Fuel vs. Feedstock - The Renewable Propane Tradeoff for a Biorefinery

By Dr. Gokul Vishwanathan
Director of Research & Sustainability
Propane Education & Research Council

Foreword

Last year we published a whitepaper comparing the economics of using renewable propane as a refinery feedstock for hydrogen production versus selling it into the market as a transportation fuel. Since the energy market and trading prices are dynamic in nature, it is important to update that study. In this updated analysis, we look at the value proposition of renewable propane for 2023 (and beyond), considering recent market dynamics along with a market sensitivity analysis. Much of the introductory material is being republished with specific updates to the narrative, techno-economic model, and data plots.

Introduction

Several traditional oil refineries are being repurposed to produce renewable fuels. The momentum in the U.S. is geared towards the production of renewable diesel (RD) and sustainable aviation fuel (SAF) and to a lesser extent renewable gasoline. In fact, the impetus is so strong that it is expected that U.S. will be a lead exporter of RD and SAF soon, as demand is catching up with fast rising supply[1]. Typical biorefineries using feedstocks with triglycerides (TAG) (e.g., fats, oils, and grease) will either produce RD or SAF as their main product with byproducts such as renewable naphtha and renewable propane (RP) (or renewable liquefied petroleum gas (RLPG)). Renewable naphtha can be sold into the gasoline or plastics markets. A biorefinery is often met with a dilemma with the RP byproduct and has three options to consider:

1. Use it as process gas and reduce their dependence on traditional natural gas.
2. Use it as a feedstock for producing renewable hydrogen either through an onsite steam-methane reformer (SMR) or through technologies such as H2bridgeTM from Haldor Topsoe[2,3]. Renewable hydrogen is in turn used in the hydrotreating process for lowering the carbon intensity (CI) of the main product i.e., RD or SAF. In addition, this reduces the cost of hydrogen procurement or hydrogen production for the biorefinery.
3. Separate, store and sell RP through an offtake agreement to a propane marketer or retailer.

Option 1 is something we have analyzed thoroughly with our partners at the National Renewable Energy Laboratory (NREL) along with the value proposition of RP. This report is publicly available[4]. The tradeoff between Options 2 and 3 is very important and our conversations with biorefineries highlight that most prefer Option 2 to Option 3 for several reasons including the presence of an onsite SMR facility for producing renewable hydrogen, additional capex for separation and storage of RP, and finally, for not completely understanding the market pull of RP. This paper shows that Option 3 - the separation, storage, and sale of RP - has a better value proposition than producing renewable hydrogen from this very valuable byproduct, especially under current market conditions.

First, let's look at the current market of conventional propane in the U.S. The U.S. is the biggest producer and exporter of propane in the world. We roughly produce 30-40 billion gallons of propane per year and export more than 50% of the produced propane. We consume around 10 billion gallons of retail propane for residential and commercial applications, agriculture, on-road and off-road applications, and power generation. So, there is a lot of dependence on this clean, low carbon fuel especially in off-grid, rural, and locations plagued with frequent electricity grid disturbances. Thus, RP can act as a great drop-in replacement for decarbonizing conventional propane that is already low in carbon content compared to gasoline and diesel.

[1] https://rbnenergy.com/sail-away-supply-demand-imbalance-will-make-the-us-a-leading-exporter-of-rd-and-saf

[2] https://renewables.topsoe.com/h2bridge

[3] https://www.biobased-diesel.com/post/how-do-we-maximize-the-carbon-efficiency-of-renewable-fuel-production

[4] Baldwin, R.M., Nimlos, M.R., and Zhang, Y. Techno-economic, Feasibility and Life Cycle Analysis of Renewable Propane, A Report Prepared for the Propane Education and Research Council. https://www.nrel.gov/docs/fy23osti/83755.pdf.

At the Propane Education and Research Council (PERC), we revised a previously created simple techno-economic model to understand the sensitivity of Options 2 and 3 - whether it is better for a biorefinery to produce renewable hydrogen using RP and to use it to lower the carbon intensity of their primary product (e.g., RD or SAF) or to directly sell RP as a product through offtake agreements with propane retailers. The revenue streams that were accounted for RP include the market wholesale price of propane, EPA Renewable Fuel Standard (RFS), Renewable Identification Number (RIN) credits[5] and California Low Carbon Fuel Standards (LCFS) credits[6]. RP qualifies for LCFS if it is used as a fuel for the transportation market (including forklifts) and qualifies for D5 RIN credits if the carbon intensity of RP is 50% lower than the benchmark carbon intensity and is used in transportation applications. More details can be found on this in the PERC sponsored NREL techno-economics analysis report[4]. In addition, in this revised analysis, the incremental cost of hydrogen procurement or production for a biorefinery that intends to sell RP (rather than use it internally to produce hydrogen) was also included.

Assumptions of the Techno-Economic Analysis

***Table 1**: Assumptions of the techno-economic analysis representing March 2023 market conditions.*

Parameter	Value
RD capacity of biorefinery (gallons/year)	542,029,520
RP capacity of biorefinery (gallons/year) (assuming 5% by mass of TAG Feedstock)	35,000,000
RP density (lb/gallon)	4.2
RD density (lb/gallon)	7.093
Wt.% of feedstock to RP	3.25%
Wt.% conversion of feedstock mass to fuels	85.0%
Carbon intensity of all products (gCO2eq/MJ)	45
LCFS trading price ($/ton)	$66
2023 benchmark carbon intensity for gasoline (gCO2eq/MJ)	88.25
2023 benchmark carbon intensity for diesel (gCO2eq/MJ)	89.15
D4/D5 RIN price ($)	$1.80
Diesel wholesale market value ($/gallon)	$2.72
Propane wholesale market value ($/gallon)	$0.88
Reduction in RD carbon intensity by using renewable hydrogen produced by RP (gCO2eq/MJ)	2-10

The baseline assumptions of the analysis are outlined in Table 1, which represent current (March 2023) market dynamics. For producing 35,000,000 gallons/year of RP as byproduct, the biorefinery would have a production capacity of approximately 542,000,000 gallons per year of RD considering 3.25% of the mass of the TAG feedstock yields RP and an 85% biorefinery conversion rate of feedstock to fuels. The baseline carbon intensity of the renewable fuel products is assumed to be 45 gCO2eq/MJ, which is a worst-case scenario using animal tallow as feedstock. The LCFS trading price was assumed to be $66/metric ton of CO2eq[7] representing current market conditions. The 2023 California LCFS benchmark carbon intensities for gasoline and diesel are 88.25 gCO2eq/MJ and 89.15 gCO2eq/MJ, respectively[8]. A RIN price of $1.8 was assumed here[9], and RD qualifies for 1.7 D4 RIN credits for every physical gallon of RD. Similarly, RP qualifies for 1.1 D5 RIN for every physical gallon of RP. Currently, both D4 and D5 RINs are trading at the same price[9]. The wholesale prices of diesel and propane were assumed to be $2.72/gallon (average of NY Harbor, Los Angeles, and Gulf Coast) and $0.88/gallon (Mont Belvieu), respectively[10]. It is assumed that hydrogen obtained from RP can reduce the carbon intensity of RD by 2-10 gCO2eq/MJ[11].

Incremental Cost of Hydrogen for a Biorefinery

A biorefinery that is using RP as a feedstock for producing renewable hydrogen will reduce its dependence on externally procured hydrogen or in-house produced hydrogen either from natural gas or from an electrolyzer. However, a biorefinery that intends to sell RP into the market will have to purchase or produce this additional hydrogen at an incremental cost (i.e., for only the portion of hydrogen that comes from RP). Hence, for a biorefinery that intends to sell RP into the market, this incremental procurement cost was added as a penalty. For simplicity, incremental hydrogen cost calculations were computed using pure soybean oil as feedstock. As per Li et al.[12], 1 kg of RD is produced using 1.26 kg of soybean oil. For such a configuration, the hydrogen energy input to the hydrotreater was 4.18-4.81 MJ (depending on the soybean oil composition). Nearly 1.93 MJ of RLPG, renewable naphtha and fuel gas were produced as byproducts in the hydrotreating process. In the current analysis, it was assumed that 90% of the energy share of the byproducts is RLPG i.e., 1.74 MJ is attributed to propane and butane, while the remainder energy share was attributed to naphtha and fuel gas. Table 2 outlines the assumptions for the calculation of incremental cost of hydrogen. An on-site

[5] https://www.epa.gov/fuels-registration-reporting-and-compliance-help/rin-trades-and-price-information

[6] https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard

[7] https://www.neste.com/investors/market-data/lcfs-credit-price#f17a4e46

[8] https://casetext.com/regulation/california-code-of-regulations/title-17-public-health/division-3-air-resources/chapter-1-air-resources-board/subchapter-10-climate-change/article-4-regulations-to-achieve-greenhouse-gas-emission-reductions/subarticle-7-low-carbon-fuel-standard/section-95484-annual-carbon-intensity-benchmarks

[9] https://www.epa.gov/fuels-registration-reporting-and-compliance-help/rin-trades-and-price-information

[10] https://www.eia.gov/todayinenergy/prices.php

[11] In conversations with biorefineries, onsite SMRs lead to a carbon intensity reduction of 3-7 gCO2eq/MJ for RD when using renewable hydrogen produced from RP. H2bridgeTM can lead up to 10 gCO2eq/MJ reduction in carbon intensity as per reference number 2.

[12] Li, Yuan, Hui Xu, Daniel Northrup, and Michael Wang. "Effects of soybean varieties on life-cycle greenhouse gas emissions of biodiesel and renewable diesel." Biofuels, Bioproducts and Biorefining, 2022.

SMR was assumed to have a 75% efficiency for converting RLPG to hydrogen. In addition, industrial (or wholesale) hydrogen price of $3/kg or $5/kg, depending on the size of the refinery, was assumed. Larger refineries were assumed to purchase or produce hydrogen at $3/kg, while medium sized refineries were assumed to purchase or produce hydrogen at $5/kg.

Five different scenarios were evaluated here, and refineries were qualified as large (35 M gallons of RP per year) and medium sized (10 M gallons of RP per year and approximately 155 M gallons/year of RD). In addition, market dynamics was classified as favorable and adverse for RP depending on the RIN and LCFS trading prices i.e., RP sale is favored when RIN prices are trading higher and LCFS prices are trading lower and vice-versa.

***Table 2**: Assumptions for evaluating incremental hydrogen cost for a biorefinery.*

Parameter	Value
RD yield (kg)	1
Hydrogen input (MJ)	4.5
RP yield (MJ)	1.74
Steam-methane-reformer efficiency	75%
Industrial price of hydrogren for in-house production or procurement	$3 or $5

- **Case 1:** Large refinery (35 M gallons/year of RP) with favorable market conditions for RP as outlined in Table 1. Price of incremental hydrogen production or purchase was assumed to be $3/kg.
- **Case 2:** Large refinery (35 M gallons/year of RP) with adverse market conditions for RP. In this case, a RIN price of $0.5 (such as in February 2020) and a LCFS trading price of $218/ton of CO2 (such as in February 2020) were assumed. Price of incremental hydrogen production or purchase was assumed to be $3/kg.
- **Case 3:** Medium sized refinery (10 M gallons/year of RP) with favorable market conditions for RP as outlined in Table 1. Price of incremental hydrogen production or purchase was assumed to be $5/kg.
- **Case 4:** Medium sized refinery (10 M gallons/year of RP) with adverse market conditions for RP. In this case, a RIN price of $0.5 (such as in February 2020) and a LCFS trading price of $218/ton of CO2 (such as in February 2020) were assumed. Price of incremental hydrogen production or purchase was assumed to be $5/kg.

Techno-Economic Analysis Results

The model results for cases 1, 2, 3, and 4 are shown in Figures 1, 2, 3, and 4, respectively. Figures 1(a), 2(a), 3(a) and 4(a) show the incremental value proposition of using RP as a feedstock for producing renewable hydrogen and thereby reducing the carbon intensity of RD for all the market conditions and refinery sizes. Figures 1(b), 2(b), 3(b) and 4(b) show the value stacking and net revenue derived from RP sale (including the incremental cost for hydrogen that cannot be produced using RP) for all the market conditions and refinery sizes. The incremental value stacking of RD includes LCFS credits, but not RINs as RINs do not incentivize a lower carbon intensity product and provide a flat credit if the renewable fuel is a certain percentage lower in carbon intensity compared to the benchmark carbon intensity. For example, RD with a carbon intensity of 45 gCO2eq/MJ will enjoy the same RINs compared to RD with a carbon intensity of 15 gCO2eq/MJ. However, California LCFS incentivizes fuels with lower carbon intensities. For example, RD with a carbon intensity of 15 gCO2eq/MJ will enjoy larger credits compared to RD with a carbon intensity of 45 gCO2eq/MJ.

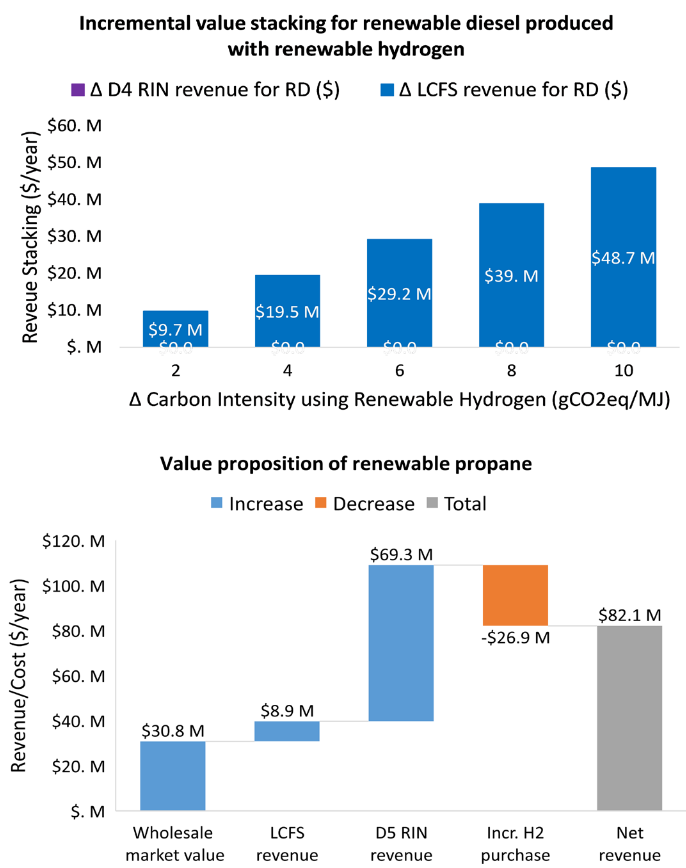

***Figure 1:** Model results for a large biorefinery with favorable market conditions for (a) RD incremental revenue stacking and (b) RP revenue stacking.*

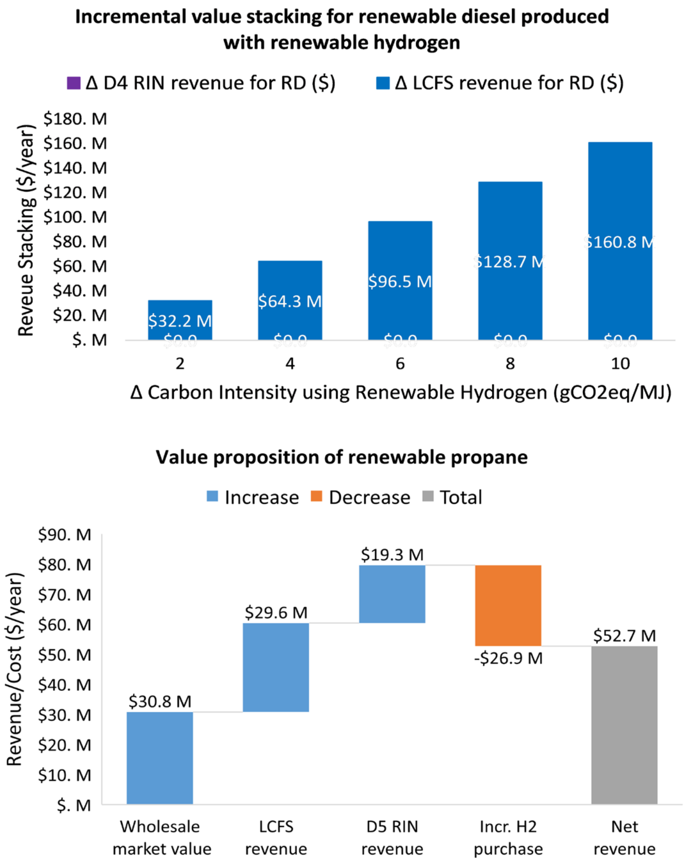

Figure 2: *Model results for a large biorefinery with adverse market conditions for (a) RD incremental revenue stacking and (b) RP revenue stacking.*

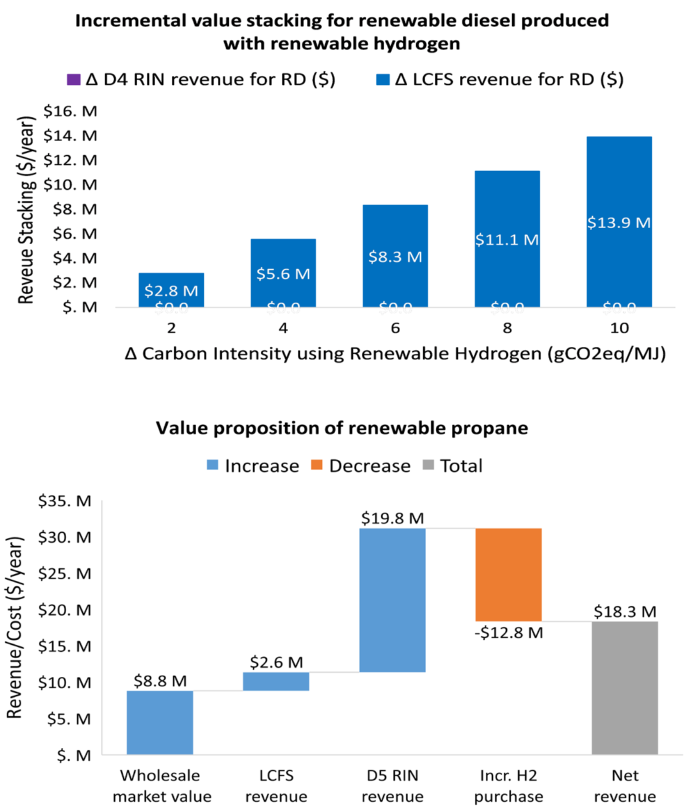

Figure 3: *Model results for a medium sized biorefinery with favorable market conditions for (a) RD incremental revenue stacking and (b) RP revenue stacking.*

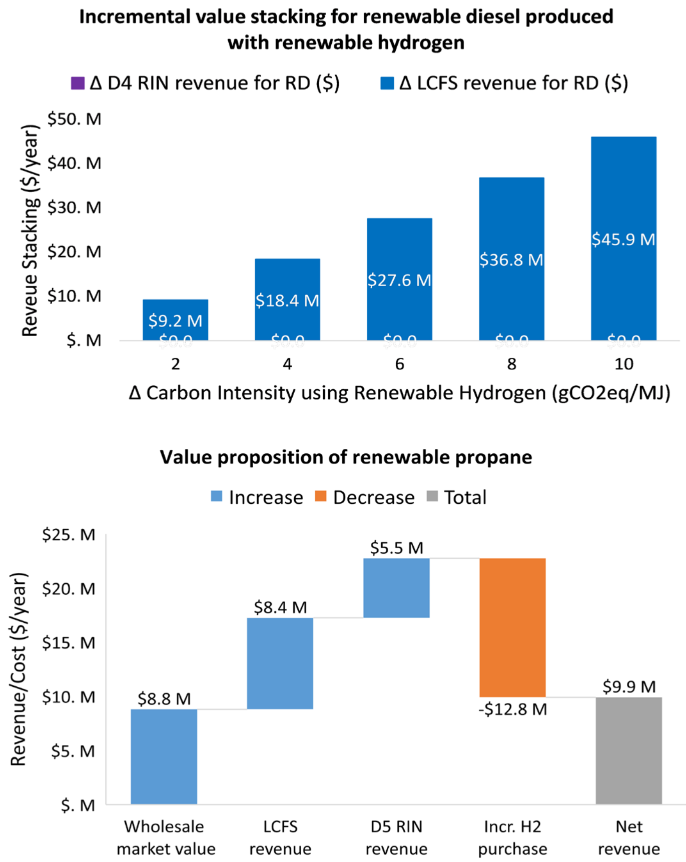

Figure 4: *Model results for a medium sized biorefinery with adverse market conditions for (a) RD incremental revenue stacking and (b) RP revenue stacking.*

Several salient conclusions that can be drawn from these tradeoff charts:

1. Irrespective of the size of the biorefinery, current market conditions are extremely favorable for sale of RP rather than its use as feedstock for hydrogen production. RIN trading prices have been stable since 2021 hovering well over $1, while CA LCFS prices have plummeted since January of 2022. Albeit speculative, these markets conditions may be here to stay, considering the U.S. will soon be an exporter of RD and SAF as supply is exceeding demand. Existing biorefineries can capitalize on the market conditions by selling RP and getting a faster payback on the capex of the separation equipment, especially if the hydrogen conversion only yields a reduction in carbon intensity of RD by 8 gCO2eq/MJ or lower.

2. For adverse market conditions for RP, biorefineries (irrespective of their size) can entertain selling RP into the market if the hydrogen conversion only yields a nominal reduction in carbon intensity of RD by 2-3 gCO2eq/MJ.

3. The value proposition of RP sale increases with 1) the size of the biorefinery and 2) with < $5/kg production or procurement cost of hydrogen.

A change in the baseline carbon intensity from 45 gCO2eq/MJ (as in Table 1) to 20 gCO2eq/MJ does favorably impact revenue generation of RP but does not change the conclusions drastically.

Conclusions:

1. There is tremendous market pull for renewable propane in the U.S. Biorefineries must consider the sale of renewable propane and can leverage California LCFS and EPA D5 RIN credits for significantly improving its value proposition. This is a better move than using it as a refinery feedstock for producing hydrogen, especially under current market conditions and/or when the hydrogen enables only a nominal reduction of renewable diesel's carbon intensity.

2. The revenue scale tips towards renewable propane for the following cases:

   a. Lower LCFS trading price

   b. Higher D5 RIN trading price

   c. Large biorefineries

   d. <$5/kg procurement or production cost of hydrogen

3. There is a bearish outlook on LCFS price at least until 2024 due to LCFS credit surplus, primarily driven by adoption of light duty electric vehicles[13]. In addition, supply of renewable fuels is also outpacing demand causing LCFS price to drop. On the contrary, an increase in the demand for the agricultural feedstocks for ethanol and biomass-based diesel production, and consequentially their price increase, has driven the RINs to trade at higher prices[14]. In short, market conditions are dictating the trading prices and tipping the scale toward the favorability of renewable propane sale.

PERC is aware that several biorefineries are using renewable propane as hydrogen feedstock. We encourage and urge biorefineries to conduct their own techno-economic analysis to evaluate the value proposition of renewable propane sale versus its use as hydrogen feedstock. Biorefineries can contact PERC for further discussions regarding this techno-economic model and the value proposition of renewable propane.

---

[13] https://kleinmanenergy.upenn.edu/news-insights/a-bearish-outlook-for-californias-low-carbon-fuel-standard/

[14] https://www.eia.gov/todayinenergy/detail.php?id=53019

Learn more at **propane.com**

1140 Connecticut Ave. NW, Suite 1075 / Washington, DC 20036

P 202-452-8975 / F 202-452-9054