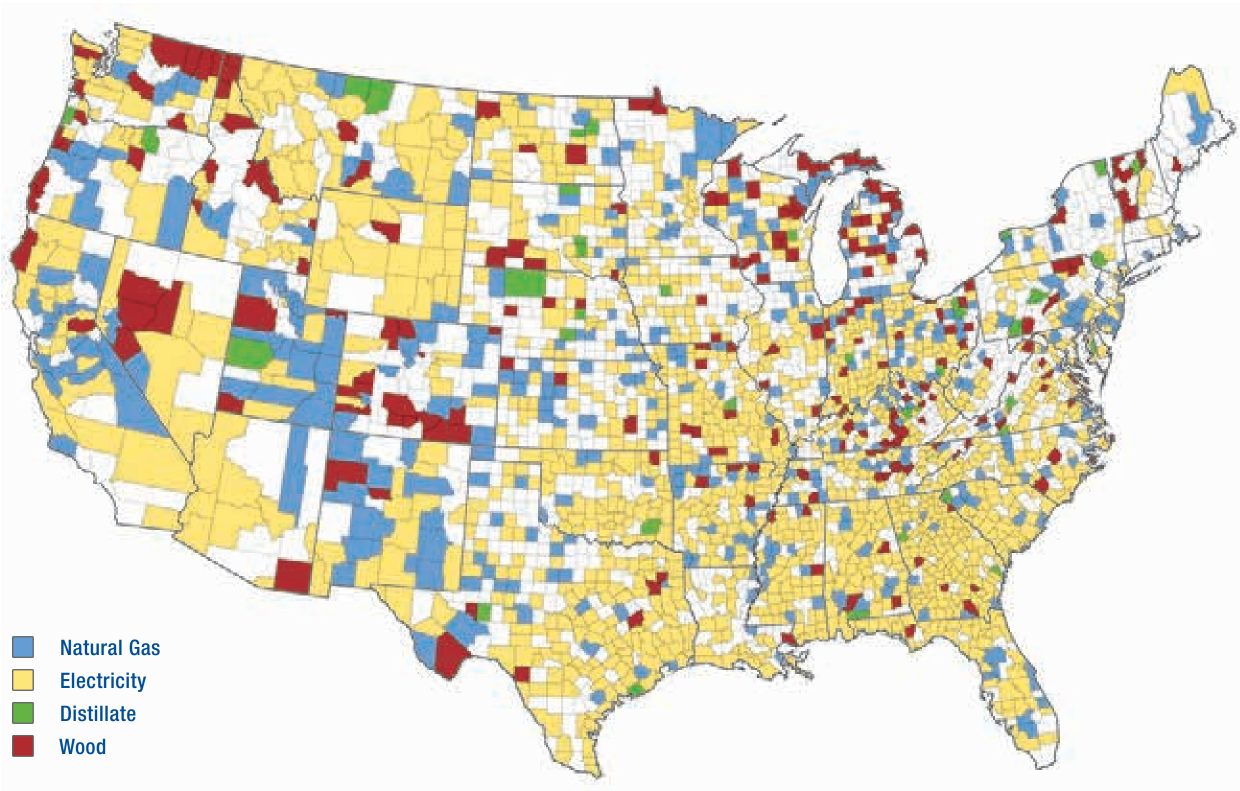


Fig. J **Fuel with Largest Market Share Growth between 2009 and 2011 in Counties where Propane Lost Market Share**



In more than 71% of the 2,012 counties where propane lost market share between 2009 and 2011, electricity was the fastest growing residential space heating fuel (see map in Figure J above). Much of the loss in market share to electricity has occurred in regions of the country, including the Midwest and Southeast, where electricity supply is dominated by coal-fired power generation. These regions are subject to increases in electricity prices due to increasing costs of coal power generation associated with more stringent environmental regulations. While these cost increases are unlikely to change the market dynamic in the short term, higher electricity costs after 2015 likely will slow down propane customer losses in these regions.

2.4 Energy Policy

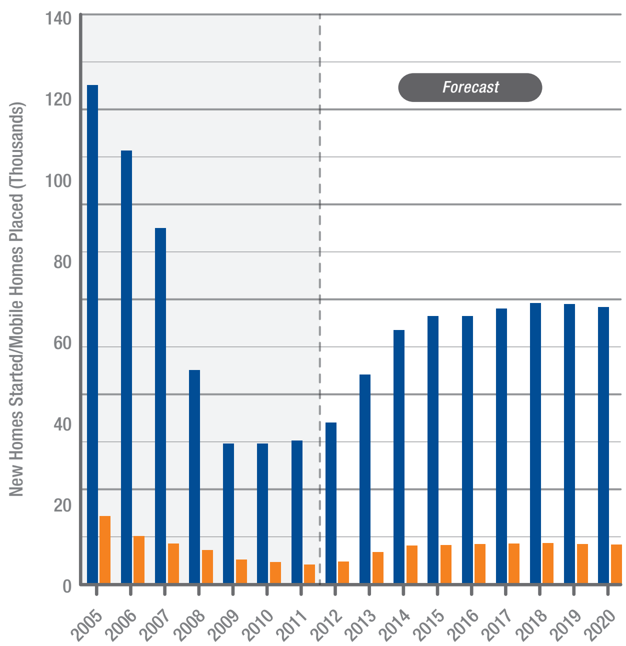
National energy policies, such as alternative fuel and energy efficiency tax credits, make propane applications more attractive in the marketplace. However, these policies are also likely to increase the energy efficiency of propane applications, accelerating a long term trend that is reducing propane sales per application relative to existing equipment. New energy policies and regulations also have the potential to tilt the playing field in favor of electricity or other fuels in certain applications.

Building and Equipment Efficiency Standards

Existing equipment efficiency standards and building codes have driven a long term decline in average propane sales per customer in the residential and commercial sectors, directly impacting propane sales to both new and existing propane customers. They also promote technological improvements in competing technologies, such as heat pumps.

In 2011, the U.S. Department of Energy finalized rules to increase minimum propane furnace efficiency from 78 percent to 90 percent starting in May 2013 for the 30 northern region states that normally experience more than 5,000 annual heating degree days. This includes the states with most of the existing propane heating load. Tightening of energy efficiency standards and building codes would have a significant impact on the economics and energy use in these applications, and

Fig.
K **New Propane Heated Households**



Source: U.S. Census Bureau, Survey of Construction 2000 - 2011, American Housing Survey, American Community Survey, ICF Estimates

would be expected to accelerate the recent decline in propane use per customer for residential heating customers. However, legal challenges to this rule have delayed implementation.[4] Even with the delay in the implementation of the new standards, existing standards are expected to result in a continuing decline in average propane use per residential customer of around one percent per year.

The national policy focus on energy issues, including energy security, energy efficiency, and emissions, is likely to result in greater promotion of high-efficiency electric appliances. The propane industry can expect to see significant expansion in the number of utility-sponsored programs that provide incentives for high-efficiency conventional heat pumps and GHPs, and high-efficiency 100 percent electric homes in many regions of the country.

Alternative Motor Fuel and Infrastructure Tax Credits

The federal alternative fuel excise tax credit provides a significant financial incentive for the use of propane as a motor vehicle fuel. This tax credit of $0.50 per gallon expired at the end of 2011, but was retroactively extended to apply to propane used to operate propane-powered vehicles through December 31, 2013. The federal alternative fuel infrastructure tax credit was also reinstated in January 2013 and provides up to 30 percent of the cost of a qualified propane refueling facility, not to exceed $30,000, through the end of 2013. Currently these tax credits are subject to renewal every year.

The propane industry is promoting the Propane Gas Act to extend these fuel tax credits through 2016, but the future of this proposal remains uncertain. The biofuel, electric, and natural gas industries are also aggressively pursuing these markets, and can be expected to substantially outspend the propane industry on vehicle development, marketing, and lobbying. Without aggressive industry support, future changes in federal and state energy policies may favor these other alternative fuels relative to propane. Long term stability of the tax credits would improve market acceptance of propane vehicles, leading to an increase in the ICF forecast of propane vehicle sales.

[4] In January, 2013, the U.S. DOE proposed delaying implementation of these standard in response to the legal challenges. Approval of this proposal likely will delay implementation of the new standards for several years.

3 Overview of Key Propane Markets

3.1 Residential Markets

Residential demand represents almost 60 percent of total consumer propane sales. The residential sector is highly regional and market specific. Even though the propane industry added more than one million new residential propane heating customers through new construction and new manufactured housing placements between 2000 and 2011, the total number of propane heated manufactured homes has been declining since 2001, and the total number of site-built heating customers has been declining since 2005.

Growth in the Northeast is offset by losses in the South, while growth in the propane market share in new site-built housing construction has been offset by losses in manufactured housing. In addition, average residential propane demand per customer has been declining due to improvements in energy efficiency and conservation.

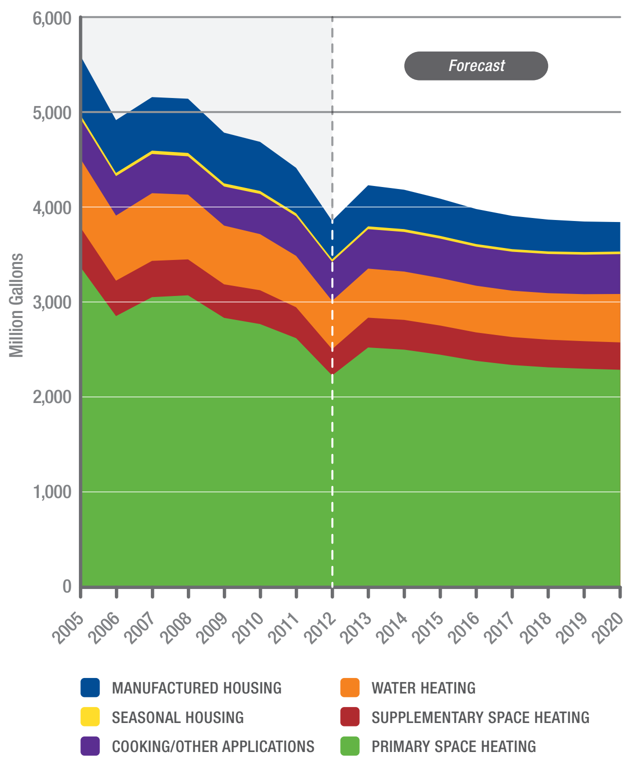
The decline in the number of space heating customers, combined with improvements in efficiency and declining use per customer has resulted in a significant long term decline in propane sales in the residential sector (see Figure L).

Residential Demand Outlook

Under steady-price conditions, the long term trend toward increased energy efficiency is expected to result in a continued decline in average propane sales per residential customer at an average of about one percent per year. Dramatic rises in heating fuel prices, such as those experienced in 2008 and 2011, accelerate this trend, driving efficiency gains at as much as twice the long term trend rate. Declines in prices, such as those experienced in 2012, slow down improvements in efficiency in the short term, but do not affect the longer term trend. Adding new residential customers through new construction represents one approach to offsetting the losses in load due to efficiency improvements. However, the residential new construction market remains depressed, with new housing starts only slowly rebounding from their 2009 lows. As such, housing starts are unlikely to reach recent housing boom levels in the foreseeable future, and we anticipate that improvements in efficiency will more than offset growth from new construction.

Part of the downturn in housing starts has been offset by modest growth in propane cooking and water heating markets. Maintaining and growing share in these markets will help position propane to capitalize on an eventual rebound in new construction.

Fig.
L
Residential Propane Demand Forecast by End Use



Overall, residential propane demand is expected to rebound in 2013 due to a return to more normal weather. Thereafter, demand is expected to fall slowly through 2015 as any growth resulting from the start of the economic recovery is offset by continued decreases in consumption due to efficiency gains. After 2015, residential demand is expected to continue to fall slowly. However, demand will depend largely on propane consumer price trends and the competition with electricity.

Opportunities in the Residential Sector

Propane remains a premium fuel in the largest and most expensive new homes that are not on the natural gas main. Owners of custom and upscale homes built off the gas main want the convenience of gas for cooking, heating, and other needs. These customers base their heating and appliance decisions on value rather than cost, and the propane industry has effectively promoted the value of propane throughout the range of residential applications.

Even in the southern sections of the country, where propane heating market share has been declining, propane cooking and water heating have been increasing, as the more upscale residences in these regions continue to demand the convenience and comfort of gas for these applications.

However, the recent increase in propane prices, combined with an increased sensitivity to first-cost issues in the homes that have been built, resulted in a noticeable decline in propane space heating market share in new construction in 2010 and 2011.

Existing customers represent a significant potential market for new propane applications. For example, many customers use propane for cooking, water heating, or clothes drying, but not for space heating. Other customers use propane for space heating, but not for water heating or cooking. More than 2.5 million existing propane customers could convert to propane heat, including more than 1 million customers in the Northeast who are likely heating with fuel oil. Almost 4 million existing propane customers do not heat water with propane, and almost 4 million existing propane customers do not cook with propane. Increasing the number of propane applications used by existing propane customers may be the most efficient way to offset declines in use per customer from improvements in energy efficiency.

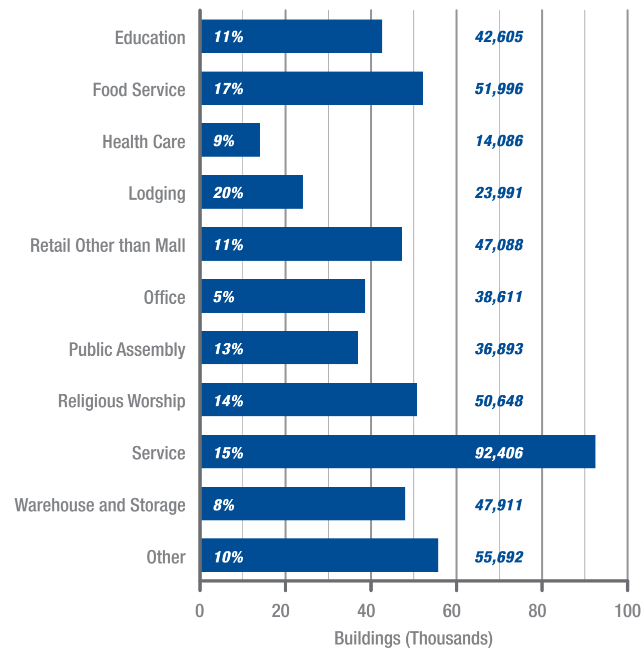
3.2
Commercial Sector Outlook

The commercial sector accounts for about 20 percent of the overall consumer propane market. The near term forecast for propane demand shows stable non-weather driven consumption in the commercial sector through 2012, with the impact of modest economic growth offset by the long term impacts of higher propane prices. Weather-sensitive demand declined in 2011 and 2012 due to warmer than normal temperatures, but is expected to rebound in 2013. This is followed by very modest growth in 2013 through 2015 linked to a rebounding economy. In the longer term, projected growth in commercial propane sales will be driven by growth in commercial activity.

The commercial sector is a very diverse market, with a much wider range of customer types and end-uses than other sectors. The market also differs widely by region

Fig. M

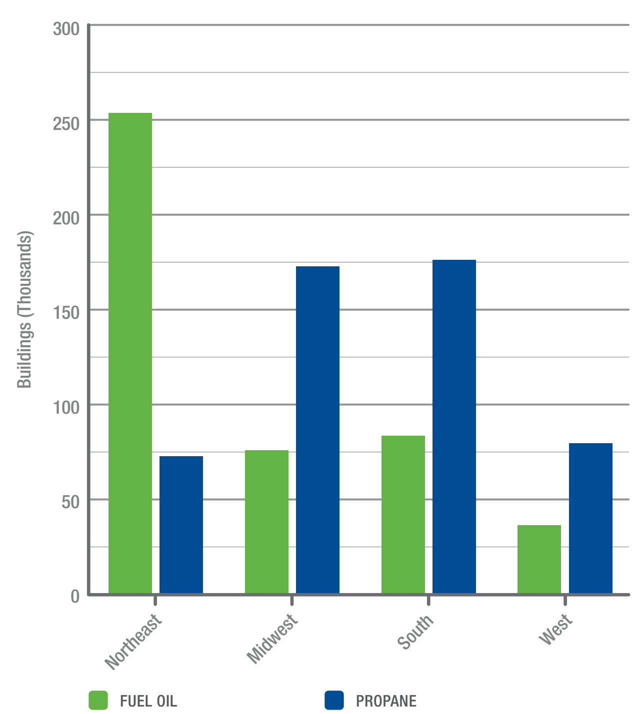
Propane Space Heating Market Share in Commercial Markets



TOTAL PROPANE BUILDINGS: ***501,927***
PROPANE MARKET SHARE: ***10.8%***

Fig. N

Propane & Fuel Oil Use: All Applications



in a manner similar to the residential sector. Recent PERC research into the commercial sector indicates that there is significant opportunity to expand sales into this market. Understanding the regional differences in fuel use and the variety of commercial propane market segments (e.g., schools, fast food restaurants, and houses of worship) can lead to new opportunities.

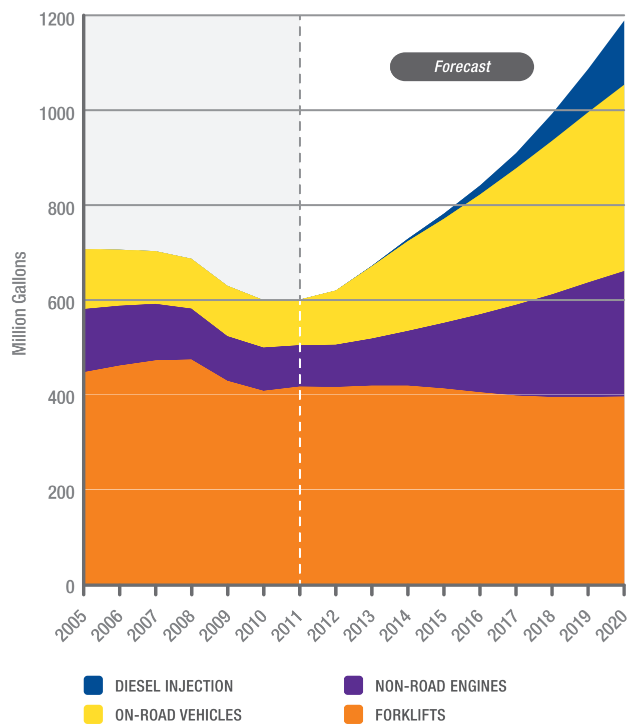
One of the key applications - and region-specific opportunities - in the commercial sector will be conversion of fuel oil heating customers. Fuel oil currently dominates the commercial heating market in the Northeast. Many potential propane heating customers already use propane for cooking and other purposes, presenting the propane industry with near term conversion opportunities with existing propane customers. The market share for fuel oil in new commercial construction has already declined substantially because of permitting issues with fuel oil storage tanks, leading to additional market opportunities for propane in new commercial construction. While fuel oil use is not as predominant in the Midwest and Western regions, there remain significant pockets of fuel oil use in the commercial sector in these regions that provide opportunities for propane.

Other key opportunities include promotion of tankless water heaters in a variety of commercial segments, including the lodging and resort industry, and in institutional and educational settings. In the commercial sector, tankless water heating can have both first cost and operating cost advantages relative to electric water heating when electric system cost savings and building space savings are fully accounted for.

3.3
Internal Combustion Engine Outlook

The internal combustion engine market offers long term potential for large growth in propane sales. ICF is projecting propane sales in this market area to double from about 600 million gallons in 2011 to almost 1.2 billion gallons in 2020. In the short term, a steep recession-driven decline in propane use in the forklift market could be partially offset by modest growth in demand for on-road vehicles, commercial mowers, and stationary engines. The increase in vehicles and applications available to the market, combined with an improvement in the propane/gasoline price relationship and an economic recovery, should lead to modest demand growth in 2012 through 2013 (see Figure O).

Fig. O **Internal Combustion Engine Propane Consumption**



After 2013, growth in new applications has the potential to significantly expand propane sales, particularly in the on-road vehicle and mower markets.

On-Road Vehicles

Propane provides a viable alternative to gasoline and diesel fuel in the on-road vehicle market, and has significant environmental advantages relative to both. In addition, recent changes in the long term relationship between propane and both gasoline and distillate fuel prices has positioned propane as a potential lower cost alternative to both gasoline and diesel powered vehicles.

In the past few years, propane vehicle sales have been constrained by the limited number of new propane vehicles and aftermarket vehicle conversion systems available to the market. Recent investments by PERC, ROUSH CleanTech, Bluebird Bus, CleanFUEL USA, and others have lead to the introduction of a number of new propane-powered vehicles in the last three years. Industry partnerships with additional original equipment manufacturers (OEMs), including the existing PERC partnership with Freightliner Custom Chassis, have the potential to rapidly expand the number of vehicles available to the market in the longer term (see Figure P).

The recent introduction of a series of new propane-powered vehicles is expected to generate a near term increase in propane sales in this market. However, the propane industry will need to overcome significant market hurdles to maximize sales in this sector.

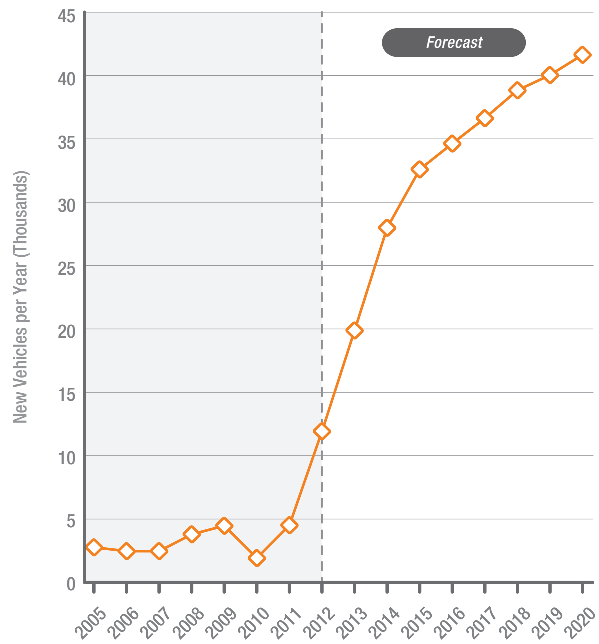
In the past, much of the alternative fuel market has been driven by customer preferences to be seen as "green," as well as the need to comply with alternative fuel objectives rather than for cost or performance reasons. In addition, much of the alternative fuel market has been sustained by vehicle[5] and fuel tax incentives. While this has helped propane in the past, the current emphasis on electric and natural gas vehicles in the national policy debate increases the potential to leave propane out of the alternative fuel conversation in the future. However, given the current disparity between propane and gasoline/diesel prices, propane vehicles make sense on a straight economic basis in many applications, including school buses, shuttles and taxis, delivery vehicle fleets, law enforcement fleets, and other fleet vehicle applications where vehicles are based at a single location.

To accelerate penetration of propane into the on-road vehicle market, the industry needs to help increase the number of vehicles available and encourage the long term extension of tax credits on equipment capital and fuel costs that are scheduled to expire at the end of 2013. Additional efforts should focus on educating consumers on the economic and environmental benefits of propane vehicles, reducing the regulatory burden for small, low-volume manufacturers and converters, and ensuring recognition of propane's environmental and energy security benefits in the national environmental policy debate.

Forklifts

The forklift market is a key market for the propane industry, representing about five percent of total odorized propane sales. However, unless the forklift industry is able to develop a new generation of propane forklifts with lower operating costs and better emissions characteristics than the currently available models, and

Fig. P **Projected Propane On-Road Vehicle Sales**



is able to market the new generation of propane lift trucks at a competitive price, ICF projects that propane sales to the forklift market will decline slowly for the foreseeable future.

The recent recession caused a substantial decline in the overall size of the forklift market. In addition, the combination of fuel price and technology changes has resulted in a loss of propane market share in this market. While demand for new lift trucks experienced healthy growth in 2011, the propane share of new forklift sales declined. Before the recent recession, propane forklifts represented more than 60 percent of the market for class four and five lift trucks. In 2011, the propane marketshare fell to less than 50 percent of the market.

Electric lift trucks represent the primary threat to propane in this market. The electric battery, battery charger, and motor technologies incorporated into electric lift trucks have continued to improve over time. In addition, the increase in the cost of propane relative to electricity has increased the expected operating costs of propane forklifts relative to their electric competitors.

5 Tax credits for the purchase of propane vehicles expired at the end of 2011, and have not been renewed.

Other Non-Road Engines

The non-road engine market provides large growth opportunities for the propane industry, although cost, regulatory, and market structure issues must be resolved to reach this market's full potential. Based on technology available today, three applications are especially promising:

Commercial Lawn Mowers: The commercial propane mower market has the potential to generate significant growth in propane demand, possibly rivaling propane forklifts as the largest market for propane engines. Currently, there are about one million commercial lawn mowers in service, with the potential to consume more than one billion gallons of propane. More than 12 OEMs have already brought propane mowers into the market.

Propane mowers burn cleaner and result in fewer emissions over competing gasoline-fired equipment and should have a longer effective equipment life and be less costly to maintain. In most regions, fuel costs are also likely to be lower with propane. However, propane mowers currently available cost considerably more to purchase than comparable gasoline equipment. In addition, there is a significant structural cost to commercial customers of switching from gasoline to propane. Switching requires changes in refueling and servicing practices, as well as employee and service personnel training practices. Maintaining a fleet using two different fuels at the same time also increases costs, while the cost of replacing an entire fleet of mowers at one time is likely to be prohibitive to many potential customers.

As a result, the distribution and servicing structure for propane mowers has developed at a slower pace than the technologies themselves, and the OEMs are not aggressively promoting the available propane models. To address these market issues, the propane industry will need to take a larger role in marketing, supporting and, potentially, financing the propane mower market if the propane sales growth potential available in this market is to be achieved.

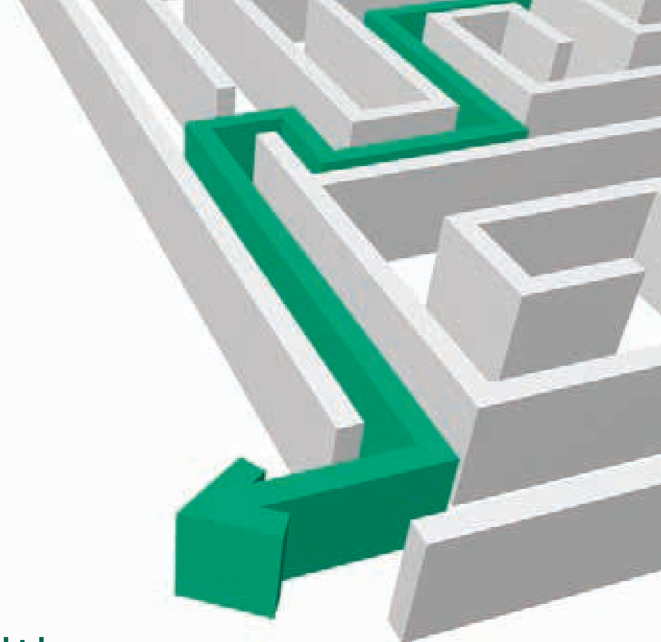
Irrigation Pumps: Irrigation pumps provide a high-volume, high-load factor market for propane. While the number of propane pumps in use declined between 2000 and 2010, this trend appears to be reversing. The new propane engines becoming available in this market are substantially cleaner and more efficient than the previous generation of irrigation engines. The major irrigation markets in the Midwest have access to relatively low cost propane, providing the potential for significant cost advantages relative to diesel fuel and gasoline. Environmental advantages of the new generation of propane engines should also stimulate growth in markets in California and the western states.

Generators: The next generation of propane generators has the potential to turn backup, portable, and remote power generation into a major source of propane sales. Kohler, Generac, and other manufacturers are bringing a variety of propane fueled generators into the market in the next two years. These units should be quieter and cleaner, and have lower maintenance costs relative to competing gasoline and diesel fuel options, and appear likely to be offered at similar price points. These units should be competitive in the backup power generation market, and could be used for electricity peak shaving in some markets with particularly high time-of-use electricity rates. In addition, the propane industry appears well situated to generate significant new propane sales in the towable generator market due to increased costs of diesel generation associated with new emissions regulations on diesel engines.

Diesel Fuel Displacement

Changes in diesel fuel prices relative to propane, as well as increases in diesel engine costs necessary to meet more stringent environmental regulations, provide the propane industry with a major opportunity to displace diesel fuel use in a wide variety of different applications. The potential size of these markets is astounding. Current diesel fuel consumption in the U.S. is the equivalent of 80 billion gallons of propane.

The propane industry has a number of applications available today capable of competing with diesel engines, including several of propane vehicles, propane irrigation engines, and portable power generation applications. Other applications, including the diesel co-injection technologies, are nearing market availability. However, there are currently large sections of the diesel market where no viable propane alternative is available or under development. Identifying the most attractive markets and applications, and developing the applications needed to serve these markets, will be an important step in growing propane markets in the next few years.



4 Key Propane Industry Challenges and Opportunities

Achieving future sustained growth of propane sales will depend on the industry's success in responding to the leading market challenges and opportunities likely to be faced in the next few years. Key propane industry challenges and opportunities include:

- Maintaining current markets.
- Understanding and taking advantage of regional market segmentation.
- Capitalizing on the changing relationship between propane and gasoline/distillate prices.
- Participating in the national energy and environmental policy and regulatory process.

4.1 Maintaining Current Markets

The biggest challenge facing the propane industry over the next 10 years may be maintaining current market share in the residential and commercial sectors. These two sectors currently account for more than 75 percent of total consumer propane sales. These sectors offer a variety of growth opportunities, both in increasing market share for existing applications, including conversion of heating oil applications to propane, and in commercialization of new technologies such as residential tankless water heaters, portable and backup generators, and commercial propane-fired heat pumps and CHP units. However, the threats to these markets remain formidable:

- Propane use per customer has fallen substantially and is expected to continue declining in response to higher prices and improvements in building and equipment efficiency.
- Electric heat pump technology is becoming more efficient and economical and is likely to continue to erode propane heating market share in many regions.
- Propane prices have increased substantially relative to electricity in most regions, and this price disparity is projected to continue.
- Since 2000, the propane industry has lost more than 350,000 manufactured home customers due to the overall collapse of the manufactured home market and to electricity inroads into new units. This trend is expected to continue.
- Growth in natural gas supply is leading to lower natural gas prices and expansions in natural gas distribution systems that lead to conversions of existing propane customers to natural gas.

Given the expected improvements in electric heating technology, and the expected promotion of electricity as a "green" energy source by the electric power industry, maintaining existing propane customers is likely to become even more difficult. Preserving the current customer base will require an aggressive and coordinated effort by the propane industry. The major propane applications in these sectors have significant non-cost advantages over competing fuels and technologies - advantages like warmer heat and the convenience of gas that add value for customers. The propane industry will need to emphasize this value proposition to capture high-opportunity markets and offset inevitable losses in markets that are driven entirely by cost rather than value.

4.2
Understanding and Taking Advantage of Regional Market Segmentation

Market threats and opportunities facing the propane industry differ by region and location. The map in Figure Q below shows the wide distribution of propane residential heating customers. With the exception of the West Coast and the South, where electricity holds most of the market, and New England where fuel oil has the highest share of the residential heating market, propane has more than 10 percent of the residential space heating market in most counties. However, the distribution varies widely depending on climate, energy prices, and availability of natural gas.

Even within specific geographic regions, there can be widely varying differences in weather patterns, customer lifestyles, electricity prices, and competition from other technologies and fuels. While many of the regional differences are concentrated in the residential and commercial sectors, differences in state regulations and electricity prices also affect propane in other demand sectors. Hence, propane industry marketing strategies that can be tailored to specific regional conditions and requirements will be more successful than a one-size-fits-all national approach.

In the residential sector, regions with significant propane market share, and significant residential new construction, are likely to provide the majority of new opportunities for propane. The map in Figure R illustrates where these areas are located. While there is good market opportunity for propane in many counties around the country, the majority of high growth markets where propane is likely to capture a significant share of the new construction and renovation markets are located in the Northeast, Upper Midwest, and Rocky Mountain regions.

Fig. Q **Propane Space Heating Market Share in 2011**

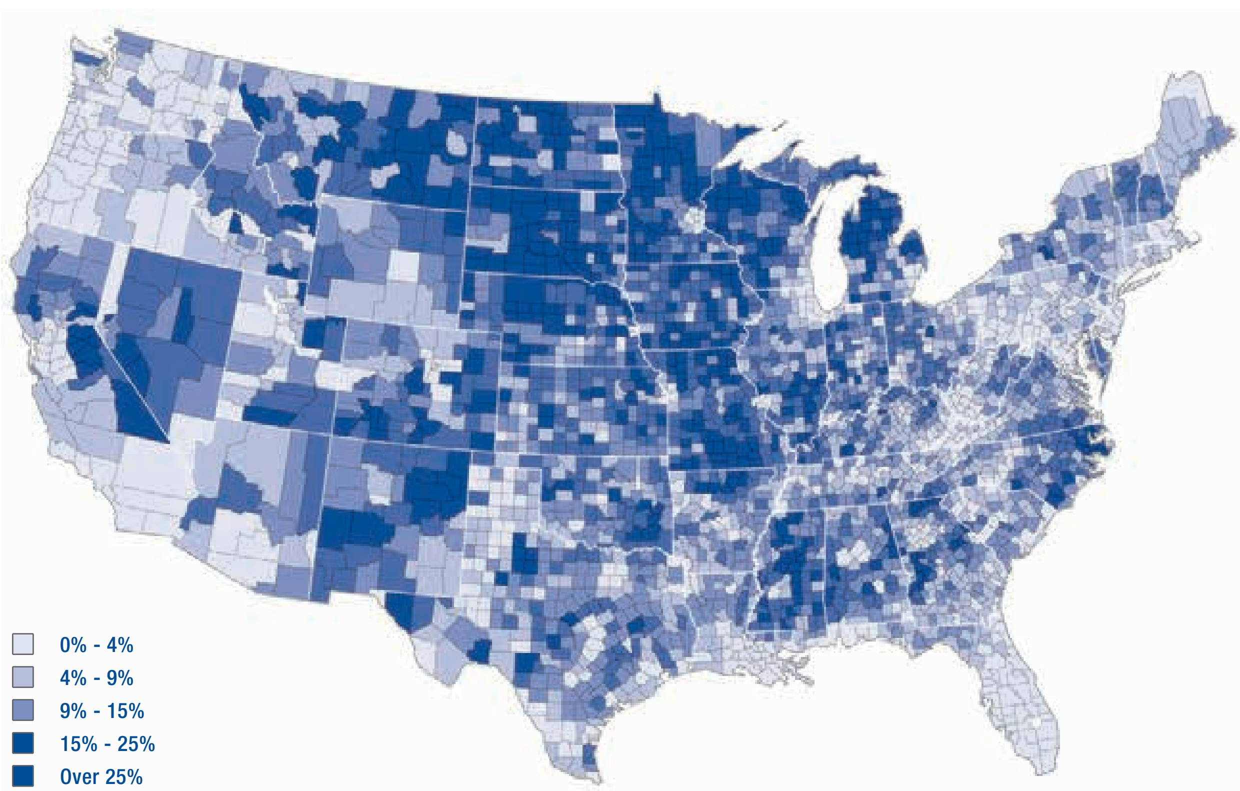
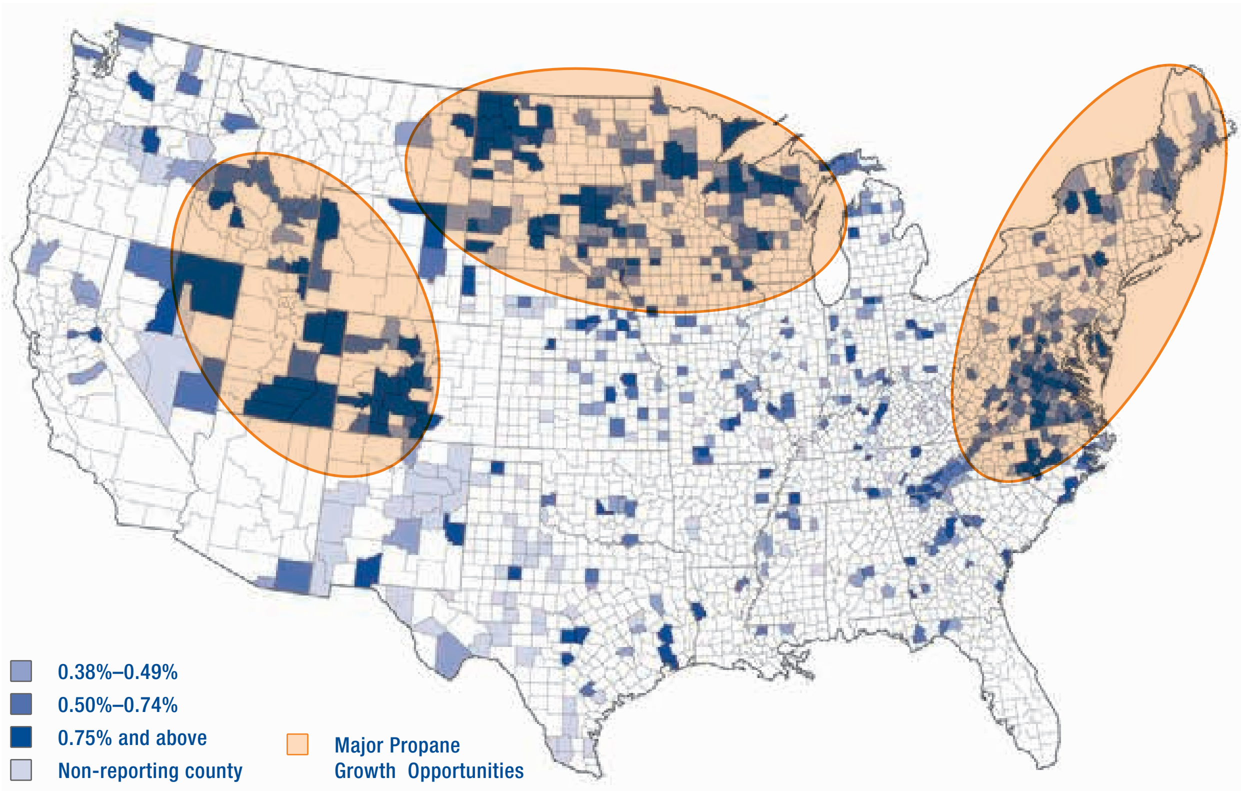


Fig.
R Counties with More Than 10% Residential Propane + Heating Oil Market Share and Above Average New Housing Construction Activity



4.3

Maximizing the Opportunities Created By Changes in Relationship between Propane and Gasoline/Distillate Prices

When multiple forms of energy are available for the same function, price becomes a prime consideration in users' energy choices. Given projected long term shifts in world energy markets, propane prices are expected to become more competitive relative to diesel and fuel oil prices over time. This change is expected to create unique opportunities in the residential and commercial heating markets in the Northeast and Midwest, as well as in the full range of diesel engine markets.

However, it is not clear that potential customers will recognize propane's operating cost advantage in heating and engine fuel applications. Encouraging current oil heating customers to invest in new, more efficient propane furnaces will require the propane industry to make a compelling case for long term consumer benefits. Communicating the benefits of propane is vital, but inducing customers to switch fuels may also require facilitating equipment conversions with up-front financing, as well as other steps to simplify the process. Likewise, in the internal combustion engine market, consumers may not be familiar with the new, more efficient generation of propane engines in non-road applications, and may have had only limited exposure to on-road propane vehicles. A major consumer education campaign can help to significantly increase consumer awareness and eventual sales of propane-powered vehicles.

Another challenge in the competition of propane with other engine fuels is that the number of propane applications for on- and off-road vehicles is currently limited. The cost of developing and introducing new propane vehicles is very high and PERC-funded applications that have been under development for several years are only now starting to reach the market. The necessary capital for new vehicle development is unlikely to come from the motor vehicle industry until manufacturers believe the market will support a high volume of new vehicle sales. Consequently, this market may require significant long term financial support by the propane industry before it can become self-sustaining.

4.4

Leveraging the Environmental and Energy Security Benefits of Propane

Propane is a cleaner-burning, lower-carbon fossil fuel than other petroleum-based products such as distillate fuel oil, kerosene, and gasoline. Propane is also a domestically produced fuel and the use of propane helps improve U.S. energy security. In contrast to natural gas, where the principal component is methane - a greenhouse gas itself - propane has a near-zero direct global warming potential, making it a preferred fuel over natural gas in some applications.

PERC and its partners are developing technologies and products that build on propane's emissions and supply benefits in applications such as distributed generation, agriculture, and transportation. However, these benefits and applications are not widely recognized by decision-makers in the current national energy and environmental policy debate. Federal and state energy and environmental policy decisions, along with the resulting tax policies and regulations on energy use, are going to play a significant role in either promoting or inhibiting use of propane in a variety of markets. If the benefits of propane are recognized and considered during energy and environmental policy discussions, propane is likely to benefit from the resulting policies and initiatives. But if these benefits are not effectively communicated and recognized, propane is likely to be regulated the same as gasoline and distillate fuel oil, which could considerably limit potential propane market growth.

As a result, the propane industry - through the appropriate national and state trade associations and companies - needs to be actively involved in the federal and state energy and environmental policy and regulatory process. The industry's companies and appropriate trade associations must engage policymakers in regulatory discussions of specific priority market development targets, such as alternative transportation fuels and distributed generation, to ensure that propane is adequately considered when new energy policies are drafted. This makes it essential for the propane industry to understand the relevant issues and policy options, know the critical stakeholders and their positions, and be seen as an important stakeholder and resource by the organizations and agencies drafting new policies and regulations.

Final Thoughts

North American energy markets in general, and propane markets in particular, are in the midst of a period of profound change. Existing propane markets face growing competition from electricity and natural gas, and existing demand is falling due to improvements in energy efficiency and in response to increases in propane prices. However, the propane industry also has an unprecedented opportunity to grow demand in a broad range of engine fuel markets as well as in markets where propane competes with fuel oil.

The rapid growth in domestic propane production is expected to support future domestic propane prices at a level below international propane prices. While ICF anticipates a modest rebound in the Mt. Belvieu to crude oil price relationship relative to year end 2012 propane prices, we anticipate the ceiling on domestic propane prices will be set at the world price of propane minus transportation costs to international markets, rather than the world price of propane plus transportation costs that set the floor on domestic propane prices during the periods when the U.S. was a major propane importer. As a result, propane prices are expected to remain very competitive relative to diesel and gasoline. This, in turn, should make propane a much more attractive alternative to conventional transportation fuels. The fuel's clean-burning and "100% domestic" production profile should provide further impetus to its expanding role in America's fuel mix.

In addition, the increase in domestic propane production from natural gas liquids provides the propane industry with the opportunity to brand itself as a clean, domestic, and secure energy source.

Taking advantage of the market opportunities and minimizing the impact of the market threats will require concerted action by the industry as a whole, including investments in new technologies and new business models.

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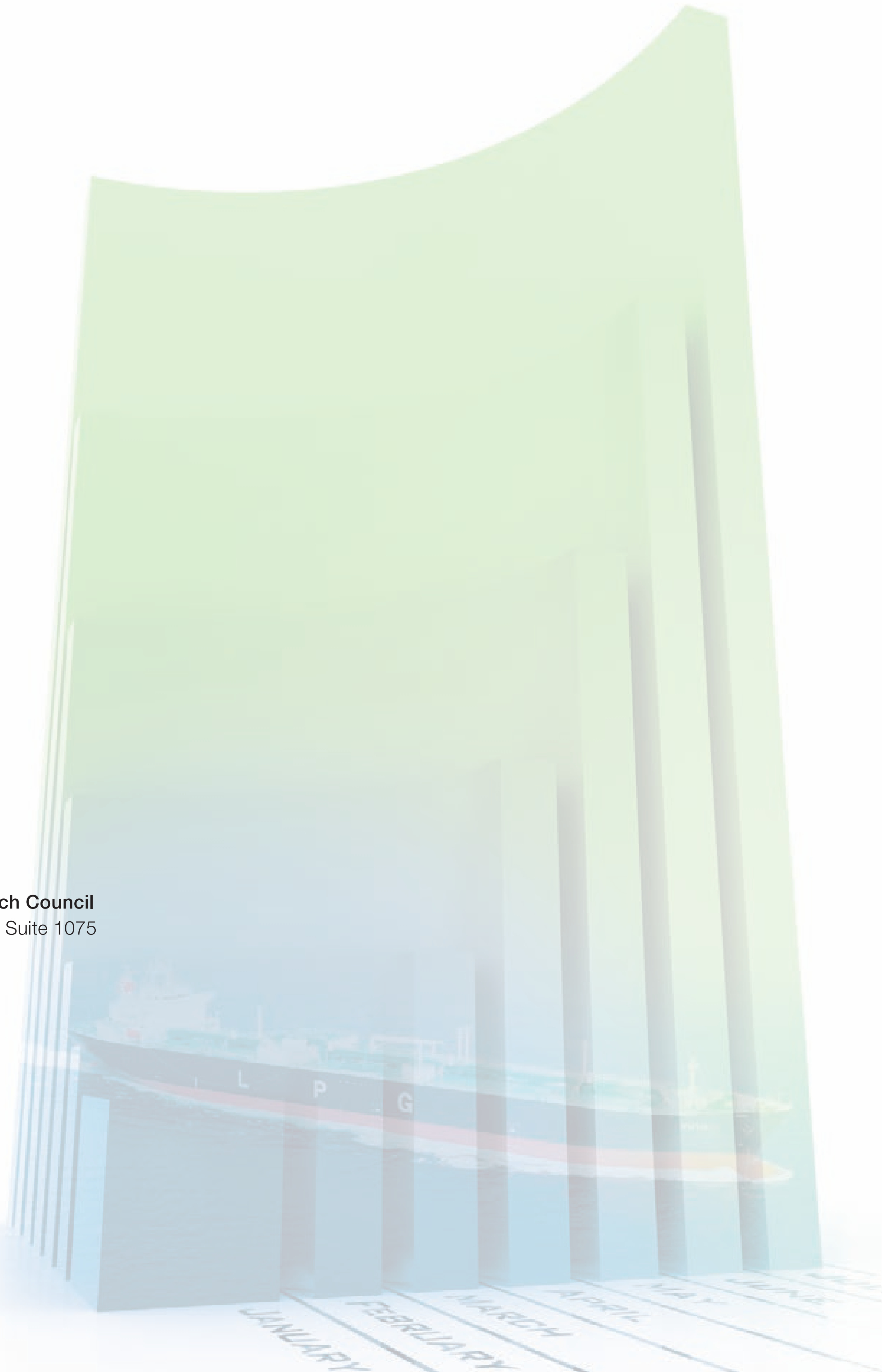

THE PROPANE AUTOGAS CALCULATOR

See how much your fleet could save by switching to propane autogas with this tool. Download the free app for Apple and Android devices today.

To learn more about why propane is the right fuel for your fleet, visit **propane.com/on-road-fleets.**

PROPANE education & research COUNCIL

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PROPANE AUTOGAS VS. DIESEL

CHOOSE LOWER COST-OF-OWNERSHIP

PROPANE EDUCATION & RESEARCH COUNCIL

PROPANE AUTOGAS CLEAN AMERICAN ENERGY™

PROPANE AUTOGAS PAYS OFF.

If you have a diesel-fueled fleet, you know all the additional costly expenses that come with today's diesel technology. Propane autogas will empower you to save more over time by offering a lower total cost-of-ownership.

THE PROPANE AUTOGAS ADVANTAGE

LOWER TOTAL COST-OF-OWNERSHIP

The costs of diesel add up quickly: expensive fuel, additional fluids, and pricey particulate filters. These are the most influential reasons why propane autogas vehicles save more money, from purchase to retirement of the asset.

POWERFUL VEHICLES

Choose from a wide selection of OEM-supported vehicles that are EPA- and CARB-certified — without sacrificing the horsepower, torque, and towing capacity you'd get from their conventionally fueled counterparts.

MORE UPTIME

With propane autogas, you can skip the downtime typically caused by diesel's extra repairs and maintenance. Propane autogas vehicles also provide superior cold-weather performance compared with diesel.

AFFORDABLE, FLEXIBLE INFRASTRUCTURE

Fleets can choose private, on-site refueling infrastructure scaled for their needs, or take advantage of flexible public or private refueling networks.

SAFE FOR EVERYONE

Propane autogas vehicles operate quieter than diesel models, allowing drivers to better focus on their passengers and the road. Standard safety features designed into propane autogas vehicle fuel systems provide added peace of mind for everyone.

CLEAN, AMERICAN-MADE FUEL

By using propane autogas, your organization can reach its sustainability goals without additional, costly emissions technology. You're also supporting our country's economy — nearly 90 percent of propane supplies are produced in the U.S.

SAVE ON THE 3 F's

Propane autogas lowers fleets' total cost-of-ownership by saving more money in these three key areas.

1

FUEL

The cost of wholesale propane falls between the price of oil and natural gas, the fuel's two sources. As a result, propane autogas is consistently less expensive than diesel, even as fuel prices fluctuate.

2

FLUIDS

New, lower-emissions diesel technology comes with an added inconvenience: diesel emissions fluid to purchase, store, and change. This is on top of needing more oil by volume compared with propane autogas. In cold temperatures, diesel vehicles also require anti-gels to prevent clogging of fuel filters and lines. Propane autogas provides reliable performance without additional fluids.

3

FILTERS

To meet emissions requirements, new diesel technology requires diesel particulate filters that must be cleaned every 200,000 miles. Excessive idling will accelerate cleaning intervals. Either way, extra maintenance expenses are piled on top of additional upfront costs.

"Day-to-day maintenance on a propane bus is a lot less than on a diesel model. You don't have the multi-thousand particulate filters, and you don't have to put any other fluid in. I could change the oil on a propane engine three times for the cost of one diesel service."

Brian Urwin
Shop Manager, Student Transportation Inc., Omaha, Neb.

SPEND TIME ON THE ROAD... NOT ON REPAIRS

New diesel vehicles may offer fewer emissions than older diesel technology, but they're also susceptible to expensive, time-wasting repairs that aren't an issue with propane autogas.

COMMON DIESEL HEADACHES

Without proper preventative maintenance, diesel fleets can expect to spend time and money replacing injectors, exhaust gas recirculation valves and coolers, turbochargers, dirty aftercoolers, and irregular closed crankcase filters.

THE COST OF IDLING

Today's diesel engines are designed for minimal idling, which should not exceed five minutes. Excessive idling fouls injectors and damages EGR valves, turbochargers, and diesel particulate filters. It has also been proven to increase the need for engine emissions regenerations, which increases downtime and maintenance expenses.

"Without proper preventative maintenance, EPA- and CARB-compliant diesel engines can have an array of issues that you just don't have with propane-autogas-powered engines. We don't worry about the downtime and maintenance that goes into cleaning or replacing DPF filters — and those costs really add up."

Tim Stevens
President, Stevens Sausage, Smithfield, N.C.

PROPANE AUTOGAS REFUELING OPTIONS

The best refueling option for your fleet depends on its size, routes, and refueling timing. You local propane provider can help you select the right option for your situation.

USING A PRIVATE OR PUBLIC NETWORK

Small-budget fleets with limited space, or fleets needing more fueling locations along their routes can take advantage of this option with no infrastructure investment. Network refueling stations are accessible 24/7 through a card lock system.

If a network is not currently available in your area, a propane provider may create one for your fleet, if it's large enough. Alternatively, multiple fleets can team up to provide adequate load for requesting a refueling network.

STANDARD PRIVATE STATION

Best for small fleets needing a central refueling location

A 1,000- to 2,000-gallon tank and a single dispenser, which can support up to 25 vehicles

OPTION 1

PROPANE PROVIDER OWNS INFRASTRUCTURE

The fleet is responsible for site preparation: crash protection and electrical.

COST FOR FLEET

$1,500-$5,000
(SITE PREPARATION)

OPTION 2

FLEET OWNS INFRASTRUCTURE

The fleet will need to account for purchasing the propane tank, pump, motor, and dispenser.

COST FOR FLEET

$25,000-$50,000
(INFRASTRUCTURE)
+
$1,500-$5,000
(SITE PREPARATION)

ADVANCED PRIVATE STATION

Best for large fleets needing a central refueling location

Larger tanks, a canopy, and multiple dispensers to support 25 vehicles or more

OPTION 1

PROPANE PROVIDER OWNS INFRASTRUCTURE

The fleet is responsible for site preparation: crash protection and electrical for a two-dispenser setup.

COST FOR FLEET

$3,000-$7,500
(SITE PREPARATION)

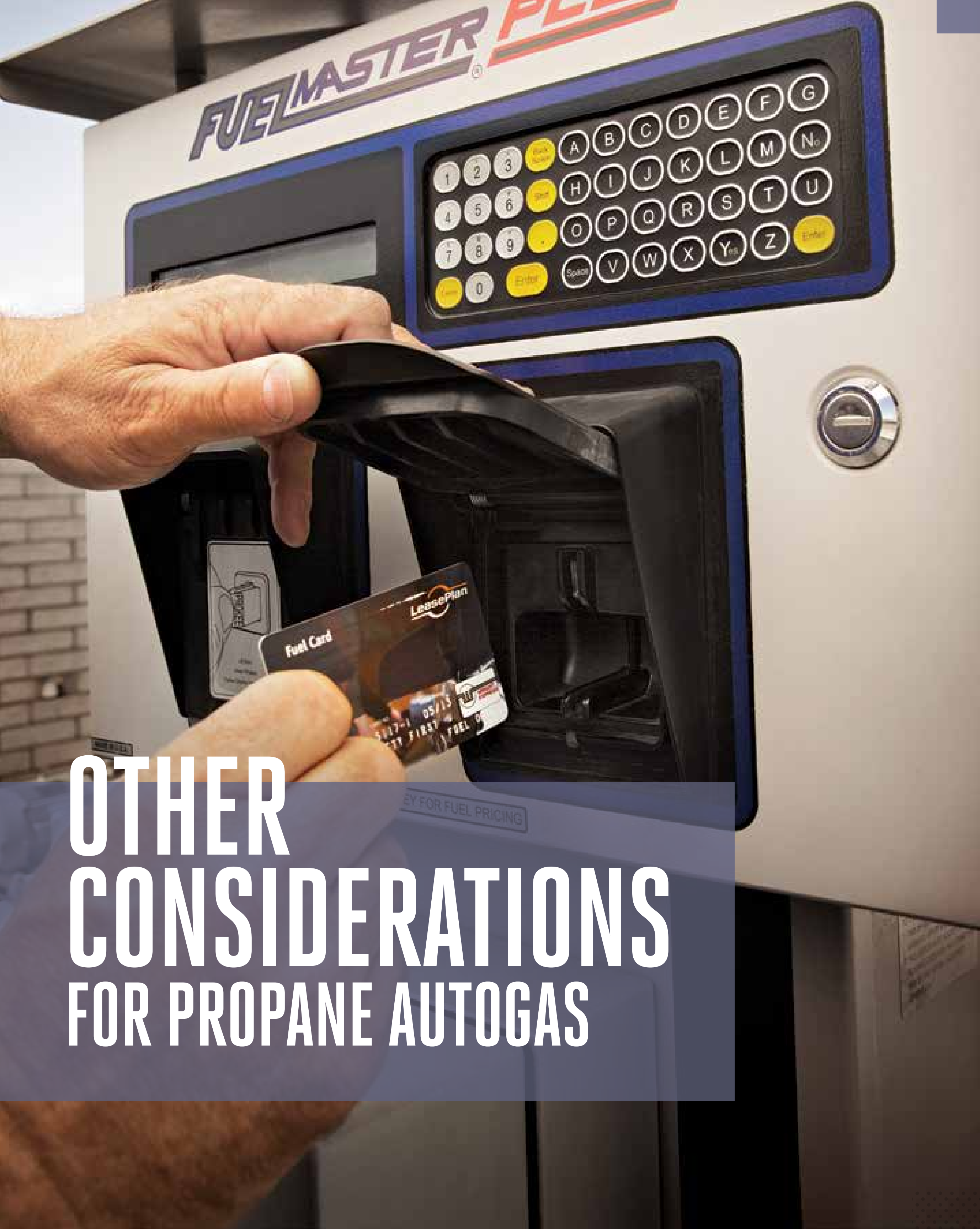
OPTION 2

FLEET OWNS INFRASTRUCTURE

The fleet is responsible for the cost of a canopy, propane tank, pump, motor, and dispenser with card lock and vehicle tracking capability, which can vary based on the complexity of the station.

COST FOR FLEET

$50,000-$200,000
(INFRASTRUCTURE)
+
$3,000-$7,500
(SITE PREPARATION)



OTHER CONSIDERATIONS

FOR PROPANE AUTOGAS

MAINTENANCE FACILITY NEEDS

Switching from conventional fuel to propane autogas is quick and cost-effective, because the requirements for a propane-autogas-vehicle repair facility are generally the same as those for conventionally fueled vehicles. Other alternative fuels, however, may require different facility requirements than conventional fuels, like additional gas detection and ventilation equipment — costing fleets more to switch.

Contact your local Authority Having Jurisdiction (AHJ) for applicable codes regarding building or modifying a propane-autogas-powered vehicle repair or maintenance facility.

PROPANE DISPENSER SPECIFICATIONS

There is a variety of technology available to use in your refueling station. It's important to choose a dispenser that will deliver a similar user experience to gasoline, is the correct dispenser for your vehicle, and will meet all applicable codes and regulations.

To learn more, download the Propane Autogas Dispenser Specifications guide from **propane.com/on-road-fleets/safety-and-training.**

"The local propane provider comes with a bobtail truck every other or every third week and fills up our tanks. We've had absolutely no issues at all, and, we didn't have to make any alterations to our facilities and shop either."

John Dufor
President, All-Star Transportation, Torrington, Conn.