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

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Today, 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). Typical biorefineries using feedstocks with triglycerides 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)). A biorefinery is often met with a dilemma of what to do with the byproducts such as RP and have 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 H2bridge™ from Haldor Topsoe[1,2]. 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.
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 will be publicly available very soon. 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, capital investment for separation and storage of RP, and finally, for not completely understanding the market pull and dynamics of RP. This paper shows that Option 3 - the separation, storage, and sales of RP - has a better value proposition than producing renewable hydrogen from this very valuable byproduct.

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 produce roughly 30 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 finally power generation. So, there is a lot of dependence on this clean, low-carbon fuel especially in off-grid, rural, and other locations 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.

At the Propane Education and Research Council (PERC), we created a 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 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. The revenue streams that we accounted for RP include the market wholesale price of propane, EPA Renewable Fuel Standard (RFS), Renewable Identification Number (RIN) credits[4] and California Low Carbon Fuel Standards (LCFS)[5]. RP qualifies for LCFS if it is used as a fuel for the transportation market (like RD) 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[3].

1. https://renewables.topsoe.com/h2bridge
2. https://www.biobased-diesel.com/post/how-do-we-maximize-the-carbon-efficiency-of-renewable-fuel-production
3. 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, PERC Docket # 22803, May 2022.
4. https://www.epa.gov/fuels-registration-reporting-and-compliance-help/rin-trades-and-price-information
5. https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard

Assumptions of the Techno-Economic Analysis

The baseline assumptions of the analysis are outlined in Table 1. For producing 35,000,000 gallons/year of RP as byproduct, the biorefinery would have a production capacity of approximately 352,000,000 gallons per year of RD considering 5% of the mass of the feedstock yields RP and the biorefinery has an 85% 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 price cap was set at $200/metric ton of CO2eq in 2018 by CARB. The 2022 benchmark carbon intensity for gasoline and diesel are nearly 90 gCO2eq/MJ for the California LCFS. A nominal RIN price of $1 is assumed here, and RD qualifies for 1.7 D5 RIN credits for every physical gallon of RD. Similarly, RP qualifies for 1.1 D5 RIN for every physical gallon of RP. The wholesale prices of diesel and propane are assumed to be $2/gallon and $0.85/gallon, respectively. A "green" premium was also applied on the wholesale price of diesel for the lower carbon intensity RD produced using renewable hydrogen.

Parameter	Value
RP Capacity of Biorefinery (gallons/year)	35,000,000
RP density (lb/gallon)	4.2
RD density (lb/gallon)	7.093
Wt.% of feedstock to RP	5.0%
Wt.% conversion of feedstock mass to fuels	85.0%
Carbon intensity of all products (gCO2eq/MJ)	45
LCFS trading price ($/ton)	$200.0
2022 benchmark carbon intensity for gasoline/diesel (gCO2eq/MJ)	90
D5 RIN price ($)	$1.0
Diesel wholesale market value ($/gallon)	$2.0
"Green" premium on wholesale diesel price for lower carbon intensity RD (%)	5.0%
Propane wholesale market value ($/gallon)	$0.85
Reduction in RD carbon intensity by using renewable hydrogen produced by RP (gCO2eq/MJ)	2-10[2,6]

***Table 1**: Assumptions of the techno-economic analysis.*

6. 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 points reduction in carbon intensity as per reference number 2.

7. https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=M_EPLLPA_PWR_NUS_DPG&f=M

8. https://srectradeblog.s3.amazonaws.com/SRECTrade%20-%20Clean%20Fuels%20Market%20Update%20-%20May%202022.pdf

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

Observations:

1. Wholesale price of propane was between $0.6/gallon and $0.826/gallon in 2019, between $0.489/gallon and $0.779/gallon in 2020 and between $1.022/gallon and $1.612/gallon in 2021. We use the pre-COVID nominal value of $0.85/gallon for the analysis[7]. Higher market value of propane will be more beneficial for the sales of RP as is the current situation.
2. In May 2022, there was a significant decay in the LCFS trading price with transaction price around $100/metric ton CO2eq[8].
3. Currently, D5 RINs are trading at nearly $1.5 while pre-2021, it was below $1 and as low as $0.5[9].

Techno-Economic Analysis Results

1. **Baseline Case:** For the assumptions listed on Table 1, Figure 1 shows the value stacking for the sales of RP including the wholesale market price, LCFS credits and D5 RIN credits. Figure 1 also shows the incremental value stacking for the sale of RD - the additional revenue generated by RD if its carbon intensity is reduced using renewable hydrogen produced by RP. Both these are plotted as a function of the reduction of achieved carbon intensity of RD using renewable hydrogen (between 2 and 10 gCO2eq/MJ, refer to Table 1). The incremental value stacking of RD includes LCFS credits, but not the RIN credits as RINs credits 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 25 gCO2eq/MJ will have the same RIN credits compared to RD with a carbon intensity of 15 gCO2eq/MJ. The final value stacking for RD is if the biorefinery intends to sell RD at a "green" premium price since it has a lower carbon intensity. This is often not the case however, as the reduction in carbon intensity is not that substantial to warrant a premium price.

   As can be seen from Figure 1, the sales revenue of RP is much better than the incremental revenue of RD, when using renewable hydrogen, until 6 gCO2eq/MJ reduction in carbon intensity for RD. At 8 gCO2eq/MJ reduction in carbon intensity, the revenue stacking of RP is still better than RD unless the biorefinery sells the lower carbon intensity RD at a "green" premium price rather than the wholesale market value. At 10 gCO2eq/MJ reduction in carbon intensity, the incremental value proposition of RD is marginally better than the value proposition of RP without the premium and is far better with the premium. Bottomline, the economics are much in favor for the sales of RP except for an edge case.

2. **LCFS trading price of $100/metric ton CO2eq:** Figure 2 shows the value proposition when the LCFS trading price is $100/metric ton CO2eq, which is the approximately the current trading price. As can be seen from Figure 2, the sales revenue of RP is much better than the incremental revenue of RD, when using renewable hydrogen, until 8 gCO2eq/MJ reduction in carbon intensity for RD. At 10 gCO2eq/MJ reduction in carbon intensity, the revenue stacking of RP is still much better than RD unless the biorefinery sells the lower carbon intensity RD at a "green" premium price rather than the wholesale market value. Bottomline, the economics are much in favor for the sales of RP rather than producing renewable hydrogen from it.

3. **RIN trading price of $1.5:** Figure 3 shows the value proposition when the D5 RIN trading price is $1.5, which is approximately the current trading price. As can be seen from Figure 3, the sales revenue of RP is much better than the incremental revenue of RD, when using renewable hydrogen, until 8 gCO2eq/MJ reduction in carbon intensity for RD. At 10 gCO2eq/MJ reduction in carbon intensity, the revenue stacking of RP is still much better than RD unless the biorefinery sells the lower carbon intensity RD at a "green" premium price rather than the wholesale market value. Bottomline, the economics are much in favor for the sales of RP rather than producing renewable hydrogen from it.

4. **Renewable fuel carbon intensity of 10 gCO2eq/MJ:** Figure 4 shows the value proposition comparisons if the biorefinery is producing the renewable fuels (RD, RP etc.) at a much lower carbon intensity of 10 gCO2eq/MJ. As can be seen from Figure 4, the sales revenue of RP is much better than the incremental revenue of RD, when using renewable hydrogen, until 8 gCO2eq/MJ reduction in carbon intensity for RD. At 10 gCO2eq/MJ reduction in carbon intensity (i.e., RD at 0 gCO2eq/MJ), the revenue stacking of RP is still much better than RD unless the biorefinery sells the lower carbon intensity RD at a "green" premium price rather than the wholesale market value. Bottomline, even in this case, the economics are much in favor for the sales of RP rather than producing renewable hydrogen from it.

5. **Today's market conditions:** Finally, Figure 5 shows the results reflecting today's market conditions. Assumptions include a wholesale diesel price of $4.25/gallon, a wholesale propane price of $1.6/gallon, a LCFS trading price of $100/metric ton CO2eq and a RIN price of $1.5. The carbon intensity of the product is assumed to be 25 gCO2eq/MJ, typical of rendered used cooking oil feedstock based renewable fuel. As seen from Figure 5, the value proposition of RP is unanimously better than RD in all cases even if there is a "green" premium on the wholesale RD price.

This analysis only looks at the revenue generated from each of the products but not the capital expenditure of the SMR or the propane separation and storage infrastructure. Under nearly all conditions, the revenue generated by selling RP is far substantial than selling a marginally reduced carbon intensity RD such that any capital costs for RP's capture and storage can be absorbed with immediate returns.

Conclusions:

1. There is tremendous market pull for propane and renewable propane in the US. 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 far superior move than using it as a feedstock for renewable hydrogen production.

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

    a. Lower LCFS trading price than the 2018 ceiling value of $200/metric ton of CO2eq.

    b. Higher D5 RIN trading price.

    c. Higher market value of propane.

    d. Lower carbon intensity of renewable fuels produced at the biorefinery.

    e. And sale of lower carbon intensity renewable diesel without any "green" premium on wholesale market value.

3. A very rare combination of market dynamics with a higher carbon intensity renewable fuel produced at the biorefinery (e.g., 45 gCO2eq/MJ) and a renewable diesel carbon intensity reduction of 10 gCO2eq/MJ or more enabled by renewable hydrogen (produced by renewable propane) can favor renewable diesel's incremental value proposition relative to the sales of renewable propane. In nearly all the cases studied above, the value proposition of renewable propane is far superior to the incremental value proposition of a reduced carbon intensity renewable diesel.

Biorefineries can contact PERC for further discussions regarding this techno-economic model and the value proposition of renewable propane.

Figures 1-5

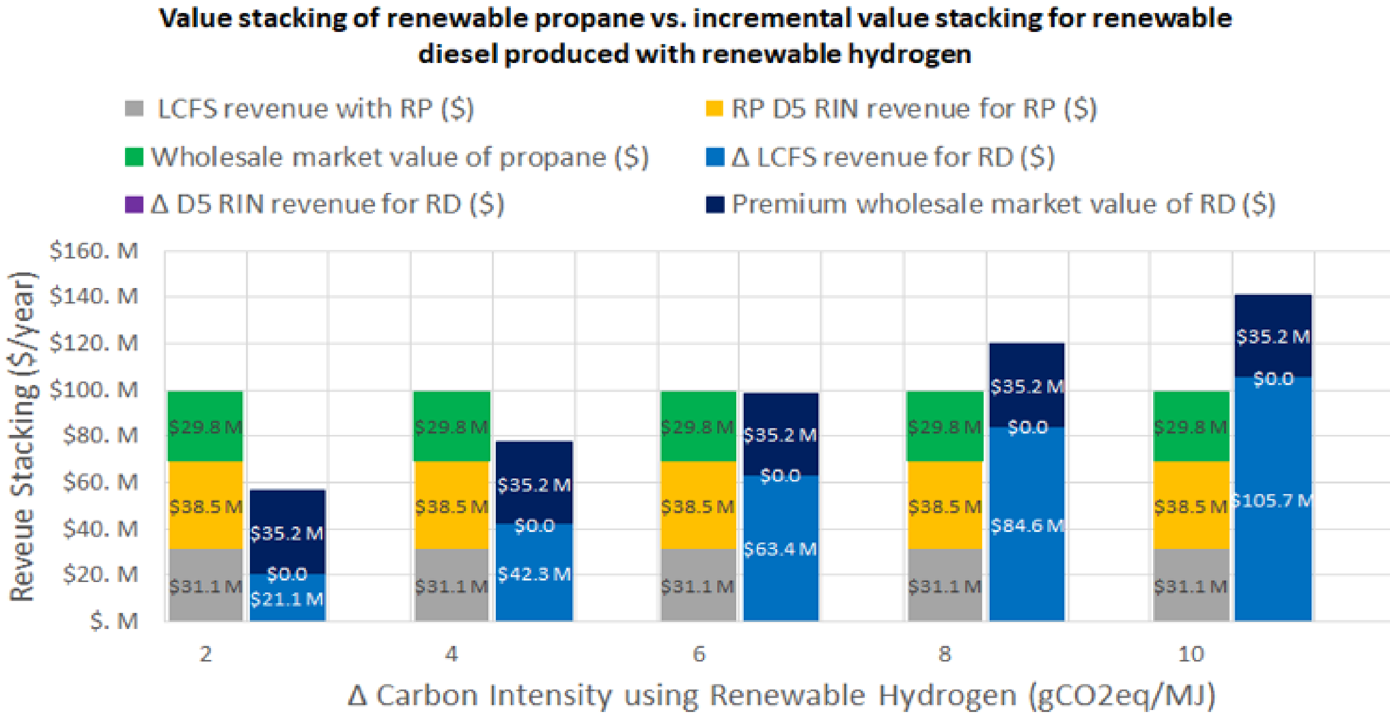

Figure 1: *Value stacking for RP compared to incremental value stacking for RD for the baseline case.*

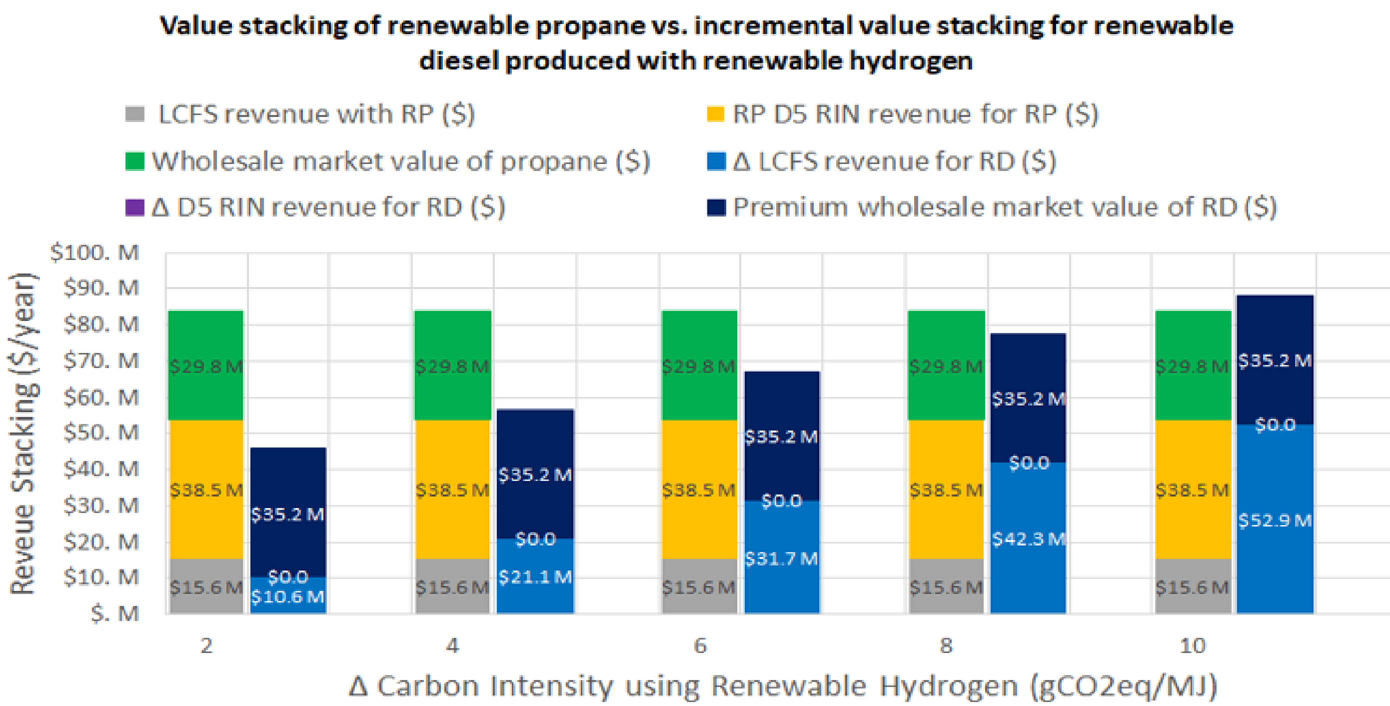

Figure 2: *Value stacking for RP compared to incremental value stacking for RD for LCFS credit price of $100/metric ton CO2eq.*

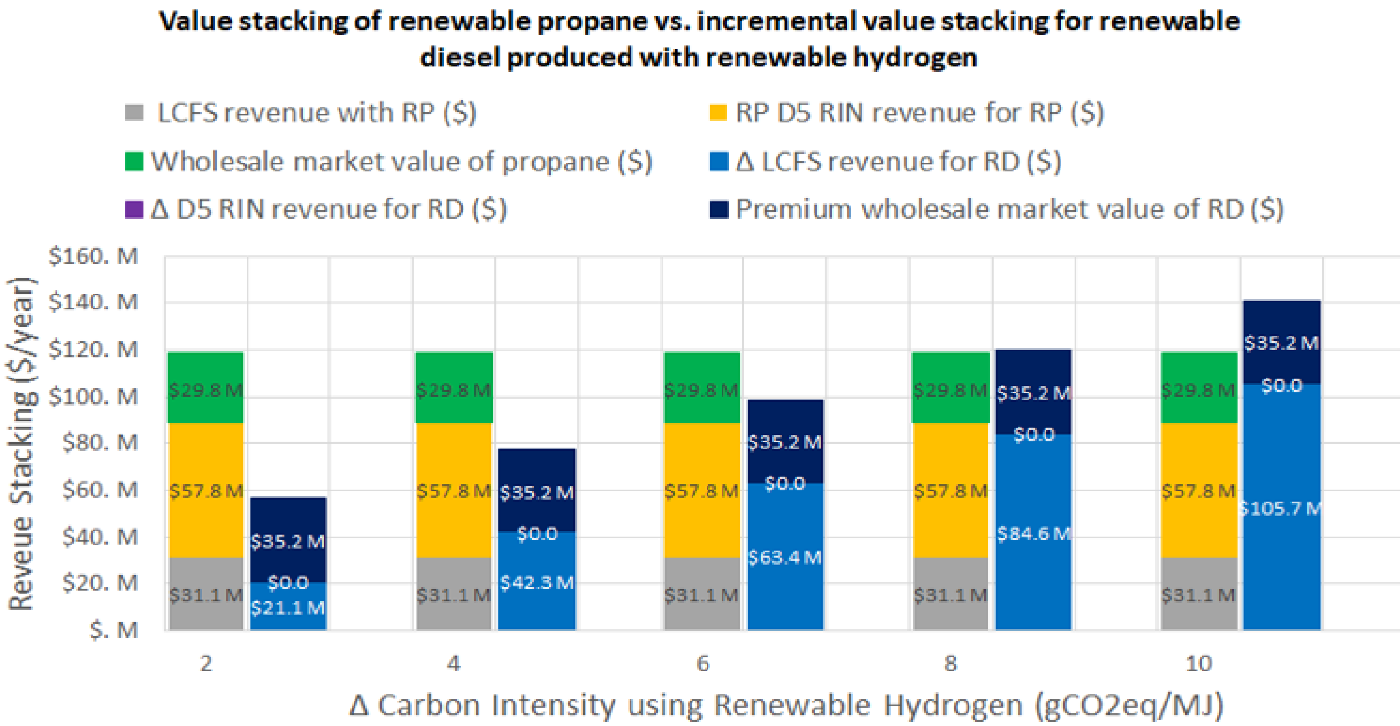

***Figure 3**: Value stacking for RP compared to incremental value stacking for RD for RIN price of $1.5.*

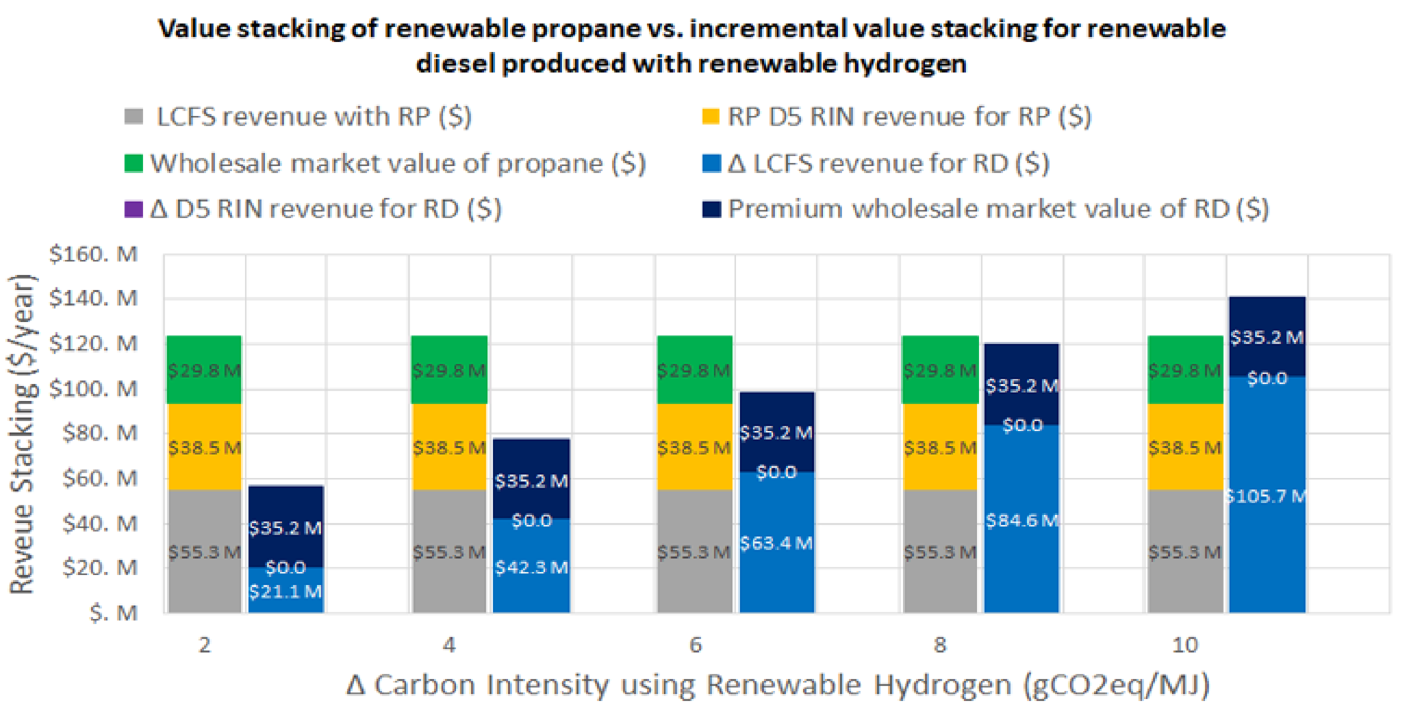

***Figure 4**: Value stacking for RP compared to incremental value stacking for RD for product carbon intensity of 10 gCO2eq/MJ*

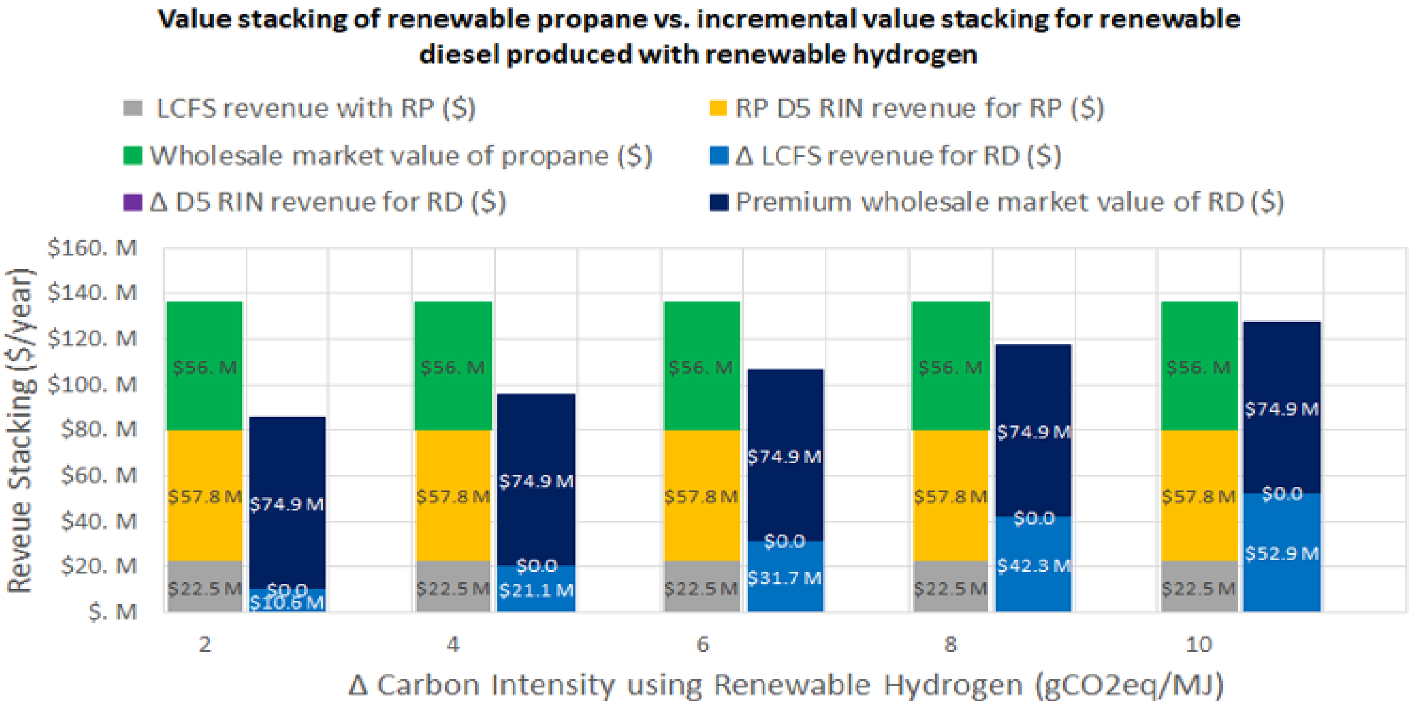

Figure 5: *Value stacking for RP compared to incremental value stacking for RD reflecting today's market conditions.*

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