Second-generation hydrocarbon fuels from oil palm by-products
Anjan Ray

Abstract
The production of renewable fuels worldwide continues to expand as a consequence of volatility in petroleum prices, commitments to greenhouse gas reduction by governments and the need for future energy security, especially in regions with high dependence on fossil fuel imports.

Renewable hydrocarbon diesel and jet fuels can be produced using the UOP/ENI Ecofining™ and UOP Renewable Jet processes. Unlike conventional fatty acid methyl ester (FAME) based bio-diesel, the deoxygenated hydrocarbons produced in these UOP processes have fuel quality attributes that are very similar to the corresponding petroleum derived fuels.

Biomass such as agricultural and forestry wastes are emerging as promising sources of renewable liquid, gaseous and solid fuels. The RTP™ process converts biomass to RTP green fuel, a pyrolysis oil that can be used as process fuel in boilers, furnaces and kilns or for power generation. Use of RTP green fuel can also significantly reduce the energy cost, greenhouse gas impact and carbon footprint of user industries. Conversion of RTP green fuel to hydrocarbon transportation fuels has been demonstrated.

While palm oil is primarily used for edible purposes, the technologies described above offer significant potential for conversion of by-products from the palm plantation and downstream processing sectors – such as palm stearin and expended palm fruit bunch – into second-generation hydrocarbon fuels. It is important that appropriate sustainability criteria be applied to selection and utilization of by-products and residues from the palm sector for production of such fuels.

Key words
Renewable fuels, biomass, Rapid Thermal Processing / RTP, oil palm

1. Introduction
First-generation biofuels, such as ethanol derived from carbohydrates and FAME (fatty acid methyl ester) obtained from triglycerides, typically offer lower energy densities relative to the corresponding fossil fuels, gasoline and diesel, respectively. The presence of oxygen in these first-generation biofuel molecules also necessitates the establishment of dedicated blending infrastructure and possibly engine modifications at increased levels of biofuel blend component.

Email: Anjan Ray (Anjan.Ray@Honeywell.com)
Regional Commercial Director, UOP India Pvt. Ltd., 5th Floor, Building 9B, DLF Cyber City, DLF City Phase – III, Gurgaon 122002, Haryana, India

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This is reflected in concerns raised by the automotive sector. For instance, The Japan Automobile Manufacturers Association, Inc (JAMA), said in a statement on biodiesel in 2009 \( [1] \) that “JAMA cannot recommend the use of FAME-blended diesel of more than 5% FAME content except for the vehicles specially designed and operated by fleet users with special vehicle management qualification. Furthermore, the fueling pumps of high FAME content diesel should be provided with clear labeling (indicating specific FAME content) to prevent mis-fuelling of regular vehicles. In the case that high FAME content diesel is to be introduced widely as a policy, JAMA strongly recommends the use of HVO (hydro-treated vegetable oil) or BTL (biomass to liquid) as blend-stocks for the production of FAME-blended diesel of more than 5% FAME content equivalent.”

Further, ethanol and FAME biodiesel production are likely to be constrained by yields per acre of the necessary feedstock to these processes, and – in cases where the feedstock could be used for food production – such as corn, sugarcane juice or crude palm oil – there has been significant debate on whether this is a sustainable approach \( [2] \).

At the same time, there is clearly a need to improve energy access in many parts of the world, and to improve energy security for nations that import a significant part of their fuel. The key conflicting challenges have been referred to as the Four Imperatives \( [3] \):

- Improved energy security to underpin economic development
- Reduced dependence on fossil fuels, especially on substantial crude oil imports by energy deficient nations
- Reduced greenhouse gas (GHG) emissions
- Minimized adverse effects on food security, water supply and quality, agricultural land and forests

A desirable approach to biofuels, therefore, should address at least two key elements:

- Utilization of existing hydrocarbon fuel infrastructure through the use of “drop-in” identical or near-identical substitutes for currently used fossil fuels
- Use of feedstocks that are obtained from renewable resources in a sustainable manner

There are already a number of approaches to production of drop-in fuels. This paper deals with two options with special emphasis on the oil palm value chain, especially keeping in mind the issues around sustainable deployment of bio-resources originating from oil palm plantations.

2. Honeywell Green Diesel™ and Honeywell Green Jet Fuel™ from oils and fats

The UOP/ENI Ecofining™ process involves treatment of oils and fats, typically triglyceride lipids (although other esters can be used and free fatty acids can be tolerated to a significant extent), with hydrogen under pressure in the presence of a catalyst to produce Honeywell Green Diesel™ with useful co-product hydrocarbons like naphtha, renewable jet fuel and light ends (mainly propane) that can be thought of as a renewable-origin LPG equivalent. The naphtha fraction can be a feedstock for (1) a reforming unit for producing gasoline, (2) a steam cracking unit to produce polymer grade olefins or (3) a steam reforming unit to produce hydrogen.

From the process flow diagram shown in Figure 1, it can be seen that there are two main reaction steps – a deoxygenation step to produce a mixture of straight-chain paraffins, followed by an isomerization step to optimize the cloud point and cetane number.

Ecofining is capable of converting a wide variety of lipid triglyceride feedstocks – such as jatropha oil, camellina oil, used cooking oil, palm-derived lipids, etc. – into Honeywell Green Diesel, which not only meets the specifications of conventional ultra-low sulfur diesel (ULSD) from petroleum refineries, but also outperforms conventional ULSD in terms of cetane number, SOx and NOx emissions. It may be recalled that NOx emissions are a concern for FAME biodiesel \( [4] \).

High feedstock flexibility is a consequence of the final product properties being relatively independent of the input lipid profile. This permits use of different feedstocks depending on prevailing cost and availability, and makes plants built using this technology easily adaptable to emerging, scalable, non-food options such as short rotation crops, used
cooking oil and algal lipids. Figure 2 summarizes observed yield of hydrocarbon liquid during a deoxygenation study in which various feedstocks were fed at different times during a continuous run in a pilot plant over several thousand hours.

This flexibility offers the potential to reduce competition for natural resources such as water and land and minimize conflict with food security while delivering a measurably reduced carbon footprint in the overall life cycle. In the palm sector, one can avoid use of crude palm oil – which is used for production of edible oil – and use other palm-derived lipids instead (e.g. palm stearin) that are non-edible co-products of palm oil refining and are typically used in applications like soaps, cosmetics etc.

In addition to this, Honeywell Green Diesel™ provides several additional benefits:

- Replacement or blending of petro-diesel with Honeywell Green Diesel reduces
fossil carbon footprint and undesirable emissions, including NOx and SOx.

- Honeywell Green Diesel is chemically analogous to normal diesel, so engine modification is not required for blends of Honeywell Green Diesel and petro-diesel

- The cold-flow performance, as indicated by the cloud point, can be tuned as desired in the Ecofining process

Further, recent studies have shown \(^5\) that the addition of Honeywell Green Diesel™ to B5 (a 5% blend of palm oil methyl ester biodiesel and 95% Euro-IV compliant fossil-derived diesel) progressively decreases NOx emissions, CO\(_2\) emissions and particulate matter as well as improves fuel consumption with increasing Honeywell Green Diesel™ content relative to B5 as a baseline.

Over and beyond the natural fats and oils that can be extracted from the palm fruit, oil palm plantations also yield very significant quantities of biomass from multiple points in the palm processing value chain. These include empty palm fruit bunch (EFB), mesocarp fiber, palm fronds and the trunks of the palm tree itself. Such lignocellulosic biomass can be thought of as a storehouse of energy derived from incident solar radiation via photosynthesis, as also a sink for carbon dioxide captured from the air and a reservoir of water drawn from the ground.

A variety of technologies exist for deploying the energy content in biomass. These include – for instance – direct combustion in boilers, gasification, bio-methanation, cellulosic ethanol production, and thermochemical processes such as fast thermal pyrolysis.

Rapid Thermal Processing, RTP™, from Envergent Technologies LLC, a joint venture between UOP, a Honeywell company having nearly a century of refining expertise and Ensyn, a global pioneer in pyrolysis technology, converts biomass at relatively high yields to a liquid fuel (RTP green fuel), an energy delivery intermediate that can be stored and transported conveniently. RTP green fuel can be combusted on its own or co-fired with other fuels, including furnace oil, diesel and coal. It can be deployed for power generation, and also offers promise for upgrading to transport fuels in the foreseeable future. Development of upgrading technology for conversion of RTP green fuel to renewable gasoline, diesel and jet fuel is in progress \(^6\).

3. Production of RTP green fuel from biomass residues

In the RTP™ process, outlined in Figure 3, biomass such as empty palm fruit bunch (EFB), is rapidly heated in an oxygen-starved environment to approximately 500°C using a circulating fluidized bed reactor system similar to the one used in the UOP Fluid Catalytic Cracking (FCC) technology \(^7\).

EFB is dried and sized to minimize moisture and optimize particle size for effective heat transfer. Hot sand is used to break down the biomass during a short contact time at most a few seconds, producing a liquid (RTP green fuel) that is recovered by quenching. In addition, some quantity of non-condensable by-product gas is produced along with some char, both having useful calorific value (Table 1). The by-product gas can be used to generate heat or power that can be used for process utilities. The char is combusted in a Reheater vessel to maintain the temperature of the circulating sand and the hot exhaust gas from this combustion can be used for pre-drying of the feedstock. This makes the RTP™ process virtually self-sustaining from an energy standpoint.

**Table 1: RTP Product Components**

<table>
<thead>
<tr>
<th>Feed, wt%</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardwood Whitewood</td>
<td>100</td>
</tr>
</tbody>
</table>

**Typical Product Yields, wt% Dry Feed**

| RTP green fuel       | 70    |
| By-Product Vapor     | 15    |
| Char                 | 15    |

Typical properties of RTP green fuel are summarized below in Table 2. It conforms to ASTM D7544, Standard Specification for Pyrolysis Liquid Biofuel.
Table 2: Typical properties of RTP green fuel

<table>
<thead>
<tr>
<th>Property</th>
<th>Value / Range</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Heat of Combustion, MJ/kg Point, °C</td>
<td>15 min</td>
<td>ASTM D240</td>
</tr>
<tr>
<td>Pyrolysis Solids Content, wt%</td>
<td>2.5 max</td>
<td>ASTM D7544, Annex I</td>
</tr>
<tr>
<td>Water Content, wt%</td>
<td>30 max</td>
<td>ASTM E203</td>
</tr>
<tr>
<td>pH</td>
<td>Report</td>
<td>ASTM E70</td>
</tr>
<tr>
<td>Kinematic Viscosity, cSt @ 40°C</td>
<td>125 max</td>
<td>ASTM D445</td>
</tr>
<tr>
<td>Density, kg/dm3 @ 20°C</td>
<td>1.1 – 1.3</td>
<td>ASTM D4052</td>
</tr>
<tr>
<td>Sulfur Content, wt%</td>
<td>0.05 max</td>
<td>ASTM 4294</td>
</tr>
<tr>
<td>Ash Content, wt%</td>
<td>0.25 max</td>
<td>ASTM 482</td>
</tr>
<tr>
<td>Flash Point, °C</td>
<td>45 min</td>
<td>ASTM D93, Procedure B</td>
</tr>
<tr>
<td>Pour Point, °C</td>
<td>-9 max</td>
<td>ASTM D97</td>
</tr>
</tbody>
</table>

Figure 3: RTP Process Flow Diagram
It may be noted that RTP green fuel contains very low levels of sulfur and is produced in a nearly carbon-neutral way. Thus, it offers an attractive option for existing high-sulfur fuel users seeking to reduce their sulfur emissions as well as the carbon footprint. A life cycle greenhouse gas emission study \cite{8} is shown in Figure 2.

Existing hardware such as boilers, furnaces and kilns that combust fuel oils to generate heat can be adapted with relatively minor modifications for use of RTP green fuel instead. This offers possibilities across a wide swath of industries including electrical generation, forestry, refining and petrochemicals, pulp and paper and other energy-intensive sectors.

As the primary objective of the RTP process is production of liquid biofuel as an energy delivery intermediate, pretreatment is important in order to maximize liquid yields for a given feedstock. Moisture content needs to be reduced as far as possible, the feedstock sized sufficiently small to ensure effective heat transfer and fluidization and extraneous particles like stones and metal pieces should be separated upstream of the RTP process to avoid damage to equipment. Table 3 shows the range of yields that can be expected from properly pretreated feedstock of different origin.

Expended palm fruit bunches (EFB) have been successfully processed into RTP green fuel in scales of up to 100 tons per day. Palm plantations can thus export the energy inherent in this biomass as RTP green fuel over significant distances to industrial fuel users elsewhere.

<table>
<thead>
<tr>
<th>Biomass Feedstock Type</th>
<th>Typical RTP green fuel Yield, wt% of Dry Feedstock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardwood</td>
<td>70 – 75</td>
</tr>
<tr>
<td>Softwood</td>
<td>70 – 80</td>
</tr>
<tr>
<td>Hardwood Bark</td>
<td>60 – 65</td>
</tr>
<tr>
<td>Softwood Bark</td>
<td>55 – 65</td>
</tr>
<tr>
<td>Corn Fiber</td>
<td>65 – 75</td>
</tr>
<tr>
<td>Bagasse</td>
<td>70 – 75</td>
</tr>
<tr>
<td>Waste Paper</td>
<td>60 – 80</td>
</tr>
<tr>
<td>EFB of Palm</td>
<td>65 – 75</td>
</tr>
</tbody>
</table>

RTP green fuel can also be further upgraded to offer a new alternative for the transportation fuel market. Construction is under progress in Hawaii of a biofuels demonstration unit that will
convert pyrolysis oil derived from forest residuals, algae and other cellulosic biomass into green transportation fuels. Backed by a $25 million U.S. Department of Energy award, the Honeywell UOP Integrated Biorefinery will upgrade biomass into high-quality renewable gasoline, diesel and jet fuel. The project is part of the DOE’s efforts to help spur the creation of the domestic biofuel industry, drive domestic job creation and reduce U.S. dependence on foreign oil. The project will also support the Hawaii Clean Energy Initiative goal to achieve 70 percent clean energy by the year 2030.

Located at the Tesoro Corp. refinery in Kapolei, the Integrated Biorefinery will be used to demonstrate viability of the technology, test the fuels produced and evaluate the environmental footprint of the fuels and the process technology. The project began initial RTP green fuel production in 2012 and is expected to be fully operational by 2014.

4. Conclusions
Deployment of bio-derived materials as sources of renewable fuels and energy can contribute to reduced consumption of fossil fuels such as petroleum products and coal and thereby the reduction of greenhouse gas emissions as well as other emissions, such as SOx and NOx, during thermal and electrical energy production. If such biofuels are drop-in replacements for existing fossil fuels, significant additional investments in blending and handling infrastructure as well as engine and equipment modification can be avoided.

In the palm plantation and palm oil refining sectors, Ecofining™ and Renewable Jet processes from UOP are available for conversion of palm-derived lipids to drop-in liquid hydrocarbon biofuels. The RTP™ process from Envergent Technologies LLC offers the possibility of conversion of palm plantation residues to RTP green fuel, an energy delivery intermediate that can be used for process energy, electrical power generation and offers the potential for upgrading into transport fuels in the foreseeable future.

References

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