9/24/2012

California Energy Commission
Dockets Office, MS-4
1516 Ninth Street
Sacramento, CA 95814-5512

RE: Docket Number 12-ALT-02

ARRO Autogas is a California company dedicated to the sales and distribution of propane as a transportation fuel throughout the western states. We are developing a network of publicly accessible, 24 hour/7 day per week Autogas refueling sites at gasoline stations as well as other convenient locations initially in southern California. Our customers include early adopters of propane Autogas including ThyssenKrupp, Direct TV, Prime Time Shuttle, Roadrunner Shuttle and others noted in the press. More information on ARRO Autogas is available through our website: www.arroautogas.com.

We greatly appreciate this opportunity to comment on the 2013-14 Investment Plan Update. Although ARRO would certainly welcome funding support for rolling out additional locations, we believe it to be more important that demand for propane Autogas be enhanced. We can build stations if we know we have customers that need them. If one cannot lower the impediments to placing Autogas powered vehicles into California, building additional refueling sites is of little merit.

The 2012 - 2013 Investment Plan Update For The Alternative and Renewable Fuel and Vehicle Technology Program from Assembly Bill 32 (Núñez, Chapter 488, Statutes of 2006), has established a goal of reducing greenhouse gas emissions to 1990 levels by 2020, and Executive Order S - 3 - 05 has established a goal of reducing greenhouse gas emissions to 80 percent below 1990 levels by 2050. We submit that greater use of propane in California transportation is a cost effective, suitable answer to this challenge.

The attached Energetics report Propane Reduces Greenhouse Gas Emissions: A Comparative Analysis 2009 states:

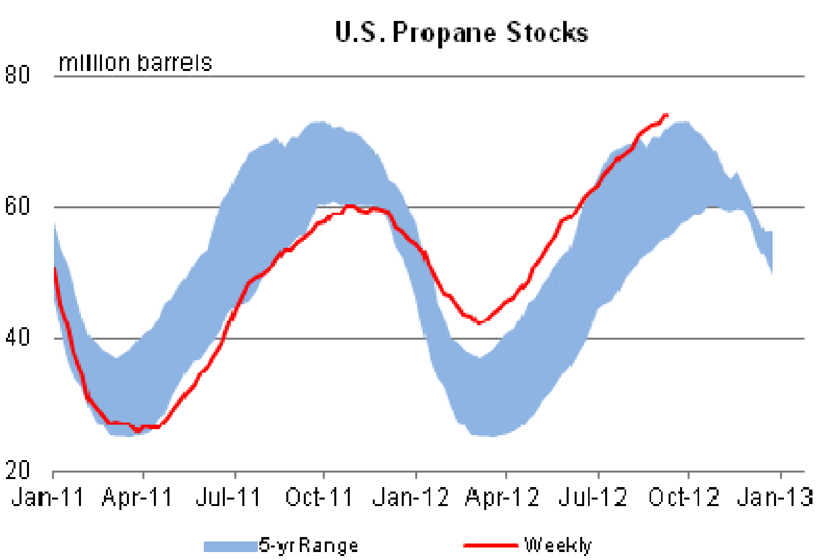
> "Propane is among the most attractive options for avoiding greenhouse gas emissions in every application considered. At the point of use, propane emits fewer greenhouse gases than gasoline, diesel, heavy fuel oil, or E85 ethanol per

> unit of energy. Natural gas (methane) generates fewer greenhouse gas emissions per British thermal unit than propane, but methane is chemically stable when released into the air and produces a global warming effect 25 times that of carbon dioxide. This means that 1 kilogram of methane produces the same effect in the atmosphere as 25 kilograms of carbon dioxide. Propane's short lifetime in the atmosphere and low carbon content distinguish it from other fuel sources as an important energy option in a carbon-constrained world."

The propane industry has demonstrated substantial tailpipe reductions in CO, CO_2 and NOx when using Autogas in transportation. Of greater advantage, there is economic benefit to offering strong financial support to increased use of propane in California transportation. According to the attached ICF International report entitled Propane Supply Sources and Trends (AUG 2012), the US has become a net exporter of propane. From that report:

> "In 2011, 98% of U.S. propane supply was produced in the U.S. or Canada. And 69% of total U.S. supply of propane came from ***natural gas liquids*** produced in the U.S and Canada. [Only] 28% of total U.S propane supply was produced by U.S. crude oil refineries from domestic and imported crude oil alongside the production of gasoline and distillate fuel oil."

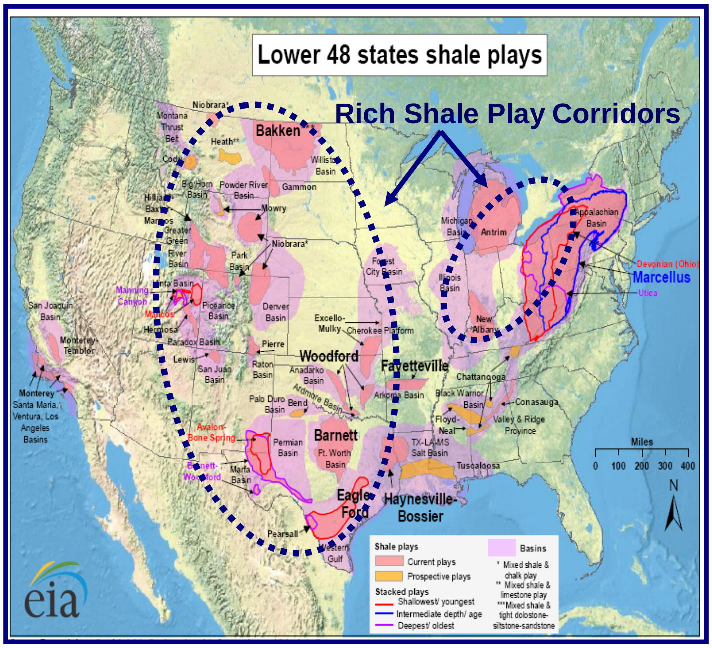
According to US EIA data as of September 14, 2012, total U.S. propane supply exceeds the five year range and surpasses the same period last year by over 33%. ICF projects this trend to grow over the next five years.



Source: http://www.eia.gov/oog/info/twip/twip_propane.html

Growing propane supplies across the US are a result of shale production in the mid and eastern portions of the country. However, growth in indigenous California supply of propane is not as well documented. Anecdotal evidence suggests that while local production may not have significantly increased, excess summer production once exported to Nevada consumption markets, storage in Bumstead AZ and/or Mexico has been curtailed, as excess supply from the Overthrust area of Wyoming and South Dakota pushes further into markets historically served with California propane production. Consequently, we now have a LOT of propane in California.

Rich Hydrocarbon Natural Gas Plays



Rich Plays	NGL (GPM) Content*
Avalon/Bone Springs**	4.0 to 5.0
Bakken**	4.0 to 9.0
Barnett	2.5 to 3.5
Cana-Woodford	4.0 to 6.0
Eagle Ford***	4.0 to 9.0
Granite Wash	4.0 to 6.0
Green River**	3.0 to 5.0
Niobrara**	4.0 to 9.0
Piceance-Uinta	2.5 to 3.5
Green River	2.5 to 3.5
Marcellus (Rich)	4.0 to 9.0

* gpm – gallons of NGLs per 1000 cu. ft.
** Oil Shale Plays
*** Both an Oil and Gas Shale Play

37 envantage

The result of historical supply levels of propane within California has been an expected decrease in the price of propane, not only at the wholesale level but across the consumer spectrum. Today, a propane powered fleet can purchase transportation fuel for about $2.09 per gallon including all taxes. This is a price equivalent to less than $2.40/GGE or $3.20/DGE. Please refer to www.arroautogas.com for up to the minute pricing at our sites.

Notwithstanding the price differential, not many fleets in California can take advantage of this opportunity. How is this possible? First and foremost, the state of California has no coordinated interagency planning (do we dare say desire?) to take advantage of this new supply dynamic. While staff at CEC works diligently to implement plans supporting the use of a variety of alternative fuels, CARB works overtime to confirm that no fuel is used (other than traditional fuels) without rigorous, time consuming and ultimately expensive testing of systems that allow vehicular use of alternative fuels. At a recent workshop held in El Monte, CARB staff was asked the last time the cost impact of their regulations to California citizens was conducted, since their mission, in addition to protecting the environment and improving air quality, includes the mandate to assess the impacts of its actions on the state economy. The answer was 1994.

While the state budget continues to founder, the CEC is tasked with spending $204 million (to date) of dwindling state funds in order to offset crippling costs caused by CARB protocols implemented eighteen years ago. This disjointed activity introduces great risk into the marketplace-to the point where only highly funded, well connected (to OEMs) fuel system manufacturers dare to apply to the state for permission to sell their products. Once and if success is achieved at CARB, the system manufacturer must repeat an excessively expensive demonstration process for each engine family it wishes to support.

The time it takes to submit data and gain approval from CARB is an additional and separate impediment. When fuel systems do hit the market, they are typically late for a given model year. For example, Roush has yet to release the F250/350 pickup for model year 2012. The order window, given projected CARB release of certification, was opened this past August for less than 30 days. Ford no longer builds a 2012 version of this pickup and so customers that were unable to order in August, must now wait a minimum of six months in which to order a 2013 model of the same truck with a propane Autogas option.

Let's add to that the non-recovered costs by industry. Roush Cleantech has risked literally millions of dollars certifying to CARB that their products do not increase the tailpipe emissions of a limited variety of gasoline platforms. CleanFuel USA can boast of only one certification currently available for the GM 4500 series cutaway van using a 6.0 liter engine. Smaller manufacturers of propane systems that produce a wide variety of products with EPA certification look at California requirements and turn away. The financial risk is too great and thus the potential market in California remains underserved.

So...California sets a goal to reduce the use of imported oil products, lower carbon emissions in transportation and reduce costs to California consumers. Both natural gas and propane are in a great position to help accomplish these valuable goals. Yet, California sets its own significant roadblocks in place to preclude success. Unfortunately for the citizens of California, this absurdity can only be resolved from within.

We agree and concur with the Western Propane Gas Association in its request for additional flexibility in directing vehicle purchase incentive funding through the MOR (manufacturer of record). The OEM dealer network will sell a vehicle with or without

CEC funding and therefore has little incentive to participate in the current grant structure. It is the MOR (Roush, CleanFuel or BAF for that matter) that is forced to recover exorbitant cash outlays by selling their product at inflated prices. At least funding through the MOR masks the problem California frankly has created for itself.

However, ARRO wishes to deviate with a "one price fits all incentive" concept as WPGA proposes. We believe the customer who purchases the alternative fueled vehicle shouldn't be exposed to the added cost of the vehicle resulting from requirements that Roush and others do not have to experience outside of California. These added certification costs vary from platform to platform and should be directly subsidized by California. The resulting option cost to the vehicle purchaser should be a flat amount of some competitive albeit subjective value ($5,000?), one reflecting an amount that provides a strong ROI through fuel cost savings and thus provides a market incentive for vehicle purchase.

In other words-pay a lump sum grant to the vehicle system developer to reimburse them for their time, trouble and costs in getting the system approved by CARB. In trade, require the manufacturer to commit to a cost estimate in advance of funding. And then hold the manufacturer to a reasonable sales price for their product that a consumer will be willing to pay.

California was once a strong market for propane Autogas use. It is the obstruction tactics of California agencies such as CARB that have reduced this market to a fraction of its former being. California drivers are denied the ability to use clean, domestic and inexpensive fuels through no fault of their own. Nor does the average citizen have any ability to confront this problem. Since California funding is available to work through this challenge, it should be directed back to companies striving to accomplish the task of providing products that Californians can purchase.

Again, we thank you for the opportunity to provide comments.

Sincerely yours,
ARRO Autogas

William Platz
President

Propane Reduces Greenhouse Gas Emissions:

A Comparative Analysis

2009

Prepared by

ENERGETICS
A Subsidiary of VSE Corporation

PROPANE education & research COUNCIL

PROPANE
EXCEPTIONAL ENERGY®

Acknowledgements

This report was sponsored by the Propane Education & Research Council (PERC) and prepared by Energetics Incorporated. Matt Antes, Ross Brindle, Kristian Kiuru, Michael Lloyd, Matt Munderville, and Lindsay Pack, all with Energetics, are the principal authors of the report. Valuable guidance was provided by Brian Feehan, Mark Leitman, Greg Kerr, and Brandon Robinson at PERC.

Table of Contents

Executive Summary

This report quantifies the greenhouse gas (GHG) emissions profile of propane compared to other fuels in selected applications of importance to the U.S. propane industry. The analysis presented in this report represents an expansion and update to a study sponsored by the Propane Education & Research Council and prepared by Energetics Incorporated in 2007, *Propane Reduces Greenhouse Gas Emissions: A Comparative Analysis*. This updated analysis uses the latest data regarding energy consumption rates, emissions factors, and equipment efficiencies to estimate greenhouse gas emissions associated with the use of various energy options in a range of residential and commercial, on-road, off-road, and agriculture applications. This study reassesses the greenhouse gas emissions profile of energy choices in seven applications previously analyzed in the 2007 study and for the first time examines six new applications not considered in the earlier study.

The results of this study show that propane is among the most attractive options for avoiding greenhouse gas emissions in every application considered. At the point of use, propane emits fewer greenhouse gases than gasoline, diesel, heavy fuel oil, or E85 ethanol per unit of energy. Natural gas (methane) generates fewer greenhouse gas emissions per British thermal unit than propane, but methane is chemically stable when released into the air and produces a global warming effect 25 times that of carbon dioxide. This means that 1 kilogram of methane produces the same effect in the atmosphere as 25 kilograms of carbon dioxide. Propane's short lifetime in the atmosphere and low carbon content distinguish it from other fuel sources as an important energy option in a carbon-constrained world.

The table on the following pages provides a summary of propane's greenhouse gas emissions profile across the applications analyzed in this study. The following notes add clarity to the table:

- All greenhouse gas emissions results are normalized to the emissions of propane for easy comparison. These normalized results have no units. Lower numbers represent lower GHG emissions.
- The results for applications are normalized within each technology category, where applicable. For example, in distributed generation, all results for 30 kW generator sets (gensets) are normalized to the results for the 30 kW propane-fueled genset while results for 100 kW gensets are normalized to the results for the 100 kW propane genset.
- Each application was assessed based on a defined duration of service, such as heating a home for one year or driving 100 miles. Comparisons across applications are not meaningful.

Table E.1. Analyzed Applications by Market Segment

Residential and Commercial	On-Road	Off-Road	Agriculture
• 10-ton gas engine-driven heat pump • Desiccant dehumidifiers • Residential space heating • Residential water heaters	• GM 6.0L engine • Ford F-150 • Ford F-250 • School buses	• Commercial mowers • Distributed generation • Forklifts • Ground service equipment	• Irrigation engines

Table E.2. Greenhouse Gas Emissions Profiles for Selected Applications

10-Ton Gas Engine-Driven Heat Pump		Desiccant Dehumidifiers		Residential Space Heating		Residential Water Heating		GM 6.0L Engine		Ford F-150	
Natural Gas Engine-Driven Heat Pump	0.86	Desiccant Dehumidifier with Natural Gas Regeneration	0.89	Natural Gas Furnace	0.99	Solar with Propane Backup Storage Tank	0.40	2010 Chevy Express Cutaway (Propane)	1.00	Ethanol (E85)	0.95
Propane Engine-Driven Heat Pump	1.00	Desiccant Dehumidifier with Propane Regeneration	1.00	Propane Furnace	1.00	Natural Gas Storage Tank	0.86	2009 Chevy Express Passenger Van (Gasoline)	1.27	Propane	1.00
Central Air Source Electric Heat Pump (Best Available)	1.02	Desiccant Dehumidifier with Electric Regeneration	2.97	Electric Heat Pump	1.10	Propane Storage Tank	1.00	2009 Chevy Express Cutaway (Gasoline)	1.34	Gasoline	1.21
Central Air Source Electric Heat Pump (2010 Standard)	1.14	Desiccant Dehumidifier with Hot Water (Natural Gas-Fueled) Regeneration	1.91	Standard-Efficiency Air Source Heat Pump with Propane Furnace Backup	1.13	Fuel Oil Storage Tank	1.21				
Central Air Source Electric Heat Pump (Current Standard)	1.34	Desiccant Dehumidifier with Hot Water (Propane-Fueled) Regeneration	2.14	Fuel Oil Furnace	1.60	Electric Storage Tank	2.08				
Natural Gas Furnace and Central Air Source Electric Air Conditioner	1.42	Desiccant Dehumidifier with Hot Water (Electric) Regeneration	3.99	Electric Baseboard	2.75	Natural Gas Tankless	0.68				
Propane Furnace and Central Air Source Electric Air Conditioner	1.52	Energy Star Refrigerant Dehumidifier	0.96	Electric Furnace	3.21	Propane Tankless	0.79				
Fuel Oil Furnace and Central Air Source Electric Air Conditioner	1.70	Refrigerant Dehumidifier (Current Standard)	1.06			Electric Tankless	2.00				
Electric Furnace and Central Air Source Electric Air Conditioner	2.64										

Table E.2. Greenhouse Gas Emissions Profiles for Selected Applications (cont'd.)

Ford F-250		School Buses		Distributed Generation		Forklifts		Ground Service Equipment		Commercial Mowers		Irrigation Engines	
2010 Roush F-250 (Propane)	1.00	Diesel	0.96	30 kW Prime Micro-Turbine (Natural Gas)	0.87	Electric	0.86	Propane Belt Loader	1.00	23 hp Air Cooled Kawasaki Propane	1.00	Electric	0.84
2009 Propane Conversion Kits for F-250	1.11	Propane	1.00	30 kW Prime Micro-Turbine (Propane)	1.00	Com-pressed Natural Gas	0.98	Gasoline Belt Loader	1.85	Kubota D-902 Diesel (20–23.5 hp)	1.25	Natural Gas	0.95
2008 Ford F-250 Superduty (Diesel)	1.16	Comp-ressed Natural Gas	1.03	30 kW Prime Micro-Turbine (Diesel)	1.27	Propane	1.00	Propane Bag Tractor	1.00	23 hp Air Cooled Kawasaki Gasoline	1.94	Ethanol (E85)	0.99
2009 Ford F-250 5.4L V-8 (Gasoline)	1.23	Gasoline	1.21	100 kW Genset Standby (Natural Gas)	0.91	Diesel	1.08	Gasoline Bag Tractor	1.58			Propane	1.00
2008 Ford F-250 Harley Davidson Model 6.4L Power Stroke (Diesel)	1.30			100 kW Genset Standby (Propane)	1.00	Gasoline	1.24	Propane Cabin Service Truck	1.00			Diesel	1.13
				100 kW Genset Standby (Diesel)	1.19			Gasoline Cabin Service Truck	1.58			Gasoline	1.32
				200 kW Genset (Natural Gas)	0.91			Propane Tow Truck	1.00				
				200 kW Genset (Propane)	1.00			Gasoline Tow Truck	1.18				
				200 kW Genset (Diesel)	1.08								

Notes:

All greenhouse gas emissions results are normalized to the emissions of propane for easy comparison. These normalized results therefore have no units. Lower numbers represent lower greenhouse gas emissions.

The results for applications are normalized within each technology category, where applicable. For example, in distributed generation, all results for 30 kW gensets are normalized to the results for the 30 kW propane-fueled genset while results for 100 kW gensets are normalized to the results for the 100 kW propane genset.

Each application was assessed based on a defined duration of service, such as heating a home for one year or driving 100 miles. Comparisons across applications are not meaningful.

1. Purpose of This Report

Growing concern about the potential effects of greenhouse gas (GHG) emissions has increased the focus on technologies and energy sources that can reduce these emissions. Policymakers in the United States and abroad are considering a variety of options for addressing the issue, including carbon "cap-and-trade" schemes, carbon taxes, and voluntary agreements to limit GHG emissions. As an Environmental Protection Agency (EPA)-approved clean alternative fuel, propane offers lower greenhouse gas emissions than many other energy options without compromising performance in a wide range of applications (Clean Air Act of 2004; Energy Policy Act of 2005).

This study quantifies the greenhouse gas emissions profile of propane compared to other energy sources in 13 selected applications of importance to the U.S. propane industry and the nation. The study builds on an earlier report, *Propane Reduces Greenhouse Gas Emissions: A Comparative Analysis*, which was published in 2007. Cutting across propane market segments, including residential and commercial, on-road, off-road, and agriculture, this analysis uses energy consumption rates, emissions factors, and equipment efficiencies for various energy options to estimate greenhouse gas emissions associated with the use of those energy options.

The information contained in this report is intended to inform the propane industry and consumers as they make important decisions regarding mitigation of greenhouse gas emissions.

Table 1.1. Analyzed Applications by Market Segment

Residential and Commercial	On-Road	Off-Road	Agriculture
• 10-ton gas engine-driven heat pump • Desiccant dehumidifiers • Residential space heating • Residential water heaters	• GM 6.0L engine • Ford F-150 • Ford F-250 • School buses	• Commercial mowers • Distributed generation • Forklifts • Ground service equipment	• Irrigation engines

2. About Greenhouse Gases and Climate Change

Greenhouse gases keep the earth at a comfortable temperature, allowing most of the energy from the sun to pass through the atmosphere and warm the earth while blocking much of the outward radiation from the earth. However, increasing concentrations of greenhouse gases in the atmosphere are cause for concern. The most recent report from the Intergovernmental Panel on Climate Change (IPCC) cited "unequivocal" evidence that the world is now warming due to human activity, and that "most of the warming is very likely (odds 9 out of 10) due to greenhouse gases" (IPCC 2007b).

Greenhouse Gases Compared to Criteria Air Pollutants

Greenhouse gases are different than the criteria air pollutants that have been regulated by the EPA since 1970. Criteria pollutants, which include ozone, nitrogen dioxide, sulfur dioxide, carbon monoxide, lead, and particulate matter, are released in the atmosphere from fuel leaks, secondary reactions, or undesired byproducts during combustion. While these pollutants cause health problems and contribute to smog and acid rain, they do not directly contribute to climate change. The amount of criteria air emissions depends on several variables, including fuel characteristics, combustion conditions, and the use of pollution control equipment, and it is sensitive to maintenance and operational practices (EPA 2008).

In contrast, GHGs currently are not federally regulated. Unlike criteria pollutants, the most prevalent GHG emission — carbon dioxide (CO_2) — is a necessary byproduct of fossil fuel combustion. The amount of carbon dioxide released depends not on leaks or side reactions, but on the amount of carbon in the fuel and the amount of fuel consumed. While chemically reactive criteria air pollutants stay in the air for days or months, greenhouse gases are nonreactive and remain in the atmosphere for decades to centuries (Rubin and Rao 2002). The three GHGs of primary concern for the purposes of this study are CO_2, methane (CH_4), and nitrous oxide (N_2O). The IPCC has identified several

Table 2.1. Important Differences Between Carbon Dioxide and Criteria Air Pollutants

	Carbon dioxide	Criteria pollutants
Source of emissions	• Necessary byproduct of combustion	• Fuel leak or undesired byproduct of combustion
Regulation	• Currently unregulated at federal levels in the United States	• Federally regulated by the Clean Air Act
Quantity released	• Depends mainly on carbon content of fuel and amount of fuel consumed	• Depends on many factors, such as side reactions or leaks
Scale of impact	• Global	• Local or regional
Lifetime in atmosphere	• Decades to centuries	• Days to months

other greenhouse gases, such as hydrofluorocarbons (HFCs) and sulfur hexafluoride, but these are not considered in this report because they are not products of fossil fuel combustion.

Greenhouse Gas Emissions from Fuel Combustion

In general, lighter hydrocarbons release less CO_2 during combustion than heavier hydrocarbons because lighter hydrocarbons consist of fewer carbon atoms per molecule. The mass of CO_2 released per British thermal unit (Btu) of fuel — the "carbon content" — is a good first-order indicator of the CO_2 emissions comparison between fuels. The carbon content for eight common fuels is shown in Table 2.2.

While it is a good indicator, carbon content represents only one component of the CO_2 emissions equation. The amount of fuel consumed plays an equally important role. Fuel consumption varies by fuel type and technology for each application. For example, since compression (diesel) engines are generally more efficient than spark-ignition engines, part of the CO_2 emissions disadvantage of diesel compared to other fuels is offset. (Further details for estimating CO_2 emissions are provided in the Methodology section.)

Small amounts of CH_4 and N_2O are also emitted during combustion, though they represent a much smaller portion of the human-caused greenhouse gases compared to CO_2. In the United States, CH_4 and N_2O together represent less than 1 percent of the total CO_2-equivalent emissions from stationary combustion sources (EPA 2008).

Table 2.2. CO_2 Released per Btu

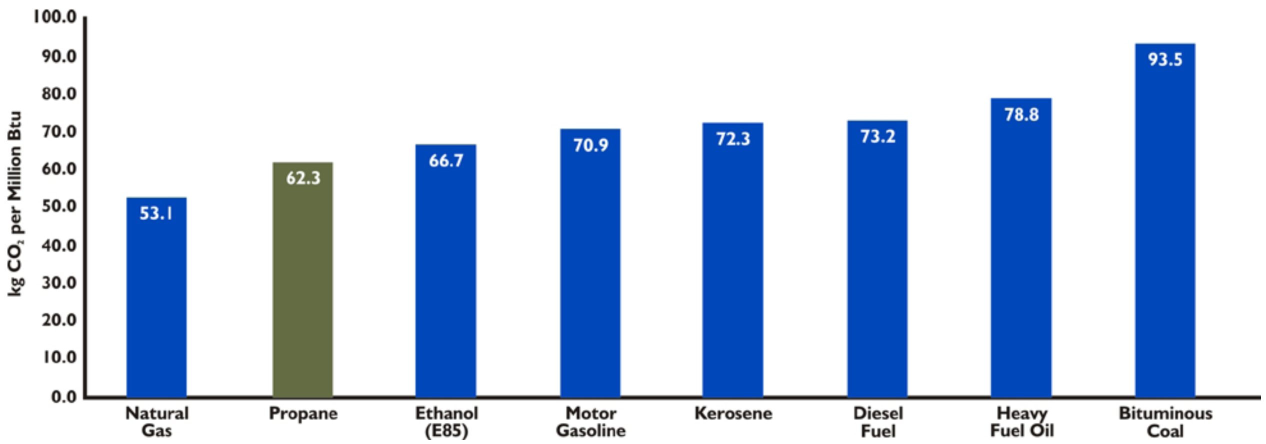
Fuel Type	kg CO_2 per million Btu
Natural Gas	53.06
Propane	62.30
Ethanol (E85)	66.70
Motor Gasoline	70.88
Kerosene	72.31
Diesel Fuel	73.15
Heavy Fuel Oil	78.80
Bituminous Coal	93.46

Estimates based on chemical composition of the fuel with 100 percent combustion, and based on average speciation of transportation fuels, except kerosene, heavy fuel oil, and bituminous coal, which are based on average speciation for stationary combustion use.

Source: EIA 2007

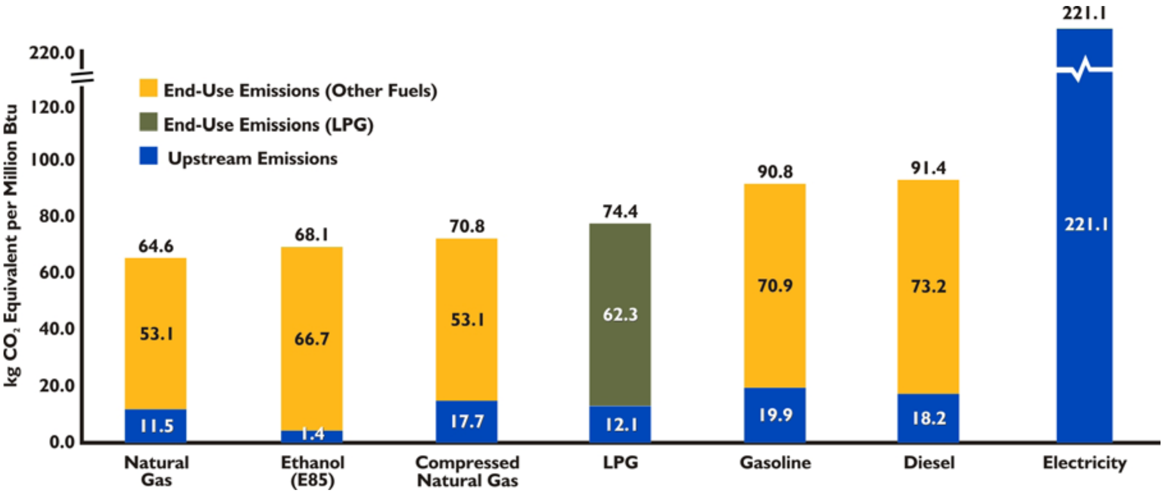
The greenhouse gas footprint of propane is relatively small compared to other fuels in terms of total emissions and emissions per unit of energy. Propane has the lowest on-site emission rate of the major energy sources, with the exception of natural gas (see Figure 2.1). In terms of life-cycle greenhouse gas emissions, propane produces significantly lower emissions than gasoline, diesel, and electricity on a per-Btu basis (see Figure 2.2). Actual life-cycle emissions levels depend on the nature and efficiency of the end-use application and therefore must be estimated on an application-specific basis.

Figure 2.1. End-Use CO_2 Emissions for Various Fuels



Source: EIA 2007
End-use emissions estimates based on chemical composition of the fuel with 100 percent combustion.

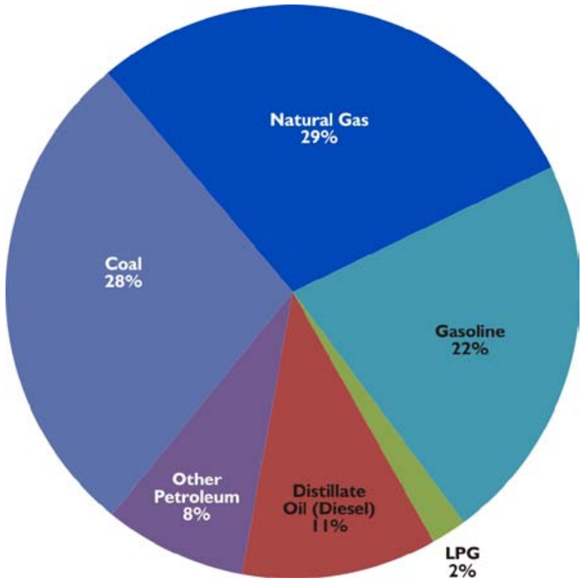
Figure 2.2. Total Greenhouse Gas Emissions for Various Fuels



Sources: EPA 2009, GREET 1.8c
End-use emissions estimates based on chemical composition of the fuel with 100 percent combustion.
Actual life-cycle emissions vary by application; in many cases, electricity provides more useful energy on a per-Btu basis.

Propane represents a small but important part of the U.S. energy sector. Figure 2.3 shows the contribution of the major fuels with propane representing approximately 2 percent of energy consumed in the United States in 2007.

Figure 2.3. Shares of U.S. Energy Consumption (2007) (Total: 78,823 trillion Btu)



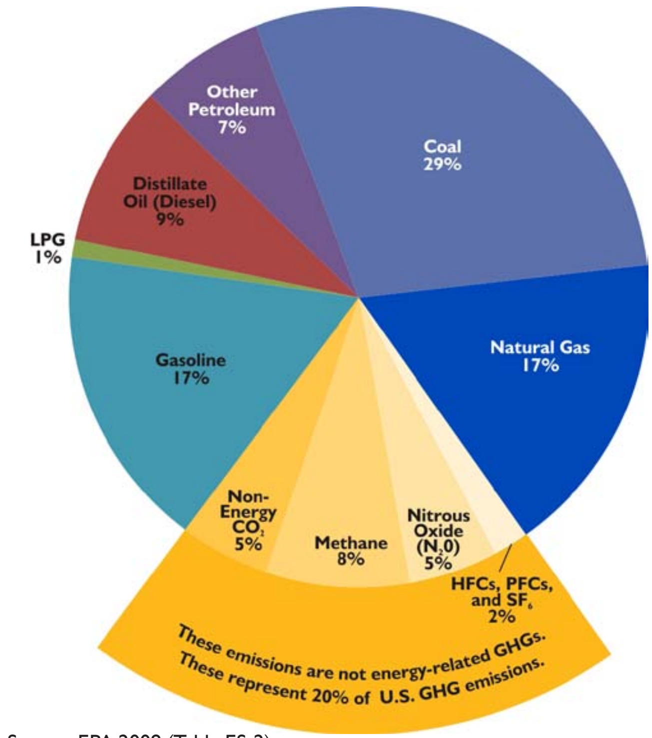
Source: EPA 2009 (Table A-10)

Because of propane's relatively low GHG emission rate, its share of GHG emissions is smaller than its share of energy supply. Figure 2.4 shows the relative contribution to total U.S. GHG emissions by fossil fuel combustion and from other sources. Greenhouse gas emissions from fossil fuel combustion represent 80 percent of total emissions, while propane combustion represents only 1 percent of total U.S. GHG emissions.

The remaining balance of emissions (20 percent) 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 [SF_6] from refrigerants and industrial processes).

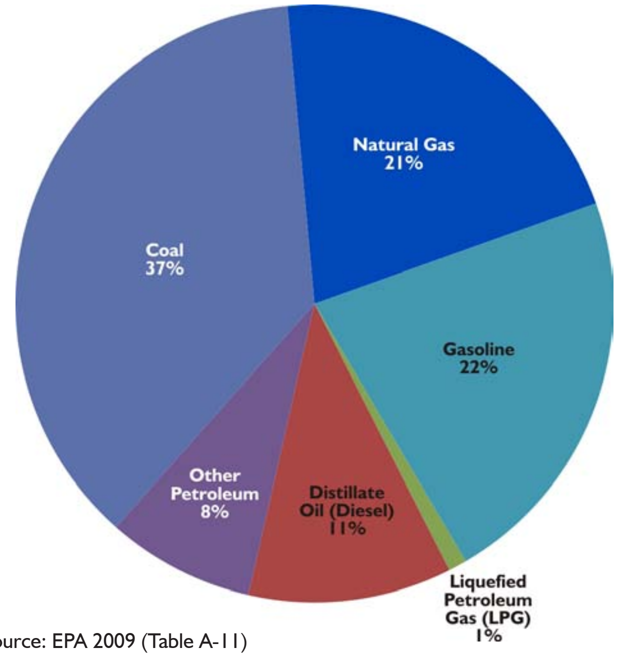
Figure 2.5 illustrates the relative contribution to total energy-related CO_2 emissions for the United States in 2007. Although propane contributes approximately 2 percent of the U.S. energy supply, its share of energy-related CO_2 emissions is just more than 1 percent. Coal, the highest-emitting major fuel, represents 28 percent of the U.S. energy supply while generating 37 percent of energy-related CO_2 emissions.

Figure 2.4. Shares of Greenhouse Gas Emissions (2007) (Total: 7,150 million metric tons CO_2)



Source: EPA 2009 (Table ES-2)

Figure 2.5. Shares of Energy-Related Greenhouse Gas Emissions (2007) (Total: 5,735 million metric tons CO_2)



Source: EPA 2009 (Table A-11)

Propane's Effect on Greenhouse Gas Emissions

Propane is not a direct greenhouse gas when released into the air. Propane vapor is unstable in the atmosphere — it is chemically reactive and commonly removed by natural oxidation in the presence of sunlight or knocked down by precipitation. It is also removed from the atmosphere faster than it takes for it to become well mixed and have impacts on global climate. Current measurements have not found a global climate impact from propane emissions.[1, 2]

When used as a fuel, propane does emit CO_2 and small amounts of N_2O and CH_4. Upstream extraction and production of fuels such as propane from natural gas or crude oil generates greenhouse gas emissions, and end-use combustion of any hydrocarbon releases CO_2 as discussed in the previous section. However, compared to conventional fuel supplies, propane generates fewer GHG emissions in almost every application. At the point of use, propane has a lower carbon content than gasoline, diesel, heavy fuel oil, or ethanol (Table 2.2). Natural gas (methane) generates fewer CO_2 emissions per Btu than propane, but natural gas is chemically stable when released into the air, producing a global warming effect 25 times that of CO_2. This means that 1 kilogram of CH_4 produces the same effect as 25 kilograms of CO_2.

With propane's short lifetime in the atmosphere and low carbon content, it is advantageous when compared to many other fuels in many applications.

Upstream vs. End-Use Emissions

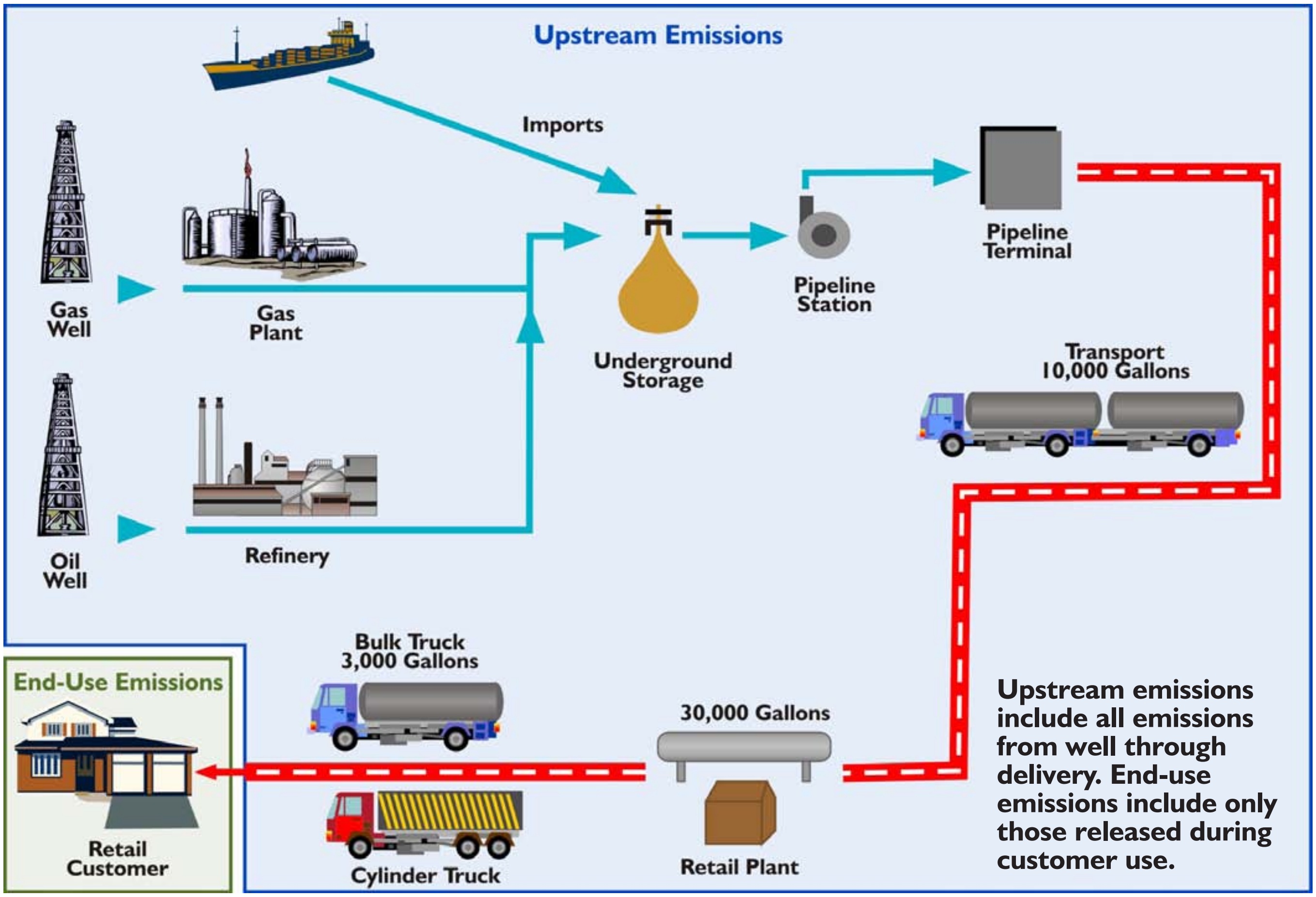
When quantifying the greenhouse gas emissions that result from the use of energy, it is important to distinguish between the emissions released at the location where the energy is consumed and the emissions released as a result of extracting, processing, and transporting a refined and usable energy product to that location. The fuel life cycle 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 technology.

Emissions released at the point of use are termed "end-use emissions," while those emissions that occur along the delivery pathway are termed "upstream emissions." Upstream emissions include all emissions resulting from

1. The Intergovernmental Panel on Climate Change (IPCC) reports that "Given their short lifetimes and geographically varying sources, it is not possible to derive a global atmospheric burden or mean abundance for most VOC from current measurements." VOCs explicitly include propane (IPCC TAR 2001).

2. While VOCs participate in the formation of tropospheric ozone, the climate effect from ozone is not highly understood by scientists and is not one of the six greenhouses gases being considered for regulation by Congress.

Figure 2.6. Upstream Supply Chain



Source: Energy Information Administration 2008

the recovery, processing, and transport of fuel to the point of delivery to the end user.

Energy use during the recovery, processing, and transport of fuels is not the only source of upstream emissions. Other production processes also release greenhouse gases. For example, the growing of crops for biofuels production requires the application of nitrogen fertilizer, which causes the formation of nitrous oxide, while natural gas refining causes the release of fugitive emissions of methane. The 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, making it a valuable tool for comparative life-cycle analyses of fuel systems.

The inclusion of upstream emissions in an analytical comparison of different fuel options can have a significant impact on the results. Limiting the comparison to end-use emissions only, for example, can give the impression that electricity, with zero end-use emissions, is an energy source with no greenhouse gas emissions. Limiting the analysis to end-use emissions would therefore mask the large fraction of upstream emissions caused by the combustion of fossil fuels for the purpose of electricity generation.

This analysis is intended to give a full life-cycle estimate of greenhouse gas emissions resulting from the use of propane and other fuels for specific applications. By reporting upstream and end-use emissions separately, this report intends to provide a better picture of the impacts of different fuels and a more useful and informative data set than would be provided by aggregating emissions or restricting the analysis to end-use emissions only.

3. Methodology

This section describes the general methodology used for all applications. Application-specific assumptions are provided in Appendix B.

Basis for Comparison of Applications

Thirteen different propane applications were analyzed in order to quantify the life-cycle greenhouse gas emissions of propane-fueled systems compared to systems powered by other fuels. These 13 applications were selected to represent not only a variety of market sectors, but also a range of market shares — from well-established propane markets such as forklifts to emerging propane technologies such as the propane-fueled light-duty truck or the propane-fueled whole-house desiccant dehumidifier.

Each propane technology was compared to systems using other fuels commonly employed for the same application. Operational variables such as size, hours of operation, and frequency of use were chosen to represent an average or typical use of the technology. Data was obtained from published test results, vendor-supplied specifications, and government studies, and was supplemented with other sources to determine what constituted a typical use. These sources were also used to estimate the energy efficiency of each fuel system. For most applications, the efficiencies were used to determine the amount of fuel needed to deliver an equivalent energy service (e.g., miles traveled or heat supplied) for propane and for each competing fuel option. For some fuels, such as electricity, energy efficiency differences from propane are the result of two different technology designs. In other instances, however, there are only slight differences in technology design between the propane-configured technology and alternate fuel configurations. Where application-specific data was not available, the relative efficiencies of the fuel systems under comparison were based on efficiencies reported for similar technologies.

Upstream Analysis

Upstream emissions as defined in this analysis are the sum of all emissions resulting from the recovery, processing, and transport of fuel from wellhead to the point of delivery to the end user. These emissions are quantified by the GREET model version 1.8c, which was used to estimate the upstream portion of the life-cycle GHG emissions of each fuel system evaluated in this study. The model is used to calculate emissions, in grams per million Btu, of multiple pollutants, including the three greenhouse gases evaluated in this study: CO_2, CH_4, and N_2O.

Table 3.1 gives the upstream emission factors used in this study, which were obtained by running the GREET model version 1.8c.

Table 3.1. Upstream Emissions Factors (grams per million Btu)

	CO_2	CH_4	N_2O	Total CO_2 equivalent
Propane	9,195	115	0.16	12,124
Natural Gas*	5,480	239	0.09	11,471
Compressed Natural Gas (CNG)	11,468	247	0.17	17,684
Electricity	213,067	287	2.81	221,083
Gasoline	16,812	109	1.14	19,871
Diesel	15,488	105	0.25	18,175
E85	-10,464	109	30.64	1,385

* Model output for CNG with compression efficiency set to 100 percent (removing emissions from compression).
Source: GREET 2009

Upstream emissions factors will vary depending on the model's input 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. For all fuels except uncompressed natural gas, the default parameter values in the model were used to calculate upstream emission factors.[3]

The upstream emissions associated with propane production depend on its feedstock — natural gas or crude oil. Propane is separated from natural gas during production and from crude oil during refining. The model attributes to propane, on a Btu-fractional basis, emissions produced from the recovery and refining of these feedstocks before the separation of propane.[4] As a result, the upstream emissions attributed to propane depend on the relative contribution of natural gas and crude oil to propane production. The feedstock shares for propane used for this analysis are 60 percent from natural gas and 40 percent from crude, which are the default values in GREET. Propane produced from crude oil has slightly higher GHG emissions than propane produced from natural gas refining.

Table 3.2 shows the formulas used to calculate total upstream GHG emissions. Upstream emission factors (in grams per million Btu) were multiplied by total fuel consumption required by each fuel system (in million Btu) in order to obtain total upstream emissions for CO_2, CH_4, and N_2O. The total mass of each gas was multiplied by its global warming potential (GWP). Total upstream emissions of GHGs, in metric tons of CO_2 equivalent, were obtained by summing the metric tons of CO_2, CH_4, and N_2O. The values used for global warming potential were those developed by the Intergovernmental Panel on Climate Change (IPCC 2007). Following the widely accepted convention established by the IPCC, results were reported in metric tons of CO_2 equivalent.

Table 3.2. Upstream GHG Emissions

Metric tons of each GHG, calculated for each fuel:
metric tons (GHG) = grams (GHG)/MMBtu (fuel) * MMBtu of fuel consumed / 10^6
Total CO_2 equivalent, calculated for each fuel:
Total metric tons of CO_2 equivalent = metric tons CO_2*(1) + metric tons CH_4*(25) + metric tons N_2O*(298)

End-Use Analysis

End-use emissions are specific to the technology used for each application, and therefore different sources were necessary to estimate various end-use emission factors. The U.S. Department of Energy and the Environmental Protection Agency publish end-use carbon content emission factors for a number of different technologies and were the source of some of the end-use emission factors used in the applications analyzed. Other sources of end-use emission factors include Delucchi 2000 and GREET 1.8c. For vehicle applications, end-use emission factors were based on those used in the GREET model for 2005 model year vehicles.[5]

Total end-use emissions were obtained in the same way as total upstream emissions, by summing the GWP-adjusted end-use emissions of CO_2, CH_4, and N_2O. Unlike upstream emissions factors, however, the units used for end-use emission factors depended on the application. While Btu-based emission factors were applied to some of the applications, the total mass of GHGs emitted from light- and medium-duty trucks was calculated on a grams-per-mile basis, rather than a grams-per-MMBtu basis. The formulas used to calculate end-use emission factors are shown by application in Table 3.3.

Table 3.3. End-Use GHG Emissions

Water heaters, forklifts, irrigation pumps, space heaters, calculated for each fuel:
metric tons (GHG) = grams (GHG)/MMBtu (fuel) * MMBtu of fuel consumed / 10^6
Light-duty trucks, medium-duty trucks, calculated for each fuel:
metric tons (GHG) = grams (GHG)/mile * miles traveled / 10^6
All applications:
Total metric tons of CO_2 equivalent = metric tons CO_2*(1) + metric tons CH_4*(25) + metric tons N_2O*(298)

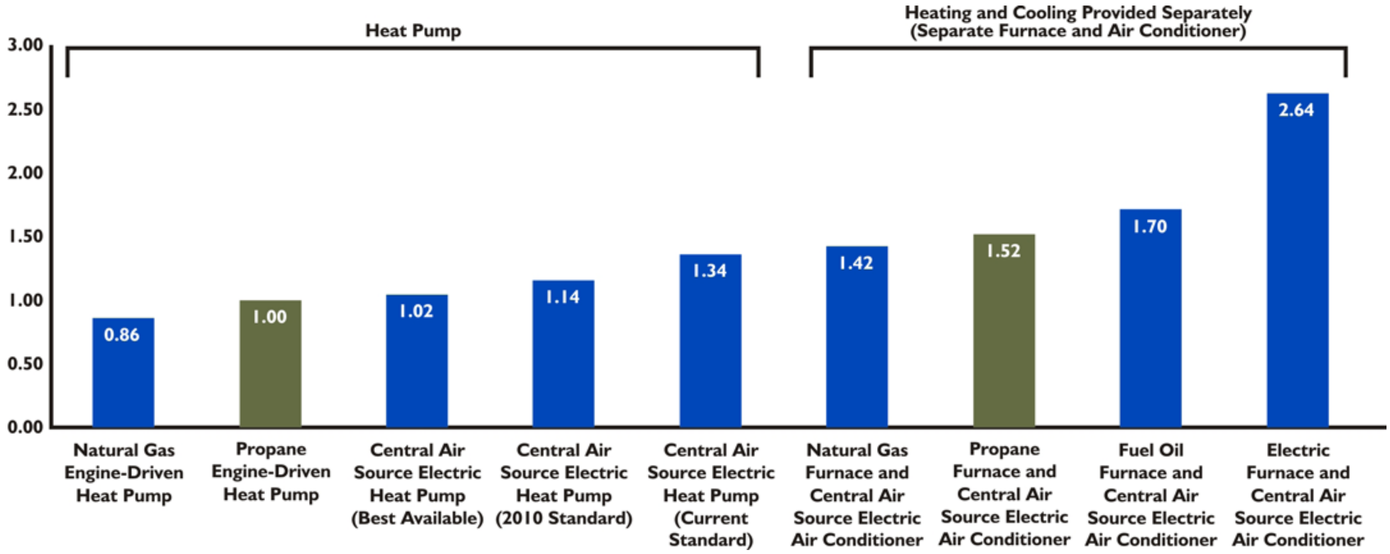
3. GREET is designed to quantify the life-cycle emissions of vehicles, and because vehicles using natural gas run on compressed natural gas (CNG), the model does not allow the user to select uncompressed natural gas as a fuel choice. Some applications in this study, however, required the comparison of propane to uncompressed natural gas. Because the compression of natural gas requires a significant amount of energy (and therefore adds to its upstream emissions), the GREET model input for natural gas compression efficiency was set to 100 percent in order to remove the emissions associated with compression. Compression efficiency as defined by the GREET model is equal to HV/(energy in + HV), where HV is the heating value of the fuel. Setting efficiency at 100 percent therefore makes the value for energy in equal to zero.

4. In other words, all products produced from either crude or natural gas are assumed to begin their life cycle at the wellhead, even though they have not been physically separated from the feedstock. If a given product stream represents 5 percent of the Btu content of the feedstock, for example, then that product is assigned 5 percent of the emissions attributed to the feedstock before refining and separation. This method of assigning emissions is not influenced by the economic value of the product or feedstock.

5. These emission factors were obtained from the spreadsheet "greet1.8c_0.xls." Vehicle performance data is tabulated for every fifth model year. The user must select the year 2010 to get performance data for 2005 model year vehicles.

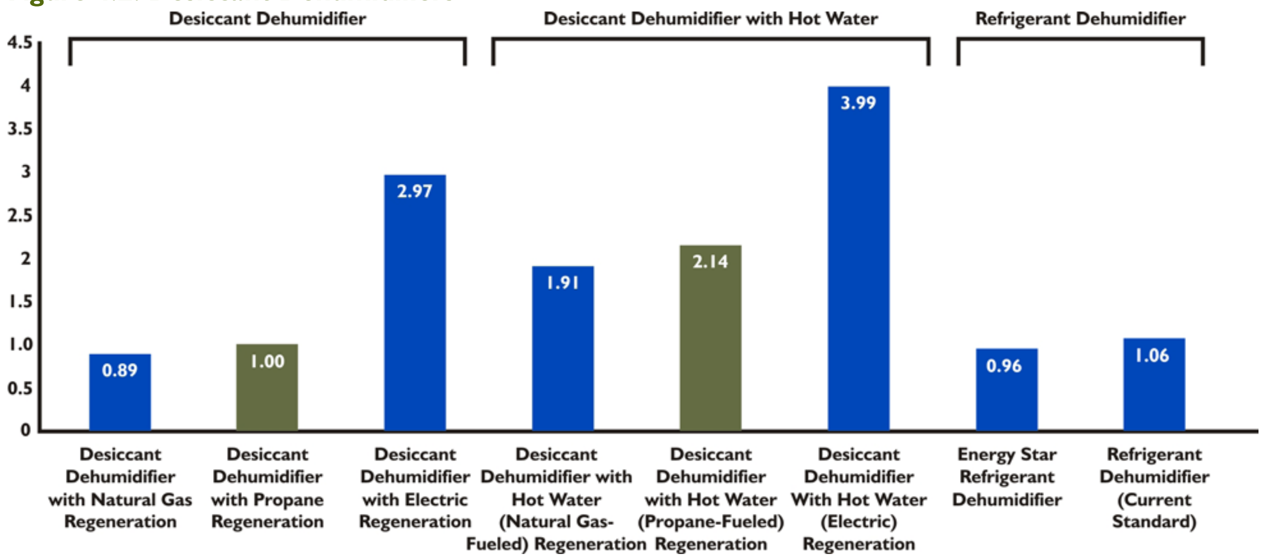
4. Summary of Findings

Figure 4.1. 10-Ton Gas Engine-Driven Heat Pump



Note: Results are normalized to propane engine-driven heat pump. Comparisons between heat pumps and heating and cooling provided separately are valid using this graph.

Figure 4.2. Desiccant Dehumidifiers



Note: Results are normalized to desiccant dehumidifier with propane regeneration. Comparisons between desiccant dehumidifiers, desiccant dehumidifiers with hot water, and refrigerant dehumidifiers are valid using this graph.

Figure 4.3. Residential Space Heating

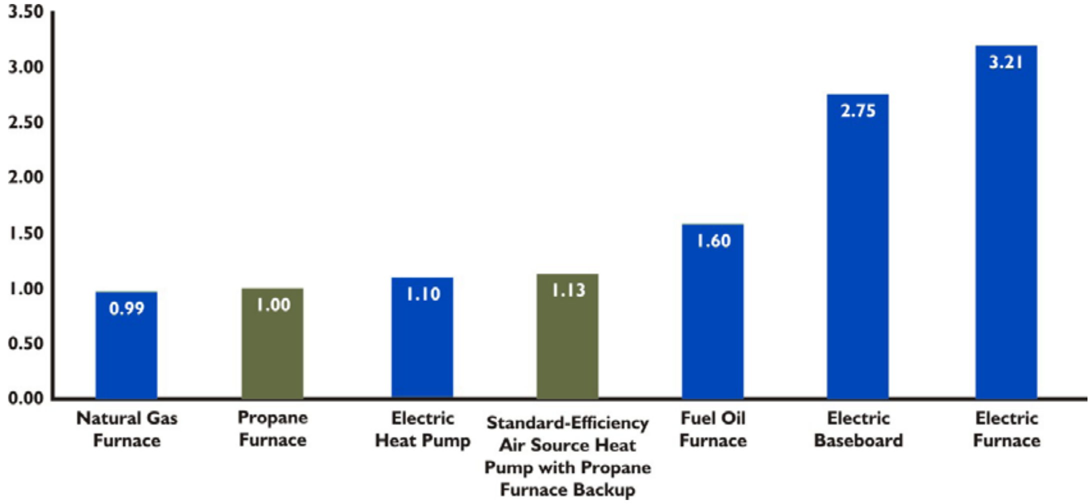
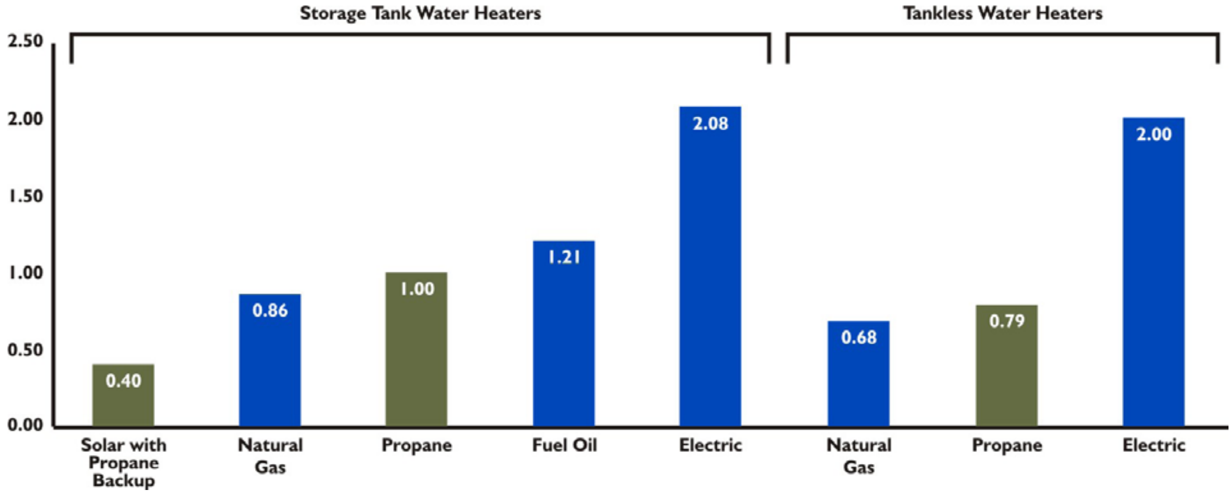


Figure 4.4. Residential Water Heaters



Note: Results are normalized to propane storage tank water heater. Comparisons between storage tank and tankless water heater units are valid using this graph.

Figure 4.5. GM 6.0L Engine

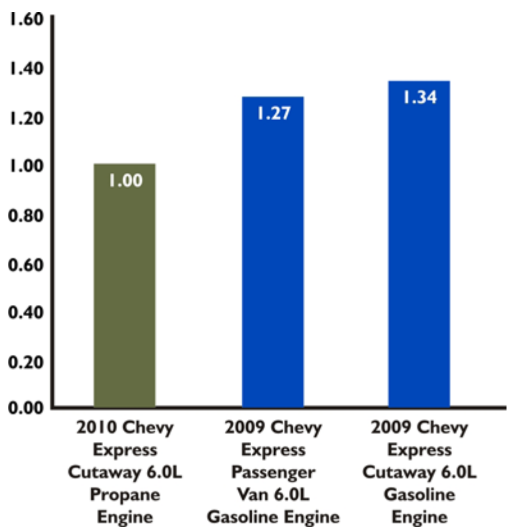


Figure 4.6. Ford F-150

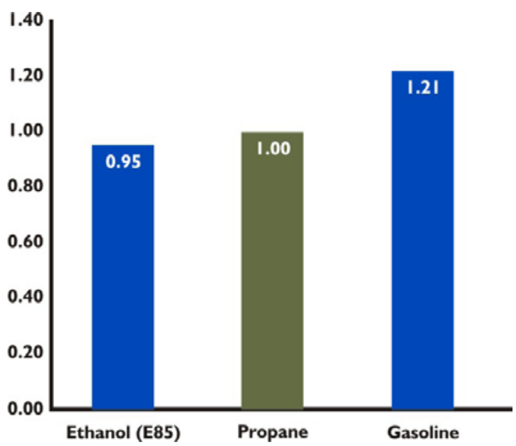


Figure 4.7. Ford F-250

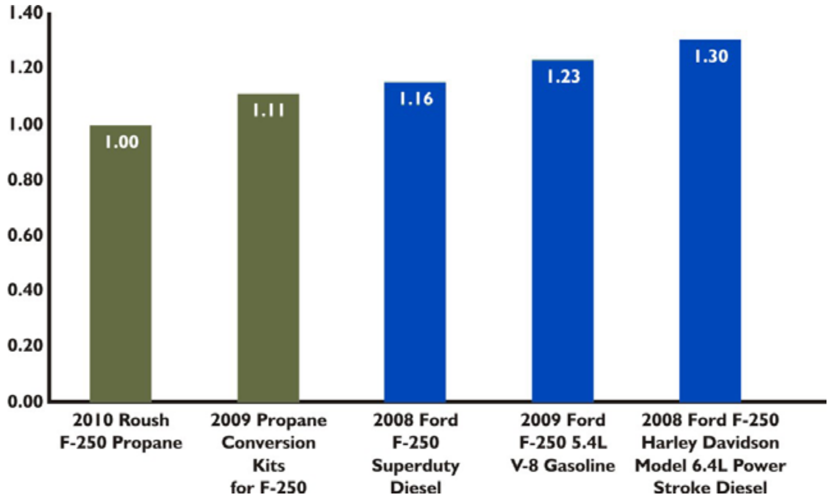


Figure 4.8. School Buses

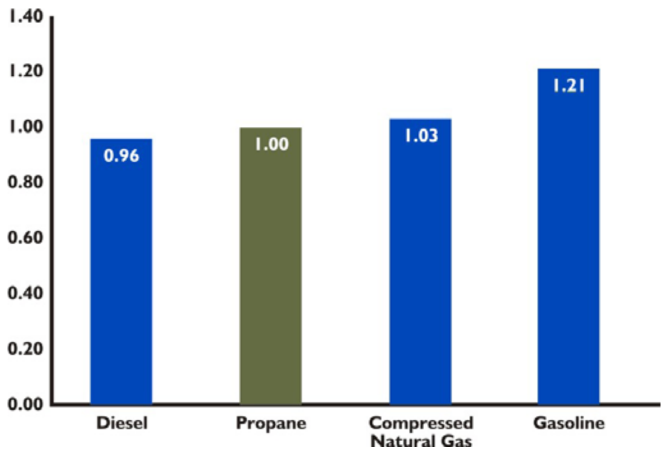
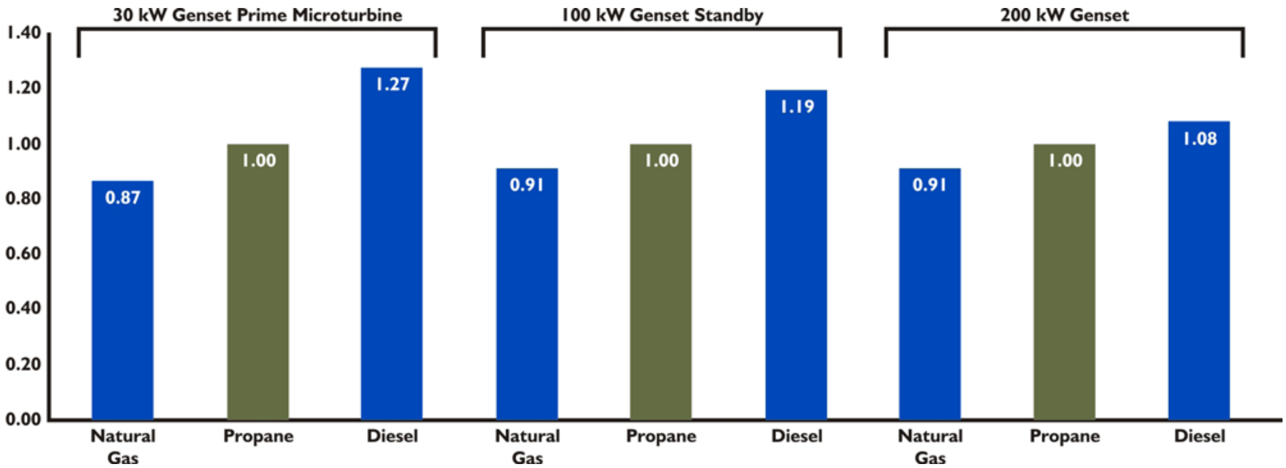


Figure 4.9. Distributed Generation



Note: Results are normalized to propane emissions for each genset type. Comparisons between different genset types are not meaningful because of the different service requirements of each genset type.

Figure 4.10. Forklifts

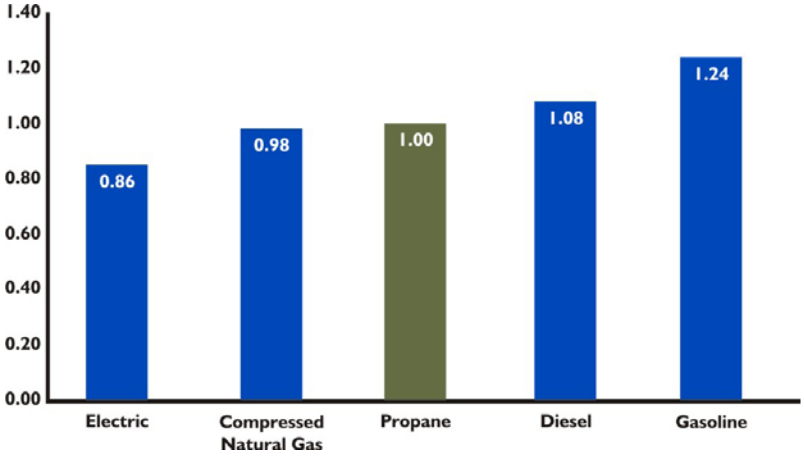
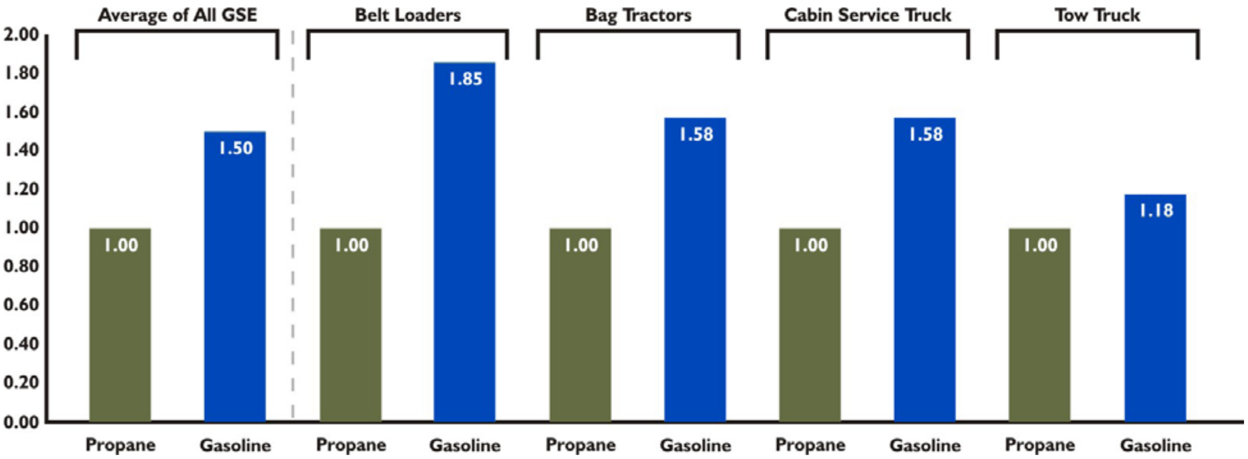


Figure 4.11. Ground Service Equipment (GSE)



Note: Results are normalized to propane emissions for each vehicle type. Comparisons between different vehicles types are not meaningful because of the different service requirements of each vehicle type.

Figure 4.12. Commercial Mowers

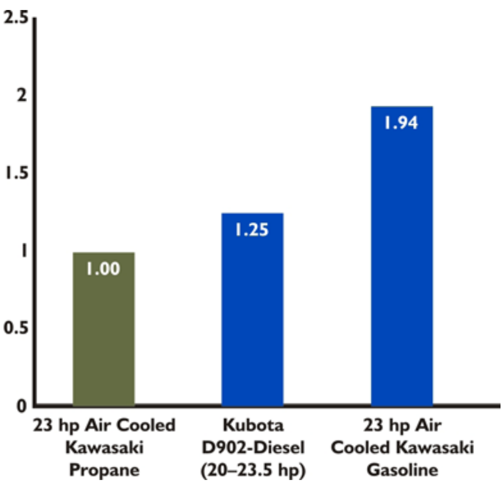
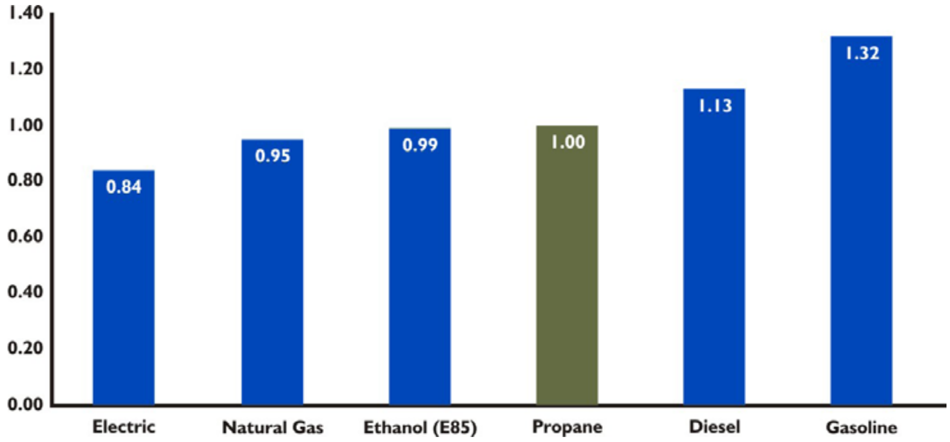


Figure 4.13. Irrigation Engines



5. Applications

The following pages present a series of one-page summaries for the thirteen applications considered in this study. Each summary contains energy end-use data, market data, and a comparison of the greenhouse gas emissions of fuels used in the application. The summaries also include a listing of key assumptions and references. A complete list of assumptions and references for each application is provided in Appendix B.

Residential and Commercial Applications

- **10-ton gas engine-driven heat pump** –10-ton propane-fueled heat pumps provide both heating and cooling in commercial buildings, combining the functions of furnaces and air conditioners into a single unit. Currently, nearly 80 percent of commercial buildings with packaged heat pumps use electricity as the energy source for heating (EIA 2003a), and nearly 100 percent use electricity for cooling, though interest in propane- and natural gas-fueled engines for this purpose are growing (EIA 2003b).
- **Desiccant dehumidifiers** – Desiccant dehumidifiers, fueled by propane, natural gas, or electricity, offer an alternative technology to remove moisture from indoor air for residential and commercial use. Approximately 91,000 U.S. households utilize high-capacity humidifiers capable of removing more than 75 pints of water per day (Census Bureau 2008; Swager and Lee 2009).
- **Residential space heating –** Homes are most commonly heated by either a centralized system that moves warm air through ducts or hot water through pipes, or by separate heating units (usually electric) distributed throughout the home. Furnaces can be gas-fired (natural gas or propane), oil-fired, or electric. Approximately 7.6 million U.S. households rely on propane for home heating (EIA 2009).
- **Residential water heaters** – 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 5.8 million U.S. households use propane for water heating (EIA 2009).

On-Road Applications

- **GM 6.0L engine** – The GM 6.0-liter engine is used in several General Motors commercial vehicle models, including the Chevy Express Cutaway Van and the Chevy Express Passenger Van. The powerful V-8 engine, which provides upwards of 300 horsepower, has been designed for quiet operation and optimum performance for commercial use.
- **Ford F-150** – Light-duty trucks, such as the Ford F-150, constitute a significant portion of the U.S. vehicle fleet. While gasoline fuels the majority of light-duty trucks in the United States, ethanol (E85) and propane have gained greater use in recent years.
- **Ford F-250** – The Ford Super Duty F-250 is a larger, heavier model truck than previous models built for commercial and industrial use. Roush has incorporated a liquid propane injection system into the F-250 engine, and other manufacturers offer conversion kits that can be used to convert gasoline-fueled vehicles to propane-fueled vehicles.
- **School buses** – Medium-duty engines are used for many commercial and municipal vehicles, including school buses. Diesel currently fuels the majority of school buses in the United States, despite the EPA considering its exhaust to be one of the air pollutants that pose the greatest risks to public health. With approximately 450,000 school buses running each school day (School Bus Fleet 2007), many school districts have been moving to alternative fuels such as propane and compressed natural gas to address this emissions issue.

Off-Road Applications

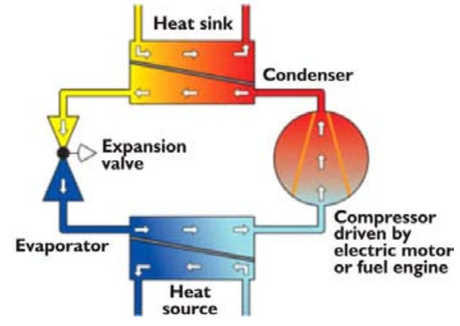
- **Commercial mowers** – Turfgrass on residential lawns, sports fields, golf courses, parks, roadsides, and public and commercial land covers more than 40 million acres in the United States (Milesi et al 2005). This turfgrass requires frequent, sometimes daily mowing which contributes to greenhouse gases. While commercial mowers are typically fueled by gasoline or diesel, small engine technology advancements and alternative fuel technologies have allowed propane-fueled mowers to enter the market.
- **Distributed generation** – Distributed generation (DG) technology provides electricity to off-grid areas and serves as a backup source of power for hospitals, factories, telecommunication centers, and other crucial operations. In total, approximately 12.3 million DG units are currently installed in the United States (DG Monitor 2005), running mainly on diesel fuel, although the use of systems that are fueled by propane and natural gas is rapidly growing.
- **Forklifts** – Unlike most vehicles, forklifts use fuel for both vehicle propulsion and load lifting work. Indoor air quality concerns restrict the use of diesel for heavy-duty jobs; electric forklifts are normally used for light-duty jobs, while propane can be used for both.
- **Ground service equipment** – Different types of airport ground service equipment, including catering vehicles, pushback tugs, baggage carts and handlers, air starters, belt loaders, and tow trucks, perform functions to support aircraft operation between flights. The use of alternative fuels for ground service needs can reduce the greenhouse emissions from airport operations, helping airports to comply with Voluntary Airport Low Emission Vehicle Program (VALE) standards.

Agriculture Applications

- **Irrigation engines** – U.S. farms rely on approximately 500,000 irrigation pumps to deliver water from reservoirs, lakes, streams, and wells for crop production (USDA 2004). 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.

10-Ton Gas Engine-Driven Heat Pump

A 10-ton (120,000 Btu/hr) propane engine-driven heat pump provides both heating and cooling for commercial use. Heat pumps are an alternative to operating two separate heating (usually via a furnace or boiler) and cooling (via dedicated air conditioner) devices. Heat pumps function by transferring heat between a source and a sink using a relatively small amount of energy, typically driven by an electric motor or a propane- or natural gas-fueled engine operating a compressor (see diagram).



Source: GrEnergy 2009

Energy efficiency standards for electric heat pumps, furnaces/boilers, and central cooling units have been established by the federal government and represent a consistent means for comparison against the propane-fueled engine heat pump. Federal standards apply to commercial package air conditioning and heating equipment with capacities of 65,000–135,000 Btu/hr. Greenhouse gas emissions analyses were conducted for two types of heat pumps (air source and water-cooled) and for separate heating and cooling units. The propane and natural gas engine heat pumps analyzed in this study transfer heat via an air-sourced configuration.

Market Data

- Nearly 80 percent of commercial buildings with packaged heat pumps use electricity as the energy source for heating. The remaining units use natural gas, propane, or other fuel to provide heat (EIA 2003a).
- The cooling energy source for commercial packaged heat pumps in the United States is provided by electricity in nearly 100 percent of units, according to a 2003 survey by the Department of Energy (EIA 2003b).

Energy End-Use and Climate Change Comparison	Energy Use (million Btu per year)		Annual Life-cycle GHG Emissions per unit (kg CO_2 equivalent per year)		
Heating/Cooling Unit	**Heating**	**Cooling**	**Upstream**	**End-use**	**Total**
Natural Gas Engine-Driven Heat Pump	90.1	130.0	2,670	11,700	14,200
Propane Engine-Driven Heat Pump	90.1	130.0	2,520	13,800	16,500
CAS* Electric Heat Pump (Best Available)[1]	33.8	42.4	16,800	0	16,800
CAS Electric Heat Pump (2010 Standard)[2]	41.0	44.3	18,800	0	18,800
CAS Electric Heat Pump (Current Standard)[2]	45.0	54.8	22,100	0	22,100
Natural Gas Furnace and CAS Electric Air Conditioner[3]	173.0	54.8	14,100	9,220	23,300
Propane Furnace and CAS Electric Air Conditioner[3]	173.0	54.8	14,200	10,900	25,100
Fuel Oil Furnace and CAS Electric Air Conditioner[3]	173.0	54.8	15,300	12,800	28,010
Electric Furnace and CAS Electric Air Conditioner[3]	142.0	54.8	43,600	0	43,600

Note: Totals may not add due to rounding.
*CAS is the acronym for Central Air Source.

Key Assumptions

1. Energy use and greenhouse gas emissions per year are based on delivering 100 million Btu of heat and 100 million Btu of heat removed (cooling). This is equivalent to a 10-ton unit operating at capacity for 10 percent of the year.
2. GHG emissions from point of extraction to point of use are based on GREET model 1.8c.

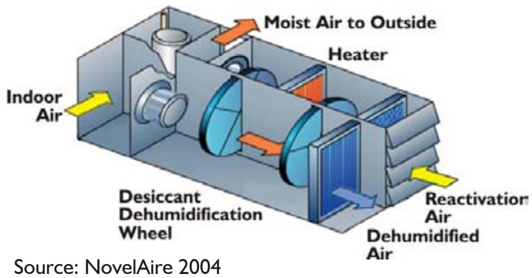
Footnotes

1. Best available unit in the category of Central Air Source Electric Heat Pump 65–135 kBtu/hr (DOE 2009c).
2. CAS Electric Heat Pump 65–135 kBtu/hr. Standards are based on federal regulations as specified by the U.S. Department of Energy (DOE 2009a)
3. CAS Electric Air Conditioner 65–135 kBtu/hr. Furnace energy standards are for units less than 225 kBtu/hr. Both the furnace and air conditioner operate at current minimum federal energy standards (DOE 2009a).

See Appendix B for full list of assumptions and references.

Desiccant Dehumidifiers

High-capacity dehumidifiers are designed to remove between 75 and 185 pints of water from the air per day. They can be configured with a refrigerant system or a regenerative desiccant. These two types of systems work differently but perform the same function of removing moisture from indoor air. Currently, the most common type for residential use is an electric-powered refrigerant dehumidifier. Desiccant dehumidifiers, which use propane, natural gas, and/or electricity, represent an alternative technology for high-capacity residential dehumidification.



Source: NovelAire 2004

Desiccant dehumidifiers adsorb moisture from the indoor air in the rotating dehumidification wheel and return the dry air back to the indoor space (see diagram). The moisture-containing portion of the wheel rotates into a regeneration section. Heat from a propane, natural gas, hot water, or electric heater causes the wheel to release its moisture, which is exhausted to the outside. Energy efficiency standards for high-capacity residential refrigerant dehumidifiers have been established by the federal government and present a consistent means for comparison with the desiccant dehumidifier technology.

Market Share of Desiccant Dehumidifier Classes

Source: Swager and Lee 2009

Market Data

- About 91,000 households in the United States use high-capacity dehumidifiers (removes >75 pints/day) (Census Bureau 2008, Swager and Lee 2009).

Energy End-Use and Climate Change Comparison	Energy Use (Btu per pint of water removed)	Annual Life-cycle GHG Emissions per unit (kg CO_2 equivalent per pint of water removed)		
Dehumidification Unit	**Heating**	**Upstream**	**End-use**	**Total**
Desiccant Dehumidifier with Natural Gas Heater[1]	1,730	0.048	0.085	0.133
Desiccant Dehumidifier with Propane Heater[1]	1,730	0.049	0.100	0.149
Desiccant Dehumidifier with Electric Heater[1]	2,000	0.443	0	0.443
Desiccant Dehumidifier with Hot Water (Natural Gas)[2]	3,700	0.104	0.182	0.285
Desiccant Dehumidifier with Hot Water (Propane)[2]	3,700	0.106	0.214	0.320
Desiccant Dehumidifier with Hot Water (Electric)[2]	2,700	0.596	0	0.596
Energy Star Refrigerant Dehumidifier (Electric)[3]	646	0.143	0	0.143
Current Standard Refrigerant Dehumidifier (Electric)[4]	718	0.159	0	0.159

Note: Totals may not add due to rounding.

Key Assumptions

1. Energy use for desiccant dehumidifiers are based on manufacturer-published specifications at full load nameplate capacity at Association of Home Appliance Manufacturers (AHAM) standard conditions (80°F, 60 percent relative humidity). Energy use for refrigerant dehumidifiers are based on minimum Energy Star or federal standards as noted.
2. Dehumidifier capacity for all types evaluated in the study fall in the range of 75–185 pints of water removed per 24 hours of operation at AHAM conditions.
3. GHG emissions from point of extraction to point of use are based on GREET model 1.8c.

See Appendix B for full list of assumptions and references.

Footnotes

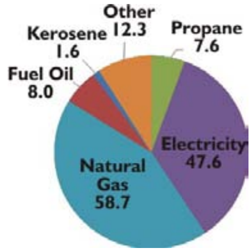
1. Desiccant dehumidifier with regeneration system fueled by propane or natural gas, or powered by electricity is based on NovelAire Comfort Dry 400 (NovelAire 2009a).
2. Desiccant dehumidifier with hot water to regenerate the desiccant cassette is based on NovelAire Comfort Dry 250 (NovelAire 2009b). The water is heated with a propane, natural gas, or electric water tank.
3. Refrigerant dehumidifiers adhere to energy standard for high-capacity units qualifying for Energy Star status (EPA 2009).
4. Refrigerant dehumidifiers adhere to federal energy standard for residential units with capacity of more than 75 pints per day, as stipulated by Energy Policy Act of 2005 (DOE 2009).

Residential Space Heating

Homes are most commonly heated by either a centralized system that moves warm air through ducts or hot water through pipes and radiators, or by separate heating units (usually electric) distributed throughout the home. Furnaces can be gas-fired, oil-fired, or electric; most gas furnaces can be fueled by either natural gas or propane. Most heat pumps use electricity to heat homes by moving heat and only rely on electrical resistance when they cannot gather enough heat from the air. This makes heat pumps more efficient than electric radiators and allows them to deliver more heat energy than the electricity that heat pumps consume. Dual-fuel systems also combine electric-powered heat pumps with propane-fueled furnaces.

Because boilers have the same range of energy efficiencies as furnaces, they were not added to this analysis, but their greenhouse gas emissions can reasonably be assumed to be comparable to those of furnaces. 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.

Space-Heating Fuels Used by U.S. Households (million households)



Source: EIA 2009

Market Data

- Approximately 7.6 million U.S. households rely on propane for home heating (EIA 2009).

Energy End-Use and Climate Change Comparison	Energy Use (Btu per heating system per year)[1]	Annual Life-cycle GHG Emissions per unit (kg CO_2 equivalent per heating system per year)		
Unit		**Upstream**	**End-use**	**Total**
Natural Gas Furnace	46.7	536	2,490	3,020
Propane Furnace	46.7	566	2,490	3,050
Electric Heat Pump	15.3	3,370	0	3,370
Standard-Efficiency Air Source Heat Pump with Propane Furnace Backup	35.1	1,600	1,850	3,450
Fuel Oil Furnace	53.1	965	3,910	4,870
Electric Baseboard	38.0	8,400	0	8,400
Electric Furnace	44.4	9,810	0	9,810

Note: Totals may not add due to rounding.

Key Assumptions

1. Estimated useful heat delivered by a propane furnace was 38 million Btu and was based on an average energy consumption of 52.6 million Btu per year of propane in a region with 4000–5499 heating degree days (EIA 2001) after estimated average efficiency (15 percent) and duct losses (15 percent) were applied.
2. Energy efficiencies are based on the highest annual fuel utilization efficiency (AFUE) reported in the GAMA Directory of Certified Efficiency Ratings (GAMA 2006) for gas and fuel oil furnaces with greater than 60,000 Btu/hr ratings.
3. Assumed 100 percent conversion efficiency of electric heaters and electric furnaces.

See Appendix B for full list of assumptions and references.

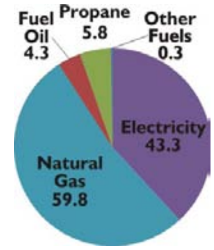
Footnotes

1. Based on a furnace delivering 38 million Btu of useful heat, typical of a furnace in a winter climate zone such as the mid-Atlantic.

Residential Water Heaters

Propane residential water heaters include both tank storage units and instantaneous ("tankless") water heaters. While storage water heaters keep a constantly available supply of hot water, tankless units heat water as it is supplied to the end user. Both storage and tankless units can be gas-fueled or electric. Gas water heaters are designed to run on either propane or natural gas. Fuel oil and solar power, however, are only used for storage tank water heating. 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 (DOE 2005d). 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.

Water-Heating Fuels Used by U.S. Households (million households)[2]



Sources: EIA 2009

Market Data

- Approximately 5.8 million U.S. households use propane for water heating (EIA 2009).

Energy End-Use and Climate Change Comparison		Energy Use (MMBtu per unit per year)[1]	Annual Life-cycle GHG Emissions per unit (kg CO_2 equivalent per unit per year)		
Unit			Upstream	End-use	Total
Storage Tank Heater	Solar with Propane Backup	7.00	73.5	398	472
	Natural Gas	15.8	181	841	1,020
	Propane	15.8	192	992	1,180
	Fuel Oil	15.6	283	1,140	1,430
	Electric	11.1	2,460	0	2,460
Tankless Water Heater	Natural Gas	12.4	143	663	806
	Propane	12.4	151	782	933
	Electric	10.7	2,360	0	2,360

Note: Totals may not add due to rounding.

Key Assumptions

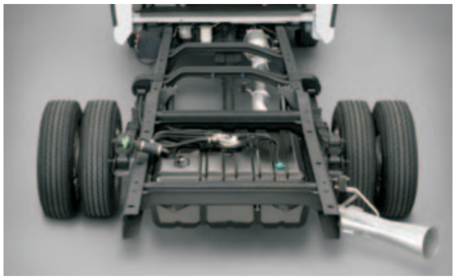
1. Energy efficiencies are based on the highest energy factor reported in the GAMA Directory of Certified Efficiency Ratings (GAMA 2006). Solar water heater energy efficiency is based on DOE 2005c.
2. Fuel consumption of propane storage tank heater is based on average residential energy consumption for water heating. Tankless propane fuel consumption is based on relative efficiency compared to a tank heater. See Appendix B for efficiency values (energy factors) used.
3. The solar water heater uses electricity for fluid circulation, which delivers 60 percent of water heating load with the remaining 40 percent from a backup propane-fueled system.

See Appendix B for full list of assumptions and references.

Footnotes

1. Based on equal hot water delivery compared to a propane storage water heater using an average 15.8 MMBtu/yr (EIA 2001), equal to 173 gallons of propane per year.
2. Includes all types of water heaters.

GM 6.0L Engine



The GM 6.0-liter engine is a powerful engine that is used in General Motors' commercial vehicles, including the Chevrolet Express Van (both Passenger and Cargo) and Chevrolet Express Cutaway. These vehicles and their applications require versatility and reliability, which can be provided by the GM 6.0-liter V-8.

The engine, part of GM's Gen IV V-8 engine family, is designed for quiet operation, featuring a quieter alternator, full-floating piston pins, and an externally mounted dampening patch on the oil pan. The 6.0-liter engine also offers a fast-idle option that is ideal when it is necessary to run multiple accessories while idling at a worksite. The engine provides long-lasting performance and engine components that can reduce maintenance needs.[1]

A growing number of federal and state vehicle emission standards and regulations have increased the availability of engines that can be run on alternative fuels, including propane. Propane's high Btu content and low emissions can offer efficient and reliable power for commercial vehicles, while reducing greenhouse gas emissions.

Market Data

- The Chevrolet Express Cargo/Passenger Van and Chevrolet Express Cutaway offer a variety of engine options, including a 4.3-liter V-6 (Cargo/Passenger only); 4.8-liter V-8 (Cargo/Passenger Van only); 5.3-liter V-8, which offers an ethanol option; 6.0-liter V-8; and 6.6-liter diesel-fueled V-8.
- The 6.0-liter V-8 provides 323 horsepower in the Chevrolet Express Cutaway and 300 horsepower in the Chevrolet Express Cargo/Passenger Van.

Energy End-Use and Climate Change Comparison	Energy Use (Btu per 100 miles)	Annual Life-cycle GHG Emissions per unit (kg CO_2 equivalent per 100 miles)		
Unit		**Upstream**	**End-use**	**Total**
2010 Chevy Express Cutaway 6.0L Propane Engine	1,090,000	13.2	69.8	83.0
2009 Chevy Express Passenger Van 6.0L Gasoline Engine	1,180,000	21.7	84.1	106
2009 Chevy Express Cutaway 6.0L Gasoline Engine	1,246,000	22.8	88.5	111

Note: Totals may not add due to rounding.

Key Assumptions

1. We assume that the fuel economy of the 2009 Chevy Express Cutaway 6.0L Gasoline Engine is 95 percent of the fuel economy of the 2009 Chevy Express Passenger Van 6.0L Gasoline Engine, due to the higher gross vehicle weight of the Cutaway.

Footnotes

1. Energy use for propane vehicle is based on variable engine load drive cycle and 90 percent of the gross vehicle weight rating (GVWR).

See Appendix B for full list of assumptions and references.

Ford F-150

Light-duty trucks, such as the Ford F-150, 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 Roush F-150 pickup uses Liquid Propane Injection (LPI) technology to make the F-150 a dedicated propane vehicle. Using an engine computer specifically calibrated for propane, the LPI system directly replaces the original equipment manufacturer (OEM) gasoline injection system. The propane-fueled F-150 offers the same performance as a gasoline-fueled pickup truck. Ethanol (E85) may also be used in Ford's flex-fuel model of the F-150, which can be fueled by either regular gasoline or E85 (composed of 85% ethanol and 15% petroleum by volume).

Market Data

- The Ford F-series pickup trucks have been the top-selling vehicles in the United States for 27 consecutive years, with close to 1 million vehicles sold in each of the past several years (Ford Motor Company 2009).

Energy End-Use and Climate Change Comparison	Energy Use (MMBtu per vehicle per year)[1]	Annual Life-cycle GHG Emissions per unit (kg CO_2 equivalent per vehicle per year)		
Unit		**Upstream**	**End-use**	**Total**
Ethanol (E85)	85.1	118	5,860	5,980
Propane	85.1	1,030	5,280	6,320
Gasoline	85.1	1,690	5,960	7,660

Note: Totals may not add due to rounding.

Key Assumptions

1. Fuel efficiencies used are from the GREET model for 6,000–8,500 lbs. GVWRs of vehicles were used to calculate fuel use for equivalent miles traveled. See Appendix B for values.
2. GHG emissions factors for E85 are specifically for combustion in a flex-fuel vehicle.

See Appendix B for full list of assumptions and references.

Footnotes

1. Based on a pickup truck traveling 10,000 miles per year at 14.7 miles per gasoline-equivalent gallon.

Ford F-250

Current generation Ford Super Duty F-250 trucks are larger, heavier-built commercial/industrial series pickup trucks with body-on-frame steel ladder frames, heavier axles, springs, brakes, and transmissions than the light-duty F-150. The F-250's standard medium-duty engine is also more powerful than the F-150's and is either a 5.4L-modular V-8 or a 6.4L powerstroke V-8 diesel.

The Roush retrofit of the F-250 pickup uses LPI technology to make the F-250 a dedicated propane vehicle. Using an engine computer specifically calibrated for propane, the LPI system directly replaces the OEM gasoline injection system. Changes to the standard F-250 include a 62-gallon in-bed fuel tank, stainless steel fuel lines, aluminum fuel rails, Roush tuning, and related hardware.

Other manufacturers, such as Technocarb, PRINS, and IMPCO, offer conversion kits for medium-duty trucks such as the Ford F-250. These propane conversion kits reportedly reduce the fuel economy of a vehicle by up to 15 percent, while some do not reduce fuel economy at all. This analysis examines the emissions-reducing capabilities of these propane kits and the dedicated propane F-250 as compared to F-250s fueled by other sources.

Market Data

- The Ford Super Duty is a line of commercial trucks (over 8,500 lbs., or 3,900 kg, GVWR) introduced in 1998 for the 1999 model year. The F-250 to F-550 Super Duty trucks are assembled at the Kentucky Truck Assembly in Louisville, Kentucky.

Energy End-Use and Climate Change Comparison	Energy Use (Btu per 100 miles)	Annual Life-cycle GHG Emissions per unit (kg CO_2 equivalent per 100 miles)		
Unit		**Upstream**	**End-use**	**Total**
2010 Roush F-250 Propane	830,000	10.1	53.8	63.9
2009 Propane Conversion Kits for F-250	922,000	11.2	59.5	70.7
2008 Ford F-250 Superduty Diesel	809,000	14.7	59.2	73.9
2009 Ford F-250 5.4L V-8 Gasoline	866,000	17.2	61.6	78.8
2008 Ford F-250 Harley Davidson Model 6.4L Power Stroke Diesel	906,000	16.5	66.4	82.8

Note: Totals may not add due to rounding.

Key Assumptions

1. Based on reported fuel economies, each vehicle was assumed to travel 100 miles. The total GHG emissions were calculated based on the total fuel used to travel 100 miles. Results were normalized to the Roush 2010 F-250 LPG total GHG emissions.
2. The EPA does not measure the fuel economy of medium-duty trucks such as the F-250. All reported F-250 fuel economy data is taken from secondary sources.
3. The Roush 2010 F-250 propane-fueled truck is still in the developmental stages. Roush estimates a 600-mile range from 55 usable propane gallons.

See Appendix B for full list of assumptions and references.

School Buses

Medium-duty engines are used for many commercial and municipal vehicles, including school buses. Diesel currently fuels the majority of school buses in the United States today, despite the fact that exposure to diesel exhaust is known to cause a number of adverse health effects.

Diesel exhaust is also among the air pollutants considered by the EPA to pose the greatest risks to public health (CARB 1998, EPA 2003). As a consequence, many school districts across the country have been looking for alternatives to diesel in order to fuel their school bus fleets. A propane-fueled school bus using an EPA-certified 8.1L LPI system is one such alternative.

Market Data

- There are approximately 450,000 school buses transporting 24 million school children each school day (School Bus Fleet 2007).
- Propane fuels more than 1,400 of the school buses in the United States (PERC 2000).

Energy End-Use and Climate Change Comparison	Energy Use (MMBtu per bus per year)[1]	Annual Life-cycle GHG Emissions per bus (kg CO_2 equivalent per bus per year)		
Unit		**Upstream**	**End-use**	**Total**
Diesel	189	3,440	13,800	17,300
Propane	240	2,900	15,100	18,000
Compressed Natural Gas	252	4,460	14,000	18,500
Gasoline	240	4,770	17,000	21,800

Note: Totals may not add due to rounding.

Key Assumptions

1. Uses fuel efficiencies for diesel and CNG buses reported in ANTARES Group 2004.
2. Fuel efficiencies for propane- and gasoline-fueled vehicles were estimated by applying the ratio of fuel efficiencies used by the GREET model for 6,000–8,500 lbs. GVW vehicles (the largest size class in the model) to CNG school bus fuel efficiency reported by ANTARES Group.

Footnotes

1. Based on a standard size (Type C) school bus traveling 9,000 miles per year.

See Appendix B for full list of assumptions and references.

Distributed Generation

Distributed generation refers to the production of electricity at or near the point at which the power is used. Distributed generation systems are used in residential, commercial, and industrial sectors as a prime source of electricity or as a backup source in case of emergency. Prime generators are often used in remote areas not reached by the power grid or by users that require greater reliability than the local utility can provide. Backup generators include standby supply for hospitals, factories, telecommunication centers, and other critical operations.

Generation capacities for on-site usage typically range from a few kilowatts to several hundred kilowatts. Types of DG that are fueled by propane include microturbines, generator sets (gensets), polymer electrolyte membrane (PEM) fuel cells, and solid oxide fuel cells (SOFC).[1] Microturbines operate like jet engines that produce electricity instead of thrust, while gensets consist of a combustion engine driving an electrical generator. Fuel cells generate electricity by the chemical combination of fuel and oxygen. GHG emissions analyses were conducted for three combinations of capacities, operating use (prime/standby), and type (microturbine/genset), and are intended to present an emissions profile representative of common distributed generation use.

Market Data

- In total, there are approximately 12.3 million DG units installed in the United States with an aggregate capacity of 222 GW (DG Monitor 2005).
- In the commercial sector, about 5 percent of businesses have the ability to generate electricity on site, with 78 percent of those businesses using DG for emergency backup generation (EIA 2006).
- Most of the installed DG capacity is combustion gensets, with alternative types of DG rapidly growing. The microturbine industry is an emerging technology, with the leading supplier — Capstone — having delivered about 2,500 units (30 kW and 60 kW units) (Gas Plants, Inc. 2006).

Energy End-Use and Climate Change Comparison		Energy Use of Representative DG (MMBtu/unit/yr)[2]	Annual Life-cycle GHG Emissions per unit (kg CO_2 equivalent per year)		
Unit			Upstream	End-use	Total
30 kW prime microturbine	Natural Gas	1,100	12,700	58,800	71,500
	Propane	1,100	13,400	69,100	82,600
	Diesel	1,150	20,900	84,300	105,000
100 kW standby genset	Natural Gas	22.0	253	1,170	1,420
	Propane	20.9	253	1,300	1,560
	Diesel	20.3	370	1,490	1,860
200 kW prime genset	Natural Gas	5,360	61,500	285,000	346,000
	Propane	5,090	61,700	318,000	380,000
	Diesel	4,490	81,700	329,000	411,000

Note: Totals may not add due to rounding.

Key Assumptions

1. Energy use is based on vendor specs for power-only (no CHP) 60Hz gensets operating at 100 percent nameplate load for 7 hours per day for prime and 20 hours per year for standby gensets.
2. Emissions from point of extraction to point of use are based on GREET model 1.8c.

See Appendix B for full list of assumptions and references.

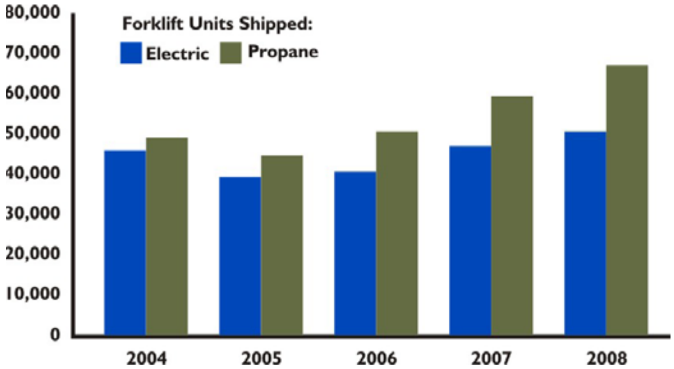
Footnotes

1. GHG emission profiles for PEMs and SOFCs have not been separately evaluated in this study.
2. Representative generators for 30 kW microturbines: Capstone C30 Liquid Fuel, Capstone C30 Natural Gas; 100kW genset: John Deere J150U, Cummins 100GGHH; 200kW genset: Armstrong AJD200, Caterpillar G3508

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: Class 1–3 forklifts are electric-motor driven and Class 4–6 are driven by internal combustion engines. More than 670,000 propane-fueled forklifts currently operate in the United States.

Electric and Propane Forklift Units Shipped in the United States



Source: ITA 2006

Unlike most vehicles, forklifts use fuel not only for vehicle propulsion (with maximum speeds usually of 10–15 mph) but also for load lifting work. A large variety of forklifts can run on propane. Other energy sources commonly used to power forklifts are electricity, compressed natural gas, gasoline, and diesel. Fuel choice may depend on load size and air quality concerns; electric forklifts are normally used for light-duty jobs, while diesel fuel is typically used for heavy-duty loads and is restricted to outdoor use for air quality reasons. Propane is used for both light- and heavy-duty applications.

Energy End-Use and Climate Change Comparison	Energy Use (MMBtu per forklift per year)[1]	Annual Life-cycle GHG Emissions per forklift (kg CO_2 equivalent per forklift per year)		
Unit		**Upstream**	**End-use**	**Total**
Electric	25.6	5,650	0	5,650
Compressed Natural Gas	91.6	1,620	4,860	6,480
Propane	88.5	1,070	5,520	6,590
Diesel	78.2	1,420	5,720	7,140
Gasoline	89.9	1,790	6,380	8,170

Note: Totals may not add due to rounding.

Key Assumptions

1. Assumes as in Delucchi 2000 that two-thirds of forklift energy use goes to vehicle propulsion and one-third goes to lifting.
2. For forklifts powered by fuels other than propane, the relative efficiencies of lifting and propulsion compared to a propane-based system were used to estimate the fuel consumption of those vehicles.
3. Thermal engine efficiencies estimated by Delucchi were used to calculate fuel required for lifting work.
4. Relative fuel efficiencies used by the GREET model for 6,000–8,500 lbs. GVW vehicles were used to calculate fuel required for propulsion.

See Appendix B for full list of assumptions and references.

Footnotes

1. Based on an average propane-fueled forklift using 973 gallons of propane per year (Delucchi 2000) while operating at less than 100 horsepower.

Ground Service Equipment

Ground service equipment includes vehicles that service and support the operations of aircraft between flights on the airport apron. Examples include catering vehicles, pushback tugs, baggage carts and handlers, air starters, belt loaders, and tow trucks.

Ground service equipment frequently sits unused for long periods of time, during which traditionally used diesel fuel tends to stratify, creating performance issues. Additionally, daily usage of ground service equipment in the busy aviation industry has created increasing emissions concerns. In 2003, Congress established the Voluntary Airport Low Emission Vehicle Program (VALE) to reduce airport ground emissions at commercial service airports located in air quality nonattainment and maintenance areas.

Using propane to power ground service equipment can help to address these issues. Rather than stratifying while stagnant, propane remains in a uniform state. Additionally, this analysis demonstrates the potential of propane-fueled ground service equipment to respond to increasing regulations through a reduction in greenhouse gas emissions.

Market Data

- Commercial service airports are defined as public airports receiving scheduled service and with more than 2,500 enplaned passengers in a year. According to the Federal Aviation Administration, in 2007 there were 517 existing commercial service airports.
- The aviation industry contributes only 3 percent of global greenhouse gas emissions, but that number is expected to increase to 5 percent by 2050 (Airports Council International North America 2008).

Energy End-Use and Climate Change Comparison		Energy Use (Btu per hour)	Annual Life-cycle GHG Emissions per unit (kg CO_2 equivalent per hour)		
Unit			**Upstream**	**End-use**	**Total**
Average	Propane	N/A	N/A	N/A	8.38
	Gasoline	N/A	N/A	N/A	12.6
Belt Loaders	Propane	74,800	0.907	4.7	5.63
	Gasoline	114,000	2.26	8.16	10.4
Bag Tractors	Propane	124,000	1.51	7.86	9.37
	Gasoline	162,000	3.21	11.6	14.8
Cabin Service Truck	Propane	111,000	1.34	7.01	8.35
	Gasoline	144,000	2.87	10.4	13.2
Tow Truck	Propane	135,000	1.64	8.53	10.2
	Gasoline	131,000	2.61	9.41	12.0

Note: Totals may not add due to rounding.

Key Assumptions

1. Ground service equipment results are based on the calculated GHG emissions per hour.
2. The data in this analysis is based on a study conducted by the Air Canada Ground Handling Services and Transport Canada (Propane-Powered Airport Ground-Support Equipment Winter 2006).
3. It is assumed that the propane used during the study in Canada is of the same composition as propane produced in the United States.

See Appendix B for full list of assumptions and references.

Commercial 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 greenhouse gas 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.

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

Market Data

- Turfgrass is the largest irrigated crop in the United States, covering more than 40 million acres (Milesi et al 2005).[1]
- The total annual economic impact of the turfgrass industry in the United States is an estimated $62 billion (Haydu 2006).

Energy End-Use and Climate Change Comparison	Energy Use (Btu per hour)	Annual Life-cycle GHG Emissions per unit (kg CO_2 equivalent per hp-hr)		
Lawnmower Unit		**Upstream**	**End-use**	**Total**
23 hp AC Kawasaki Propane	94,100	0.050	0.258	0.308
Kubota D-902 Diesel (20—23.5 hp)	83,200	0.076	0.308	0.383
23 hp Air Cooled Kawasaki Gasoline	15,000	0.130	0.468	0.598

Note: Totals may not add due to rounding.

Key Assumptions

1. Commercial lawn mower results are based on the calculated GHG emissions per hour under medium to heavy load for a propane, gasoline, and diesel mower.
2. Propane and gasoline mower data is based on a study conducted by the Department of Plant Sciences at University of Tennessee, "Emissions, Economic and Performance Analysis of a Propane vs. Gasoline Fueled Mower." February 2009.
3. The fuel consumption of a lawn mower is assumed to be based on the engine size (horsepower) and the load on the mower.

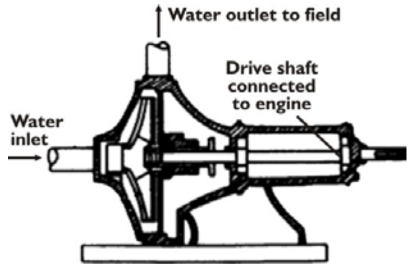
See Appendix B for full list of assumptions and references.

Footnotes

1. Based on calculation that 168, 812 km^2 = 40,478,826.7 acres.

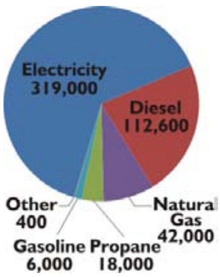
Irrigation Engines

Irrigation pumps deliver water from reservoirs, lakes, streams, and wells to farm fields at essential times to ensure productive crop harvests. Most irrigation pumps are centrifugal, driven by an engine connected to the drive shaft (see diagram). The smallest pumps are often operated by electric motors, while higher capacity wells tend to be operated by diesel, natural gas, and propane engines.[1]



Source: Scherer 1993

Energy Sources of U.S. Irrigation Pumps



Source: USDA 2004

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 type of engine, operating conditions, engine load, and maintenance.

This emissions analysis compares properly loaded and maintained 100-horsepower engines driving centrifugal irrigation pumps. Operating an irrigation pump at speeds outside of its optimal range can increase engine load, drastically decreasing engine performance and increasing fuel consumption.

Market Data

- In 2003, growers spent approximately $1.55 billion on energy for irrigation (USDA 2003).
- In the United States, there are approximately 500,000 irrigation pumps, powered by fuels and electricity (USDA 2004).

Energy End-Use and Climate Change Comparison	Energy Use[1] from 100 hp Irrigation Pumps (MMBtu/unit/yr)	Annual Life-cycle GHG Emissions per 100 hp Irrigation Pump (kg CO_2 equivalent)[2]		
Unit		Upstream	End-use	Total
Electric	217	47,900	0	47,900
Natural gas	842	9,660	44,700	54,400
Ethanol (E85)	829	1,150	55,300	56,500
Propane	767	9,300	47,900	57,200
Diesel	704	12,800	51,600	64,400
Gasoline	829	16,500	58,800	75,300

Note: Totals may not add due to rounding.

Key Assumptions

1. Upstream emissions (from point of extraction to point of use) are based on GREET model 1.8c.
2. Emissions at point of use are based on a 100 hp irrigation pump operating 749 hours per year.

See Appendix B for full list of assumptions and references.

Footnotes

1. Electricity (Smajstrla and Zazueta 2003; DOE-EPA 2007); Natural gas (Evans, Sneed, and Hunt 1996); Ethanol E85 (Smajstrla and Zazueta 2003; DOE-EPA 2007); Propane (Smajstrla and Zazueta 2003); Diesel (Smajstrla and Zazueta 2003); Gasoline (Smajstrla and Zazueta 2003).
2. Credit is given to ethanol for carbon sequestration during crop production.

Appendix A. Glossary

Carbon Dioxide (CO_2) Equivalent

The amount of carbon dioxide by weight emitted into the atmosphere that would produce the same estimated radiative forcing as a given weight of another radiatively active gas. Carbon dioxide equivalents are computed by multiplying the weight of the gas being measured (for example, methane) by its estimated global warming potential (which is 21 for methane). "Carbon equivalent units" are defined as carbon dioxide equivalents multiplied by the carbon content of carbon dioxide (i.e., 12/44) (EIA 2009).

End Use

Pertaining to the ultimate consumption of energy or fuel (adapted from "end user," EIA 2009).

Global Warming Potential (GWP)

An index used to compare the relative radiative forcing of different gases without directly calculating the changes in atmospheric concentrations. GWPs are calculated as the ratio of the radiative forcing that would result from the emission of one kilogram of a greenhouse gas to that from the emission of one kilogram of carbon dioxide over a fixed period of time, such as 100 years (EIA 2009).

Greenhouse Gases (GHG)

Those gases, such as water vapor, carbon dioxide, nitrous oxide, methane, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride, that are transparent to solar (short-wave) radiation but opaque to long-wave (infrared) radiation, thus preventing long-wave radiant energy from leaving Earth's atmosphere. The net effect is a trapping of absorbed radiation and a tendency to warm the planet's surface. (EIA 2009).

Life Cycle

The process from raw material acquisition (including exploration and production) through end use by the consumer.

Radiative Forcing

A change in average net radiation at the top of the troposphere (known as the tropopause) because of a change in either incoming solar or exiting infrared radiation. A positive radiative forcing tends on average to warm Earth's surface; a negative radiative forcing on average tends to cool Earth's surface. Greenhouse gases, when emitted into the atmosphere, trap infrared energy radiated from Earth's surface and therefore tend to produce positive radiative forcing (EIA 2009).

Upstream

Pertaining to any process, or the sum total of processes, used to produce or deliver energy up to the point of consumption by the end user, consisting of all processes used in the transformation of raw feedstock into fuel, including raw material extraction, processing, transportation, distribution, and storage (adapted from diagram, Argonne National Laboratory 2007).

Appendix B. Assumptions and References

Purpose of Report

References

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About Climate Change

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10-Ton Gas Engine-Driven Heat Pump

Assumptions

1. Energy use and greenhouse gas emissions per year are based on delivering 100 million British thermal units (Btu) of heat and 100 million Btu of heat removed (cooling). This delivery of heat and heat removed is equivalent to a 10-ton unit operating at capacity for 10 percent of the year.
2. A propane engine heat pump operates at the minimum coefficient of performance (COP) parameters for heating and cooling as shown in PERC **Docket 12314** (PERC 2007).
3. A natural gas engine heat pump operates at equivalent COP parameters as specified for the propane heat pump in PERC **Docket 12314** (PERC 2007).
4. Heat pumps, air conditioners, and furnaces operate at minimum federal standards, unless otherwise noted.
5. Federal standards are specified by the U.S. Department of Energy (DOE). Standards relevant for comparison in this study are provided for central air source electric heat pump 65–135 kBtu/hr; central water-cooled, evaporatively cooled, and water source electric heat pump 65–135 kBtu/hr; and central air source electric air conditioner 65–135 kBtu/hr (DOE 2001, DOE 2009a).

6. DOE appliance standards refer to "commercial package air conditioning and heating equipment," which includes air-cooled, water-cooled, evaporatively cooled, or water source (not including ground water source) electrically operated, unitary central air conditioners, and central air conditioning heat pumps for commercial application (U.S. House of Representatives 2005).
7. Furnace energy standards analyzed in the study are applicable for units less than 225,000 Btu/hr, as stated in DOE regulations, which can apply to residential or light commercial use. The DOE commercial furnaces and boiler standards are applicable for units larger than 225,000 Btu/hr, which is larger than the 10-ton (120,000 Btu/hr) system in this study. Federal efficiency standards for furnaces less that 225,000 Btu/hr are 78 percent for propane, natural gas, and fuel oil; the electric furnace standard is 95 percent. For comparison, federal efficiency standards for commercial furnaces larger than 225,000 Btu/hr are about 80 percent for gas and 81 percent for fuel oil (DOE 2009b).
8. A central furnace's efficiency is measured by the annual fuel utilization efficiency (AFUE), which is the ratio of heat output of the furnace compared to the total energy consumed by the furnace. AFUE does not include the heat losses of the duct system or piping. The average duct energy efficiency for heating is assumed to be 74 percent, and the efficiency for cooling is 70 percent (Modera 1993).
9. Upstream emission factors were based on the output of the GREET model (GREET 1.8c). See text for a discussion of the assumptions used with this model.
10. Global warming potentials (GWP) are used to combine the three greenhouse gases into metric tons of carbon dioxide equivalent. GWPs for this study are based on 100-year time horizon: CO_2 = 1, methane = 25, nitrous oxide = 298 (IPCC 2007).
11. End-use emissions factors are based on figures provided by U.S. Department of Energy, Energy Information Administration, Appendix H of the instructions to Form EIA-1605 (EIA 2007).

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Desiccant Dehumidifiers

Assumptions

1. Energy use for desiccant dehumidifiers is based on manufacturer-published specifications at full load nameplate capacity at Association of Home Appliance Manufacturers (AHAM) standard conditions (80°F, 60% relative humidity). NovelAire Comfort Dry 250 specs are the basis for the desiccant dehumidifier with hot water regeneration. NovelAire Technologies Comfort Dry 400 specifications are used as the basis for desiccant dehumidifiers with propane regeneration and desiccant dehumidifiers with natural gas regeneration. NovelAire Nauticus 250 specs are the basis for the desiccant dehumidifier with electric regeneration (NovelAire Comfort Products 2009a, 2009b; NovelAire Technologies 2009).
2. Energy use for refrigerant dehumidifiers is based on minimum Energy Star or federal standards as noted. The current energy standard for refrigerant dehumidifiers is 2.25 liters per kilowatt-hour (kWh) for units with capacity greater than 75 pints per day, as specified in the Energy Policy Act of 2005. These standards became effective October 1, 2007. Note that the Energy Independence and Security Act of 2007 modifies the federal minimum standard effective October 1, 2012, increasing the minimum energy efficiency to 2.5 liters per kWh for units with a capacity greater than 75 pints per day. The Energy Star minimum standard for units with a capacity of 75–185 pints per day is 2.5 liters per kWh (DOE 2009; EPA/DOE 2009).
3. Dehumidifier capacity for all desiccant dehumidifier types evaluated in the study falls in the range of 75–185 pints of water removed per 24 hours of operation at AHAM standard conditions.
4. For desiccant dehumidifiers with propane or natural gas regeneration operating at maximum load, the gas burner is assumed to be operating at full capacity (10,000 Btu/hr).
5. The power factor for electrical input for the process blower, regeneration blower, desiccant wheel drive motor, and controls in the desiccant dehumidifier is assumed to be 0.60. The power factor for the refrigerant dehumidifier system is assumed to be 0.85, based on the compressor as the primary power user.
6. Energy factors for water heaters delivering hot water for regeneration for the desiccant dehumidifiers are based on the highest reported energy factor in the Gas Appliance Manufacturer's Association (GAMA) Directory of Certified Efficiency Ratings for storage tank water heaters. Energy factors for different energy sources are as follows: propane = 0.67, natural gas = 0.67, electric = 0.95 (GAMA 2006).
7. Upstream emission factors were based on the output of the GREET model (GREET 1.8c). See text for a discussion of the assumptions used with this model.
8. GWPs are used to combine the three greenhouse gases into metric tons of carbon dioxide equivalent. GWPs for this study are based on 100-year time horizon: CO_2 = 1, methane = 25, nitrous oxide = 298 (IPCC 2007).
9. End-use emissions factors are based on figures provided by the U.S. Department of Energy, Energy Information Administration, Appendix H of the instructions to Form EIA-1605 (EIA 2007).

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Residential Space Heating

Assumptions

1. Different fuel systems were evaluated based on the emissions resulting from the delivery of an equivalent energy service — the amount of useful heat supplied to the home.
2. Estimated useful heat delivered by a propane furnace was 38 million Btu and was based on an average energy consumption of 52.6 million Btu per year of propane in a region with 4000–5499 heating degree days (EIA 2001) after estimated average efficiency losses (15 percent) and duct losses (15 percent) were applied.
3. The highest reported energy efficiency for each type of space heater was used in the analysis. The energy efficiency of a space heater 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 2005b).
4. The energy efficiency for gas and fuel oil furnaces were based on the highest reported AFUE in the GAMA Directory of Certified Efficiency Ratings (GAMA 2006). AFUE values for furnaces were the following: propane and natural gas = 95.7, fuel oil = 85.0. An AFUE of 100 was assumed for the electric furnace based on the upper end of the range given in DOE 2005b.
5. Electric heat pump energy efficiency is determined by its heating season performance factor (HSPF), which is the ratio of heat delivered in Btu to the electricity consumed in watt-hours. A HSPF of 10.0 was used for the heat pump, since it was the highest value in the range reported in DOE 2005b.

6. Duct heat losses of 15 percent were assumed for the furnace and heat pump systems, and were applied after conversion efficiency losses. The heat transfer efficiency of the electric resistance baseboard heating system was assumed to be 100 percent based on DOE 2005a.
7. It was assumed that gas and oil furnaces met GAMA's guideline for electrical efficiency (GAMA 2006), meaning their electricity usage during a typical heating season is 2 percent or less of the total energy used by the furnace. Therefore, emissions resulting from electricity consumption by these furnaces were not calculated.
8. Upstream emission factors were based on the output of the GREET model version 1.8c (GREET 1.8c). See text for a discussion of the assumptions used with this model.
9. GWPs are used to combine the three greenhouse gases into metric tons of carbon dioxide equivalent. GWPs for this study are based on 100-year time horizon: CO_2 = 1, methane = 25, nitrous oxide = 298 (IPCC 2007).
10. End-use emissions factors are based on figures provided by the U.S. Department of Energy, Energy Information Administration, Appendix H of the instructions to Form EIA-1605 (EIA 2007).
11. In colder climates, dual fuel systems (e.g., standard air-source heat pump with high-efficiency propane furnace backup) use approximately 63 percent of the propane used by a high-efficiency propane furnace system alone. The remaining service load is provided by electricity.

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Residential Water Heaters

Assumptions

1. The highest reported energy efficiency for each type of water heater was used in the analysis. The energy efficiency of a water heater is designated by its energy factor, which is the ratio of the heat delivered (as hot water) to the energy consumed (i.e., electricity, natural gas, propane, or oil) according to a specific test procedure (DOE 2000).

2. Energy factors for all water heaters except solar water heaters were based on the highest reported energy factor in the GAMA Directory of Certified Efficiency Ratings for each type of unit (GAMA 2006). The GAMA source did not include solar hot water heater efficiency ratings. The energy factor of solar hot water heaters was based on the highest value in the range provided by DOE's Office of Energy Efficiency and Renewable Energy (DOE 2005c). This energy factor assumes that some amount of electricity is used to circulate fluid. Energy factors for storage tank water heaters were the following: solar = 11.0, propane = 0.67, natural gas = 0.67, heat pump = 2.28, fuel oil = 0.68, electric = 0.95. Energy factors for tankless water heaters were the following: propane = 0.85, natural gas = 0.85, electric = 0.99.
3. Although heat pump water heaters may be used for tankless water heating, there were no tankless heat pump models listed in the GAMA directory; therefore, they were not evaluated in the analysis.
4. Solar water heaters are typically integrated with another hot water heating system running on gas, oil, or electricity. Solar water heaters typically serve 50–75 percent of the hot water load (DOE 2005c). Typical values for propane were selected as the backup system, with the solar water heater system serving 60 percent of the load.
5. Fuel consumption of the propane storage tank heater was based on the average fuel consumption of a residential hot water heating system of 15.8 MMBtu (EIA 2001).
6. Upstream emission factors were based on the output of the GREET model (GREET 1.8c). See text for a discussion of the assumptions used with this model.
7. GWPs are used to combine the three greenhouse gases into metric tons of carbon dioxide equivalent. GWPs for this study are based on 100-year time horizon: CO_2 = 1, methane = 25, nitrous oxide = 298 (IPCC 2007).
8. End-use emissions factors are based on figures provided by the U.S. Department of Energy, Energy Information Administration, Appendix H of the instructions to Form EIA-1605 (EIA 2007).

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GM 6.0L Engine

Assumptions

1. Fuel economy data is only available for the Chevy Express Passenger Van, 3500 gasoline model, which has a gross vehicle weight (GVW) of 9,600 lbs. The GVW of the Chevy Express Cutaway 3500 series models can range from 9,900 to 14,200 lbs., while the 4500 series GVW is 14,200 lbs. (available with 6.0L gasoline engine or 6.6L diesel engine options). No fuel economy data is available for the gasoline cutaway. Therefore, we assume the Cutaway achieves 95 percent of the fuel economy of the Passenger Van using the same engine due to the higher GVW of the Cutaway.
2. This analysis uses the low range of published fuel economy data from General Motors for gasoline models. Published fuel economy ranges include data using all available engine options. In the gasoline model, the 6.0L engine is the largest, justifying the use of the low end of published ranges.
3. Upstream emission factors were based on the output of the GREET model (GREET 1.8c). See text for a discussion of the assumptions used with this model.
4. GWPs are used to combine the three greenhouse gases into metric tons of carbon dioxide equivalent. GWPs for this study are based on 100-year time horizon: CO_2 = 1, methane = 25, nitrous oxide = 298 (IPCC 2007).
5. End-use emissions factors are based on figures provided by the U.S. Department of Energy, Energy Information Administration, Appendix H of the instructions to Form EIA-1605 (EIA 2007).

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Ford F-150

Assumptions

1. Different fuel systems were evaluated based on the emissions resulting from the delivery of an equivalent energy service (miles traveled).

2. A typical pickup truck was estimated to travel 10,000 miles per year.
3. The following fuel economy values (in gasoline-equivalent gallons) were used in the GREET model version 1.8c (GREET 1.8c), and in the comparative analysis: propane, gasoline, and E85 = 14.7.
4. Upstream emission factors were based on the output of the GREET model (GREET 1.8c). See text for a discussion of the assumptions used with this model.
5. GWPs are used to combine the three greenhouse gases into metric tons of carbon dioxide equivalent. GWPs for this study are based on 100-year time horizon: CO_2 = 1, methane = 25, nitrous oxide = 298 (IPCC 2007).
6. End-use emission factors were based on those used in the GREET model for 6,000–8,500 lbs. GVW vehicles, given in grams per mile in the "greet1.8c_0.xls" input file provided with the model (GREET 1.8c).

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Ford F-250

Assumptions

1. Based on reported fuel economies, each vehicle was assumed to travel 100 miles. The total greenhouse gas emissions were calculated based on the total amount of fuel that would be consumed to travel 100 miles. Results were normalized to the total GHG emissions of the propane-fueled Roush 2010 F-250.
2. The U.S. Environmental Protection Agency (EPA) does not measure the fuel economy of medium-duty trucks such as the F-250. All reported F-250 fuel economy data is taken from secondary sources such as magazine reviews and truck comparisons.
3. The Roush 2010 F-250 propane truck is still in the developmental stages. It is currently estimated to have a 600-mile range on 55 usable gallons.
4. Propane conversion kits reportedly degrade the fuel economy of a vehicle from 0–13 percent. A 6.5 percent decrease in fuel economy for propane compared to regular gasoline is estimated for the purposes of this analysis (Technocarb 2007).
5. Upstream emission factors were based on the output of the GREET model (GREET 1.8c). See text for a discussion of the assumptions used with this model.
6. GWPs are used to combine the three greenhouse gases into metric tons of carbon dioxide equivalent. GWPs for this study are based on 100-year time horizon: CO_2 = 1, methane = 25, nitrous oxide = 298 (IPCC 2007).
7. End-use emissions factors are based on figures provided by the U.S. Department of Energy, Energy Information Administration, Appendix H of the instructions to Form EIA-1605 (EIA 2007).

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School Buses

Assumptions

1. Different fuel systems were evaluated based on the emissions resulting from the delivery of an equivalent energy service (miles traveled).
2. The assumption of 9,000 miles traveled per year was based on the same assumption by ANTARES Group (ANTARES Group 2004).
3. The following fuel economy values (in diesel-equivalent gallons) were used in the comparative analysis: propane school bus = 5.2; CNG school bus = 5.0; diesel school bus = 6.6; gasoline school bus = 5.2. Fuel efficiency for CNG and diesel vehicles were those reported by ANTARES. This source assumed that propane buses had the same fuel economy as CNG vehicles. But because the fuel tanks of CNG vehicles are heavier than those of propane vehicles and create a fuel economy penalty, the relative fuel efficiencies used by the GREET model (GREET 1.8c) were used to get a more accurate estimate of propane fuel economy. Relative fuel efficiencies from the GREET model for 6,000–8,500 lbs. GVW vehicles, model year 2010, were used to estimate the fuel economy of propane as well as gasoline school buses. The fuel economy of the propane vehicle in the GREET model is 5.3 percent higher than that of a CNG vehicle (on an equivalent gallon basis). This difference was applied to the reported fuel economy for CNG school buses in order to calculate fuel economy for a propane bus. Because the GREET model assumes that propane and gasoline vehicles have the same fuel efficiency on an equivalent gallon basis, gasoline bus fuel efficiency was assumed to be equal to the propane bus value.
4. Upstream emission factors were based on the output of the GREET model (GREET 1.8c). See text for a discussion of the assumptions used with this model.
5. GWPs are used to combine the three greenhouse gases into metric tons of carbon dioxide equivalent. GWPs for this study are based on 100-year time horizon: CO_2 = 1, methane = 25, nitrous oxide = 298 (IPCC 2007).
6. End-use emission factors were based on those used in the GREET model for 6,000–8,500 lbs (GREET 1.8c).

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Distributed Generation

Assumptions

1. Energy use is based on vendor specs for power-only (no CHP) 60Hz generator sets (gensets) operating at 100 percent nameplate load.
2. End-use energy consumption data is based on reported fuel use in vendor specifications of representative generators. Representative generators for 30 kW microturbines: Capstone C30 Liquid Fuel, Capstone C30 Natural Gas; 100kW genset: John Deere J150U, Cummins 100GGHH; 200kW genset: Armstrong AJD200, Caterpillar G3508 (Armstrong AJD200; Capstone C30 Liquid Fuel 2006; Capstone C30 Natural Gas 2006; Caterpillar G3508 2001; Cummins 100GGHH; John Deere J150U).
3. Capstone C30 microturbine is operated at ambient temperatures above 35°F (a propane pump and vaporizer is unnecessary.) (Gas Plants, Inc. 2006)
4. Energy content of fuels is based on EIA 2007a and EIA 2007b.
5. It is assumed that a representative standby generator operates 20 hours per year. (15 min. per week for exercising = 13 hours, plus 7 hours of operation average in a poor power area) (E-mail correspondence with PERC May 15, 2007).
6. Prime power units can operate from 4 to 10 hours per day. Operation of 7 hours per day is assumed for an average unit (E-mail correspondence with PERC May 15, 2007).
7. Upstream emission factors were based on the output of the GREET model (GREET 1.8c). See text for a discussion of the assumptions used with this model.
8. GWPs are used to combine the three greenhouse gases into metric tons of carbon dioxide equivalent. GWPs for this study are based on 100-year time horizon: CO_2 = 1, methane = 25, nitrous oxide = 298 (IPCC 2007).
9. End-use emissions factors are based on figures provided by the U.S. Department of Energy, Energy Information Administration, Appendix H of the instructions to Form EIA-1605 (EIA 2007c).

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Forklifts

Assumptions

1. Average fuel use of 973 gallons of propane per year is based on market data provided in Delucchi 2000, which cites 400,000 forklifts using 389 million gallons of propane annually.
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. This fraction was not based on actual usage data but was considered by the author to be a reasonable assumption.
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 GREET model for 6,000–8,500 lbs. GVW vehicles, model year 2010, were used to calculate fuel use for equivalent miles traveled. The ratio of the fuel economy of each vehicle type (in miles per gasoline-equivalent gallon) relative to a gasoline-fueled vehicle are as follows: electric = 3.5; propane and gasoline = 1.0, CNG = 0.95; diesel = 1.31.
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%. Electric motor thermal efficiency was assumed to be 95%.
6. Upstream emission factors were based on the output of the GREET model version 1.8c (GREET 1.8c). See text for a discussion of the assumptions used with this model.
7. GWPs are used to combine the three greenhouse gases into metric tons of carbon dioxide equivalent. GWPs for this study are based on 100-year time horizon: CO_2 = 1, methane = 25, nitrous oxide = 298 (IPCC 2007).
8. End-use emissions factors are based on figures provided by the U.S. Department of Energy, Energy Information Administration, Appendix H of the instructions to Form EIA-1605. (EIA 2007).

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Ground Service Equipment

Assumptions

1. Data for ground service equipment was taken from a study that examined the feasibility of substituting propane for gasoline to reduce fuel costs and emissions from ground support equipment at the Calgary International Airport. Twelve pieces of ground service equipment were converted from gasoline to propane engines, and the study was conducted from August 2005 through January 2006 (Air Canada Ground Handling Services 2009).
2. The chemical composition of the propane used in Calgary was assumed to be similar to propane in the United States, with an energy content of 96,125 Btu/gal.
3. In cases in which multiple vehicles of the same type were studied, the data was averaged. For example, the data from five baggage tractors was averaged for both propane and gasoline.
4. Upstream emission factors were based on the output of the GREET model (GREET 1.8c). See text for a discussion of the assumptions used with this model.
5. GWPs are used to combine the three greenhouse gases into metric tons of carbon dioxide equivalent. GWPs for this study are based on 100-year time horizon: CO_2 = 1, methane = 25, nitrous oxide = 298 (IPCC 2007).
6. End-use emissions factors are based on figures provided by the U.S. Department of Energy, Energy Information Administration, Appendix H of the instructions to Form EIA-1605 (EIA 2007).

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Commercial Mowers

Assumptions

1. Commercial lawn mower results are based on the calculated greenhouse gas emissions per hour under medium to heavy load for propane, gasoline, and diesel mowers.
2. Propane and gasoline mower data is based on a study conducted by the Department of Plant Sciences at University of Tennessee (University of Tennessee 2009).
   - The engines in this study are a 23 horsepower (hp) gasoline-fueled, air-cooled Kawasaki and a similar 23 hp air-cooled Kawasaki that was modified to run on propane.
   - Throughout the study the fuel economy of the propane mower continually improved based on upgrades and modifications to optimize the engine. Three different results in regards to the propane mower are presented in this study: best case, worst case, and average

fuel economy. The GHG emissions result for propane mowers is based on the best case energy consumption results presented in the University of Tennessee study because they were obtained after engine optimization. When properly optimized, propane engines can provide comparable fuel economy to a gasoline engine based on the higher octane rating of propane, even as propane has a lower energy content per volume compared to gasoline.

3. It is assumed that the fuel consumption of a lawn mower is generally based on the engine size (horsepower) and the load on the mower. Data has shown a linear increase in fuel consumption as engine size increases and fuel type is kept consistent.
4. The diesel engine, while not included in the University of Tennessee study, is presented due to its similar engine size (23 hp) to the propane and gasoline engines. However, this fuel economy is reported from vendor specifications rather than a scientific study as in the case of the propane and gasoline data.
5. Upstream emission factors were based on the output of the GREET model (GREET 1.8c). See text for a discussion of the assumptions used with this model.
6. GWPs are used to combine the three greenhouse gases into metric tons of carbon dioxide equivalent. GWPs for this study are based on 100-year time horizon: CO_2 = 1, methane = 25, nitrous oxide = 298 (IPCC 2007).
7. End-use emissions factors are based on figures provided by the U.S. Department of Energy, Energy Information Administration, Appendix H of the instructions to Form EIA-1605 (EIA 2007).

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Irrigation Engines

Assumptions

1. Fuel and electricity use are based on performance standards determined for internal combustion engines using standard accessories, including a water pump, fan, and radiator (Smajstrla and Zazueta 2003).
2. Methane and nitrous oxide emission factors are based on Delucchi 2000 unless otherwise noted below.
3. It is assumed that methane emissions are 2 percent higher from E85 combustion than gasoline combustion based on a hydrocarbon emissions analysis from small engines (Varde 2002).
4. Carbon content (kg CO_2/million Btu) of all fuels evaluated assumes 99 percent combustion (DOE 1994, table B.1).

5. Energy content of fuels based on EIA 2007a; Bioenergy Feedstock Information Network 2007; and Evans, Sneed, and Hunt 1996.
6. There is no meaningful difference in engine efficiency between E85 and gasoline. Fuel usage of E85 is higher due to ethanol's lower energy content (EPA/DOE 2007).
7. Upstream ethanol emissions are based on the GREET model for converting corn to ethanol. The emissions and energy use involved in the production of corn are calculated on the basis of the amount of fuel and chemicals (fertilizer, herbicides, and insecticides) used per bushel. Energy efficiency of 97.7 percent is assumed for ethanol transportation, storage, and distribution.
8. It is assumed that a representative irrigation pump operates 749 hours per year (Autumn Wind Associates 2004, page 20).
9. Upstream emission factors were based on the output of the GREET model (GREET 1.8c). See text for a discussion of the assumptions used with this model.
10. GWPs are used to combine the three greenhouse gases into metric tons of carbon dioxide equivalent. GWPs for this study are based on 100-year time horizon: CO_2 = 1, methane = 25, nitrous oxide = 298 (IPCC 2007).
11. End-use emissions factors are based on figures provided by the U.S. Department of Energy, Energy Information Administration, Appendix H of the instructions to Form EIA-1605 (EIA 2007b).

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ICF INTERNATIONAL

Propane Supply Sources and Trends

Prepared For The:
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About ICF

Since 1969, ICF International (NASDAQ:ICFI) has been serving government at all levels, major corporations, and multilateral institutions. With more than 4,500 employees worldwide, we bring deep domain expertise, problem-solving capabilities, and a results-driven approach to deliver strategic value across the life cycle of client programs.

At ICF, we partner with clients to conceive and implement solutions and services that protect and improve the quality of life, providing lasting answers to society's most challenging management, technology, and policy issues. As a company and individually, we live this mission, as evidenced by our commitment to sustainability and carbon neutrality, contribution to the global community, and dedication to employee growth.

Summary

There is a fairly widespread impression that most of the propane consumed in this country comes from crude oil or is imported from other countries, and is subject to the same types of energy security risks associated with gasoline, diesel fuel, and other products produced from imported crude oil. However, due to recent changes in propane supply trends, these impressions are no longer valid. Today, propane is a domestically produced energy source.

Due to growth in propane production from domestic natural gas liquids, the U.S. propane industry has recently achieved three major supply milestones:

1) In 2010, the U.S. became a net exporter of propane for the first time in more than 30 years.
2) In 2011, total U.S. production of propane from domestically produced natural gas liquids exceeded total U.S. consumer propane demand for the first time.
3) In the first quarter of 2012, total U.S. propane supply produced from U.S. and Canadian resources exceeded total propane demand, including both consumer propane demand and industrial feedstock demand, for the first time.

The domestic supply of propane is expected to continue to grow over time due to growth in natural gas liquids production in association with shale gas and shale oil.

Sources of U.S. Propane Supply

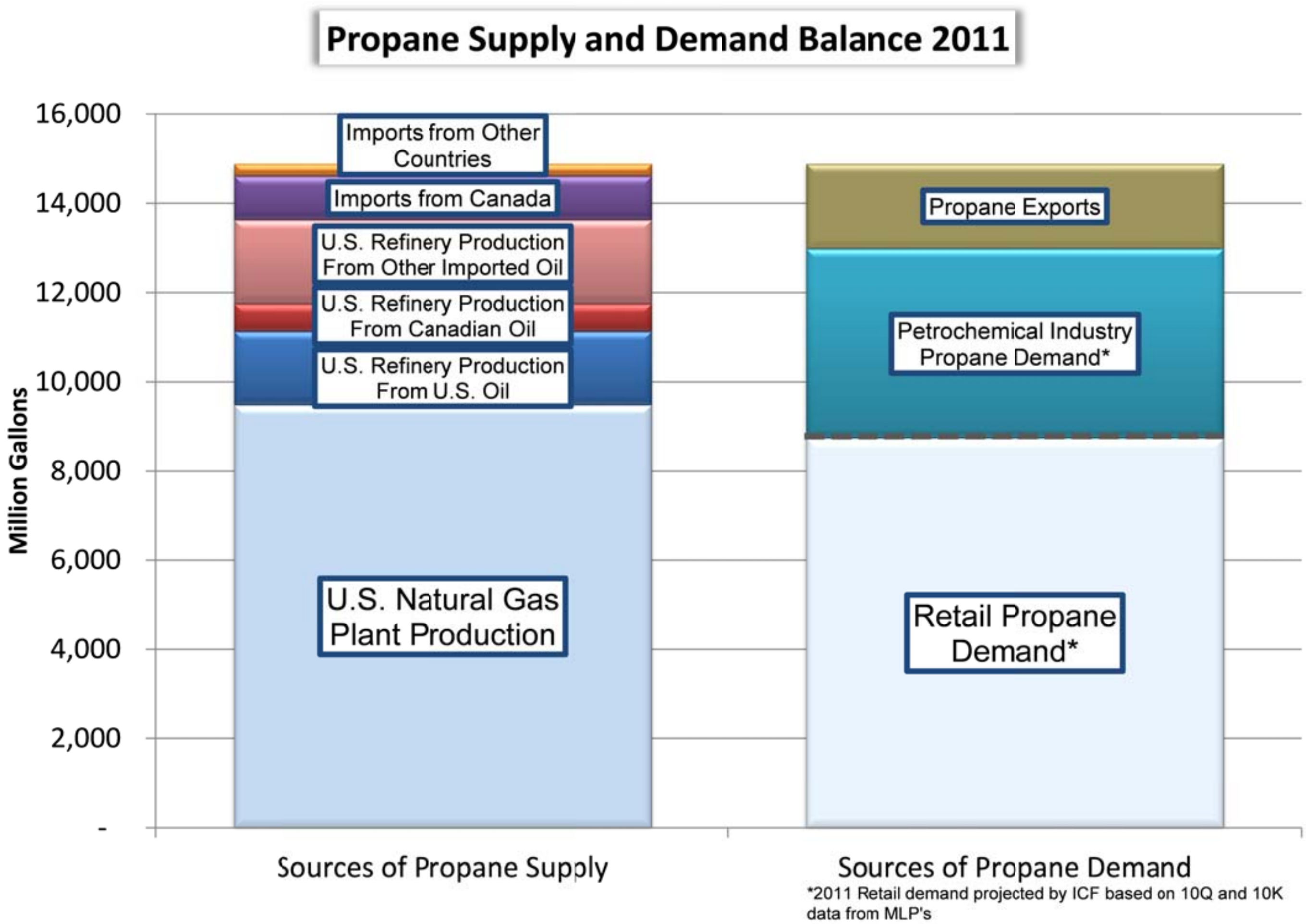
In 2011, 98% of U.S. propane supply was produced in the U.S. or Canada. And 69% of total U.S. supply of propane came from natural gas liquids produced in the U.S and Canada. 28% of total U.S propane supply was produced by U.S. crude oil refineries from domestic and imported crude oil alongside the production of gasoline and distillate fuel oil.

In 2011, 85.5% of U.S. propane supply was produced from U.S. and Canadian resources. 14.5% of total U.S. propane supply was imported from, or produced from crude oil imported from other countries. However, 12.4% of total U.S. propane supply was exported. Hence, on a net basis, only 2.1% of U.S. propane supply used in the domestic market was imported, or produced from resources imported from countries other than Canada.

Propane production from domestic resources has been increasing rapidly, and during the first quarter of 2012, U.S. propane exports exceeded the volume of propane imported or produced from imported resources for the first time. During this period, 88% of U.S. propane supply was produced from domestic and Canadian resources, and 12% of total U.S. propane supply was imported from, or produced from crude oil imported from countries other than Canada However, 14.6% of total U.S. propane supply was exported. Hence, on a net resource basis, U.S. propane exports exceeded the volume of propane imported or produced from resources imported from countries other than Canada.

Propane Supply Outlook

The propane supply outlook is very positive. The percentage of U.S. propane supply produced from domestic resources has been increasing for the last few years, from 73% in 2005 to 85% in 2011. This trend is expected to continue. Production of propane from natural gas liquids associated with new shale gas production will increase rapidly between 2012 and 2020, leading to a substantial increase in U.S. propane supply.


Propane Supply and Demand Balance 2011
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
-
Million Gallons
Imports from Other Countries
Imports from Canada
U.S. Refinery Production From Other Imported Oil
U.S. Refinery Production From Canadian Oil
U.S. Refinery Production From U.S. Oil
U.S. Natural Gas Plant Production
Propane Exports
Petrochemical Industry Propane Demand*
Retail Propane Demand*
Sources of Propane Supply
Sources of Propane Demand
*2011 Retail demand projected by ICF based on 10Q and 10K data from MLP's

Section 1: Introduction

There is a fairly widespread impression that most of the propane consumed in this country comes from crude oil or is imported from other countries. This leads to the impression that propane supply is subject to the same types of energy security risks associated with gasoline, diesel fuel, and other products produced from imported crude oil.

The impression that propane is produced from crude oil also leads to the conclusion that the environmental impacts of propane are similar to the environmental impacts of other petroleum products, including gasoline, diesel fuel, and distillate fuel oil.

However, these impressions are no longer accurate for today's propane market.

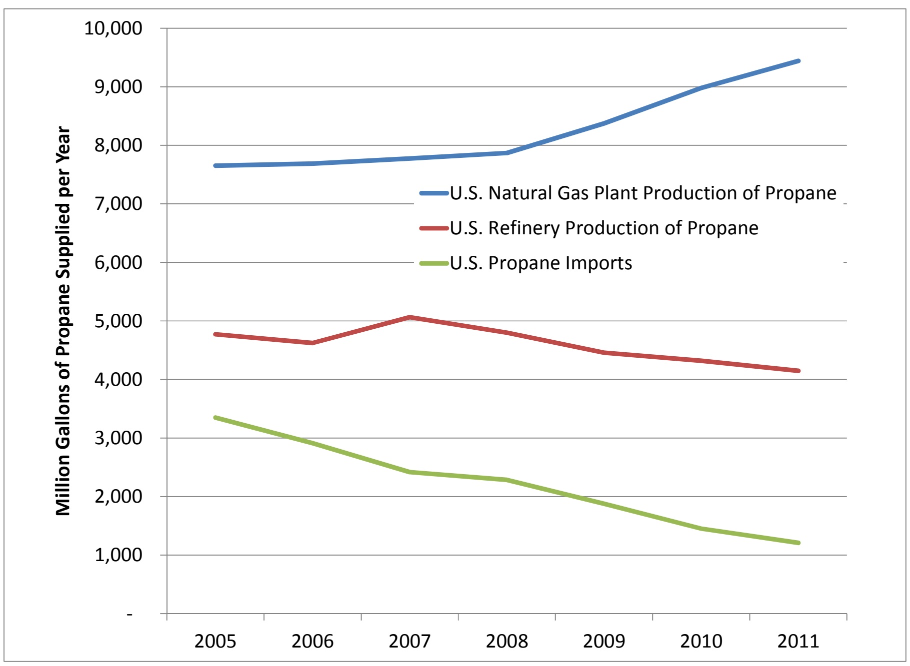
- In 2011, 98.1% of total U.S. propane supply was produced in the U.S. and Canada.
- 85.5% of all U.S. propane supply is produced from U.S. and Canadian natural gas and crude oil resources.
- 68.6% of U.S. propane supply comes from U.S. and Canadian natural gas liquids.
- The U.S. produces more propane than is consumed in the country, and is a net exporter of propane. In 2011, the U.S. exported 12.7% of the total U.S. propane supply.
- Propane is generally significantly cleaner than gasoline and diesel fuels with respect to environmental impacts, including carbon emissions.

Historically, the U.S. propane industry has relied on three primary sources of propane:

1) Propane produced by gas fractionation plants from domestically produced natural gas liquids.
2) Propane produced by U.S. refineries from both domestic and imported crude oil.
3) Imported propane.

While all three of these sources of propane remain important, the mix has changed dramatically in the last few years (Figure 1).

Figure 1: Changing Sources of Propane Supply



Between 2005 and 2011, the amount of propane produced in the U.S. increased by about 9%, from 12.4 billion gallons to 13.6 billion gallons. During the same period, the amount of propane produced from domestic natural gas liquids increased by more than 1.8 billion gallons per year, while refinery production from crude oil declined by 621 million gallons per year. The increase in domestic production offset a decline in imports of 2.1 billion gallons per year, and an increase in propane exports of 1.2 billion gallons per year during the same period.

The primary driver behind the changes in propane supply has been the shale oil and gas resource revolution. The growth in natural gas liquids production from shale oil and gas resources is resulting in a rapid increase in domestic propane production from natural gas liquids, reducing the reliance on imported propane and refinery propane.

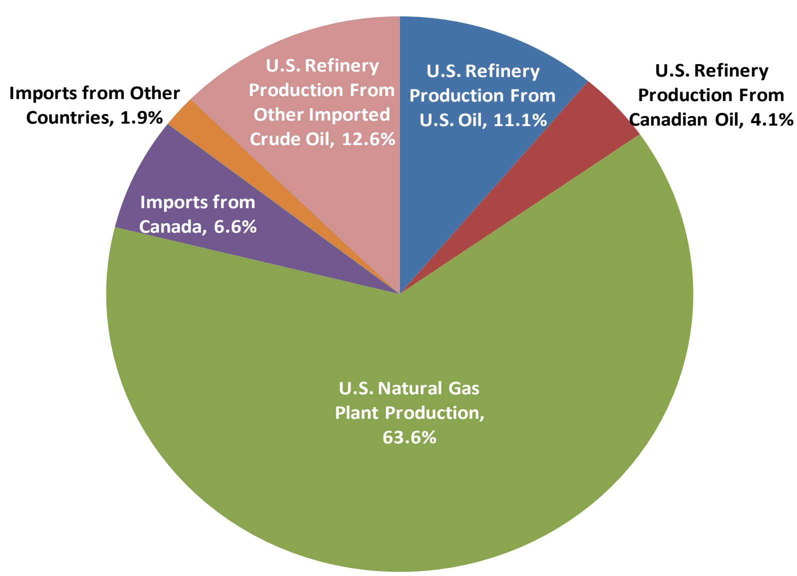
Section 2: Current Sources of U.S. Propane Supply

In 2011, 98.1% of U.S. propane supply was produced in the U.S. and Canada. 1.9% of total propane supply was imported from other countries. 87.3% of the total U.S. supply of propane was consumed in the United States, and 12.7% of total propane supply was exported.

From a resource perspective, 14.5% of total U.S. propane supply was imported from, or produced from crude oil imported from outside of the U.S. and Canada. However, 12.4% of total U.S. propane supply was exported to other countries. Hence, on a net basis, only 2.1% of the propane supply used in the domestic market was imported from outside of the U.S. and Canada.

Figure 2 shows the sources of U.S. propane supply for 2011.[1] More detailed data for 2005 through the first quarter of 2012 is included in Attachment 1.

Figure 2: Sources of 2011 Propane Supply



[1] The propane supply shown in Figure 2 reflects total propane supply including imports, as well as propane supply exported to other countries. During this time period, propane exports accounted for 12.7% of total propane supply.

Propane from Natural Gas Liquids Production – 68.6% of total U.S. propane supply was produced from natural gas liquids at natural gas liquids processing and fractionation plants in the U.S. and Canada. The gas processing plants separate the natural gas liquids – ethane, propane, and butane – from wet gas that comes from producing natural gas and oil wells.

- 63.6% of total U.S. propane supply was produced from natural gas liquids at domestic gas processing and fractionation plants.
- In addition, about 75% of the propane imported from Canada, accounting for 5.0% of total U.S. propane supply, was produced from Canadian natural gas liquids.

Propane from Domestic Crude Oil Refining – 27.9% of the total U.S. propane supply was produced by U.S. crude oil refineries alongside the production of gasoline and distillate fuel oil.[2]

- 11.1% of the U.S. propane supply was produced in U.S. refineries from oil produced in the U.S.
- 4.1% of the U.S. propane supply was produced in U.S. refineries from crude oil imported from Canada.
- 12.6% of the total U.S. propane supply was produced in U.S. refineries from oil imported from countries other than Canada, including Middle Eastern and South American oil producing countries. This is roughly equal to the amount of propane exported from the U.S. to other countries, primarily in Central and South America.

Propane from U.S. and Canadian Hydrocarbons - From a resource perspective, 85.5% of U.S. consumer grade propane supply was produced from U.S. and Canadian hydrocarbon resources.

- 74.7% of U.S. propane supply was sourced from hydrocarbon resources (crude oil and natural gas liquids) produced in the U.S.
- An additional 10.7% was sourced from hydrocarbon resources (crude oil and propane from natural gas liquids) produced in Canada.

Propane From Imported Hydrocarbons - The remaining 14.5% of propane supply was imported from countries other than Canada or produced in U.S. refineries from crude oil imported from countries other than Canada.

- 1.9% of total propane supply was imported from countries other than Canada.
- 12.6% of total propane supply was produced in U.S. refineries from crude oil imported from countries other than Canada.

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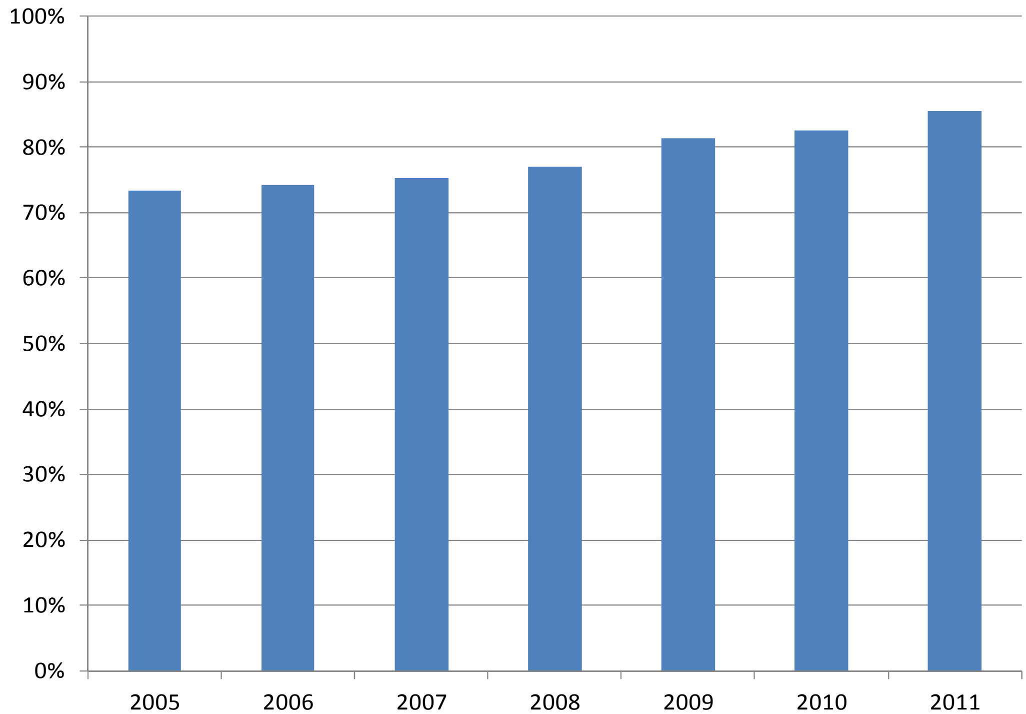
[2] Refineries produce both propane and propylene. In 2011, for the first time, refinery production of propylene was greater than refinery production of propane. Propane and propylene are both widely used in the chemical feedstock market. Only a very small amount of propylene is sold into the consumer market for niche uses such as welding; the vast majority of propylene is used as chemical feedstock. Propylene is not produced during the fractionation of natural gas liquids.

However, in 2011 the U.S. also exported 12.4% of the total propane supply. Hence, on a net basis, the U.S. relied on petroleum resources from outside of the U.S. for only 2.1% of total propane consumption.

The percentage of propane produced from Domestic and Canadian resources has been increasing for the last several years (Figure 3), from 73.5% in 2005 to 85.5% in 2011.

Figure 3: Share of Total U.S. Propane Supply Produced From Domestic and Canadian Resources



Section 3: Propane Supply Outlook

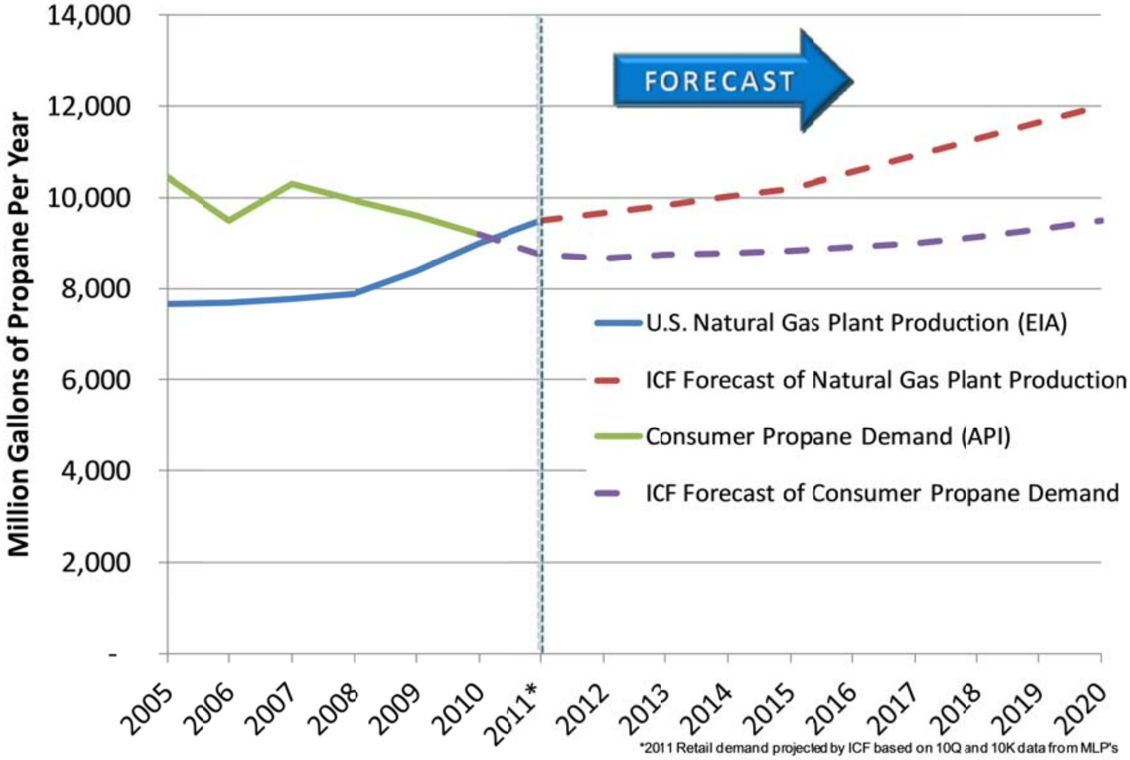
The U.S. propane supply outlook is primarily dependent domestic natural gas and crude oil production trends. ICF and most other industry experts are projecting U.S. natural gas and oil production to increase substantially in the next 10 years, with most of the growth coming from the development of the new shale gas resource base.

Since much of the shale gas resource base is “wet” gas with a high proportion of natural gas liquids, growth in production from the shale gas resources will lead to growth in domestic propane production. In addition, given current low natural gas prices, the petroleum exploration and development industry is targeting “wet” gas resources with a larger yield of high value liquid products, including propane, in order to maximize returns.

ICF is projecting growth in shale gas resource development to result in growth in production of natural gas liquids sufficient to add 1.8 billion gallons of propane per year to U.S. propane supply by 2015, and 3.6 billion gallons of propane per year by 2020 (Figure 4).

U.S. oil production is also expected to increase over time, displacing crude oil imports, and increasing the domestic resource content of propane produced in U.S. refineries.

Figure 4: Outlook for Changes in Propane Supply Demand Balance



Propane Imports

Canadian imports are likely to continue falling slowly as conventional natural gas production in the Western Canadian Sedimentary Basin continues a long term decline, resulting in declines in natural gas liquids production. While shale gas production from Canada will increase over time, it is not projected to be sufficient to support growth in Canadian propane exports to the United States.

Propane imports from countries other than Canada will continue at very modest levels to meet specific market needs, but are not expected to be a significant part of U.S. propane supply for the foreseeable future.

Section 4: Propane Demand Outlook

While domestic production of consumer grade propane has been increasing, total consumer demand has been falling. According to the American Petroleum Institute (API) survey "Sales of Natural Gas Liquids and Liquefied Refinery Gases", consumption of consumer grade propane fell by 24% between 2000 and 2010. This trend is expected to continue through the end of 2012 and potentially 2013. After 2013, ICF is projecting modest growth in propane demand.

Demand factors include:

- Continuing improvements in end-use propane efficiency due to higher appliance energy standards and improved building efficiency codes are likely to offset much of the growth in consumer propane demand in the next few years.
- Market penetration of propane-fueled vehicles and other new propane engine technologies offsets losses in other markets and results in moderate growth in propane demand after 2013.
- Additional propylene production from dedicated propane to propylene plants has the potential to absorb some new propane supply. The ICF forecast of propane demand includes the impact of two announced propane to propylene plants, with the first plant potentially coming online in 2015.

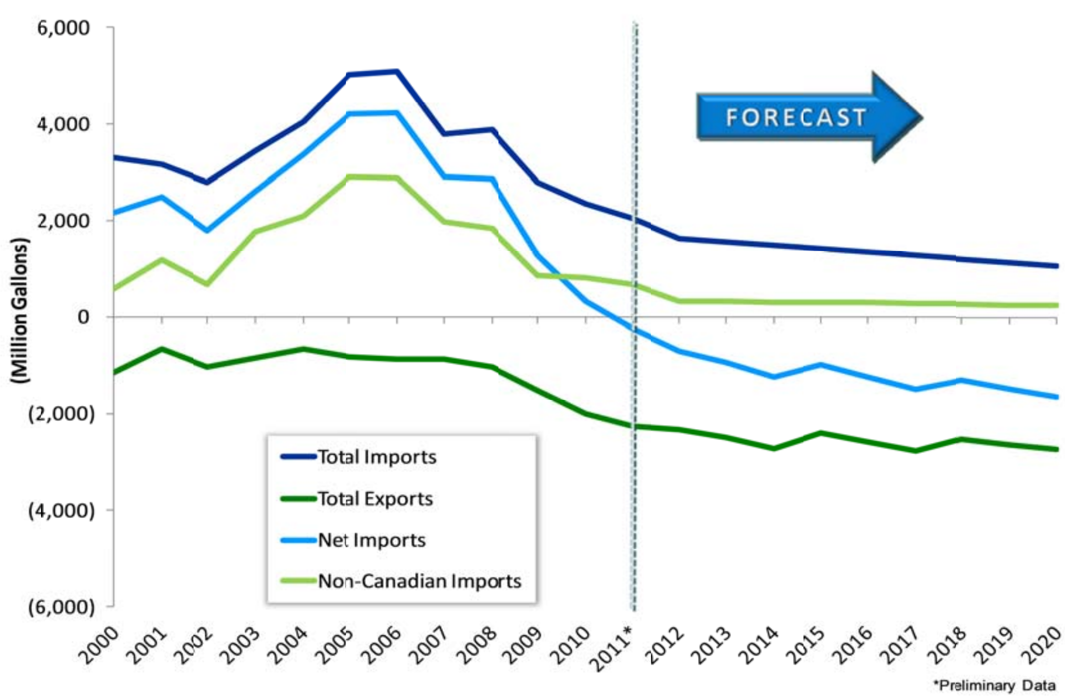
Propane Exports

Overall, growth in domestic propane supply is expected to outpace potential growth in propane demand, leading to continued growth in propane exports (Figure 4). Propane exports are currently running at or near the capacity of the available export terminals. However, a number of projects to increase export capacity, including both new and expanded terminals, are currently underway and are expected to come on-line in 2012 and 2013.

Impact of Potential New Consumer Propane Demand on Propane Markets

The changes in propane supply and demand create an opportunity to increase propane demand without requiring additional investments in supply infrastructure or increasing U.S. reliance on foreign sources of energy. The major impact of any growth in propane demand will be to reduce exports of domestically produced propane.

Figure 5: U.S. Propane Import and Export Projection to 2020



Section 5: Impact of Changes in Propane Supply on Carbon Emissions

Propane is a relatively clean fuel. Without sophisticated emissions control devices, use of propane typically emits much lower levels of CO, particulate matter (PM), and evaporative VOC's, and similar levels of NOx and exhaust VOC's when compared to gasoline and diesel fuel.[3] While these emissions differences are important in many applications, current emissions standards for on-road vehicles result in similar emissions levels for propane, gasoline, and diesel fuel with respect to these standard criteria pollutants. However, propane also has significantly lower carbon emissions than gasoline and diesel fuel.[4] Carbon emissions are inherent to the fuel, and cannot be controlled with existing emissions technologies.

As the sources of propane supply have shifted from crude oil refining to natural gas liquids fractionation, the total carbon emissions associated with using propane have declined.

The chemical composition of the consumer grade propane sold in the U.S. is very similar regardless of whether the propane is produced in a natural gas plant, a refinery, or is imported from other countries.[5] However, the carbon emissions associated with producing propane differ based on the source of the propane. Refineries typically are much more energy intensive, and have higher carbon emissions per unit of output than natural gas fractionation facilities. Overall, ICF estimates that propane produced from natural gas liquids reduces carbon emissions by about 16% relative to propane produced in a refinery.[6]

As the percentage of U.S. propane supply sourced from natural gas plant production has increased from 58.0% of the total U.S. propane supply in 2005 to 68.6% of the total U.S. propane supply in 2011, the per gallon CO2 emissions associated with using propane have fallen by about 1.8%.

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[3] Research conducted by Argonne National Laboratories on a previous generation (1999) of propane vehicles indicated no change in exhaust VOCs or NOx, a 90–95% reduction in evaporative VOCs, a 20–40% reduction in CO, and an 80% reduction in exhaust coarse particulate matter (PM10) relative to gasoline vehicles.

[4] The Environmental Protection Agency has calculated the total emissive value of the burning of propane on-site to be 63.02 kg CO2e/MMBtu, or 5.8 kilograms of CO2e per gallon (kg CO2e/gallon) of propane. The Propane Education and Research Council has estimated average upstream emissions associated with the production and distribution of propane as of 2007 to be 12.1 Kg CO2e/ MMBtu, or 1.1 Kg CO2e per gallon. Based on these sources, the total carbon emissions associated with propane consumption are 74.6 Kg CO2e per MMBtu, or 6.9 Kg CO2e per gallon of propane. This is 12% lower than the estimated value for gasoline, and 15% lower than the estimated value for diesel on a per MMBtu basis.

[5] Chemical composition of marketed propane can vary by source within fairly narrow limits determined by the specifications of the marketed product. In the U.S., consumer propane typically meets HD5, which requires the product to contain a minimum of 90% propane and not more than 5% propylene, with the remainder consisting of other chemical products, including iso-butane, butane, ethane, or methane.

[6] ICF estimates that the carbon footprint associated with propane fractionation from natural gas liquids is about one percent of the carbon content of the propane fuel, while the carbon footprint associated with refinery production of propane is about 18% of the carbon content of the propane fuel.

Attachment 1:

U.S. Propane Supply and Demand (Million Gallons)

	2005	2006	2007	2008	2009	2010	2011	2012 Q1
Propane Supply								
U.S. Natural Gas Plant Production of Propane	**7,654**	**7,688**	**7,774**	**7,868**	**8,375**	**8,979**	**9,478**	**2,611**
U.S. Refinery Production of Propane	**4,771**	**4,625**	**5,065**	**4,799**	**4,459**	**4,322**	**4,150**	**1,020**
From U.S. Oil	1,696	1,555	1,713	1,594	1,656	1,618	1,654	414
From Canadian Oil	512	547	631	641	604	578	617	174
From Other Imported Crude Oil	2,563	2,523	2,721	2,564	2,199	2,126	1,879	432
U.S. Propane Imports	**3,351**	**2,914**	**2,417**	**2,286**	**1,879**	**1,454**	**1,269**	**390**
From Canada	1,727	1,508	1,376	1,414	1,337	1,009	985	347
Canadian Natural Gas Liquids	1,502	1,282	1,142	1,145	1,057	777	739	261
Canadian Refineries	224	226	234	269	281	232	246	87
From Other Countries	1,624	1,406	1,042	871	541	445	284	43
Total Propane Supply From North American Resources	**11,589**	**11,297**	**11,494**	**11,517**	**11,972**	**12,184**	**12,735**	**3,546**
Total Propane Supply From Natural Gas Liquids	**9,156**	**8,970**	**8,916**	**9,014**	**9,431**	**9,756**	**10,217**	**2,871**
Total Propane Supply	**15,776**	**15,227**	**15,257**	**14,953**	**14,713**	**14,755**	**14,897**	**4,020**
Propane Demand								
Consumer Demand	**10,431**	**9,499**	**10,295**	**9,945**	**9,600**	**9,191**	**8,731**	**2,478**
Petrochemical Industry Demand	**4,786**	**5,036**	**4,153**	**4,204**	**3,755**	**3,894**	**4,277**	**955**
Propane Exports	**559**	**692**	**809**	**803**	**1,358**	**1,670**	**1,889**	**587**
Total Exports to Canada	40	46	53	50	31	39	42	11
Total Exports to Other Countries	519	646	756	753	1,327	1,631	1,847	575
Total Propane Demand	**15,776**	**15,227**	**15,257**	**14,953**	**14,713**	**14,755**	**14,897**	**4,020**

U.S. Propane Supply and Demand (Percent of Total)

	2005	2006	2007	2008	2009	2010	2011	2012 Q1
Propane Supply								
U.S. Natural Gas Plant Production	**48.5%**	**50.5%**	**51.0%**	**52.6%**	**56.9%**	**60.9%**	**63.6%**	**64.9%**
U.S. Refinery Production of Propane	**30.2%**	**30.4%**	**33.2%**	**32.1%**	**30.3%**	**29.3%**	**27.9%**	**25.4%**
From U.S. Oil	10.8%	10.2%	11.2%	10.7%	11.3%	11.0%	11.1%	10.3%
From Canadian Oil	3.2%	3.6%	4.1%	4.3%	4.1%	3.9%	4.1%	4.3%
From Other Imported Crude Oil	16.2%	16.6%	17.8%	17.1%	14.9%	14.4%	12.6%	10.7%
U.S. Propane Imports	**21.2%**	**19.1%**	**15.8%**	**15.3%**	**12.8%**	**9.9%**	**8.5%**	**9.7%**
From Canada	10.9%	9.9%	9.0%	9.5%	9.1%	6.8%	6.6%	8.6%
Canadian Natural Gas Liquids	9.5%	8.4%	7.5%	7.7%	7.2%	5.3%	5.0%	6.5%
Canadian Refineries	1.4%	1.5%	1.5%	1.8%	1.9%	1.6%	1.7%	2.2%
From Other Countries	10.3%	9.2%	6.8%	5.8%	3.7%	3.0%	1.9%	1.1%
Total Propane Supply From North American Resources	**73.5%**	**74.2%**	**75.3%**	**77.0%**	**81.4%**	**82.6%**	**85.5%**	**88.2%**
Total Propane Supply From Natural Gas Liquids	**58.0%**	**58.9%**	**58.4%**	**60.3%**	**64.1%**	**66.1%**	**68.6%**	**71.4%**
Total Propane Supply	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**
Propane Demand								
Consumer Demand	**66.1%**	**62.4%**	**67.5%**	**66.5%**	**65.2%**	**62.3%**	**58.6%**	**61.6%**
Petrochemical Industry Demand	**30.3%**	**33.1%**	**27.2%**	**28.1%**	**25.5%**	**26.4%**	**28.7%**	**23.8%**
Propane Exports	**3.5%**	**4.5%**	**5.3%**	**5.4%**	**9.2%**	**11.3%**	**12.7%**	**14.6%**
Total Exports to Canada	0.3%	0.3%	0.3%	0.3%	0.2%	0.3%	0.3%	0.3%
Total Exports to Other Countries	3.3%	4.2%	5.0%	5.0%	9.0%	11.1%	12.4%	14.3%
Total Propane Demand	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Data Sources: U.S. Energy Information Administration (EIA), American Petroleum Institute (API), U.S. International Trade Commission (ITC), and ICF International.

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