THE REMARKABLE GROWTH OF RENEWABLE DIESEL

Introduction:

Since its creation in 1894[1], diesel engines have been the engine of choice for heavy-duty transport vehicles and equipment[2]. Though more expensive than gasoline, diesel engines are 20 – 30 % more fuel-efficient and cost-effective, operating far more efficiently than gas or gasoline-powered engines while requiring less maintenance. As of today, countless industrial and commercial generators are diesel-powered. However, diesel emissions are still as deadly as gasoline emissions, releasing greenhouse gases and ground-level ozone into the environment[3]. As the world strives towards net-zero carbon emissions, we must address diesel to lower its greenhouse gas emissions.

In response, scientists developed renewable diesel (RD). Like all alternative fuels, renewable diesel can either replace or supplement petroleum derived hydrocarbon diesel, working at an efficiency at or near that of diesel while emitting fewer pollutants from combustion[4]. In practical studies of renewable diesel, researchers reported a significant decrease in the "carbon intensity" of renewable diesel compared to standard, clocking in at a staggering 65% decrease[4]. RD is a new discovery, but one that is experiencing remarkable growth in recent years. Still, there is room for further development, as the higher price of RD compared to hydrocarbon diesel, makes it less viable as a complete replacement. Therefore, in this article we will define renewable diesel, assess the growth of the RD industry worldwide, and note recent advancements in RD research, remarking on their positive implications on future RD development.

What is Renewable Diesel?

Firstly, it is pertinent to define renewable diesel as is used in this article. As the name suggests, renewable diesel is an alternative to diesel made from renewable fats and oils and processed to match the chemistry of petroleum diesel[4]. However, alternative diesel exists already, known as biodiesel or FAME (Fatty Acid Methyl Ester) diesel[5]. This diesel is produced by transesterification, where organic fats and oils react with alcohols and catalysts, typically methanol, to create fatty acid alkyl esters that can be blended into petroleum diesel to create a more sustainable blend[5]. Figure 1 illustrates the production of FAME diesel and its byproducts.

Unlike renewable diesel, transesterification is a much more established process, taking root in 1937 and growing in prominence since the 1980s[6]. However, it came with its fair share of problems. Unlike petroleum diesel, biodiesel formed from this process contains oxygen, which reduces the fuel's energy and renders the diesel susceptible to oxidation and other forms of corruption due to the unsaturation of many FAME components[5]. Renewable diesel excels here, as it is a hydrocarbon, just like petroleum diesel[4]. While this results in higher production costs, it also enables renewable diesel to work as a direct replacement or a blend of standard diesel, whereas biodiesel typically can only function as a blend of 5-20 % in petroleum diesel. Thus, renewable diesel is similar to biodiesel in that it is derived from renewable oils and fats but treated differently to match the properties of petroleum diesel. Regardless, its steeper price serves as a reminder that renewable diesel still has a way to go towards affordability and efficiency[7].

Growth and International Spread

Still, renewable diesel presents a promising path toward reducing global carbon production, one that is simple to integrate into existing systems and promises a significant reduction in global emissions. Renewable diesel production boomed in 2021[8], as production capacity expanded to 1.6 billion gallons, a twofold increase compared to the past year. The demand for RD exploded worldwide, with Europe holding the largest share in the market production at 45% due to its early acceptance of the fuel source, that acceptance also stemming from the adoption of the Renewable Energy Directive (RED) II9. Following Europe, the largest producers of RD appear to be the United States and the Asia Pacific region[9].

The U.S., as the sole source of RD in the North American area, contains 16 RD production plants as of 2022[8], trending towards the western half of the U.S. due to California's Low Carbon Fuel Standard plan, which incentivized the use of cleaner transportation fuels[10]. Additionally, renewable diesel production requires petroleum refining technology, which allowed RD production to center around existing petroleum refinery complexes and further benefit from the preexisting transportation infrastructure of those same refineries[8].

Thus, while the worldwide industry for renewable diesel is large and continues to flourish, the largest factors behind RD growth, and subsequently RD research, appear to be in the EU, the U.S., and the Asia Pacific regions[9]. This would make sense, as all three areas are significantly large in population and industry. Thus, attempts to curb emissions through innovative technologies would be most impactful from those regions, with industries large enough to fund these innovations and populations dense enough that the changes would significantly alter the emissions from those areas. Consequently, the U.S., EU, and Asia Pacific regions are major proponents in RD research and development, as their mutual interest in the fuel resulted in scientific efforts to optimize yield and reduce waste.

Flaws and Recent Innovations:

While renewable diesel was undoubtedly a leap forward in alternative fuels, it was still flawed. In particular, the cost of production remained steep, despite the budding prominence of RD over alternatives like biodiesel[8]. For the formation of renewable diesel, the feedstock requires a catalyst for conversion[11]. In practice, noble metal catalysts like palladium and platinum are prioritized due to their selectivity to deoxygenation, but such catalysts are expensive and scarce[12]. Paired with the fact that noble metal catalysts rapidly deactivate, exploring options for cheaper and recyclable catalysts, such as Ni-Mo or Ni-Co hydrotreating catalysts, could potentially reduce the cost of production.

Thus, a group of Malaysian researchers decided to experiment with reducing the cost. A 2021 study published by the group indicated their intent to combine noble metals with a dissolved copper solution to form bimetallic catalysts[11] through redox reactions. The resulting catalysts would then possess enhanced catalytic properties with high stability, thus producing cheaper catalysts with greater hydrocarbon yield. The results of the experiment held to the group's hypothesis, as the bimetallic catalysts exhibited flexibility, stability, and other unique properties[11]. Still, the results further concluded that different metal combinations favored different reactions and that further research was necessary to enhance the efficiency and potency of bimetallic catalysts. This discovery is quite significant, as pure noble catalysts are a roadblock to production. While this concept is still in a prototype phase, it has the potential to shake up the industry, as cheaper and more powerful catalysts could

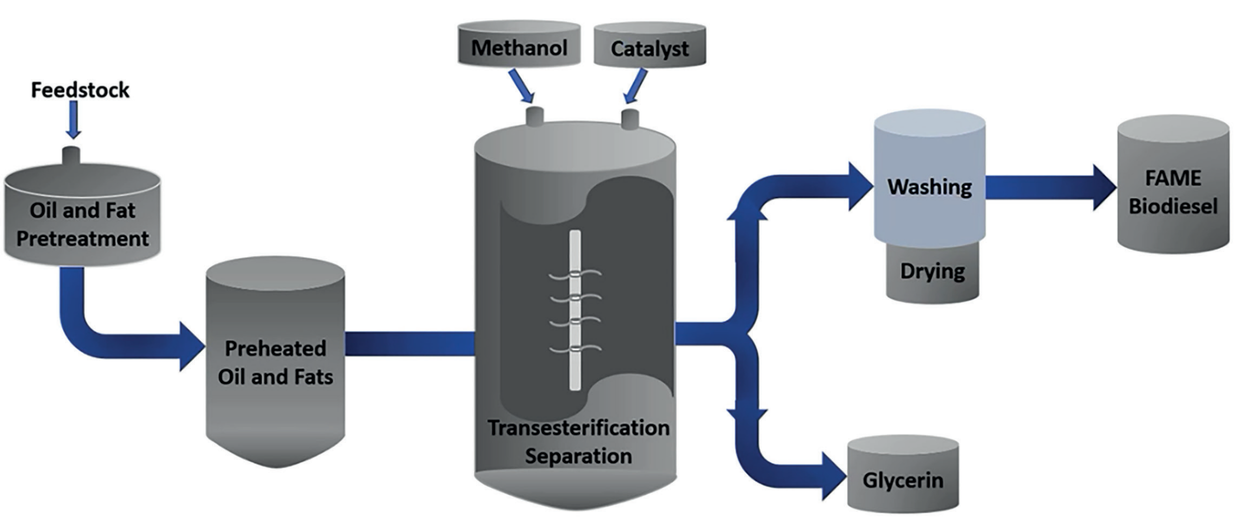

Figure 1: An illustration of FAME diesel production. Source: https://farmdocdaily.illinois.edu/2023/02/biodiesel-and-renewable-diesel-whats-the-difference.html

substitute. The price of renewable diesel could reduce alongside production costs, and renewable diesel could further compete with the price of petroleum diesel. If the follow-up research yields positive results, renewable diesel may be an affordable alternative to petroleum diesel.

Additionally, a separate Malaysian study experimented with another approach to producing RD, one taking advantage of one of Malaysia's natural exports: palm oil[13]. The palm oil industry is lucrative, having exported $15 billion of the product in 2021 alone[14]. An overlooked factor of the exportation, however, is the refining process. Refining crude palm oil creates a byproduct called palm fatty acid distillate (PFAD). The substantial amounts of palm oil refined and produced for exportation naturally result in equally copious quantities of PFAD that remain unused. However, the group noticed that PFAD has a high composition of free fatty acids. Due to its abundant supply and low cost, the group proposed that PFAD could be a viable renewable feedstock for renewable diesel production.

From this hypothesis, the group converted the PFAD into an RD through solventless and hydrogen-free catalytic deoxygenation, using a NiO-ZnO catalyst in the process, as indicated in Figure 4. The product experienced an 83.4 percent yield from the original amount and equally high selectivity. The resulting diesel was also viable for automotive diesel engines, and the experimental reactor system proved compatible with current industrial production plant facilities. This discovery could be significant if this feedstock is deemed viable. As the technology used aligned with modern systems, Malaysian RD industries could gain a proper foothold in a global market, as it rests on an untapped supply of feedstock that will only continue to grow as its palm oil industry does. Furthermore, if PFAD proves to be an especially useful feedstock, Malaysia could become a prominent exporter of feedstock as well, allowing for a boom in global feedstock supply.

Moving away from direct applications of RD, American researchers pursued a method of assessing the sustainability of RD pathways, which is just as important as the pathways themselves. In 2021, the University of Nebraska published an article presenting a multi-criteria decision matrix for the sustainability analysis of renewable diesel processes. This matrix analyzed several aspects of the pathway, including environmental conditions, economic constraints, technical quirks, and fuel-quality aspects[15]. The algorithm then ranks the paths by distance from the ideal and non-ideal solutions. From ranking the pathways, then, the study concludes that the most sustainable alternatives were Fischer-Tropsch diesel and catalytic hydrotreatment of vegetable oils (GD I) while also remarking that algae-based green diesel (GD III) was the least due to its high impact on water scarcity and steep production costs. The logistics of the model are stunning, and if this model is proven to work effectively and accurately, it could be implemented for sustainability assessments, allowing users to determine the most viable course of action for future RD industries.

Furthermore, a research group in Spain experimented with the implementation of renewable diesel with a Euro VI-D hybrid bus[16]. This experiment used an RD with hydrotreated vegetable oil (HVO) under "urban driving conditions." In the study, the bus using standard diesel was evaluated alongside the same bus using the renewable alternative, with both buses being evaluated under different thermal conditions to simulate hot and cold engines. After testing, the group concluded that the RD bus experienced a cleaner and more efficient combustion process, leading to less carbon emissions and greater engine efficiency. The group attests that renewable fuel could work as a total or partial substitute, with potential application for public transportation in other urban environments.

Finally, while a sizable portion of RD research is centered in the U.S. and Asia, other countries are also progressing toward innovation. For instance, a research group in Brazil assessed the viability of an RD that utilized sugarcane as a feed stock[17]. Similar to the previous study in Malaysia, Brazil is one of the world's top exporters of sugarcane, composing half of the world's export of the product in its 2021/2022 fiscal year[18]. As a result, the country holds the greatest potential for the direct sugar-to-hydrocarbon (DSHC) route for RD engines. Capitalizing on this, Amyris Biotechnology Inc. developed farnesane[17], the renewable diesel in question. With this fuel, researchers evaluated its application in a single-cylinder compression ignition engine, representing the small-scale power generation of isolated rural areas in Brazil. In assessing the machine's combustion, performance, and pollutant emissions under different loads, the group concluded that the use of farnesane both reduced NOx emissions significantly and nearly eradicated particulate matter and exhibited an increase in combustion efficiency and fuel conversion efficiency. This is significant, as small-scale, and rural communities can then utilize this fuel source, reducing the community's carbon emissions while not compromising on the power generation necessary for those communities.

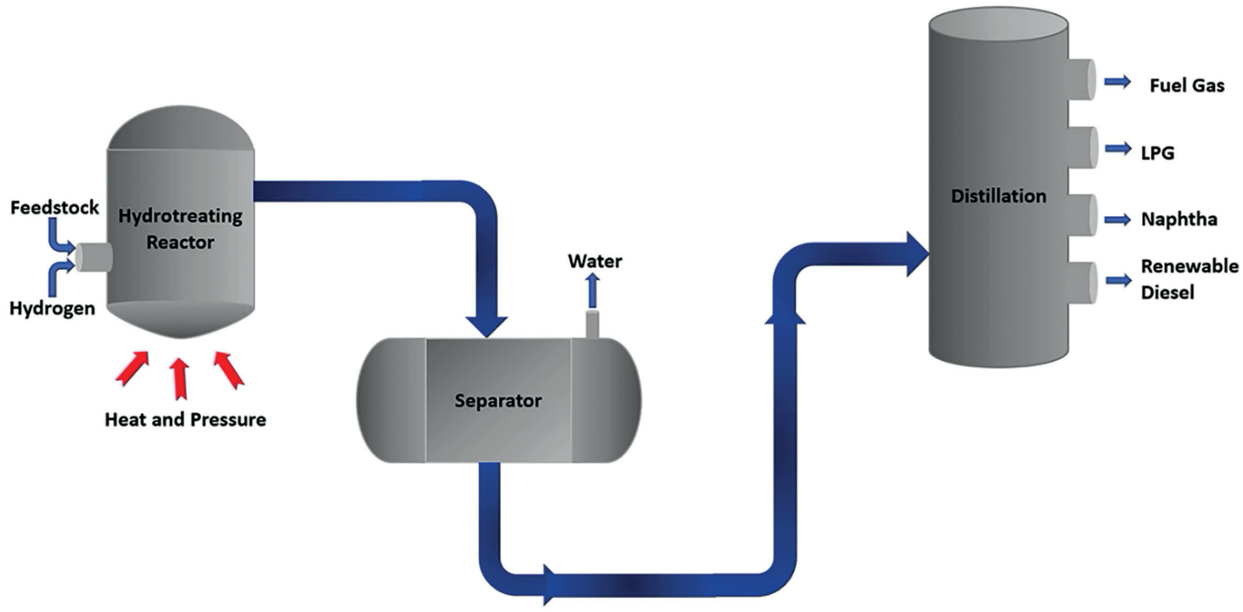

Figure 2: An illustration of renewable diesel production.
Source: https://farmdocdaily.illinois.edu/2023/02/biodiesel-and-renewable-diesel-whats-the-difference.html

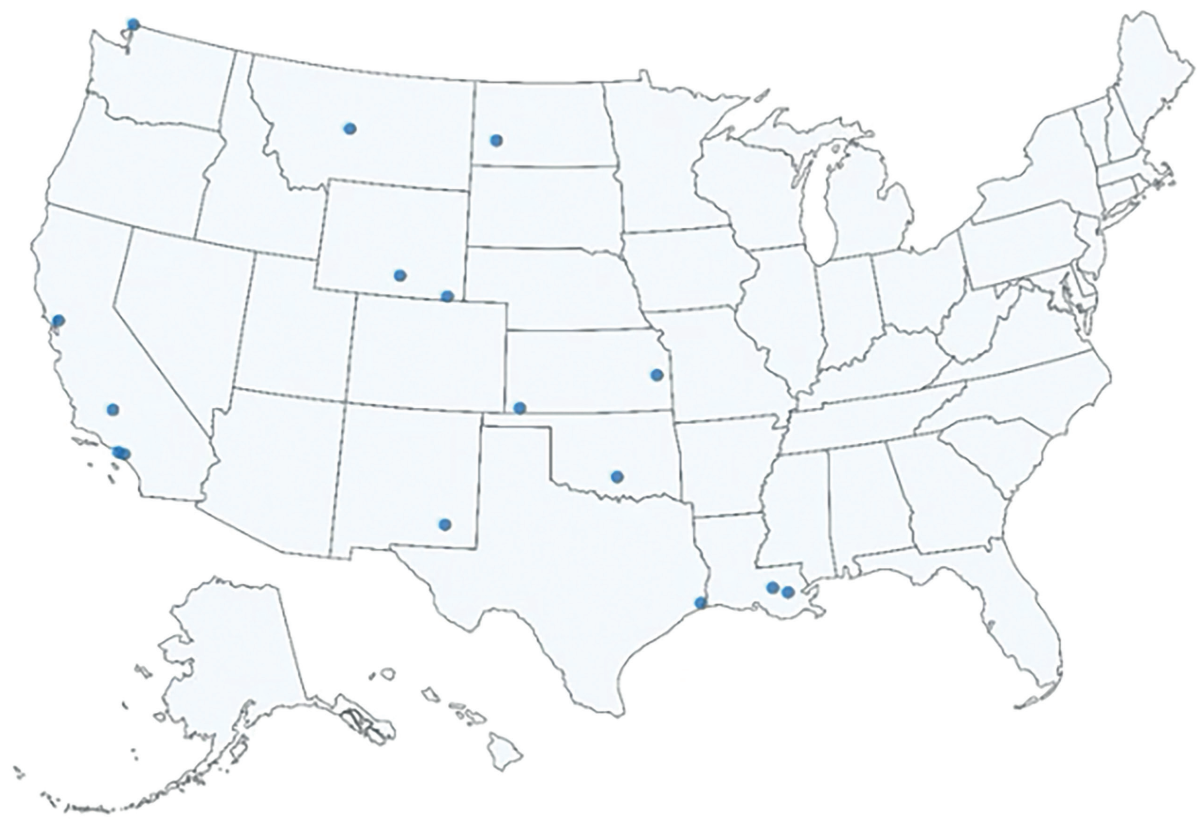

Figure 3: A Depiction of all RD plants in the US as of December 2022.
Source: https://farmdocdaily.illinois.edu/2023/03/overview-of-the-production-capacity-of-u-s-renewable-diesel-plants-through-december-2022.html

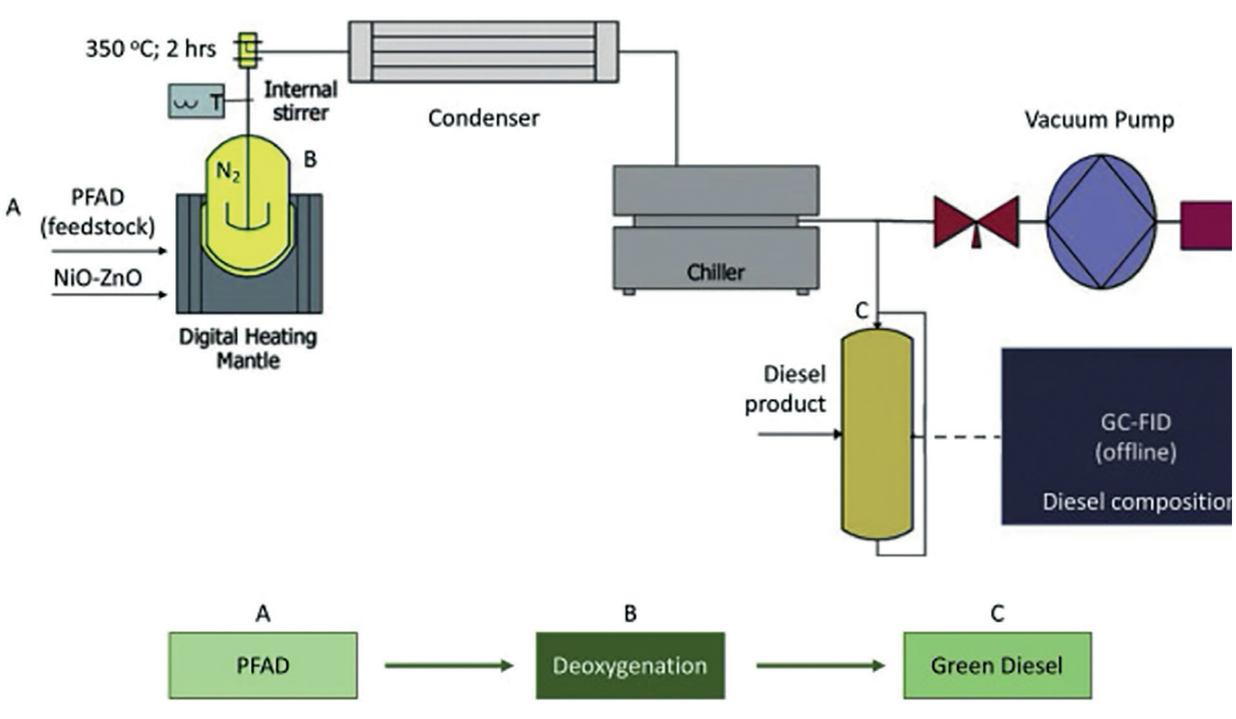

Figure 4: An illustration of PFAD deoxygenation.
Source: https://www-sciencedirect-com.proxy.library.stonybrook.edu/science/article/pii/S095965262032895X#sec2

Conclusion

As these developments prove, renewable diesel is a promising industry. Despite being a relative newcomer in the field of biofuels, RD is booming, as production grows by the billions[8] and consumption grows larger. Research on RD is constantly shifting and evolving, as new pathways are found, and old pathways are optimized. If there is one surefire conclusion to draw from the growth of renewable diesel, it is that it will continue to advance. Vehicles are already ready for their use, production is scaling up, and RD has a strong foothold in global markets. Still, there is room for growth: as the price of RD still needs to be reduced to compete with standard diesel, and RD can still be made more efficient and more viable for both large and small-scale generators. The fuel source is still budding, though, and scientists are working diligently towards those goals, and little by little they will be realized. Eventually, renewable diesel will be able to compete with petroleum diesel and the transportation industry will be even more sustainable as a result.

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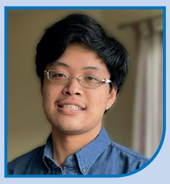
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