PROPANE education & research COUNCIL

RENEWABLE & LOW CARBON PROPANE

How Propane Will Contribute

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Propane Education & Research Council

WHY RENEWABLE?

LOW EMISSIONS +
AFFORDABLE COSTS

=

PRODUCTIVE SOUND POLICY
and REAL PROGRESS

WHY RENEWABLE PROPANE?

- Low carbon intensity
- Inexpensive feedstock
- Available feedstock
- Low energy conversion
- Final product competitively priced
- Available infrastructure

COMMERCIAL PRODUCTION OF RENEWABLE PROPANE

- Current production is directly linked to the amount of RHD produced.
- Carbon Intensity (CI) depends on feedstock
  - Renewable propane CIs are the same as those for RHD under the California LCFS
  - Conventional propane has a CI of 83g CO_2/MJ in California

	Used Cooking Oil	Raw UCO	Corn Oil	Animal Fats	Soybean Oil
CA LCFS Carbon Intensity for REG renewable propane, by feedstock [g CO_2/MJ]	24.35	18.99	34.32	35.71	56.57

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Business Sensitive – Not for Distribution

Bio-propane: Production Pathways and Preliminary Economic Analysis
Final Report
January 2, 2018

Executive Summary

The National Renewable Energy Laboratory, under sponsorship by the Propane Research and Education Council (PERC) and the Western Propane Gas Association (WPGA), has been investigating pathways for production of renewable propane. A number of pathways have been identified, some consisting of immediate and near term opportunities while others are longer range. This report is focused on a technical and economic evaluation of the availability of bio-propane from AltAir's Paramount California HEFA-jet refinery. Results show that approximately 3.5MM gallons per year bio-propane could be recovered from refinery off-gasses, however in the absence of subsidies recovery of propane is not currently cost effective due to the small throughput of the AltAir refinery. Recovery of propane becomes cost effective with either inclusion of credits for renewable fuels or higher tallow feedrates. Carbon intensity of bio-propane from AltAir's operation is estimated to be 31.5 g CO_{2e}/MJ (base case using natural gas-derived H_2) and 24.7 g CO_{2e}/MJ (using biomass-derived H_2), corresponding respectively to 59.3% and 68.0% carbon intensity reduction when compared to fossil propane. Availability of bio-propane from other similar sources outside California is explored. In addition we present an analysis of the technical and economic feasibility for production of dimethyl ether (DME) which can be blended with propane. Bio-DME presents a technically and economically attractive alternative with a greater than 90% carbon intensity reduction when compared to petroleum-derived fuels. Finally, other long-range technologies originally identified in the NREL whitepaper on this subject[1] are discussed.

Introduction and Background

Fossil propane is traditionally recovered as a by-product of natural gas liquids processing or from petroleum refinery process gases, and has been subject to rather broad swings in price as indicated by the historical data in Figure 1[2]. Regulatory mandates in the State of California are placing increasingly stringent requirements on fuels suppliers, including the following which are scheduled to be in force by 2020[3]:

- 10% carbon intensity reduction for petroleum-based transportation fuels,
- reduction in petroleum fuel use to 15% below 2003 levels,
- GHG emissions reduction to 1990 levels.

Among the solutions being considered by the propane industry to meet these

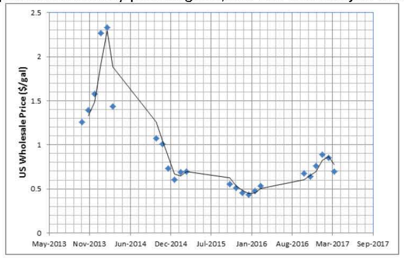

Figure 1. US wholesale propane prices

[1] R.M. Baldwin, "Routes to Bio-propane", NREL Whitepaper, September 16, 2016
[2] https://www.eia.gov/dnav/pet/pet_pri_wfr_a_EPLLPA_PWR_dpgal_m.htm
[3] https://www.arb.ca.gov/homepage.htm

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Review

Process Technologies and Projects for BioLPG

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check for updates

Abstract: Liquified petroleum gas (LPG)—currently consumed at some 300 million tonnes per year—consists of propane, butane, or a mixture of the two. Most of the world's LPG is fossil, but recently, BioLPG has been commercialized as well. This paper reviews all possible synthesis routes to BioLPG: conventional chemical processes, biological processes, advanced chemical processes, and other. Processes are described, and projects are documented as of early 2018. The paper was compiled through an extensive literature review and a series of interviews with participants and stakeholders. Only one process is already commercial: hydrotreatment of bio-oils. Another, fermentation of sugars, has reached demonstration scale. The process with the largest potential for volume is gaseous conversion and synthesis of two feedstocks, cellulosics or organic wastes. In most cases, BioLPG is produced as a byproduct, i.e., a minor output of a multi-product process. BioLPG's proportion of output varies according to detailed process design: for example, the advanced chemical processes can produce BioLPG at anywhere from 0–10% of output. All these processes and projects will be of interest to researchers, developers and LPG producers/marketers.

Keywords: Liquified petroleum gas (LPG); BioLPG; biofuels; process technologies; alternative fuels

1. Introduction

Liquified petroleum gas (LPG) is a major fuel for heating and transport, with a current global market of around 300 million tonnes per year. As are all fossil fuels, LPG is under pressure to decarbonise. To this end, its main fossil competitors have introduced bio-alternatives: biodiesel for diesel; bioethanol for gasoline; and biogas or biomethane for natural gas. LPG has followed suit in 2017–18 with the introduction of BioLPG [1]. Based on discussions with the industry and detailed searches of the commercial literature, the author estimates current worldwide production of BioLPG at about 200 thousand tonnes per year. Nearly all of this is produced via hydrogenation of animal and plant oils, much of those being wastes.

There is great interest among the LPG industry and decarbonisation-proponents to expand production volumes of BioLPG. This could happen by increasing capacity for hydrogenation and by commercialization of other process routes to BioLPG. This paper aims to support that process by giving researchers and process-developers an initial roadmap: it reviews all possible processes and known projects for producing BioLPG. The contents were compiled through an extensive literature review and interviews with participants and stakeholders. The paper should be of interest to researchers, developers, and LPG producers/marketers.

BioLPG can be produced by seven general processes (Table 1). Two of them (in green) are most promising:

- Hydrotreating of bio-oils is already producing 200 kilotonnes of biopropane, with some additions planned;
- Gaseous conversion and synthesis of cellulosics and organic waste does not yet generate any BioLPG, but BioLPG production this way is technically feasible, is under exploration and the potential feedstock availability is huge.

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BioLPG

A survey of markets, feedstocks, process technologies, projects and environmental impact

Final report V 3.3

Atlantic Consulting

26 June 2018

Renewable Propane, in commercial practice, is identical to the fossil counterpart. That is, the chemical structure and physical properties are the same – they just come from different sources.

RENEWABLE PROPANE COMPOSITION

Comparison with common specifications:

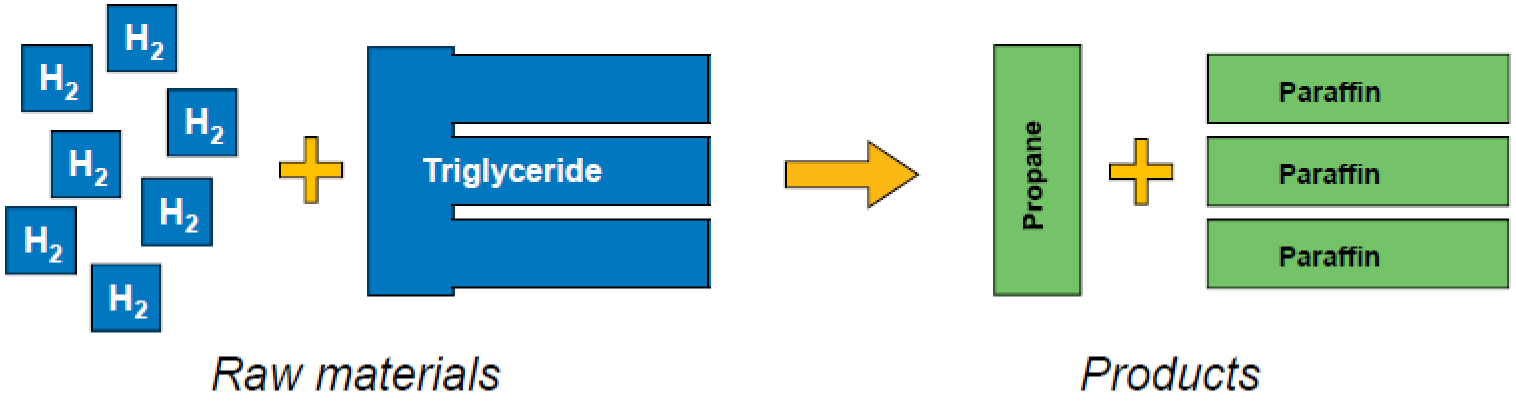
	REG renewable propane	Pipeline specs	HD5 spec	HD10 spec
Propane	92 – 95%	90% min	90% min	85% max
Propylene	non-detectable	5% max	5% max	10% max
Butane and C4+	5 – 8% (butane & isobutane)	2.5% max	7% max	n.a.
Sulfur	non-detectable	123 ppm	n.a.	n.a.

Notes: Data current as of 5/10/18

Source: REG Internal Analysis

HOW DO WE MAKE RENEWABLE PROPANE?

RNP is **hydrocarbons** made from biological oils and fats (**triglycerides**) by **hydrotreating**.

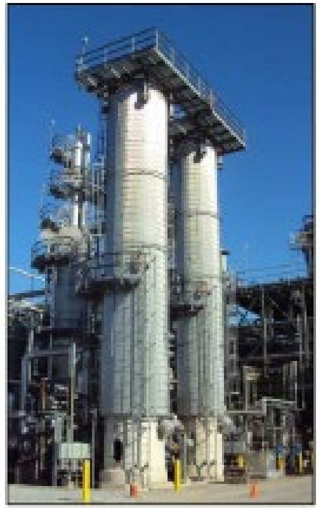


Hydrotreating Reaction

VOCABULARY

- Hydrocarbons: molecules consisting only of carbon and hydrogen (i.e., no oxygen, sulfur, or other atoms)
- Hydrotreating: reacting molecules with hydrogen to remove atoms other than hydrogen or carbon
  - Also called "hydro-deoxygenation" when oxygen is removed. A side effect is the removal of double bonds in the molecules (saturation)
- Isomerization: a process that rearranges the structure of a molecule without adding or removing atoms from the molecule
  - Also called "hydro-isomerization" when hydrogen is used to facilitate

BIO-SYNFINING™ OVERVIEW



Process Technology

Pretreatment	Hydrotreating	Isomerization	Fractionation
Remove feedstock impurities	React feedstock with hydrogen to produce hydrocarbons	Rearrange hydrocarbon molecules to reduce diesel cloud point	Separate hydrocarbons into finished products (diesel, naphtha, LPG)

POTENTIAL GLOBAL BIOLPG PRODUCTION LONG TERM (MILLION TON/YEAR)

Feedstock	2018	2030	2040	2050	Process path
Cellulosics	0	94	101	108	Advanced chemical processes
Mixed waste	0	15	15	15	Advanced chemical processes
Bio-oils	0.2	3.3	4.2	5.2	Hydrotreating
Sugar	< 0.1	0.15	0.15	0.15	Fermentation
Product					
BioLPG	0.2	112	120	128	
% LPG demand	0.07%	33%	33%	33%	

LONG TERM FEEDSTOCKS FOR RENEWABLE PROPANE

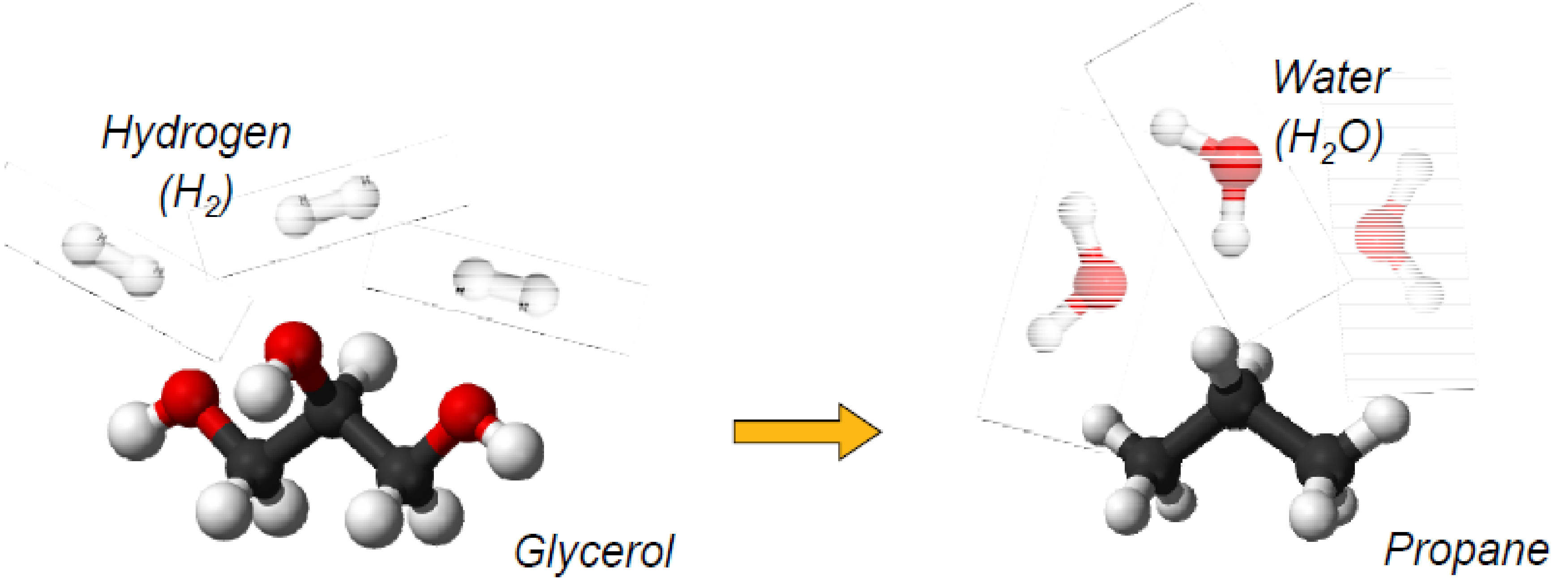
Feedstock	Structure	Sources

Cellulosics	Polymeric hydrocarbons with about 25% oxygen content by weight	Agricultural residues
		Corn (maize) stover (stalks and leaves)
		Food processing waste
		Rice husks
		Sugarcane bagasse
		Wood
		Woody biomass
		    Forest residues
		    Small round wood
		    Arboricultural arisings
		    Sawmill co products
		    Short rotation forestry
		Wheat straw, other straw

Mixed waste	Hydrocarbons and cellulosics. About 20-30% of the total hydrocarbons in municipal waste are fossil-based.	Municipal waste Sewage sludge
Atmospheric carbon dioxide[11]		Air and water

HYDROTREATING EXAMPLE

Glycerol to Renewable Propane



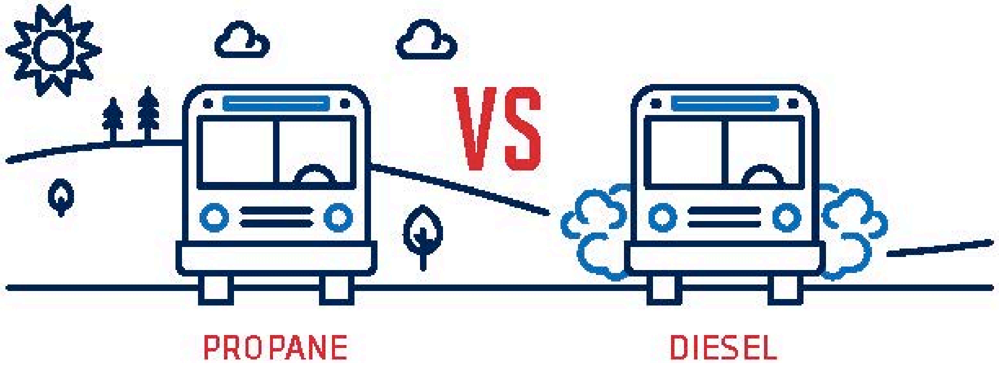
Criteria Pollutants from All Renewable Production is Important Too

96%

NOx REDUCTION

VERSUS CLEAN DIESEL BUS

Duty cycle: Low speed, stop-and-go route



Source: 2018 West Virginia University study, comparing 2015 LPG Blue Bird school bus (6.8L, 10 Cylinder) with 2014 ultra-low sulfur diesel Blue Bird school bus (6.7L, 6 cylinder).

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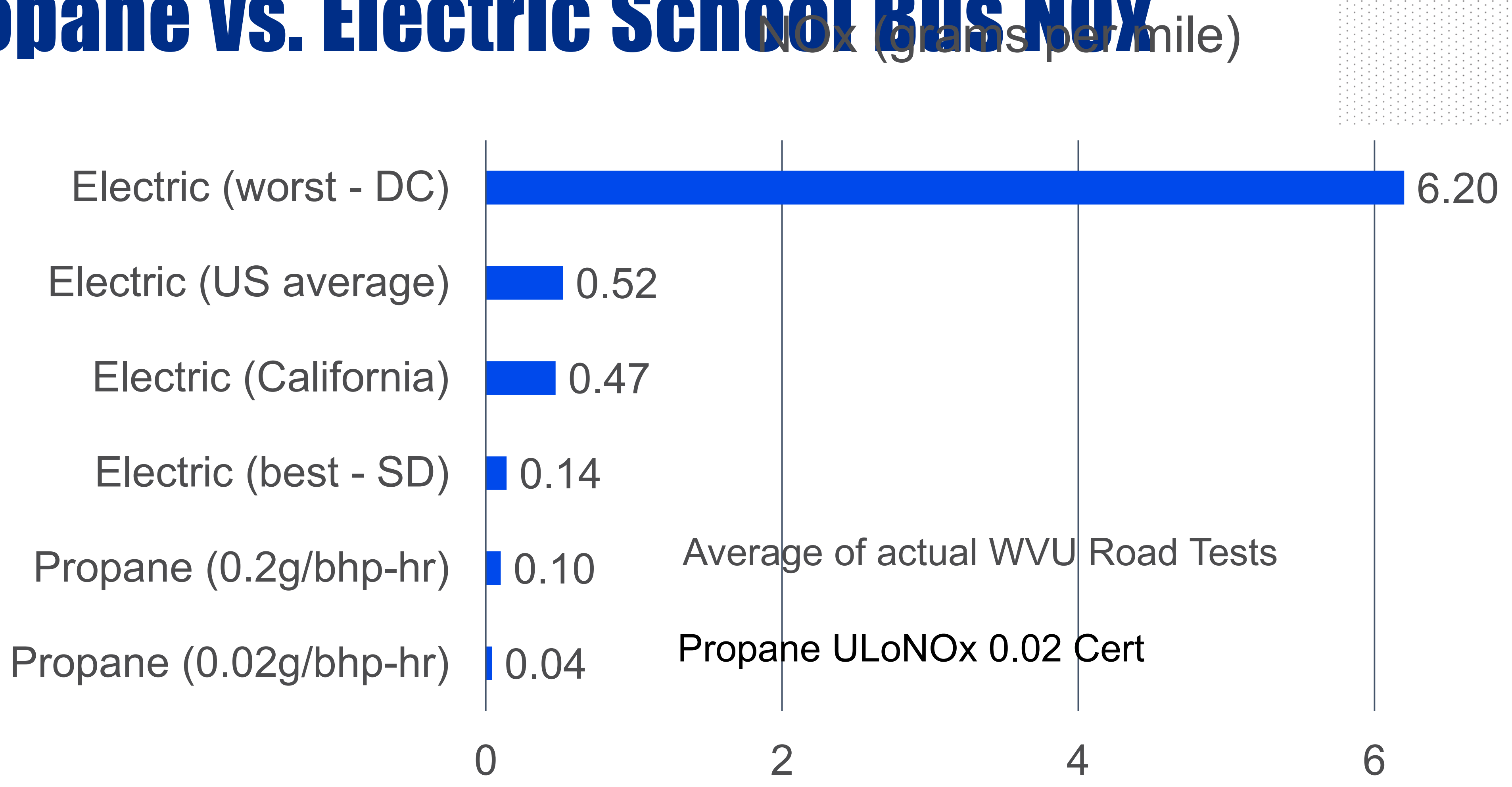
Electric School Bus N

- 2017 Energy Information Agency annual data for power generation and NOx emissions by state
- Manufacturer claimed Type C electric school bus energy consumption: 1.4 kWh / mile
- Massachusetts pilot project: 2.38 kWh / mile

Electric School Bus Energy Consumption (kWh/mi) →				1.40
STATE	GENERATION (Megawatthours)	NOx (Metric Tons)	NOx (g/kWh)	NOx (g/mile)
SD	10,935,719	1,075	0.098	0.14
NH	17,446,841	1,972	0.113	0.16
WA	115,912,028	14,385	0.124	0.17
NJ	75,644,513	9,752	0.129	0.18
SC	93,080,948	13,851	0.149	0.21
CT	34,562,654	5,982	0.173	0.24
OR	62,713,747	12,179	0.194	0.27
CA	206,146,392	68,521	0.332	0.47
TX	452,794,463	165,551	0.366	0.51
US-Total	4,034,268,431	1,505,762	0.373	0.52
WY	46,741,846	37,423	0.801	1.12
UT	37,411,876	31,759	0.849	1.19
NM	33,597,413	34,741	1.034	1.45
HI	9,812,050	16,114	1.642	2.30
AK	6,497,466	20,871	3.212	4.50
DC	66,871	296	4.426	6.20

https://www.eia.gov/electricity/data/state/

Propane vs. Electric School Bus NOx



Electric emissions based on electric school bus energy consumption of 1.4 kWh per mile

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