Renewable Fuels: Feedstock, Catalyst, and Process Advances

Multi-Client Study Proposal

June 2022
Renewable Fuels: Feedstock, Catalyst, and Process Advances

I. ABSTRACT

The rapid expansion and development of renewable fuels is upon us all! Executives, commercial development and R&D managers, and investors need to appreciate and understand the huge competitive forces as well as the rapidly changing technical process developments that will impact this business over the next five to ten years.

In the fuels industry and business, it is clear renewables (diesel, SAF, gasoline) will supersede biofuels (transesterification of oils/fats, 1st generation bioethanol) due to improved cost performance, flexible but broad product slates, and drop-in capabilities. What hasn’t been fully considered are the technological solutions that will address this complex and growing market. Additionally, feedstock supply and logistics are some of the biggest unknowns that will be crucial to the success of any renewable fuel investment.

Nonetheless, the renewable fuels market is growing at a fast pace as companies and governments look to take advantage of tax credits, prepare for new regulations, strive for the decarbonization of fuels, and improve their energy independence. Figure 1 exemplifies the growing demand for renewable fuels while fossil-based gasoline, diesel, and jet fuel all expand at minimal rates in this decade and may even begin to move towards negative rates beyond that.

In this new multi-client study, The Catalyst Group Resources will:

1. **Examine** the supply/demand and logistics of feedstocks and projected capacities for renewable diesel, gasoline, SAF, and other chemicals like naphtha, propane, etc.
2. **Provide a view** of the industry today and where it’s going. Who are the players in the value chain, what are their roles, and what options and gaps exist from a strategic perspective moving forward? What are the current and future regulations and tax credits?
3. **Benchmark** the catalytic and process advances, including CAPEX/OPEX, operating parameters, and LCAs of leading technology licensors and grassroots vs. retrofit approaches.
4. **Identify** the new catalyst and process technologies to address this trend towards renewables and to develop an understanding of the growing renewables market and impact on traditional markets.
II. BACKGROUND

Renewable fuels are different from biofuels. Whereas biofuels (biodiesel, bioethanol) are derived from biomass, they can only be blended with petroleum fuels, usually at levels below 15%, because the esterification and fermentation production methods create different molecular compositions than petroleum derived fuels. On the other hand, renewable fuels, which must meet relevant standards, are produced by different processes and catalysts to emulate the same molecular structure as petroleum fuels. These can be blended at far greater rates than biofuels and can even be “drop-in” fuels.

1. Feedstocks for Renewable Fuels

As mentioned above, the reliable supply of feedstocks for a renewable fuels application are critical. First and second-generation feedstocks can be economically processed into a variety of fuels, with bioethanol and biodiesel being the predominant ones today with increasing shares of renewable diesel and SAF. This study will analyze the regional feedstock logistics and supply chains to provide subscribers with projections of current and future feedstock availability. In addition to looking at supply and demand, TCGR will identify feedstock characteristics such as composition, yield, economics, and the hurdles to overcome for more widespread usage. The catalytic solutions from one feedstock to the next will differ, so the study will also evaluate how catalyst technology needs to adapt. Figure 2 provides a brief overview of the renewable fuels value chain, from feedstocks to technologies to the companies making it happen.

2. Renewable Diesel

In the U.S., California’s Low-Carbon Fuel Standard (LCFS) provides a credit for renewable fuels use with an estimated 150,000 bpd demand in 2020. California has been the most aggressive, with the stated goal of replacing 100% of its petroleum diesel with renewable diesel by 2030. Already Oregon and Washington have followed, and it is anticipated that up to 10 other states will follow suit by 2025. In Europe, RED II and the “Fit for 55” initiative are increasing individual country by country demand for...
renewable products. Additionally, the electrification of heavy-duty transportation is unlikely to occur in a significant scale this decade. For these reasons, refiners have rapidly increased CAPEX on new and retrofit renewable diesel and SAF capabilities to comply with increasing GHG regulations and capitalize on what is already a profitable market in some regions.

To keep pace, licensors and catalyst producers are supplying both revamped and new technologies that can process a variety of biomass and waste feedstocks into drop-in renewable fuels. **Honeywell/UOP’s Ecofining™ technology** is an industry leader, claiming 80% reduction in GHG emissions and the ability to produce green diesel and jet fuel and renewable naphtha for petrochemical production. **Topsoe’s HydroFlex™ process** enables hydrotreatment of almost any feedstock to produce renewable gasoline, diesel or jet fuel. **ExxonMobil** has begun offering its EMRD™ process and BIDW™ catalyst for renewable diesel. **Neste MY Renewable Diesel™** reduces 90% GHG emissions compared to fossil diesel. **Axens’ Vegan® technology** (see Figure 3) also produces renewable diesel and jet from a range of feeds. There are also several startups, like Gevo and Anellotech, with variants of claimed advantages on the cost/performance basis and **TCGR will benchmark these newer companies as well.**

3. **SAF and Renewable Gasoline**

SAF development and deployment is also rapidly rising. Currently commercially it is occurring on a trial basis, with less than 1% of the global demand being served. When SAF is blended with conventional jet fuel it must meet ASTM D1655 to be used in existing aircraft infrastructure. In the U.S., United Airlines has been a leader using it at LA International since 2016 and San Francisco International since 2018. Currently, six SAF fuel categories have been approved under the D7566 standard and when blended to be certified as ASTM D1655 equivalent. These include FT hydroprocessing synthesized paraffinic kerosenes (SPK) from solid biomass, ester and fatty acids from cooking oil, fats, algae, and vegetable oils, isoparaffin fuels from fermented sugars, SPK with aromatics, alcohol-to-jet SPK from isobutanol or ethanol and catalytic hydrothermolysis from fats, oils, and greases.

Renewable gasoline should also not be ignored, as there are a number of planned plants intending to manufacture all renewable fractions of diesel, SAF, gasoline and naphtha for petrochemicals. There are also a number of other commercialized processes (i.e., ExxonMobil’s Methanol-to-Gasoline (MTG) technology, Topsoe’s Tigas™ technology) and others already available which may show better molecular controls. What is notable is that both the science and manufacturing catalysis advances are now allowing producers to molecularly tailor their fuel products.
III. THE NEED FOR THE STUDY

$ Billions $ at Stake as a Growing Share of Renewable Fuels Substitute Crude Oil Feedstocks…

Never has there been such a compelling case to understand and appreciate these changes that are coming upon you.

_It's not enough to be green, it must also be economic…_

Already like all technology cycles which began with 1\textsuperscript{st} generation processes, we are seeing licensed process improvements but also 2\textsuperscript{nd} generation processes and catalysts being deployed in an effort to improve quality standards, as well as to reduce the CAPEX and OPEX in new processes. Renewable feedstocks have their own challenges including more and different contaminants, as well as producing products with more oxygenates that must be removed in final polishing steps. Newer system configurations are integrating more steps into single passes. This detailed report is timely in benchmarking and helping investors evaluate the winners. Manufacturing cost/performance is everything in dealing with commodity markets.

What will happen to 1\textsuperscript{st} Generation Biofuels Producers? Will they convert? Can they convert?

What’s unknown is how much conversion towards full renewables is likely to take place between now and 2030 and what impact this will have on the renewable fuel markets. These competitive issues will have a large influence on the viability of different expansion projects and will be addressed in TCGR’s study.

Critical topics this study will address include:

- Supply/Demand of feedstocks and renewable fuels and catalyst markets
- How much conversion is likely to take place with existing producers
- Which segments i.e., manufacturing assets in place, will be most easily converted and why
- Advances to catalyst and process technology, CAPEX/OPEX improvements and LCA considerations
- Benchmarking and SWOT of today’s renewable fuel technologies
- Long term strategic impact on crude oil and fossil-based fuels
Subscribers will benefit from TCGR’s deep industrial knowledge, having been producing techno-economic and LCA assessments of traditional/and bio-based fuels and chemicals for almost 40 years. This study also complements other recent studies produced by TCGR, demonstrating TCGR’s unique capabilities and insight in the renewable fuels and chemicals industries:

- **Unconventional Catalytic Olefins Production II: Technological Evaluation and Commercial Assessment** *(completed in October 2021)*
- **Oil-to-Chemicals II: New Approaches from Resid and VGOs** *(completed in June 2019)*
- **Advances in Catalytic Science for the Upgrading, Conversion, and Co-Processing of Circular Feedstocks** *(in production; to be completed in 2022)*
- **CO₂ Reduction via Biomass Conversion in Energy and Chemicals** *(in production; to be completed in 2022)*

As is the case in all TCGR multi-client studies, this will be a highly client-centric approach. “Charter” subscribers (i.e., those that sign up prior to study launch) will be essential in submitting their most pressing questions, thus making this a document that reflects the needs of the industry.

IV. SCOPE AND METHODOLOGY

TCGR’s study will document the technological and commercial progress being made towards producing increasing quantities of renewable fuels, like gasoline, diesel, and jet fuel (SAF). As can be seen in the preliminary Table of Contents (see page 6), Section III of the report will provide subscribers with a complete picture of the supply/demand dynamics of the full range of feedstocks for renewable fuels, along with the challenges that exist with the upgrading and co-processing of various feeds.

Sections IV and V will cover catalyst and process advances to renewable technologies, including industry provided and known data on techno-economics and life cycle analyses (LCA). These sections will also cover developmental stage technologies which could disrupt the marketplace in 5+ years. Lastly, TCGR will examine leading commercial strategies and review the investment landscape and offer its recommendations in the concluding Section VI.

TCGR’s unique background and established global Dialog Group® ensures expert capability and skill level in this study area. TCGR will utilize numerous deeply experienced experts in catalytic biomass upgrading technologies and markets to assist us to provide insights beyond what other sources that do not have the reach and industrial experience can provide.

As it does in each of its industrially-focused multi-client studies, TCGR will seek input from “charter” subscribers to help shape the report’s final scope/ToC so that it covers and emphasizes the most pertinent content due to the large volume of research and the numerous approaches to renewable/sustainable fuels that might be of interest. As such, TCGR studies are “by the industry, for the industry.”
Preliminary Table of Contents *

Renewable Fuels: Investment Shifts and Process Advances

I. INTRODUCTION
   A. Economic Environment Drivers and Opportunities, Critical Factors Affecting Decisions, etc.
   B. Regulation by Fuel and Region
   C. Industry View – Value Chain and Players, Renewable Fuels Market Size and Growth, Impacts on Catalyst Demand

II. EXECUTIVE SUMMARY

III. ANALYSIS OF FEEDSTOCKS
   A. Composition Analysis and Supply/Demand:
      i. Oils and Fats, Recycled and Virgin
      ii. Agricultural and Forestry Waste
      iii. Energy Crops
      iv. Refuse and Industrial Wastes
      v. Other
   B. Pretreatment to Reach Manufacturing Standards
   C. Co-processing of Different Feedstocks
   D. Analyses and Impacts to Future Market Demand

IV. CATALYST AND PROCESS ADVANCES IN RENEWABLE DIESEL
   A. Commercial/Licensed Processes (Neste NEXBTL, Topsoe HydroFlex, UOP Ecofining, Axens Vegan)
   B. Recent Improvements to Licensed Processes (Shell Renewable Refining, XOM EMRD, CLG ISOTERRA, REG BioSynfining)
   C. Techno-economic and LCA of Processes and Products
   D. Emerging Processes - SWOT
   E. Developments in the Next Five Years

V. CATALYST AND PROCESS ADVANCES IN SAF, GASOLINE, AND OTHERS
   A. Commercial/Licensed Processes (LanzaJet AtJ, Neste NEXPinus, Topsoe TIGAS, UOP RTP, Clariant Sunliquid & GTL)
   B. Recent Improvements to Licensed Processes (Velocys, Biojet, Verbio, NextChem, Novozymes)
   C. Techno-economic and LCA of Processes and Products
   D. Emerging Processes - SWOT
   E. Developments in the Next Five Years

Note: Since Renewable Natural Gas (RNG), while a renewable fuel, is mostly derived from biogas and purified to natural gas specifications, TCGR deemed it out of scope for this study.

VI. STRATEGIC ANALYSES AND BUSINESS RECOMMENDATIONS
   A. Key Points on Technology Changes
   B. Likely Ten-Year Business Scenarios
   C. Industry SWOT
   D. Impact on Refinery Operations, CO₂/GHG Emissions (LCA)
   E. Impact on Crude Oil Consumption

* Charter subscribers (those who sign up for the study prior to launch) will have the opportunity to work with TCGR to further refine the scope of the report by delineating areas of particular interest, notably in Sections III-V for inclusion in the assessment.
V. QUALIFICATIONS

The Catalyst Group Resources, a member of The Catalyst Group, works with clients to develop sustainable competitive advantages in technology-driven industries such as chemicals, refining, petrochemicals, polymers, specialty/fine chemicals, biotechnology, pharmaceuticals, and environmental protection. We provide concrete proven solutions based on our understanding of how technology impacts business.

Using our in-depth knowledge of molecular structures, process systems, and commercial applications, we offer a unique combination of business solutions and technology skills through a range of client-focused services. Often working as a member of our clients' planning teams, we combine our knowledge of cutting-edge technology with commercial expertise to:

- Define the business and commercial impacts of leading-edge technologies
- Develop technology strategies that support business objectives
- Assess technology options through strategy development, including:
  - Independent appraisals and valuations of technology/potential
  - Acquisition consulting, planning and due diligence
- Provide leading-edge financial methodology for shareholder value creation
- Lead and/or manage client-sponsored R&D programs targeted through our opportunity identification process
- Provide leading information and knowledge through:
  - World-class seminars, conferences and courses
  - Timely technical publications

The client-confidential assignments conducted by The Catalyst Group include projects in:

- Reinventing R&D pipelines
- Technology acquisition
- Technology alliances
- Market strategy

We have built our consulting practice on long-term client relationships, dedication, and integrity. Our philosophy is clear and focused:

We Provide the "Catalysts" for Business Growth by Linking Technology and Leading-Edge Business Practices to Market Opportunities
VI. DELIVERABLES AND PRICING

This report is timely and strategically important to those industry participants and observers both monitoring and investing in the development and implementation of technologies for renewable fuels. TCGR’s report, based on technology evaluations, commercial/market assessments and interviews with key players will go beyond public domain information. As a result, subscribers are requested to complete and sign the “Order Form and Secrecy Agreement” on the following page.

The study, “Renewable Fuels: Feedstock, Catalyst, and Process Advances,” is expected to be available 3-4 months after launch.

<table>
<thead>
<tr>
<th>Participation</th>
<th>Deadline</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charter subscribers*</td>
<td>prior to launch</td>
<td>$24,000</td>
</tr>
<tr>
<td><strong>Renewable Fuels: Feedstock, Catalyst, and Process Advances</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-launch subscribers</td>
<td>after launch</td>
<td>$27,000</td>
</tr>
<tr>
<td><strong>Renewable Fuels: Feedstock, Catalyst, and Process Advances</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Charter subscribers (those who sign up for the study prior to launch) will have the opportunity to work with TCGR to further refine the scope of the report by delineating areas of particular interest, notably in Sections III-V, for inclusion in the assessment.

Notice to Subscribers of TCGR’s reports “Oil-to-Chemicals: Technological Approaches and Advanced Process Configurations” or “Oil-to-Chemicals II: New Approaches from Resid and VGOs”:

Due to the complementary nature of this study to TCGR’s previous reports in this area, TCGR is offering a discount of $1,000 of “Renewable Fuels: Feedstock, Catalyst, and Process Advances” to subscribers of the above-mentioned studies. Subscribers are requested to contact Chris Dziedziak at +1 215.628.4447 or cdziedziak@catalystgrp.com if further details are required or to determine if your organization is entitled. When completing the order form, please make sure to indicate your company’s subscription to the earlier report.
ORDER FORM AND SECRECY AGREEMENT

Please enter our order for “Renewable Fuels: Feedstock, Catalyst, and Process Advances” to be completed within 3-4 months of study launch, as follows:

___ “Renewable Fuels: Feedstock, Catalyst, and Process Advances” as a “charter” subscriber (i.e., prior to study launch) for $24,000 ($27,000 after study launch). Fees include report delivery in printed (2 copies) and electronic format (PDF).

___ Please send us _____ additional printed copies @ $250 each.

___ * * * We are subscribers to either of TCGR’s “Oil-to-Chemicals” multi-client studies and are therefore entitled to the $1,000 discount off the subscription rate. * * *

In signing this order form, our company agrees to hold this report confidential and not make it available to subsidiaries unless a controlling interest (>50%) exists.

Signature: ____________________________ Date: ___________________
Name: _______________________________ Title: ___________________
Company: _____________________________
Billing Address: __________________________
Shipping Address (no P.O. Boxes): __________________________

Express delivery services will not deliver to P.O. Boxes

City: ___________________________ State/Country: _____________
Zip/Postal Code: _______________ Phone: _______________
E-mail: ___________________________ Fax: _______________

This report and our study findings are sold for the exclusive use of the client companies and their employees only. No other use, duplication, or publication of this report or any part contained herein is permitted without the expressed written consent of The Catalyst Group Resources.