URS

March 26, 2015

Mr. David Breen
Port of Portland
P.O. Box 3529
Portland, OR 97208

Subject: Summary of Document Changes
Propane White Paper, Final Draft

Dear Mr. Breen:

AECOM (formerly URS Corporation) presents the revised Final Draft of the Propane White Paper. This document has been revised from the previously submitted Final Draft version dated March 4, 2015, based on additional provided comments. The following text summarizes the changes made from the March 4th version of the Propane White Paper to assist readers who received the previous version.

1. Cover page: The date of the report was changed from March 4, 2015 to March 26, 2015.
2. Issue 1, Production Methods in North America, Page 5: The fourth paragraph under Issue 1, Production Methods in North America, on Page 5 was broken into two paragraphs. Also, a sentence in the paragraph was revised as follows:

   Revised text:

   Both processes begin when underground ~~oil~~ fields are tapped by drilling ~~oil~~ wells.
3. Issue 1, Disposition and Capture as a By-Product in North America, Page 8: The text in the first paragraph under Issue 1, Disposition and Capture as a By-Product in North America, on page 8 has been revised. The paragraph was revised as follows:

   Revised text:

   In natural gas processing and petroleum extraction, propane can either be flared off, or captured at the wellhead for alternate uses such as alternate fuel or an agent in petrochemical manufacturing. Typically flaring is associated with oil production and performed when it is not economic to capture (e.g., when no pipeline exists to transfer the material captured to an economic end use). In some regions, such as the Bakken fields, the primary reason for flaring during oil production is objection is to the crude product and that no pipeline infrastructure exists to capture and transport the natural gas. Historically, such gas was vented or flared.
4. Issue 1, Disposition and Capture as a By-product in North America, Page 9: The fifth/final paragraph under Issue 1, Disposition and Capture as a By-Product in North America, on page 9 has been moved under Issue 2, Propane and Climate sub-heading, now on page 15. The final sentence of the paragraph was revised to read as follows:

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Revised text:

Overall, propane emissions play a very limited role in tropospheric ozone formation.

5. Issue 2, Propane and Climate, Table 1 and text, Page 15: A full reference was added for Table 1. Note that the previous GWP values did not all come from the same reference source. As a result the GWP values changed for Ethane (from 3 to 5.5) and Butane (from 6 to 4). This new reference includes the updated GWP values from the IPCC Fourth Assessment Report (2007). This reference and values are consistent with the global warming potentials (GWPs) used by the EPA under their latest amendments.

   In addition, the two paragraphs below Table 1 were revised for improved readability. The original and revised paragraphs are included below (references are included in actual report, not below).

   Original text:

   The above table lists the global warming potential, in CO2 equivalents, of the five gases, four of which are combustible. These GWP estimates are established based on the release of the gas, *in its raw state to the atmosphere.* A ton of methane, with a GWP of 25, emits 2.8 kg of CO2 for every kg of fuel. Thus, one ton of methane (1,000 kg or 2,204.6 lb.) will emit 2,800 kg of CO2 when combusted, or about 2.8 tons of CO2. Thus, a ton of methane released to the atmosphere is the equivalent of releasing 25 tons of CO2 while combusting a ton of methane results in a release of only 2.8 tons of CO2. In the case of methane, it is best to burn it before releasing it.

   Conversely, propane has a GWP of 3.3 but when burned as fuel, it releases 3 kg of CO2 for every kg of fuel. A ton of combusted propane will result in a release of 3 tons of CO2e. Thus, the release of propane to the atmosphere is roughly equivalent to the global warming impact of burning a ton of propane instead. The emissions rate for propane combustion is roughly 0.0058 metric tons CO2e per gallon of propane. For propane suppliers subject to cap and trade, this emissions rate can be used in conjunction with a market price ($ per allowance) to determine the allowance price per gallon of propane.

   Revised text:

   The above table lists the global warming potential (in CO2 equivalents) of the five gases, four of which are combustible. These GWP estimates refer to the global warming potential of each gas released *directly* to the atmosphere. For example, 1 ton of methane (GWP = 25) released *directly* into the atmosphere would have a climate impact equivalent to releasing 25 tons of CO2. Comparatively, *combustion* of 1 ton of methane would generate 2.8 tons of CO2. Therefore, in terms of global warming impact, it is preferable to combust methane instead of directly releasing it, since a ton of methane released *directly* to the atmosphere is the equivalent of releasing 25 tons of CO2, while *combusting* a ton of methane results in a release of only 2.8 tons of CO2.

> Conversely, 1 ton of propane (GWP = 3.3) released *directly* into the atmosphere would have a climate impact equivalent to releasing 3.3 tons of CO2. *Combustion* of 1 ton of propane would result in a release of 3 tons of CO2. Therefore, the global warming impact of directly releasing a ton of propane to the atmosphere is roughly equivalent to the global warming impact of burning a ton of propane instead. The emissions rate for propane combustion is roughly 0.0058 metric tons CO2 per gallon of propane. For propane suppliers subject to cap and trade, this emissions rate can be used in conjunction with a market price ($ per allowance) to determine the allowance price per gallon of propane.

Please let me know if you have any questions or comments on the changes to the document. If you would like to discuss, please call me at (503) 478-2766.

Sincerely yours,

Craig Riley, LEED AP BD+C
Project Manager

Attachments:
Final Draft, Propane White Paper

Propane White Paper
FINAL DRAFT

March 26, 2015

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Port of Portland

Prepared by:

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Purpose and Statement of Limitations

The purpose of this document is to address the following seven issues:

1. Describe current trends within the propane industry in North America, including sources of propane, production methods, disposition and capture as a by-product, and propane's role as a feedstock in the petrochemical industry.

2. Describe propane's role in the global future of energy, economy and climate change initiatives.

3. Describe the cradle-to-grave greenhouse gas (GHG) lifecycle analysis of propane as an export to Asian markets compared to other energy sources for various market segments (e.g., residential and commercial heating, vehicles, agriculture and manufacturing).

4. Characterize propane in comparison with other fuels in terms of energy density and GHG emissions per unit of energy.

5. Characterize propane GHG emissions in comparison to other petrochemical feedstock GHG emissions.

6. Characterize propane GHG emissions for a mix of fuel combustion and other petrochemical feedstock end uses.

7. Characterize propane and any associated minor constituents according to their contribution to GHG emissions, air toxics, ozone formation or ozone layer depletion.

The document begins with a background section on the GHG modeling approach used in the analysis as well as an overview of globally accepted GHG quantification and reporting standards.

URS has used background information, literature, articles, and other data in preparing this document, which reflects our interpretation of this information and is generally applicable as of the date of this document. URS has relied on this information and is neither responsible for nor has been able to fully validate the accuracy of this information. The lifecycle greenhouse gas (GHG) emissions results presented in this document are first-order estimates and should not be construed as final or portrayed as such. These first-order estimates can be refined as additional information about particular projects becomes available.

This document in its entirety is intended for the sole use of the Port of Portland and as background for discussions with other stakeholders. The scope of services performed during this work effort may not be appropriate to satisfy the needs of other users, and any use or re-use of this document or of the findings or conclusions presented herein is at the sole risk of said user.

Background

This background section provides an overview of the modeling approach used in this paper including globally accepted GHG quantification and reporting standards.

Modeling Approach

The GHG emissions model used as a basis for this analysis is the GREET model produced by the U.S. Department of Energy's Argonne National Laboratory. GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) fully evaluates energy and emission impacts of a variety of fuels. The updated GREET used in this analysis (i.e., version 2.0) includes more than 1000 fuel production pathways. GREET allows different fuels to be evaluated on a full fuel-cycle basis.

The GREET model is used by states including Oregon and California to estimate lifecycle GHG emissions associated with transportation fuels used in those states. The GREET model adheres to the international GHG standards by allocating a different share of overall emissions to each oil and gas product and byproduct.

GREET is being used by the state of California for its Low Carbon Fuel Standard (LCFS) with some modifications. The Oregon Department of Environmental Quality is using GREET for the Oregon Clean Fuels Program (similar to California's LCFS). Use of the GREET model for the lifecycle GHG emissions analysis in this paper ensures that GHG lifecycle emissions estimates are fully aligned with GHG emissions calculation methodologies used in Oregon. This analysis maximizes use of the GREET model by using the model as a basis for estimated lifecycle GHG emissions for each of the alternatives to propane.

Global Standards for Quantifying and Reporting GHG Emissions

The Greenhouse Gas Protocol (GHG Protocol)[1] is the most widely used international accounting tool for government and business leaders to understand, quantify, and manage GHG emissions. The GHG Protocol serves as the foundation for nearly every GHG standard and program in the world - from the International Standards Organization to The Climate Registry - as well as hundreds of GHG inventories prepared by individual companies.

The GHG Protocol also offers developing countries an internationally accepted management tool to help their businesses to compete in the global marketplace and their governments to make informed decisions about climate change.

The GHG Protocol is the basis for quantification and reporting standards implemented by The Climate Registry and has also led to numerous complementary standards, protocols, and guidelines including:

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[1] The Greenhouse Gas (GHG) Protocol, developed by World Resources Institute (WRI) and World Business Council on Sustainable Development (WBCSD), sets the global standard for how to measure, manage, and report greenhouse gas emissions. See: http://www.ghgprotocol.org/

- GHG Protocol Corporate Accounting and Reporting Standard (2004): A standardized methodology for companies to quantify and report their corporate GHG emissions. Also referred to as the Corporate Standard.
- GHG Protocol Product Lifecycle Accounting and Reporting Standard (2011): A standardized methodology to quantify and report GHG emissions associated with individual products throughout their lifecycle. Also referred to as the Product Standard.
- GHG Protocol for Project Accounting (2005): A guide for quantifying reductions from GHG-mitigation projects. Also referred to as the Project Protocol.
- GHG Protocol for the U.S. Public Sector (2010): A step-by-step approach to measuring and reporting emissions from public sector organizations, complementary to the Corporate Standard.
- GHG Protocol Guidelines for Quantifying GHG Reductions from Grid-Connected Electricity Projects (2007): A guide for quantifying reductions in emissions that either generate or reduce the consumption of electricity transmitted over power grids, to be used in conjunction with the Project Protocol.
- GHG Protocol Land Use, Land Use Change, and Forestry Guidance for GHG Project Accounting (2006): A guide to quantify and report reductions from land use, land-use change, and forestry, to be used in conjunction with the Project Protocol.
- Measuring to Manage: A Guide to Designing GHG Accounting and Reporting Programs (2007): A guide for program developers on designing and implementing effective GHG programs based on accepted standards and methodologies.

Together, these standards encourage GHG emissions to be quantified consistently from one location to another throughout the world. These standards also ensure that all emissions are accounted for and that no emissions are double counted. For the development and production of oil and gas products and by-products, double counting is avoided by allocating total emissions across all oil and gas products and by-products so that the sum of the emissions that were assigned is equivalent to the total emissions. If total emissions were assigned to each and every product, that would result in substantial over counting of actual emissions and violate the well-established international standards for GHG accounting.

Comparison of GREET and The Climate Registry Emissions Estimates

Each member of The Climate Registry (TCR) annually reports its Scope 1 (direct) GHG emissions and Scope 2 (indirect) GHG emissions in accordance with the TCR's General Reporting Protocol (GRP). Most TCR members report under the operational control provisions of the GRP. This means that members report all direct GHG emissions from their owned equipment (i.e., Scope 1 emissions) and all indirect emissions associated with their electricity and heat purchases (i.e., Scope 2 emissions).

Direct (Scope 1) GHG emissions include:

- *Stationary combustion* of fuels in any stationary equipment including boilers, furnaces, burners, turbines, heaters, incinerators, engines, flares, etc.;

- *Mobile combustion* of fuels in transportation sources under the facility's ownership (e.g., rail switcher locomotive[s]);
- *Physical and chemical processes* other than fuel combustion (e.g., for manufacturing); and
- *Fugitive sources or* intentional or unintentional releases within the owner's facility from processing, transmission, storage, and use of fuels and other substances, that do not pass through a stack, chimney, vent, exhaust pipe or other functionally-equivalent opening (such as methane leakage from natural gas transport).

Indirect (Scope 2) GHG emissions include GHG emissions associated with the production of purchased electricity and heat.

TCR's GRP requires a reporting facility or entity to report according to its operational and/or financial control over emissions subject to TCR reporting. This analysis assumes that propane export terminals have 100% financial and 100% operational control over their scope 1 and scope 2 GHG emissions resulting from terminal operation. Scope 1 emissions are due to direct emissions from equipment within the reporting entity's jurisdiction (in this analysis, the fence line of the export terminal). Scope 2emissions are universally defined to include emissions associated with purchased electricity and/or heat Scope 2 emissions occur at facilities owned by third parties.

Under TCR's GRP, facilities are not responsible for reporting lifecycle emissions for products passing through their facilities except for that portion of the product's lifecycle emissions that occur within the facility. For example, if there is combustion at the facility that is used to handle or process the material that occurred within the facility (e.g., process heating emissions or tanker truck engine emissions), those would be included. Any physical processes that are required to transfer and/or handle the product that release GHGs within the facility would be included. Finally, leaks such as natural gas (methane) from valves within a facility would also be included. All other upstream and downstream lifecycle emissions are not required to be reported under TCR's GRP..

Almost all products that are processed and/or travel through an export terminal will have small emissions within the terminal compared to their product lifecycle emissions. This is particularly true for fuels. TCR quantification protocols provide rigorous methods for estimating direct and indirect GHG emissions occurring within a facility.

Conversely, a lifecycle assessment of an individual product, which is the focus of this analysis, provides an estimate of GHG emissions across a wide geographic area for activities that are almost entirely outside of the scope of TCR reporting for an export facility. The export facility emissions reported to the TCR will therefore differ from emissions estimated by this lifecycle analysis for emissions from a terminal. TCR reporting is based on a facility's actual emissions within a calendar year. This analysis is based on projected emissions using a hypothetical model.

Low carbon fuel standard programs, including Oregon's Clean Fuels Program, include indirect emissions associated with lifecycle emissions. Consistent with international accounting protocols, agencies seek to implement LCFS programs in a manner that does not double count indirect emissions that occur at facilities that are subject to greenhouse gas reduction requirements. For example, in California, where a cap and trade program is in effect, the electric utilities are the point of regulation for indirect emissions associated with electricity use. Like the low carbon fuel standard program, the cap and trade program is an important element in the state overall plan to achieve future statewide emission reduction targets. If the same indirect emissions get counted in both the LCFS and cap and trade programs, then it results in over- or under- counting of actual statewide emissions.

Oregon DEQ's lifecycle values included in its Clean Fuels Program are preliminary. The agency is using an older version of the GREET model and the value for propane is based on a single study in the literature. Further enhancements and changes to the lifecycle carbon intensity values in the Oregon program are planned. Likewise, California is currently modifying its version of the GREET model.

The upstream process emissions of competing fuels used in Asia are not adequately specified in available literature. This document therefore assumes that upstream emissions of competing fuels used in Asia would be the same as the modeled upstream emissions of those same fuels in North America (as calculated by GREET).

Different models and methods are available to estimate lifecycle emissions of various fuels and feedstocks. The modeling methods tend to vary most significantly with regard to how upstream emissions are allocated to byproducts of oil and gas production. Some studies allocate a portion of GHG emissions due to oil and gas extraction activities based on the carbon content of the outgoing fuel products while other studies allocate GHG emissions to products based on the level of energy needed to produce those products. Allocation methods can have a significant impact on upstream emissions estimates. However, methods for calculating emissions associated with fuel combustion are more standardized and such emissions account for 70% or more of each fuel's total lifecycle emissions.

Under the California Cap and Trade program, the power plant is responsible for the emissions associated with electricity sold to end users. The compliance costs of cap and trade are typically passed from the power plant to the utility to utility customers (buyers of the electricity). Both the TCR and the state of California require reporting of electricity and heat purchases. However, cap and trade compliance obligations do not apply to purchased electricity and/or heat.

In California, the cap and trade applicability threshold is 25,000 metric tons of direct CO2e emissions per year. Indirect emissions do not count towards the applicability threshold. In the state of Washington, a proposed export terminal capable of accommodating a propane throughput of 47,000 barrels per day has estimated GHG emissions of 5,000 metric tons CO2e per year. If this facility were located in California, the facility would not be subject to cap and trade because its emissions would be well below the applicability threshold. Facilities and consumers in California that are not directly subject to cap and trade face pass through costs for purchased fuels, electricity and steam. Fuel providers typically have a cap and trade compliance obligation and are allowed to pass through the costs of cap and trade through to their customers.

Issue 1. Describe current trends within the propane industry in North America, including sources of propane, production methods, disposition (e.g., flaring) and capture as a by-product, and propane's role as a feedstock in the petrochemical industry

Production Methods in North America

Propane is produced as part of natural gas processing and crude oil refining. In natural gas processing, the heavier hydrocarbons that naturally accompany natural gas ("wet gas" at the well head), such as propane, butane, and pentane, are removed prior to the natural gas entering the pipeline distribution system (a significant amount of ethane is never removed from the natural gas and is distributed as natural gas with the methane). In crude oil refining, propane is the first product that results at the start of the refining process, and is therefore always produced when crude oil is refined. Propane is a by-product of two other processes: natural gas extraction (i.e., predominantly methane) and crude oil processing and refining. Propane is not the driver for extraction projects.

The processing of natural gas involves separation of natural gas liquids (NGLs) from the raw natural gas. NGLs include ethane, propane, butane (normal and iso-), (iso) pentane and pentanes plus (sometimes referred to as natural gasolines).

When natural gas is removed from underground gas reservoirs, it is normally referred to as a "wet" gas. The term "wet" means that the gas is a mixture of hydrocarbon gases and, in some cases, liquids. Once removed from the ground, the different gases and liquids are separated, processed, and refined. In the United States, commercially available "propane" is a blend of propane, ethane, butane and minor quantities of other volatile organic compounds. The composition of NGLs varies widely from one shale formation to another and can contain 75% propane and 25% butane plus other trace constituents.[2]

Crude oil is separated into its various parts and refined into marketable products at refineries.

Propane and other liquefiable gases are isolated from petrochemical mixtures in one of two ways—by separation from the natural gas phase of petroleum and by refinement of crude oil. Both processes begin when underground fields are tapped by drilling wells. The gas/oil hydrocarbon mixture is piped out of the well and into a gas trap, which separates the stream into crude oil and "wet" gas, which contains natural gasoline, liquefied petroleum gases, and natural gas.

Although propane is most easily isolated from the "wet gas" mixture, it can be produced from crude oil. Crude oil undergoes a variety of complex chemical processes, including catalytic cracking, crude distillation, and others. The amount of propane produced by refinery processing is small compared to the amount separated from natural gas. Propane produced at refineries is commonly used as a fuel for refineries or to make LPG or ethylene.

The "wet" gas comes off the top of the trap and is piped to a gasoline absorption plant, where it is cooled and pumped through an absorption oil to remove the natural gasoline and liquefied petroleum gases. The remaining dry gas, about 90% methane, comes off the top of the trap and is piped to end users and distributors.[3]

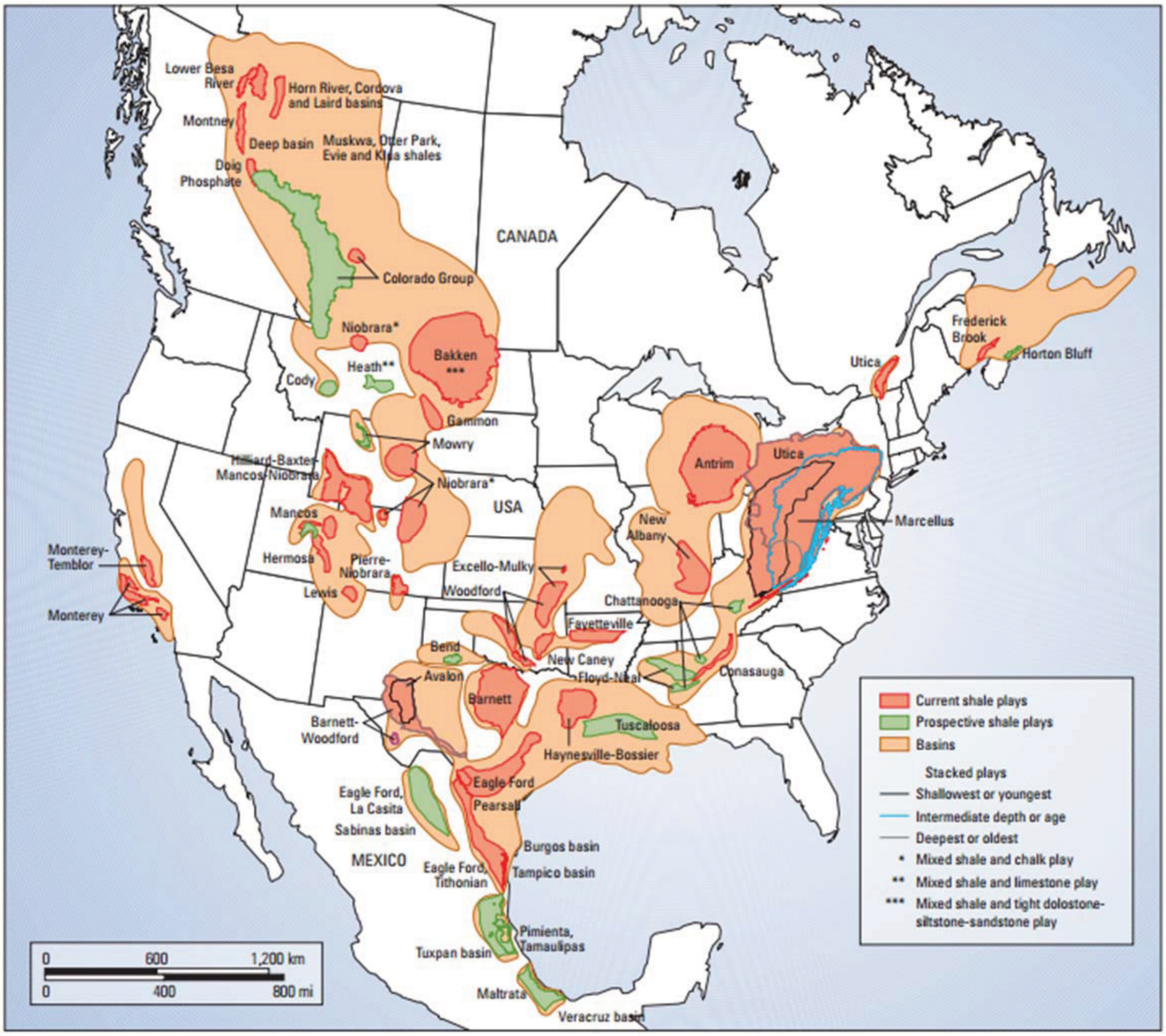
Liquid petroleum gases, including propane, are separated from crude oil or natural gas liquids by heating to separate out constituents by a distillation process. The heating process produces many different gaseous hydrocarbons, including propane and butane. These different gases are captured under pressure and slowly cooled. Each of the gases will condense into a liquid, one at a time, as the temperature drops below the associated boiling point of each gas. Both propane and butane are captured in this manner and are typically stored as liquids under pressure.

Sources of Propane in North America

Due to increased shale gas production across North America, North American propane production is increasing, propane imports are declining and propane exports are increasing.[4] A map of the most significant shale gas formations is provided below in Figure 1. As can be seen, these formations exist throughout many parts of the United States and western Canada. According to the Natural Gas Annual, gross withdrawals from shale gas wells increased from 5 Bcf/d in 2007 to 33 Bcf/d in 2013, representing 40 percent of total natural gas production. As a result of increased shale gas production, the U.S. has quickly become the world's largest exporter of propane. Between 2012 and 2013 alone, U.S. propane exports rose from 0.20 to 0.33 million barrels per day (bpd). This growth is seen in the steep rise in U.S. exports of propane and propylene in Figure 2.[5] Growth in U.S. propane exports are expected to persist well into the next decade as NGL production in the U.S. continues on its upward trend.[6]

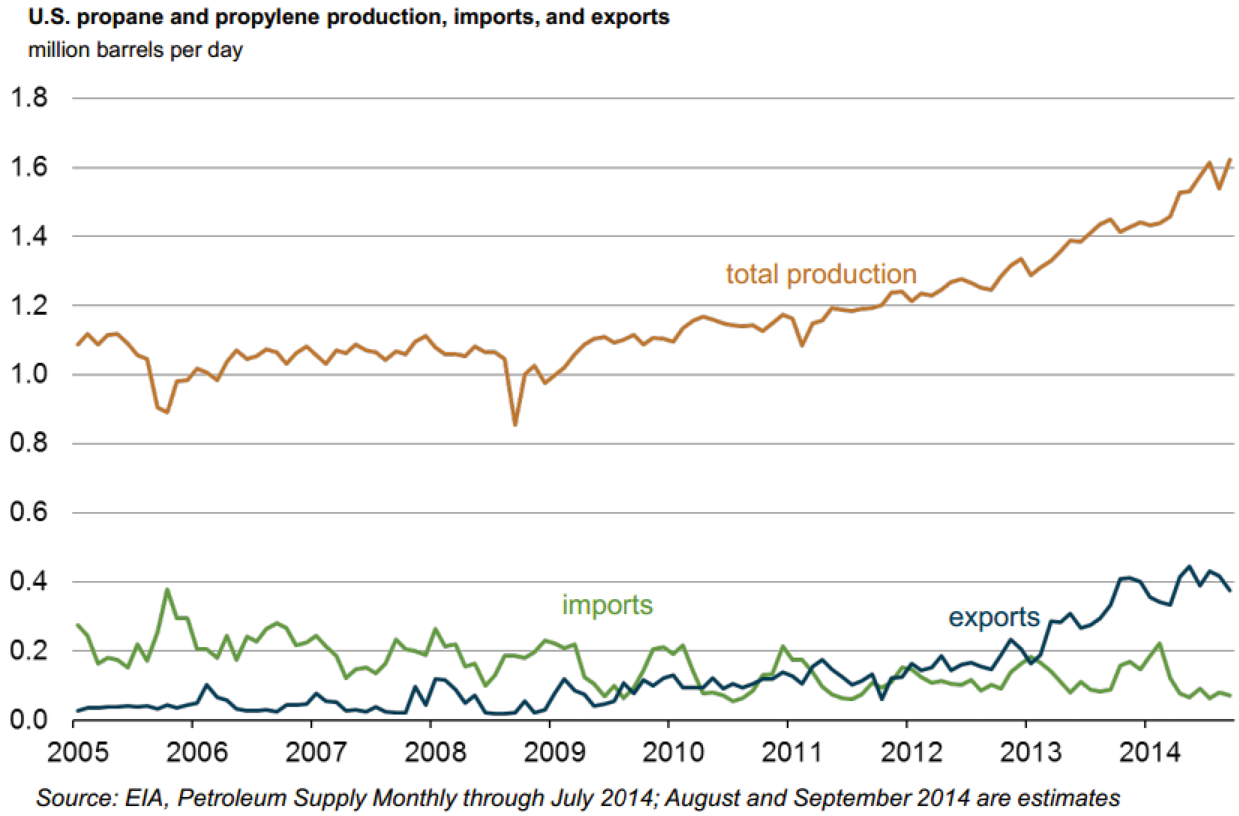
[2] http://www.eia.gov/conference/ngl_virtual/eia-ngl_workshop-anne-keller.pdf
[3] http://www.madehow.com/Volume-3/Propane.html
[4] EIA (2013), 'U.S. exports of liquefied petroleum gases projected to continue through 2040', Today in Energy, May. Available online at: http://www.eia.gov/todayinenergy/detail.cfm?id=11091
[5] EIA (2014), 'U.S. Exports of Propane and Propylene'. http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=MPREXUS2&f=M
[6] EIA (2013), 'U.S. exports of liquefied petroleum gases projected to continue through 2040', Today in Energy, May. Available online at: http://www.eia.gov/todayinenergy/detail.cfm?id=11091

Figure 1 – North American Shale Gas Plays



^ North America shale plays. (Adapted from Kuuskraa et al, reference 6.)

Figure 2 – US Propane Production and Trade Trends



U.S. NGL production has risen sharply in the last decade with the development of a number of liquids-rich shale gas fields. The U.S. Energy Information Administration (EIA) projects shale gas production to increase from 23% of total U.S. gas production in 2010 to 49% by 2035.[7] Increased shale gas production is also driving an increase in supplies of propane.

Disposition and Capture as a By-Product in North America

In natural gas processing and petroleum extraction, propane can either be flared off, or captured at the wellhead for alternate uses such as alternate fuel or an agent in petrochemical manufacturing. Typically, flaring is associated with oil production and performed when it is not economic to capture (e.g., when no pipeline exists to transfer the material captured to an economic end use). In some regions, such as the Bakken fields, the primary reason for flaring during oil production is that no pipeline infrastructure exists to capture and transport the natural gas. Historically, such gas was vented or flared.

Increasingly stringent flaring and venting requirements in North America are likely to contribute to increased capture of propane that would otherwise be flared or vented.

[7] Annual Energy Outlook, U.S. EIA. http://www.eia.gov/forecasts/aeo/er/pdf/0383er%282012%29.pdf

In the Bakken fields in North Dakota, approximately 30% of the associated gas (which includes propane, ethane and butane) has historically been burned in flares.[8] Propane, butane, and ethane, along with nitric oxides (NOx), may react near ground level and increase ground level ozone. Concentrations of these compounds tend to be short-lived in the atmosphere which helps explain why these compounds have nominal climate impacts. When natural gas is flared, the carbon in the gas is converted to CO_2, a greenhouse gas. Regulations in North Dakota currently allow 26% of associated gas to be flared, but that figure will decline to 10% by 2020.[9] These regulations also prohibit venting of natural gas due to the GHG impacts of methane contained in the natural gas. The model used for this analysis, GREET version 2.0, estimates fugitive, vented and flared emissions from extraction and refining activities.

In Alberta, environmental regulations cut the amount of natural gas flared by 80 percent from 1996 to 2010 and further reductions are anticipated.[10] In British Columbia, regulations will eliminate routine flaring by 2016.[11] These and other controls on upstream releases of methane from fuel production should result in future declines in lifecycle GHG emissions of natural gas and related byproducts over time.

Propane's Role as a Combustion Fuel

Propane is used in over 48 million U.S. households as well as many businesses for water and space heating, indoor and outdoor cooking, clothes drying, and backup power. Additionally, many industries increasingly choose propane to fuel vehicles and equipment lowering exhaust GHG, criteria air pollutant, and air toxics emissions.[12] Propane is an approved clean alternative fuel under the Clean Air Act of 1990.[13] Propane is also defined as a clean fuel by the Energy Policy Act of 1992. It is used as an alternative to diesel fuel to eliminate diesel particulate emissions, a primary health concern. Propane is also used to fuel buses, light- and medium-duty trucks, vans, shuttles, taxicabs, and police and government vehicles.[14] To incentivize alternative fuel vehicle development, the Alternative Motor Fuels Act of 1988 established vehicle manufacturer incentives in the form of CAFE credits. Other key federal legislation incentivizing the use of alternative fuels, including propane, include the Energy Policy Act of 1992, Energy Policy Act of 2005, Energy Independence and Security Act of 2007, Energy Improvement and Extension Act of 2008, Tax Relief, Unemployment Insurance Reauthorization, and Job Creation Act of 2010, American Taxpayer Relief Act of 2012, and Tax Increase Prevention Act of 2014.

Because of its lower lifecycle carbon intensity relative to conventional fuels, propane is defined as a clean fuel under Oregon's Clean fuels Program (Oregon Administrative Rules 340). As such, importers of propane destined for use as a transportation fuel within Oregon are eligible to generate fuel credits.

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[8] http://www.eenews.net/assets/2013/11/06/document_gw_01.pdf
[9] "North Dakota aims to reduce natural gas flaring," October 2014 U.S. Energy Information Administration http://www.eia.gov/todayinenergy/detail.cfm?id=18451
[10] http://www.aer.ca/about-aer/media-centre/news-releases/news-release-2014-08-15
[11] http://www.energyplan.gov.bc.ca/PDF/BC_Energy_Plan_Oil_and_Gas.pdf
[12] http://www.atmos-chem-phys.net/11/13395/2011/acp-11-13395-2011.pdf
[12] http://cdiac.ornl.gov/pns/current_ghg.html
[12] http://unfccc.int/ghg_data/items/3825.php
[13] http://onlinelibrary.wiley.com/doi/10.1029/91JD01345/abstract;jsessionid=C74532AB7C67821F75782BBAFBE842D0.f04t01
[14] U.S. Department of Energy Alternative Fuels Data Center. http://www.afdc.energy.gov/laws/key_legislation

More than 1.2 billion gallons of propane were sold in the U.S. for agricultural use in 2009.[15] This includes propane that is used to run pumps and engines, heat buildings, and dry and process crops.

Propane's Role as a Feedstock in the Petrochemical Industry

Propane and ethane are among the leading feedstocks used to produce olefins (propylene and ethylene), which are the primary feedstocks for producing polymers and oligomers used in the manufacture of plastics, resins, fibers, elastomers, lubricants, and gels.[16] Propylene and its derivatives are key components of countless end use products. Examples include automobile headlights, taillights, disk brake pads and bumpers; carpets; CDs and optical disks; clear film food wrap; eyeglasses; medical uses such as medicine bottles and vials, medical syringes, disposal containers (e.g., sharps containers) and diagnostic devices, cell phones and electronics, flexible foams used in bedding and furniture; rigid foam insulation; impact-resistant and bullet-proof windows; molded plastic goods such as bicycle helmets, food containers, kitchen utensils and wastebaskets; nitrile rubber hoses, seals and gaskets; paints and protective coatings; grocery bags; synthetic fibers for blankets, sweaters, socks and fleeces; water cooler bottles; and wood products such as plywood, oriented strand board and laminates.[17]

GHG emissions from propane use as a feedstock in the petrochemical industry consist only of process emissions and emissions from storage and transportation. Small amounts of propane fuel may be combusted in such processes.[18] According to the U.S. Environmental Protection Agency (USEPA), plastics do not generate GHGs when landfilled since they do not biodegrade.[19]

Internationally, the sharp rise in U.S. propane exports has allowed Asian petrochemical companies to gain access to this new source of supply.[20] When used as feedstock, propane is not combusted and is not considered a greenhouse gas because the associated carbon atoms never become airborne. However like other feedstock products, propane used as a feedstock for petrochemical manufacturing has lifecycle emissions.

Propane's role as a feedstock in the petrochemical industry can vary. During 2013, when propane prices increased relative to ethane prices, ethylene crackers[21] began substituting ethane for propane. This

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[15] "Propane Industry Impact on U.S. and State Economies," Propane Education & Research Council.
[16] "Industry Canada – Petrochemicals Industry Profile" http://www.ic.gc.ca/eic/site/chemicals-chimiques.nsf/eng/bt01135.html
[17] Shell Oil Company,
http://www.shell.com/global/products-services/solutions-for-businesses/chemicals/products/lower-olefins/propylene.html
[18] According to U.S. EIA, less than 1% of propane used for petrochemical manufacturing in the U.S. was combusted. The remaining 99% of propane used in the U.S. petrochemical industry was used as a feedstock. "How much oil is used to make plastic?" http://www.eia.gov/tools/faqs/faq.cfm?id=34&t=6
[19] http://www.epa.gov/climatechange/wycd/waste/downloads/plastics-chapter10-28-10.pdf
[20] http://www.oxfordenergy.org/wpcms/wp-content/uploads/2014/07/The-US-Shale-Revolution-and-the-changes-in-LPG-Trading-Dynamics-A-Threat-to-the-GCC.pdf
[21] Natural gas liquids (principally ethane, propane, and butanes) are "cracked" at high temperatures to yield the primary petrochemical building blocks of ethylene, propylene, butylenes and butadiene. In Canada, ethylene is the primary petrochemical product made in the largest quantity from whichever feedstock is used. Having feedstock options for ethylene manufacturing allows companies to use the lower cost feedstock.

trend continued into 2014, as the price spread between propane and ethane widened.[22] Propane is not the only route to propylene. In China, dozens of new plants are being built to use gas oil and coal.[23]

Issue 2. Describe propane's role in the global future of energy, economy and climate change initiatives.

Energy and Economic Considerations

Global propane production reached just over 3.2 billion barrels per year in 2013, up by 2.3% from 2012, while global propane consumption rose to just over 3.0 billion barrels per year, up by 2.8% from 2012. The gap between propane production and consumption reached 170 million barrels per year, the same level as in 2012.

Historically two-thirds of Canada's propane was exported to the U.S., but the U.S. has become a large net exporter of propane. Consequently, Canadian propane exporters are looking for new propane markets in Asia. Global propane consumption is small relative to global consumption of gasoline, diesel, and coal. However, propane's share of global energy consumption is increasing over time relative to higher carbon intensity fuels.[24]

The figures below depict global trends in propane production and consumption. Figure 3 shows recent increases in production from North America and the Middle East. Figure 4 shows sustained growth in consumption in the Asia-Pacific region.[25]

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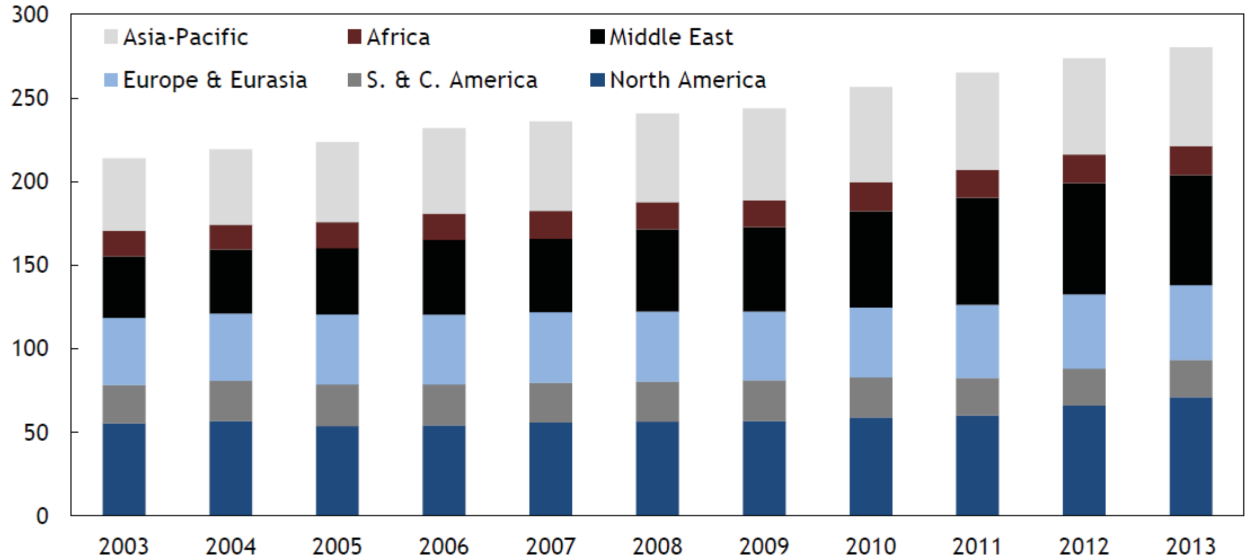
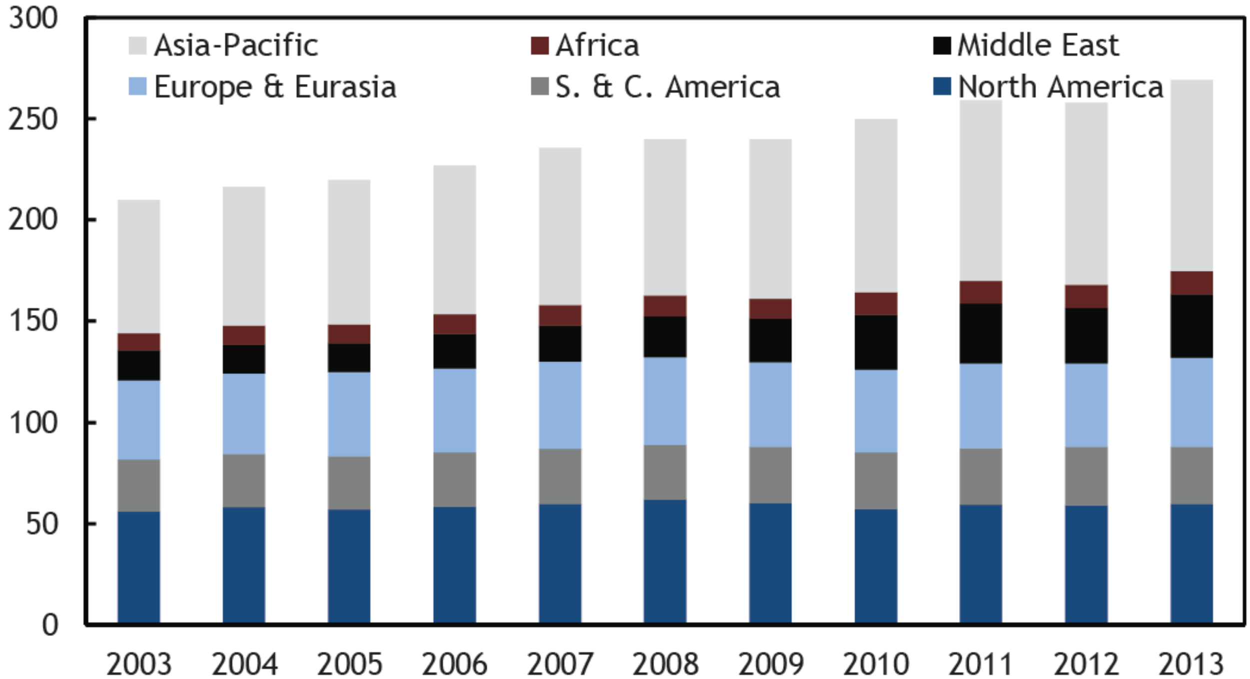
[22] http://www.eia.gov/todayinenergy/detail.cfm?id=18331
[23] http://plasticsengineeringblog.com/2013/02/20/how-shale-gas-is-changing-propylene/
[24] http://www.iea.org/publications/freepublications/publication/KeyWorld2014.pdf
[25] "Argus – Statistical Review of LP Gas Use," http://www.argusmedia.com/~/media/Files/PDFs/White-Paper/Statistical-Review-of-Global-LP-Gas-2014-White-Paper.pdf?la=en

Figure 3 – Propane Production by Region
2002 – 2013, million metric tons



Source: Argus, Statistical Review of Global LP Gas

Figure 4 - Propane Consumption by Region
2002 - 2013, million metric tons

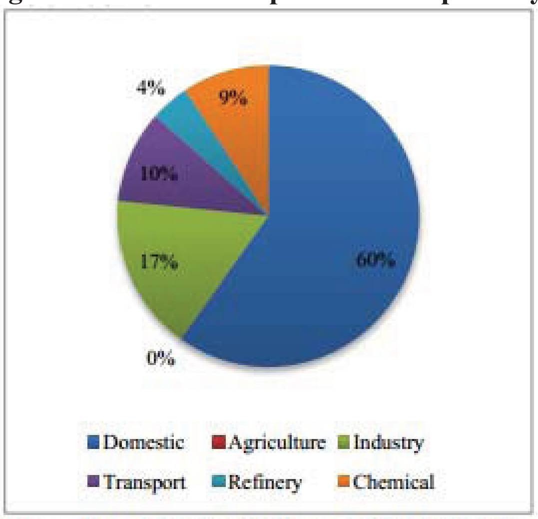


Source: Argus, Statistical Review of Global LP Gas

In 2012, the U.S. became a net exporter of propane. U.S. propane exports are projected to grow by more than 500,000 bpd between 2011 and 2017.[26] The EIA projects the U.S. will be a net exporter of propane through 2040 because of consistent growth in natural gas and oil production. In addition, the expansion of the Panama Canal is expected to substantially impact the dynamics of propane trade by allowing more economic delivery of gulf coast propane to Asia.[27]

Propane use across the Asia-Pacific region is shown in Figure 5 below. A large share of overall use is for domestic purposes (i.e., household heating and cooking).[28]

Figure 5 - Share of Propane Consumption by Sector – Asia Pacific



Source: Argus, *Statistical Review of Global LP Gas*

China will likely remain a net propane importer as its economy continues to grow and the country increases its use of propane for a wide variety of end uses. China's top petrochemical refiner, Sinopec Corp, recently signed agreements with Phillips 66 to import about 34,000 bpd of propane from Freeport, Texas. Petrochemical companies in China are looking to use propane as a replacement petrochemical feedstock that could be cheaper than other alternatives.[29]

Global Propylene Capacity

As shown in Figure 6, propylene has traditionally been produced as a co-product from naphtha steam cracking, the dominant method of ethylene production. However in 2010, the US shale gas boom sparked an increase in ethane cracking – a cost-advantage technology which produces minimal propylene yield, triggering the loss of 3.5 million tons of production from the US market. Despite current supply shortages, the world's propylene capacity is projected to increase from around 109

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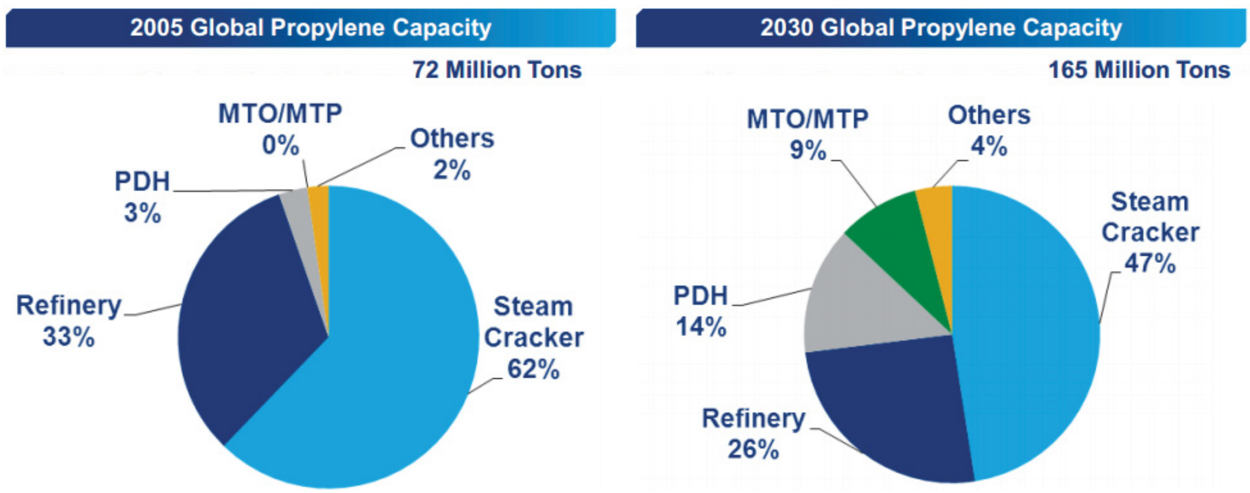
[26] US exports of liquefied petroleum gases projected to continue" U.S. Energy Information Administration. Available online at: http://www.eia.gov/todayinenergy/detail.cfm?id=11091
[27] http://www.oxfordenergy.org/wpcms/wp-content/uploads/2014/07/The-US-Shale-Revolution-and-the-changes-in-LPG-Trading-Dynamics-A-Threat-to-the-GCC.pdf
[28] "Argus – Statistical Review of LP Gas Use," http://www.argusmedia.com/~/media/Files/PDFs/White-Paper/Statistical-Review-of-Global-LP-Gas-2014-White-Paper.pdf?la=en

million tons today to 165 million tons by 2030. This is due to the rush towards new 'on-purpose' production technologies – using feedstocks such as propane, natural gas and coal.[30]

The U.S. will produce nearly 4 million metric tons (mt) per year of additional propylene by the end of 2016. The announced capacity is expected to offset the drop in production from crackers and refineries. While propylene is forecast to be in oversupply globally, the surplus will only be sufficient to meet increasing global demand of polypropylene (PP) until 2019. Increasing plastic demand from Asia – particularly in China – is expected to create deficits of more than 15 million mt by 2024, if no new PP lines are announced. There are 16 propane dehydrogenation plants being planned in China, which would produce more than 8 million mt of propylene annually. Of those plants, eight have already announced they will be using propane sourced from the United States.[31]

Figure 6 - Existing and Projected Global Propylene Capacity



Source: Wood Mackenzie

Propane and Climate

Global warming potential (GWP) is a measure of the climate impact of a specified gas over a 100 year period as compared to the climate impact of an equivalent weight of CO2 over the same time frame. GWPs for five gases of interest are provided in Table 1.

[29] http://thinkprogress.org/climate/2014/04/10/3425190/liquefied-petroleum-gas-china-export/
[30] http://www.woodmac.com/public/views/12524872
[31] http://www.platts.com/IM.Platts.Content/Downloads/PDFs/platts-global-polyolefins-outlook.pdf

Table 1 - Global Warming Potentials of Selected Gases*

Gas	GWP
Carbon Dioxide	1
Methane	25
Propane	3.3
Ethane	5.5
Butane	4

* Propane, Ethane and Butane are not regulated as GHGs under the Clean Air Act
Source: IPCC Fourth Assessment Report: Climate Change 2007

The above table lists the global warming potential (in CO2 equivalents) of the five gases, four of which are combustible. These GWP estimates refer to the global warming potential of each gas released *directly* to the atmosphere. For example, 1 ton of methane (GWP = 25) released *directly* into the atmosphere would have a climate impact equivalent to releasing 25 tons of CO2. Comparatively, *combustion* of 1 ton of methane would generate 2.8 tons of CO2.[32] Therefore, in terms of global warming impact, it is preferable to combust methane instead of directly releasing it, since a ton of methane released *directly* to the atmosphere is the equivalent of releasing 25 tons of CO2, while *combusting* a ton of methane results in a release of only 2.8 tons of CO2.

Conversely, 1 ton of propane (GWP = 3.3) released *directly* into the atmosphere would have a climate impact equivalent to releasing 3.3 tons of CO2 while *combustion* of 1 ton of propane would result in a release of 3 tons of CO2.[33] Therefore, the global warming impact of directly releasing a ton of propane to the atmosphere is roughly equivalent to the global warming impact of burning a ton of propane instead. The emissions rate for propane combustion is roughly 0.0058 metric tons CO2 per gallon of propane.[34] For propane suppliers subject to cap and trade, this emissions rate can be used in conjunction with a market price ($ per allowance) to determine the allowance price per gallon of propane.

Further, if any of the above compounds are converted to plastics, tires, or products, there is no potential for global warming except for the energy used to make the chemical conversions.

Tropospheric ozone (O3) also plays an important role in the global climate.[35] The short lifetime of ozone (hours to days) precludes a meaningful calculation of its global warming potential on the time horizons (20, 100, and 500 years) commonly used to measure GWP.[36] However, the United Nations includes the climate impact potential of O3 formation in its formulation of GWPs[37] (thus listing O3 would result in

[32] http://www.eia.gov/environment/emissions/co2_vol_mass.cfm with density conversion
[33] ibid
[34] ibid
[35] http://www.atmos-chem-phys.net/11/13395/2011/acp-11-13395-2011.pdf
[36] http://cdiac.ornl.gov/pns/current_ghg.html
[37] http://unfccc.int/ghg_data/items/3825.php

some double counting of impact potentials). O3 is not regulated by U.S. EPA as a GHG. Overall, propane emissions play a very limited role in tropospheric ozone formation.[38]

Climate Change Initiatives

Federal Laws and Regulations

At the federal level, the USEPA implements national programs related to greenhouse gas emissions and climate change under the federal Clean Air Act (CAA) and Clean Air Act Amendments (CAAA).

Federal Clean Air Act

For the first time, in 2007, in Massachusetts v. the Environmental Protection Agency, the United States Supreme Court ruled that GHGs are air pollutants that were covered under the Clean Air Act. The Court found that USEPA has a mandatory duty to enact rules regulating mobile GHG emissions pursuant to the federal Clean Air Act. The Court held that GHGs fit the definition of an air pollutant that causes and contributes to air pollution and may reasonably be anticipated to endanger public health or welfare. In 2009, the USEPA Administrator found that the current and projected concentrations of GHGs threaten public health and welfare of current and future generations and that combined emissions from new motor vehicles contribute to GHG pollution. USEPA's endangerment finding covers emissions of six key GHGs: CO2, CH4, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride (SF6). As mentioned previously, propane is not a regulated GHG under the Clean Air Act.

Mobile Source Regulations

On August 9, 2011, the USEPA and the National Highway Traffic Safety Administration (NHTSA) announced standards to reduce GHG emissions and improve fuel efficiency for heavy-duty trucks and buses. On October 15, 2012, USEPA and NHTSA established a program to reduce GHG emissions and improve fuel economy standards for new cars and light trucks through 2025 (USEPA 2012a).

Stationary Source Regulations

To address large stationary emitters of GHGs, the USEPA also established mandatory reporting of GHG emissions for facilities that emit more than 25,000 metric tons of CO2e emissions per year. On May 13, 2010, Clean Air Act permitting programs were tailored to cover the nation's largest GHG emitters: power plants, refineries, and cement production facilities. On March 27, 2012, the USEPA proposed a Carbon Pollution Standard for new power plants that would, for the first time, set limits on the amount of carbon pollution emitted by power plants (USEPA 2012b). On September 20, 2013, this proposal was withdrawn, and a new proposal was issued with a revised approach that would set separate standards for natural gas-fired turbines and coal-fired units.

[38] http://onlinelibrary.wiley.com/doi/10.1029/91JD01345/abstract;jsessionid=C74532AB7C67821F75782BBAFBE842D0.f04t01

Council on Environmental Quality Guidance

On February 18, 2010, the White House Council on Environmental Quality (CEQ) released draft guidance on the consideration of GHG in National Environmental Policy Act (NEPA) documents for federal actions. The draft guidelines include a presumptive threshold of 25,000 metric tons of carbon dioxide equivalent (CO2e) emissions from a proposed action to trigger a quantitative analysis. CEQ has not established when GHG emissions are "significant" for NEPA purposes, but rather poses that question to the public (CEQ 2010).

On June 4, 2012, CEQ finalized an update to the 2010 Federal GHG Accounting and Reporting Guidance. The guidance establishes requirements for Federal agencies in calculating and reporting GHG emissions associated with agency operations under Executive Order 13514, Federal Leadership in Environmental, Energy, and Economic Performance. Under the authority of EO 13514, the United States Fish and Wildlife Service (USFWS) has developed a climate change strategy and included sustainability practices within the USFWS Service Manual to reduce and offset GHG emissions and move towards carbon neutral practices. The USFWS Climate Change Strategic Plan includes Mitigation Goal 5, which aims to change business practices to achieve carbon neutrality by the year 2020. The plan lists objectives to assess and reduce the carbon footprint of the Service's facilities, vehicles, workforce, and operations, assess and reduce the Service's land management carbon footprint, and offset the remaining carbon balance (USFWS 2010).

The recent agreement between the U.S. and China is intended to "spur nations around the world to make their own cuts in greenhouse gases" and to halt growth in China's GHG emissions by 2030. The agreement is also expected to facilitate reaching a new global climate agreement in 2015.[39] The two countries together produce about 45% of the world's carbon dioxide.[40] The agreement sends a signal to financiers that investing in high carbon fuels for the future is becoming a risk.[41] On the same day as the U.S.-China announcement, several Southeast Asian nations jointly announced their intent to adopt national GHG reduction targets by mid-2015.[42] China is seen as encouraging other Asian nations to adopt targets, too.[43] South Korea became the first Asian country to pass a national cap-and-trade system (based on the European cap and trade system) and emission trading in Korea was scheduled to begin on January 1, 2015.[44] In South Korean, 14% of automobiles use propane gas as an alternative to gasoline, and government incentives are in place in South Korea, Japan, and India to increase the use of propane as an automobile fuel.[45]

Switching to lower GHG intensity fuels such as propane to displace coal, diesel or gasoline would likely result in GHG emission reductions.

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[39] "Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC)," http://unfccc.int/2860.php
[40] http://www.nytimes.com/2014/11/12/world/asia/china-us-xi-obama-apec.html?_r=0
[41] http://www.bbc.com/news/world-asia-china-30015545
[42] http://www.chinadaily.com.cn/world/2014-11/13/content_18908629.htm
[43] http://asia.nikkei.com/Japan-Update/China-urges-Japan-to-set-ambitious-emission-cut-target
[44] http://www.ieta.org/assets/EDFCaseStudyMarch2014/south%20korea%20ets%20case%20study%20march%202014.pdf
[45] http://wlpga.org/uploads/Modules/Publications/autogas_incentive_policies_2014.pdf

Issue 3. Describe the cradle-to-grave greenhouse gas (GHG) lifecycle analysis of propane as an export to Asian markets compared to other energy sources for various market segments (e.g. residential and commercial heating, vehicles, agriculture and manufacturing).

The lifecycle GHG emissions for propane exports can be subcategorized into three segments: upstream process emissions, transportation and storage, and emissions from fuel combustion. Process GHG emissions include emissions from initial land clearing at the well site, extraction and processing. Storage and transport GHG emissions include emissions associated with rail, pipeline, ocean vessel, and storage terminals. Finally, end use GHG emissions from fuel use include fuel combustion.

Fuel use (i.e., combustion) typically accounts for 70-90 % of lifecycle GHG emissions for fossil fuels, including propane. The following table summarizes the major components of the lifecycle for key petroleum fuels.

Table 2 - Lifecycle of Propane Fuel Exports to Asia versus Lifecycles of Other Fuels Used for Residential Heating, Commercial Heating, and Vehicle Fuel Use in Asia

Fuel/ Feedstock	Residential Heating, Commercial Heating, and Vehicle Fuel Use			
	Extraction	Transport to Refining	Refining	Transport to End Use
Propane	Propane production is incidental to domestic oil and gas extraction	Pipeline	Separates propane from other fuels	Rail transport of propane to an export terminal (diesel engines), transfer to terminal (compressors), pipeline to ocean going vessel, transport to distribution terminal in Asia, and distribution to end users
Natural Gas	With the exception of LNG use, extraction is in Asia	Pipeline	Removes inert materials and other materials likely to form liquids in pipelines	Transmission and distribution Pipelines (compressors), underground storage (dehydrators), liquefaction, refrigeration and storage, transfer to terminal (compressors), pipeline to ocean going vessel, transport to distribution terminal in Asia, and distribution to end users
Diesel	Crude extraction. Drilling, pumping, storage, flares	Pipeline, truck, rail	Refines crude into separate marketable products	Pipeline, truck, rail and truck distribution dispensing facilities, transfer to terminal (compressors), pipeline to ocean going vessel, transport to distribution terminal in Asia, and distribution to end users
Gasoline	Crude extraction. Drilling, pumping, storage, flares	Pipeline, truck, rail	Refines crude into separate marketable products	Pipeline, truck, rail and truck distribution dispensing facilities, transfer to terminal (compressors), pipeline to ocean going vessel, transport to distribution terminal in Asia, and distribution to end users
Coal	Mining	Pipeline, truck, rail	Minimal	Pipeline, truck, rail to end use facilities (typically power plants), transfer to terminal (compressors), pipeline to ocean going vessel, transport to distribution terminal in Asia, and distribution to end users

Fuel Use Displaced in Asia by Propane Exported from North America

A fundamental question is whether propane will be consumed as an alternative to other fuel sources, and in particular, as a replacement for coal. When propane is used to replace coal and/or other fuels with higher lifecycle GHG emissions, if it does not lead to an overall increase in energy use, it has an overall positive impact on reducing global GHG emissions and local air pollutants.

Substitution of propane for coal will result in significant environmental benefits including a reduction in sulfur emissions, mercury emissions, PM10 and PM2.5 emissions and a net reduction in GHG emissions. Both local community and the global community will benefit from this fuel substitution.

In order to determine the overall impact on global GHG emissions from the export of propane to Asia, an examination of energy consumption trends must be completed and activities and emissions involved in each step of the lifecycle must be considered. A recent British Columbia study[46] concluded that natural gas exports from British Columbia would, for the most part, replace coal and to a lesser degree, natural gas coming from other sources. However, increased supply of any energy source can decrease prices of energy and increase overall energy consumption, partially or wholly offsetting these savings.

Recent research[47] suggests that about 18 percent of all anthropogenic carbon dioxide emissions come from biomass burning. When new biomass grows at the same rate that it is harvested, then there is no net loading of CO2 to the atmosphere. However, when biomass consumption rates exceed the growth rates, the net effect is a significant increase in atmospheric CO2 emissions. And as noted in Issue 5 below, biomass is used by millions in Asia for home heating and cooking. Substitution of propane for biomass would result in significant environmental and health benefits including large reductions in particulate matter.

Issue 4. Characterize propane in comparison with other fuels in terms of energy density and GHG emissions per unit of energy.

The GREET model, version 2.0, was used to model the lifecycle emissions of propane fuel and its alternatives. These model results are summarized in Table 3 below. The emissions are expressed as mass of CO2e emissions per unit of fuel energy delivered to end users. The results are depicted in Figure 7. Table 4 summarizes annual GHG emission rates for the continuous export of 37,000 barrels per day of propane. GREET model output and output process flowcharts are included in Appendix A.

[46] "British Columbia LNG Greenhouse Gas (GHG) Lifecycle Analysis - Discussion Draft," February 3, 2014 http://www2.gov.bc.ca/gov/DownloadAsset?assetId=63E636239264473999EF9032145643EA&filename=british_columbia_lng_greenhouse_gas_ghg_life_cycle_analysis.pdf

[47] http://news.stanford.edu/news/2014/july/biomass-burning-climate-073114.html

Table 3 – Lifecycle GHG Emissions per Unit of Fuel Delivered to End Users – Summary of GREET Output

Fuels	GHG Emissions (grams CO2e per MJ of delivered fuel)			
	Process	**Transport and Storage**	**Use**	**Total**
Coal	5.0	1.4	92.0	97.0
Diesel	14.6	2.5	75.7	92.8
Gasoline	23.2	0.4	66.3	89.8
Propane	13.6	1.2	63.4	78.2
Natural Gas	7.9	10.8	57.7	76.3

Note: For propane, 10 gallon = 1 gigajoule (GJ) of fuel.
Source: http://www.convertunits.com/from/gallon+[U.S.]+of+LPG/to/megajoule

Figure 7 - Lifecycle GHG Emissions per Unit of Fuel Delivered to End Users (grams CO2e per MJ of Fuel Delivered)

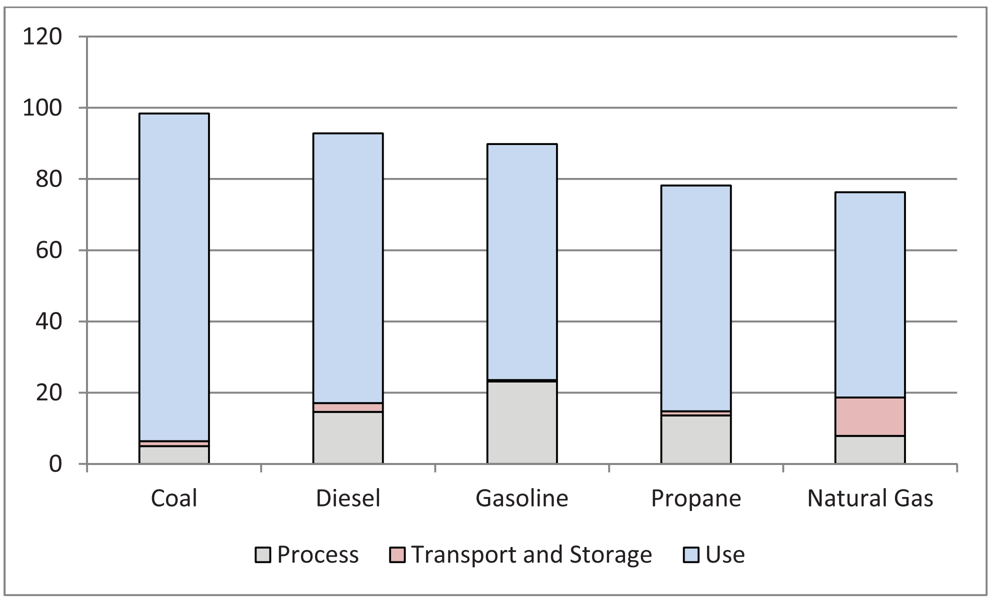


Table 4 – Lifecycle GHG Emissions for the Export of the Equivalent of 37,000 barrels per day of Propane

Fuels	GHG Emissions (metric tons CO2e per year)			
	Process	**Transport and Storage**	**Use**	**Total**
Coal	270,195	75,655	4,971,585	5,317,435
Diesel	788,969	134,827	4,091,669	5,015,465
Gasoline	1,251,326	20,400	3,582,243	4,853,970
Propane	735,714	63,307	3,425,287	4,224,308
Natural Gas	425,233	581,675	3,115,725	4,122,633

The GREET model used for this analysis includes default methane release rates (subject to change) for the following activities:

- Recovery - Completion CH4 Venting
- Recovery - Workover CH4 Venting
- Recovery - Liquid Unloading CH4 Venting
- Well Equipment - CH4 Venting and Leakage
- Processing - CH4 Venting and Leakage
- Transmission and Storage - CH4 Venting and Leakage
- Distribution - CH4 Venting and Leakage

Thus, the emissions in the tables above are inclusive of upstream emissions associated with oil and gas extraction and processing activities. Further updates to methane release rates (i.e., higher rates) are proposed in California. Oregon's version of the GREET model will also undergo updates in the future to reflect ongoing emissions research.

When natural gas leakage is factored in, life cycle GHG emissions of propane and natural gas sources are comparable.

In both Tables 3 and 4, "process" emissions are those emissions that are due to upstream process-related handling of the fuel. These handling activities include field development, extraction, separation, etc., but exclude fuel transport and storage, which are categorized separately in this analysis. The remaining and most significant component of the lifecycle is fuel combustion. As noted previously, fuel combustion typically accounts for 70 to 90% of lifecycle emissions when the fuel is burned. The energy density values for each fuel are provided in Table 5 below.

Table 5 - Energy Density of Fuels

Energy Density	MJ Per unit
Natural Gas	0.98 (MJ/standard cubic foot)
Propane	96.5 (MJ/gallon)
Gasoline	116.09 (MJ/gallon)
Diesel	129 (MJ/gallon)
Coal (All types)	15-27 (MJ/kg)

Source: Oregon DEQ Energy Density of Fuels, Table 3[48]

48 See: http://arcweb.sos.state.or.us/pages/rules/oars_300/oar_340/_340_tables/340-253-3030_12-11.pdf

Issue 5: Characterize propane GHG emissions in comparison to other petrochemical feedstock GHG emissions.

GREET also provides some capabilities for assessing the lifecycle GHG emissions of petrochemical feedstocks. The results from modeling petrochemical feedstocks in GREET is presented in Table 6.

Table 6 – Lifecycle GHG Emissions of Petrochemical Feedstock Production – Summary of GREET Output

Feedstocks	GHG Emissions (g/MJ)		
	Process	**Transport and Storage**	**Total**
Methanol from Coal	124	1.8	126.1
Methanol from NA Natural Gas	27.1	2.4	29.5
Methanol from non-NA Natural Gas	25.7	3.9	29.6
Propane	13.6	1.2	14.8

The International Energy Agency (IEA) publishes GHG emissions per ton of petrochemical end product.[49] Table 7 summarizes average GHG emissions for different petrochemical manufacturing processes involving propane or an alternative feedstock. The energy use is limited to the manufacturing process and excludes the lifecycle of petrochemical feedstocks. Table 7 shows a relatively low GHG emissions rate for processes involving propane and butane.

[49] See: http://www.iea.org/media/freepublications/technologyroadmaps/TechnologyRoadmapCatalyticProcessesAnnexes.pdf

Table 7 – Average GHG Emissions per metric ton of Petrochemical Product Produced, By Feedstock

Process	Average Energy Consumption (GJ/metric ton of propylene)	Best Practice Technology Energy Consumption (GJ/metric ton of propylene)	Average GHG Emissions (metric ton CO2e per metric ton of production)
Propylene, ethylene coproduct-polymer grade	16.50*	12	0.7
Propylene from deep catalytic cracking of VGO	8.47	7.33	0.869
Propylene from metathesis of ethylene and butylenes	0.39	0.33	0.374
Propylene from selected gas streams from coal-to-oil-- polymer grade	11.59	7.33	0.783
Propylene from Superflex technology	12.56*	7.33	0.783
Propylene, propane dehydrogenation-polymer grade	13.48	11.24	1.231
Propylene, refinery byproduct- chemical grade	8.71	7	0.3
Propylene, refinery byproduct- polymer grade	8.71	7	0.491
Propylene, refinery byproduct- refinery grade	8.71	7	0.491

Source: IEA World Energy Outlook
http://www.iea.org/media/freepublications/technologyroadmaps/TechnologyRoadmapCatalyticProcessesAnnexes.pdf

Propane dehydrogenation units combine propane, heat and a catalyst to encourage a chemical reaction to form propylene. One metric ton of propane feedstock nets 0.85 metric tons of propylene product.[50] Thus 1.1765 metric tons of propane feedstock will produce one metric ton of propylene and the propylene manufacturing process will result in 1.231 metric tons of CO2e emissions. The energy density of propane (Table 5) can then be used to estimate emissions per MJ of propane feedstock needed to produce 1 metric ton of propylene: 21 grams CO2e per MJ of propane consumed as a feedstock to produce one ton of propylene. Emissions associated with use of propane as a petrochemical feedstock are about a third of the emissions associated with combustion of an equivalent amount of propane fuel.

The intent of this paper is to determine the lifecycle emissions of propane and alternative feedstocks and to portray the effect on overall emissions when propane displaces other fuels and feedstocks in varying degrees

In conclusion, the lifecycle emissions in Table 3 and 4 above show that, with the exception of natural gas, propane has the lowest GHG emission rate per unit of delivered energy and highest energy density of any of the listed fuels. These calculations are first-order estimates.

[50] http://www.lpgasmagazine.com/propane-a-wanted-commodity-in-petrochemical-sector/

Issue 6: Characterize GHG emissions for propane for a mix of fuel combustion and other petrochemical feedstock end uses.

The ultimate end use for exported propane will depend on the buyer. The propane may be used as a fuel, as a manufacturing feedstock, or its end use may be split between fuel and feedstock. Whether the end use is as a fuel or as a feedstock, the lifecycle GHG emissions from well to product delivery to the end user are assumed to be identical. The difference in lifecycle GHG emissions will result from how emissions from combustion compare to emissions from petrochemical manufacturing using propane as a feedstock. In order to assess and compare life cycle emissions of different potential end uses, five end use scenarios were constructed and evaluated in this paper, as shown in Table 8:

Table 8 - Five Propane End Use Scenarios

Scenarios	End Use as a Feedstock	End Use as a Fuel
Scenario 1	100%	0%
Scenario 2	75%	25%
Scenario 3	50%	50%
Scenario 4	25%	75%
Scenario 5	0%	100%

Table 9 summarizes lifecycle GHG emissions of propane for each scenario. In general, propane used for petrochemical manufacturing has lower GHG emissions over its lifecycle (even when the emissions associated with propylene manufacturing are treated as if they were a part of the lifecycle of propane).

Table 9 – Summary of Lifecycle GHG Emissions for Five Propane End Use Scenarios

Scenario	Well to Product Delivery Emissions (gCO2e/MJ of Delivered Product)	Emissions Due to Fuel Use (gCO2e/MJ of Delivered Fuel)	Emissions Due to Feedstock Use* (gCO2e/MJ of Delivered Feedstock)	Total Lifecycle Emissions (gCO2e/MJ of Used Product)
Scenario 1	799,020	0	1,134,818	1,933,839
Scenario 2	799,020	856,322	851,114	2,506,456
Scenario 3	799,020	1,712,644	567,409	3,079,073
Scenario 4	799,020	2,568,965	283,705	3,651,690
Scenario 5	799,020	3,425,287	0	4,224,307

Issue 7. Characterize propane and any associated minor constituents according to their contribution to GHG emissions, air toxics, ozone formation or ozone layer depletion.

The air quality benefits and impacts of fuel switching to propane can vary widely depending on the pollutant under consideration, the location of the fuel use, the fuels displaced, fuel and equipment standards in place, age of equipment, and other factors. In general, gaseous fuels (propane and natural gas) produce net air quality benefits when they displace liquid or solid fuels in most applications. For ozone precursors (volatile organic compounds and oxides of nitrogen), oxides of sulfur, particulate matter, carbon monoxide, toxics and heavy metals, the environmental footprints of gaseous fuels are significantly lower than those of liquid fuels (heating oil and residual oil, gasoline, and diesel) and dramatically lower than those of solid fuels (coal and wood). When more sophisticated combustion and control equipment are used, the advantage of gaseous fuels diminishes but still remains significant. Electricity produces lower levels of emissions at the point of use but lifecycle emissions depend on the feedstock used in the power plant and location of use.

Indoor air pollution from cooking with biomass causes the premature deaths of an estimated four million people annually from lung cancer, cardiovascular disease, pneumonia and chronic obstructive pulmonary disease.[51] Of the 2.6 billion people relying almost exclusively on biomass for home heating and cooking, more than half of them are in China, India, and Bangladesh and another 300 to 400 million people, mostly in China and India, use coal for cooking.[52] Residential cooking and heating demands

[51] http://fr.exceptionalenergy.com/uploads/Modules/Ressources/the-socioeconomic-impact-of-switching-to-lp-gas-for-cooking.pdf
[52] http://fr.exceptionalenergy.com/uploads/Modules/Ressources/the-socioeconomic-impact-of-switching-to-lp-gas-for-cooking.pdf

account for 47% of the global demand for propane.[53] Increased use of propane would improve indoor air quality and help alleviate these health effects.

Propane produces much lower emissions of black carbon (an air pollutant and contributor to climate change) than solid and liquid fuels so fuel switching to propane would result in air quality and climate benefits. Substantial air quality, health, and climate change benefits result from efforts to reduce methane and black carbon (i.e., soot) emissions. The White House refers to black carbon as a “climate and air pollutant” suggesting that future regulations under the Clean Air Act may target reductions in black carbon.[54]

Use of propane as an automobile fuel yields 50% less carbon monoxide, 40% less hydrocarbons, 35% less nitrogen oxides (NOx) and 50% less ozone forming potential compared to gasoline and does not emit hazardous air pollutants such as benzene, toluene, ethylbenzene, and xylenes.[55] Propane as a fuel source also reduces diesel particulate emission, polycyclic aromatic hydrocarbons (PAHs), and other toxic emissions that have significant health impacts.

Propane does not affect the ozone layer. One of propane’s uses is as a refrigerant. Unlike many refrigerants, which have high ozone depletion potentials, the USEPA lists propane as having an ozone depletion potential of zero. This means that propane does not affect the ozone layer.[56]

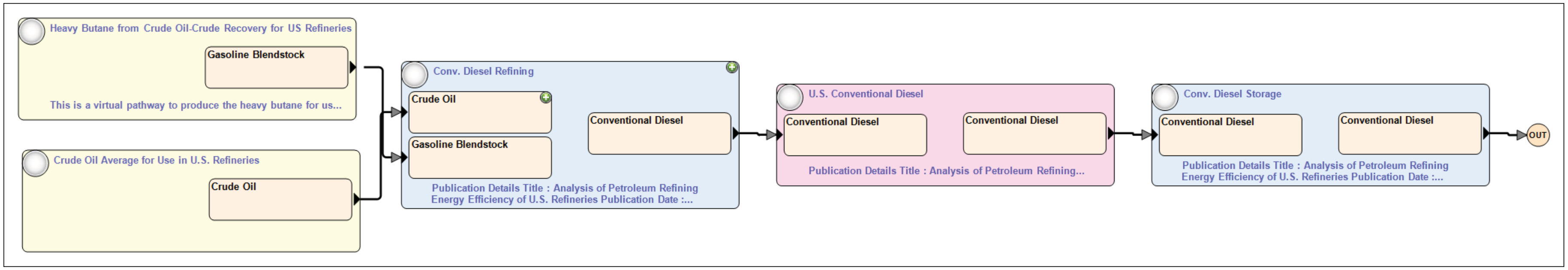
[53] http://www.who.int/indoorair/interventions/iapcosteffectiv.pdf
[54] http://www.whitehouse.gov/the-press-office/2014/09/23/fact-sheet-president-obama-announces-new-actions-strengthen-global-resil
[55] http://www.exceptionalenergy.com/en_GB/facts-figures/lpg-facts
[56] http://www.beyondhfcs.org/pages/natural-refrigerants.php

Appendix A - Fuel and Feedstock Pathway Diagrams and GREET 2.0 Modeling Results

This appendix contains output from the GREET model for the following fuels and feedstocks evaluated in this paper:

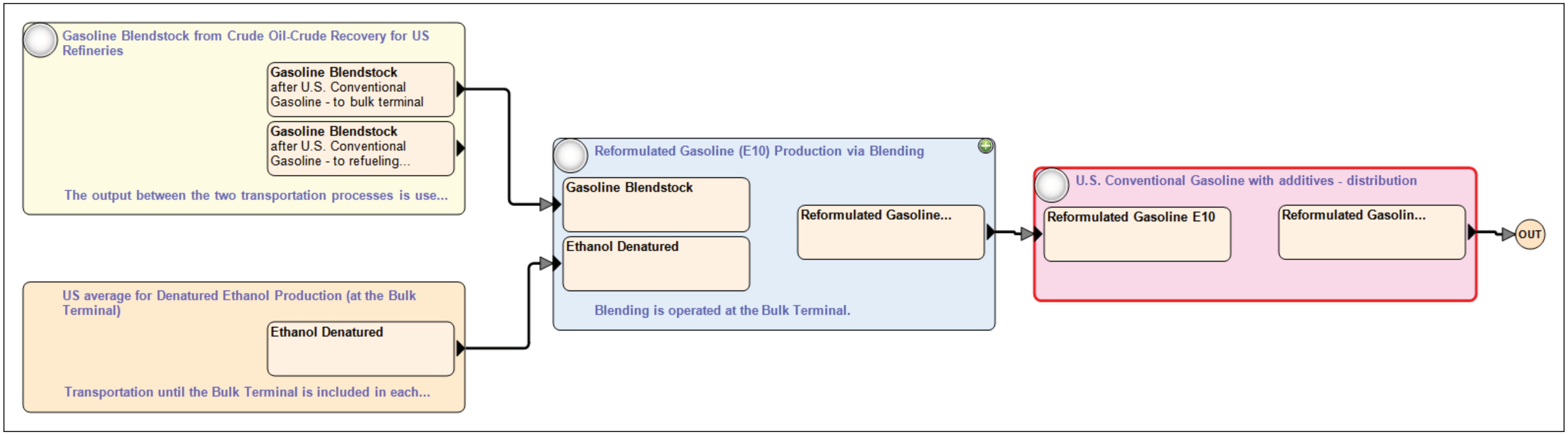
- Conventional Diesel
- Reformulated Gasoline (E10)
- Conventional Gasoline
- Propane from Crude
- Propane from Natural Gas
- Natural Gas
- Methanol from Coal
- Methanol from North American (NA) Natural Gas

Conventional Diesel



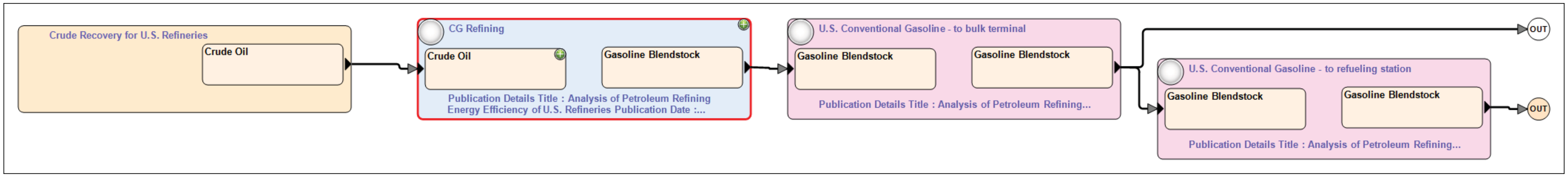
	Modeling Output from GREET 2.0 - GHG Emissions (g/MJ)						
Fuel	Heavy butane from crude oil, crude recovery for U.S. refineries	Crude Oil Average for Use in U.S. Refineries	Conventional Diesel Refining	Transportation and Storage	Total Well to Product GHG	Combustion	Total
Conventional Diesel	6.7	2.0	7.9	0.5	17.1	75.7	92.8

Reformulated Gasoline (E10)



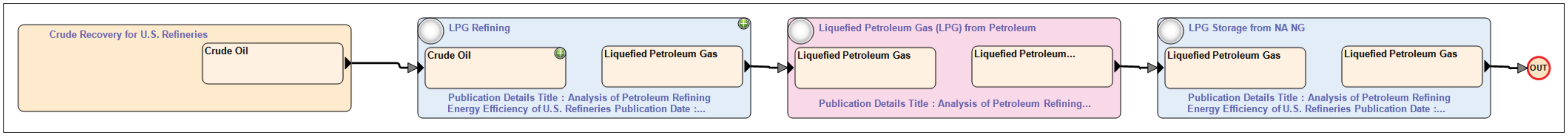
	Modeling Output from GREET 2.0 - GHG Emissions (g/MJ)						
Fuel	Gasoline Blendstock from Crude Oil, crude recovery for U.S. refineries	U.S. Average for Denatured Ethanol Production at bulk terminal	Reformulated Gasoline (E10) Production via Blending	Product Distribution	Total Well to Product GHG	Combustion	Total
Reformulated Gasoline (E10)	22.0	0	2.9	0.2	25.0	66.3	91.3

Conventional Gasoline



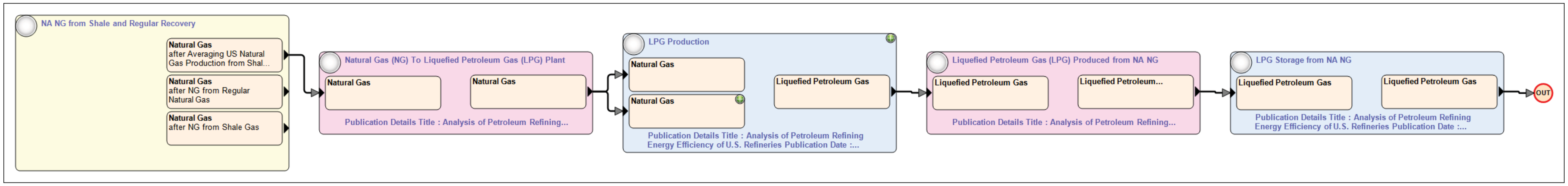
	Modeling Output from GREET 2.0 - GHG Emissions (g/MJ)						
Fuel	Crude Recovery for U.S. Refineries			Transportation and Storage	Total Well to Product GHG	Combustion	Total
Conventional Gasoline	21.4			0.6	22.0	66.3	88.3

Propane from Crude



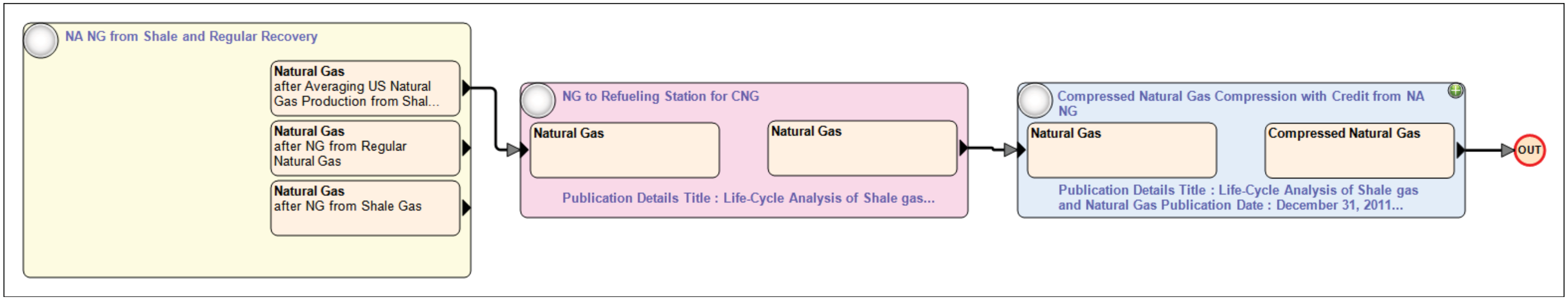
	Modeling Output from GREET 2.0 - GHG Emissions (g/MJ)						
Fuel	Crude Recovery for U.S. Refineries	LPG Refining	LPG from Petroleum	Transportation and Storage	Total Well to Product GHG	Combustion	Total
Liquefied Petroleum Gas from Crude	7.5	13.3	0.9	0.0	21.7	57.9	79.6

Propane from Natural Gas



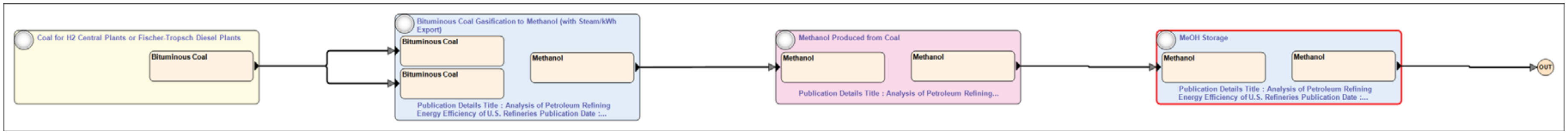
	Modeling Output from GREET 2.0 - GHG Emissions (g/MJ)						
Fuel	NG from Shale and Regular Recovery	NG to LPG Plant	LPG Production	Transportation and Storage	Total Well to Product GHG	Combustion	Total
Liquefied Petroleum Gas from Natural Gas	7.9	0.5	3.4	0.7	12.5	65.2	77.7

Natural Gas



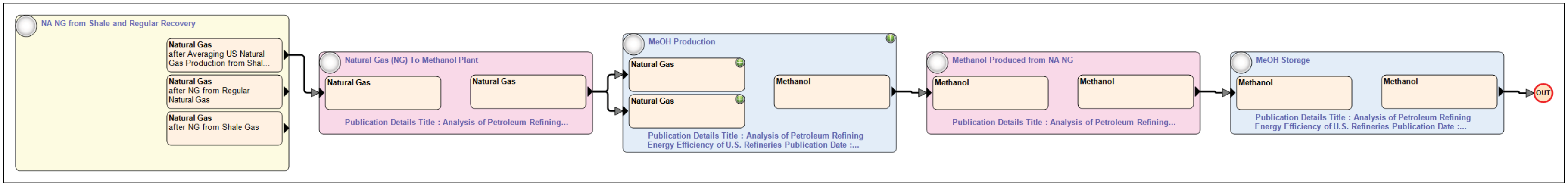
	Modeling Output from GREET 2.0 - GHG Emissions (g/MJ)						
Fuel	NG from Shale and Regular Recovery		Transportation and Storage	NG Compression	Total Well to Product GHG	Combustion	Total
Natural Gas	7.9		7.0	3.8	18.6	57.7	76.3

Methanol from Coal



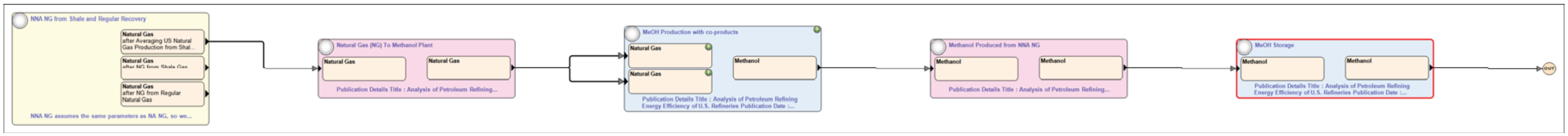
	Modeling Output from GREET 2.0 - GHG Emissions (g/MJ)						
Feedstock	Coal for H2 Central Plants or Fischer-Tropsch Diesel Plants	Bituminous Coal Gasification to Methanol (with Steam/kwh export)	Transportation and Storage		Total Production GHG	Combustion	Total
Methanol from Coal	5.8	118.5	1.8		126.1	0.0	126.1

Methanol from NA Natural Gas



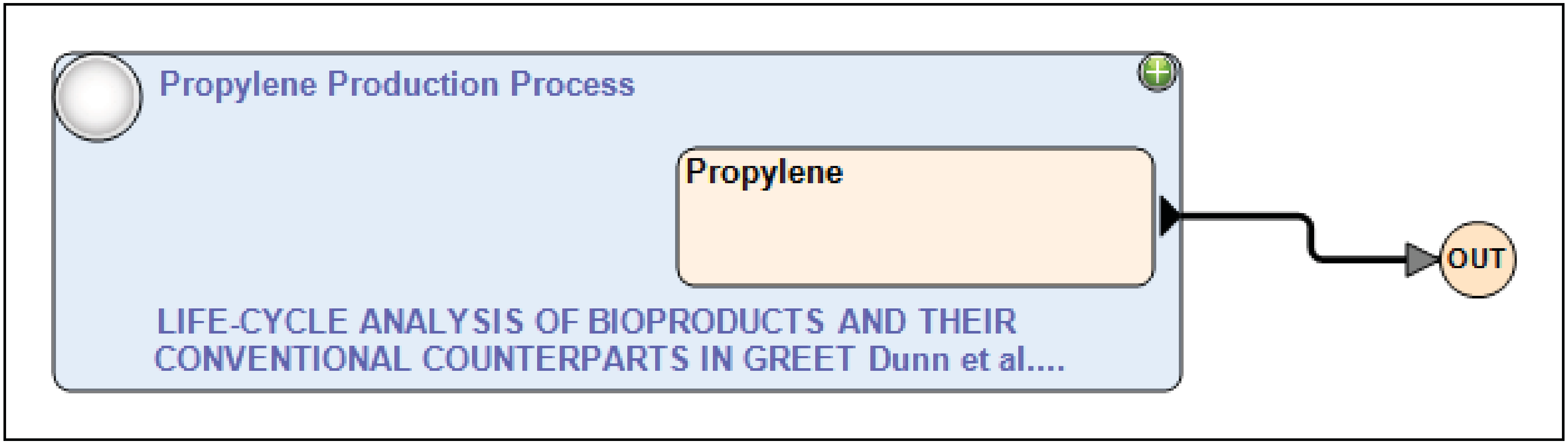
	Modeling Output from GREET 2.0 - GHG Emissions (g/MJ)						
Feedstock	NG from Shale and Regular Recovery	Natural Gas to Methanol Plant	Methanol Production	Transportation and Storage	Total Production GHG	Combustion	Total
Methanol from NA Natural Gas	7.9	0.5	19.3	1.8	29.5	0.0	29.5

Methanol from non-NA Natural Gas



	Modeling Output from GREET 2.0 - GHG Emissions (g/MJ)						
Feedstock	Non-NA NG from Shale and Regular Recovery	Natural Gas to Methanol Plant	Methanol Production with co-products	Transportation and Storage	Total Production GHG	Combustion	Total
Methanol from non-NA Natural Gas	7.9	0.5	17.8	3.4	29.6	0.0	29.6

Propylene Production



	Modeling Output from GREET 2.0 - GHG Emissions (g/MJ)						
Feedstock	Propylene Production Process				Total Production GHG	Combustion	Total
Propylene	52.4				52.4	0.0	52.4