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Design to Thrive

Ethane—a green(er), clean(er) transportation fuel opportunity

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Abstract: Given their reliance on emissions-heavy air transport and shipping transport, package delivery companies are challenged to reduce their carbon footprints. UPS-type hydraulic hybrid ground fleets can be greener by optimizing energy use in these low-emission vehicles, since stopping, and starting is key to saving fuel in these types of vehicles. With a residence time of only 78 days in the troposphere after combustion, more economical ethane (C_2H_6) can be a greener bridge in the transportation sector. Ethane can act as an alternative fuel stock to expand this vehicle truck option, provide an oil saving solution, and reduce global warming emissions without drivers changing their driving habits. This is the best use of ethane adding the highest value using the simplest technology. In 2015, an ethane bi-fuel field trial was conducted in Jewett, Texas, USA using a modified fuel injection system in a Ford F150 4.6L Triton pickup truck. Emissions results returned 2 ppm particulate matter, 0.00% Carbon Monoxide (CO), 0.01% Carbon Dioxide (CO_2), and 20.79% Oxygen. Performance results returned torque slightly better than gasoline, and fuel injection time slightly slower than gasoline, providing better combustion. A higher, 9% increase in miles/GGE (gasoline gallon equivalent) efficiency versus gasoline was produced, resulting in 30% less CO_2/mile on the same vehicle compared to gasoline. We are proposing a follow-up test. This test will show the ethane truck functions well in colder conditions, heavy traffic, that it meets or exceeds California's air pollution laws, and that the test is repeatable. This paper will provide some background on ethane production and usage, and assert that it constitutes a better fuel system for the entire United States.

Keywords: ethane, transportation, alternative, fuel, low-emission

Introduction

Municipalities around the world are working collaboratively to be the cleanest, most environmentally sustainable cities on the planet. Clearly there are issues from the latent CO_2 produced from fossil fuels, but also Liquified Petroleum Gas (LPG). These municipalities' ultimate and cumulative end goal is to reduce worldwide carbon emissions utilizing cleaner burning fuels for their vehicles. This is a noble effort. However, there are other ways to reduce carbon emissions that can achieve the same carbon reduction objective by utilizing readily available, alternative fuel stocks such as ethane. Use of ethane can result in significant decreases in energy costs, yielding positive results in these municipalities. Ethane as a green(er) clean(er) transportation fuel can be a significant opportunity for the urban and rural environment as it decomposes much faster than LPG and fossil fuels.

Given their reliance on emissions-heavy air transport, package delivery companies, and mass transit fleets are challenged to reduce their carbon footprints. A way to green their ground fleets is to optimize energy use in low-emission vehicles. Hydraulic hybrid propulsion systems deployed in the newer UPS-type delivery trucks use energy efficiently, producing less pollution than conventional delivery trucks. (USEPA 2007) UPS-type trucks are rarely used on the highway; stopping and starting is key to saving fuel with a hydraulic hybrid. Bus fleets are using Liquified Natural Gas (LNG) to lower their carbon footprint, but LNG is not an optimal fuel source. Ethane is a scalable solution down to a mid-size car, so taxis could be a part of the solution.

Ethane use can expand these vehicle options, providing an oil savings solution by reducing global warming emissions without drivers changing their driving habits. This is the best use of ethane adding the highest value using the simplest technology. There are two main areas of focus in current market trends for messenger and delivery companies with urban located large truck fleets:

- 'burn less' using hybrid vehicles; aero dynamic optimized vehicles, maximum speed reduction, or electronic modified engine control.
- 'burn clean(er)' by electric vehicles deployment and use of alternative fuels.

United Parcel Service (UPS) operates about 7,200 low-emission vehicles running on alternative fuels and technologies. (editors 2014) FedEx has one of the largest, in-service worldwide hybrid-electric fleets in the industry; almost 2,000 alternative energy vehicles. Deutsche Post DHL has 3000+ vehicles. (Connor 2013), (drrnm5 2011), (Simanaitis 2007)

If a more economical fuel source providing better carbon emissions, and is scalable down to automobiles is required, then ethane should be considered.

Project Scope

Back in 2014, UPS started using propane (C_3H_8) fuel in a test. (Lopez 2014) Ethane (C_2H_6) is far less expensive than C_3H_8, yet has similar range and is less carbon intensive. The market is for this fuel can be utilized throughout the United States, as can be used in existing gasoline engines and access existing fuel stations. The performance compared to the standard gasoline engine or LNG vehicle is improved—same driving range, less cost, less carbon emissions. Comparatively, Compressed Natural Gas (CNG) has range limitations; compressed ethane does not. Ethane has more hydrogen content per BTU than gasoline $(CH_2)_n$, hence less CO_2/mile. (Leveen 2014) This favorable result was proved in a field trial in the spring of 2015 with a dual-fuel (gasoline-ethane) Ford F-150 Triton Pickup Truck; Nucor Steel Corporation in Jewett, TX, USA sponsored this field trial. There is a real savings, financially and environmentally, by choosing ethane as a transportation fuel.

Aims of the Project

Our aim is to recover ethane in the oil refinery process or natural gas capturing process. Instead of using ethane as fuel input to boilers at refineries, or in the manufacture of plastics, we propose it be re-purposed as a transportation fuel for the use in railroad locomotives, package delivery trucks, or for similar delivery applications in other, appropriate industries. This proposition uses ethane as a transportation fuel by optimizing the storage pressure rating for the ethane on the vehicle in the onboard storage tank and via existing fuel control systems for gasoline engines. As long as the ethane is compressed to its critical pressure, and is below its critical temperature, it will be a liquid in the gas cylinder/tank. (Leveen 2014)

The forecast is that there is a glut of ethane way into the future. Hence, the arbitrage continues unless added uses, like the one we propose, will make this fuel useable throughout the USA. Industry partners like Nucor Steel Corporation have expressed interest in this opportunity. Many are looking to convert ethane to ethylene and petrochemicals, or to ship it to Europe for conversion to petrochemicals. However, the largest value add with the least capital intensity is to simply compress ethane and have a fuel that is more than twice the energy capacity as CNG, and almost as energy dense as gasoline.

Background

What is ethane?

Ethane (C_2H_6) is a liquid petroleum gas (LPG). Liquified natural gas (LNG) is primarily, 98+ % methane (CH_4), which is cooled to cryogenic temperatures to maintain a liquid state. Methane will always be a gas unless cooled below -82.6 °C (-116.68 °F). Unlike methane, due to it's very low critical temperature, ethane liquefies under compression, and does not require cooling or cryogenics.

Table 1. Critical Temperatures of Hydrocarbon Fuels

Hydrocarbon Molecule	Chemical Formula	Critical Temperature (°C)
Methane	CH_4	-82.3
Ethane	C_2H_6	+32.2
Propane	C_3H_8	+96.0
Butane	C_4H_{10}	+152.0

Source: The Engineering Toolbox (Editors 2015)

In a cylinder, if the temperature of ethane exceeds +32.17 °C, then it will become a gas. This is why the cylinder is only filled to 35% of its water volume with the liquid ethane when filled at a temperature below 32.17 °C. Cylinders holding ethane are designed for 1800 psi (pounds per square inch) or greater, yet ethane will only have a working pressure of about 600 psi.

This the most important point about ethane—its half-life in the troposphere is exponentially less than any other hydrocarbon fuels without sacrificing BTU's. (Hewitt 2003)

An expert reference point: Lindsay Leveen

Mr. Lindsay Leveen, a thermodynamics expert, chemical engineer, and award-winning journalist. He was awarded the Professional Development Award for his lifetime of achievement in chemical engineering by the American Institute of Chemical Engineering (AIChe). Mr. Leveen has consulted to major corporations in areas of energy deregulation, fuel cells, telecommunication, alternate fuels, thin film deposition, power generation, transmission and distribution, as well as a variety of other process-based technologies. At one time, he worked at L'Air Liquide where he was responsible for developing large onsite supply systems for industrial gas plants.

Mr. Leveen has visceral knowledge and a concrete understanding of ethane, and ethane's merits for application in the transportation sector. He recommends keeping ethane in the USA instead of offshoring it for use as the precursor feedstock in the manufacturing of plastics.

In late 2013, Mr. Leveen asserted compressing ethane and using it as a transportation fuel, hypothesizing compressing ethane would be more valuable than cracking it to make ethylene, the precursor feedstock for manufacturing plastics.

In 2015, Mr. Leveen predicted there would be a glut of ethane due to all the hydraulic fracturing activity in the Marcellus Shale Formation and Bakken Shale Formation. (See

Figure 1) In the fall of 2015, Mr. Leveen revealed in a report to the California Air Resources Board (CARB) there would be a glut past the year 2020.

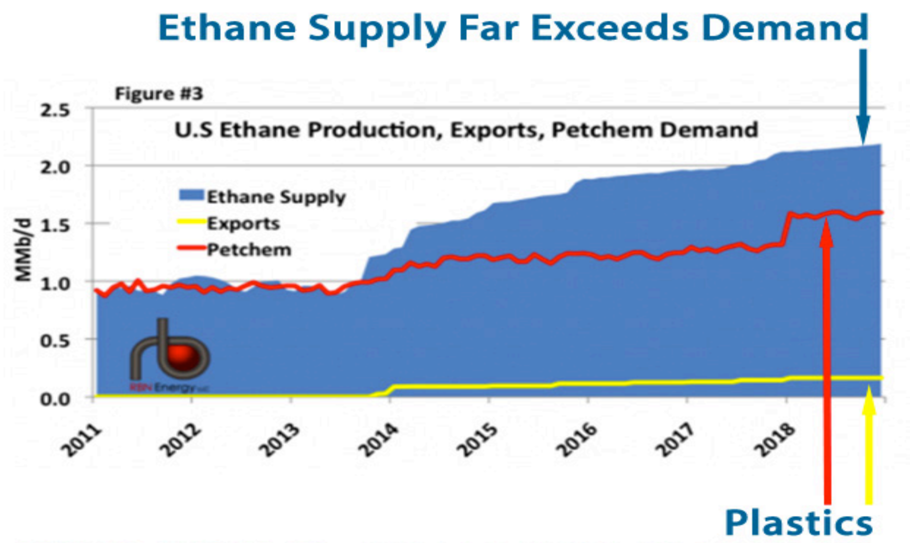

Figure 1. USA Production Exports Petrochemical Demand [Annotated] (Brazeil 2013)

In February 2017, business and financial services company, Moody's Corporation issued an affirming report on the strong LNG demand from Asia, "…will not be enough to absorb the fresh supply capacity coming online…the market will not rebalance until the early years of the next decade when global demand and LNG import infrastructure catches up with supply." (OGJ 2017)

Financial benefits

Compared to an ethane cracker, which takes upwards of four years to bring online, an ethane compression station requires two months to commence operations. (Leveen 2014)

A guesti-mate of the available feedstock of surplus ethane is about 200,000 barrels/day from the USA refining process alone. (Brazeil 2013) If one considers the shale gas in Pennsylvania and Colorado, without including Texas, there are probably about 400,000 barrels/day in surplus.

Figure 2-A shows ethane prices versus other liquid fuels in $/MMBtu. Ethane is 29 cents/gallon. A gallon of ethane has 66,000 BTU LHV (lower heating value), hence it is about half a gallon equivalent of diesel, and 0.6 gallon equivalent of gasoline. This means ethane can be bought from the LPG (Liquified Petroleum Gas) fractionator at about 50 cents/gallon on a gasoline equivalent. The NYMEX price of gasoline is over $3/gallon. And so, the big arbitrage is to place the bulk ethane in tube trailers and then smaller amounts into welding tanks aboard vehicles.

The forecast is that there is a glut of ethane way into the future. Hence, the arbitrage continues unless added uses, like the one we propose, which will be used in vehicles in the USA. As an example, industry partners like Nucor Steel Corporation have expressed interest in this opportunity, because they were investigating using ethane as a fuel for their service vehicles fleet from their natural gas wells.

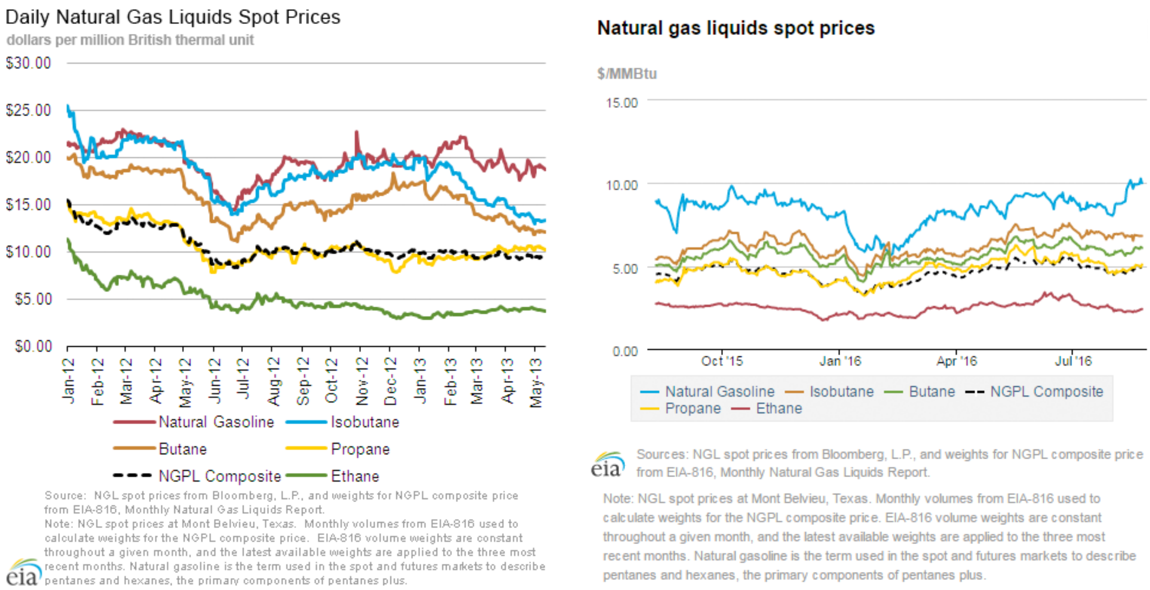

Figure 2-A&B. Natural gas liquid spot prices [January 2012 - May 2013 & October 2015 – July 2016] (USEIA, Natural gas liquids prices trend down since the start of 2012 2013), (USEIA 2016)

Environmental benefits

Compared to methane (CH_4) with a residence time in the troposphere (the lowest region of the atmosphere) of about 10 years, and carbon dioxide (CO_2) with a residence time of about 100 years, ethane's residence time is only 78 days in the troposphere. (Hewitt 2003)

The 100-year indirect global warming potential (GWP) is 5.5 for ethane, much lower than the 25 GWP of methane. (Yang 2015) This is due the highly reactive, short-lived, ubiquitous hydroxyl radical [OH], which oxidizes/destroys ethane as part of the photochemical process. (Hewitt 2003) By comparison, the rate of methane (CH_4) oxidation by OH is very slow, between 100 times and 1000 times slower than other organic compounds. (Crutzen 2006)

Sources of ethane come from oceans, vegetation, fossil fuel (conventional natural gas, shale gas, coal), modern microbial (wetlands, rice paddies, ruminants, termites, and landfills/waste) and biomass burning sources. (Sherwood 2017)

The Ethane Truck

For the first time in the world, a Ford F 150 4.6 Triton committed by Nucor Steel USA was converted to successfully use ethane fuel in a bi-fuel (gasoline or ethane) injection system. (See Figures 3-10) A prototype system was installed on the base of the IMEGA GAME LPG/CNG System, and re-designed with a 3-stage regulator. (See Figure 6) New ethane-dedicated software to optimize the system and record emissions was deployed. Compressed ethane fuel was transferred from a welding tank to the onboard fuel tank strapped into the truck bed. (See Figures 5)

The field trial was conducted in the town of Jewett located two hours travel by automobile northwest of Houston, Texas, USA. Field trial dates occurred on 10 August 2015 through 9 September 2015. Temperatures ranged from 71° F to 106° F at the start of each drive, and weather varied between sunny, overcast, and clear.


Figure 3. Ford F150 Triton Ethane Truck


Figure 4. Imega Cockpit Switch and LED Gage

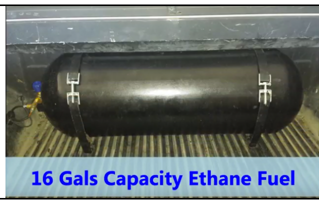

Figure 5. Ethane Modified CNG Tank w/solenoid valve

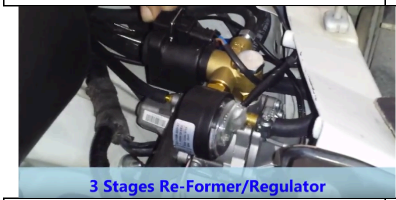

Figure 6. Reformer & 3-Stage Regulator

Figure 7. Ethane Fuel Injector Rail

Figure 8. Pressure Electronic Control Unit

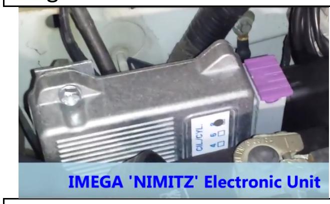

Figure 9. NIMITZ Electronic Control Unit

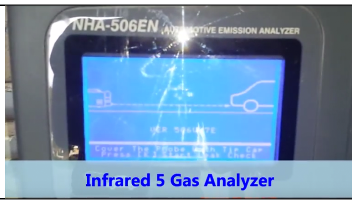

Figure 10. Infrared 5 Gas Analyzer

To view, go to *IMEGA USA Ethane Bi-Fuel NUCOR's Ford F150 4.6 Triton* YouTube VIDEO

Ethane emissions testing results

- Low NOx, low HCs (hydrocarbons)
- Zero Carbon Monoxide (CO) emissions
- 30% lower than gasoline in CO_2/mile
- Complete combustion of HCs—No methane slip like CNG or LNG
- 86 mg/mile of non-methane HC (hydrocarbon) plus NOx
- Ethane and other HCs react out in the catalytic converter
- Lowest emissions of all transportation fuels
    - Exception: Hydrogen made from PV energy or wind energy

This Ford F150 Pickup Truck model was featured in a recent policy brief produced by The Baker Institute for Public Policy. This brief revealed "thirstier vehicles offer the highest return on fuel efficiency investment." (Collins 2017)

Conclusions

Ethane when compressed and cooled with cooling tower water is a liquid under pressure; it is non-cryogenic. Companies like L'Air LIquide sell ethane in welding cylinders that are almost full of liquid ethane. An L'Air Liquide 44 litre cylinder (also known by some companies as an 1A cylinder size) with ethane has 32 pounds of ethane. This has a lower heating value of about 650,000 BTU or about 5.7 gals of gasoline. (Leveen 2014) The same cylinder if filled with methane, compressed natural gas (CNG), would hold about 290 scf (standard cubic foot) of methane at 2,400 psi (pounds per square inch), and only have 267,000 BTU. (Leveen 2014) Ethane has about 2.5 times as much energy for the same volume and mass of storage. Vehicle range depends on the BTUs stored—hence rather than CNG, compressed, liquid ethane for vehicles is proposed. This schema should be workable for a(n) (extremely) large truck fleet operator in collaboration with a company like L'Air Liquide to perform the compression and logistics.

Compressed ethane will be as good as Liquified Natural Gas (LNG), and sans the additional energy input to cool to super low temperatures. Ethane will not require additional expense for cryogenic vessels/tanks required in the cryogenic process. Compressed Natural Gas (CNG) has a limited driving range and is challenging to store. Whereas, the process proposed in this paper will yield a lower carbon fuel for a lower price than diesel or gasoline, and driving range will not be sacrificed much.

Our group seeks funding to execute a field trial in the State of California to prove the viability of the ethane vehicle requirements. Funding would also include infrastructure needs to fuel vehicles. The final report will not only show that ethane meets and exceeds the California air pollution requirements, but also reveal the costs required to convert fuel stations and vehicles to ethane usage. We believe we can also produce data to prove this fuel could be used throughout the USA as a game changer in atmospheric pollution and green gas emissions.

Many are looking to convert ethane to ethylene and petrochemicals, or to ship it to Europe for conversion to petrochemicals. **However, the largest value add with the least capital intensity is to simply compress ethane and have a fuel that is more than twice as effective as CNG, and almost as energy dense as gasoline.**

Industrial carbon producers in the steel and iron, petroleum refining, manufacturing and transportation sectors realize they must take measures to further limit climate change. These sectors must act, especially since government policy is increasing the issuance of climate instability (change) measures requiring them to pay more damages—which in turn, could affect their profits. Looking at relative responsibility based on relative profits in the supply chain activities on carbon emissions and the climate, ethane should be a worthwhile investigation.

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Notably, Brad True at Nucor Steel Corporation provided unwavering support for this endeavour, by offering frank feedback, scintillating suggestions, and constructive critiques, but by generously providing funding and resources to conduct the field trial project. The Jewett, TX staff, Bryan Linton and Matt Way, also deserve recognition for their contributions, support, and knowledge-base transfer.

The remarkable vanguard Danilo Gardi at Imega International USA Alternative Fuel Systems was instrumental and critical at steering the injection system design and direction of this pilot project proof-of-concept research—ultimately proving ethane can be game changer as a future transportation fuel stock.

Joe Marcenillo at Imega International USA Alternative Fuel Systems who constantly girded us on with his unwavering and unconditional support.

Finally, Dr. Chi-Jen Yang generously provided antecedent research in his 2015 American Chemical Society (ACS) paper "Ethane as a Cleaner Transportation Fuel."

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