

# Conversion of Waste Plastic to Lubricating Base Oil

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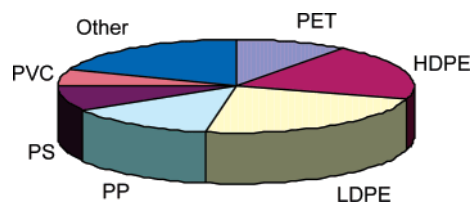
A new process has been developed for the conversion of waste plastic to lubricating base oil. It has also been demonstrated that waste plastic and Fischer–Tropsch (FT) wax can be co-processed to produce lube range molecules. The process uses a thermal, noncatalytic, atmospheric pressure pyrolysis process that converts high-molecular-weight molecules to lower-molecular-weight molecules in the lube oil range. Hydroisomerization is then used to convert this product to low-pour-point oils of unconventional base oil (UCBO) quality. The major byproduct is diesel, with little production of C4– gas. Initial experiments in bench-scale laboratory pyrolysis units were followed by tests in a 1 gal/day pilot plant. The feedstocks that were tested consisted of polyethylene (PE), 96% PE–4% poly(ethylene terephthalate) (PET), FT wax, and a 50/50 mixture of PE and FT wax. The product distribution and lube quality showed surprisingly little variation for these feedstocks. The pyrolysis yields of 385 °C+ product were in the range of 37–57 wt %, whereas the potential lube yields were 60–70 wt %, assuming all the olefins (almost all 1-olefins) could be upgraded to lube by oligomerization. Hydroisomerization of the pyrolysis bottoms yielded oil with a viscosity of 3.4–5.4 cSt, pour points between –13 to –37 °C, and a viscosity index in the range of 150–160.

## Introduction

**Background.** In the United States, plastics is the largest growing waste stream, rising from <5 wt % of total municipal solid waste (MSW) in 1980 to >11 wt % today. In 2001, of ~25 million tons of waste plastic, only ~1 million tons were recycled.<sup>1</sup> In California and elsewhere, waste plastic is a major issue, because of the growing cost of land filling. Even plastic that is collected and separated often gets sent to landfills, because of the lack of a sufficient market.<sup>2</sup> Although California state law has set a recycle rate at 25%, the rate has actually been declining in recent years, from 24.6% in 1995 to only 17.9% in 1999.<sup>3</sup>

Of the waste plastic not recycled, ~43% (or ~11 MM tons/yr) is polyethylene (Figure 1), with most of this in containers and packaging.<sup>1</sup> Polyethylene plastic is found in two main forms: high-density polyethylene (HDPE) and low-density polyethylene (LDPE). Major uses for HDPE materials include rigid containers such as bottles, as well as agricultural film. Major uses for LDPE materials include flexible films such as grocery and dry cleaning bags.

Considerable research has already been done on the liquefaction of waste polymers and co-liquefaction of waste polymers with coal, petroleum residua, and waste oil.<sup>4–10</sup> However, almost all of this work has involved



**Figure 1.** Distribution of plastics in municipal solid waste. Legend: HDPE, high-density polyethylene; LDPE, low-density polyethylene; PET, polyethylene terephthalate; PP, polypropylene; PS, polystyrene; and PVC, poly(vinyl chloride).

the conversion of plastic to transportation fuels, in most cases using both high hydrogen pressure and a catalyst to enhance conversion. Little has been reported on the conversion of waste plastic to higher-valued products. In this study, we investigate the conversion of waste polymers such as polyethylene (PE) to high-quality lubricant oils.

**Trends in Lubricant Base Oils.** Performance and environmental issues are leading to major new directions for lubricating oils. One important change is a shift

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to oils of lower viscosity to reduce engine friction and thereby improve fuel economy. These oils will be in increasing demand by automakers to meet government-mandated minimum miles-per-gallon requirements.

A second change is a reduction in oil volatility. The loss of oil due to volatility increases oil consumption, as well as evaporative emissions into the environment. For example, a strong dependence of diesel particulate emission on engine oil volatility has already been shown.<sup>11</sup>

EPA statistics show that each year in the United States, ~200 million gallons of used oil are dumped into the environment.<sup>12</sup> This problem can be largely addressed by producing oils that are more stable, thereby extending the interval between oil drains and reducing the amount of used oil that would require disposal.

A high viscosity index (VI) signifies high stability to change in viscosity over a wide temperature range. Oil having a high VI resists excessive thickening when the engine is cold and, consequently, promotes rapid starting and prompt circulation; it resists excessive thinning when the motor is hot and thus provides full lubrication and prevents excessive oil consumption. Most lubricating base oils produced today, where "base oil" refers to the lubricating oil before the addition of additives, have a VI value in the range of 95–105 and are called conventional base oils (CBOs). Base oils that will be required to meet the future needs that have been previously discussed will have to have a VI value of > 115 and are called unconventional base oils (UCBOs).

Because paraffins have low volatility for their viscosity, high thermal and oxidative stability, and high VI, these new requirements could be met by using oils which are highly paraffinic. To meet mandated fuel economy and emissions standards plus customer demands will require large quantities of these advanced oils within the next few years.

One technology for preparing the high VI UCBOs uses a highly selective molecular sieve catalyst to isomerize waxy feeds, to allow the oil to flow at low temperature, where that ability is measured by the lowest temperature at which the oil will pour, or its pour point. This technology, which was first commercialized in the United States in the early 1990s,<sup>13,14</sup> converts wax to oil, allowing the production of oils at high yield with high paraffinicity and, therefore, high VI and low viscosity.

**Development of GTL Base Oils.** There is considerable growing interest in upgrading natural gas to more-valuable liquid products for fuels and chemicals. Much of this interest centers on Fischer–Tropsch (FT) technology, which converts synthesis gas (from methane reforming or coal gasification) to waxy products. Long alkanes ( $-\text{CH}_2-$  chains) produced using FT technology are chemically similar to polyethylene. These FT wax products can then be converted to high-quality, low-sulfur fuels via hydrocracking.

In addition to fuels, lubricating oils derived from the isomerization of FT waxes are also gaining interest,

because of increased demand for lubricants with the advanced performance and environmental benefits described previously. Research is underway to identify and develop new cost-effective routes to upgrade FT products to lubricant oils through the isomerization of the wax.

Although FT waxes are high quality, their availability over the next decade is expected to be limited. Therefore, there is an effort to find other sources of feedstocks of equal quality to co-process along with FT waxes, both to meet the demand for the lubricant products, and to reduce the cost of producing these lubricants (including getting a benefit of scale). Reducing the cost of the lubricants derived from FT wax will increase the market for those lubricants and improve the overall economics for the FT process.

Other potential sources of waxy feeds include slack waxes from petroleum refining. However, the supply of these waxes is also limited, because of competition with their further refining and sales into the wax market. A new potentially significant source for waxy feed, as yet untapped, is *waste plastic*.

PE, which is the main component of waste plastic, can be considered to be similar in molecular structure to wax that is suitable for isomerization to lubricating base oil, but with a much-higher molecular weight (typically  $\sim 10^4$ – $10^6$ ). By contrast, base oil from wax isomerization is in the molecular-weight range of  $\sim 300$ – $800$ . The objective of this study was to determine to what degree polyethylene could be converted by pyrolysis to a molecular-weight range suitable for isomerization to base oil and to determine how the properties of that base oil compared to those for base oil prepared via FT wax isomerization. The necessity of hydrotreating the pyrolyzed plastic ahead of catalytic isomerization was examined, as was the effect of adding an impurity plastic (PET) to the feed. In addition, we also examined co-processing with FT wax that contained a large fraction of high-boiling components.

In this paper, we describe work that has been performed to examine a combined pyrolysis–hydroisomerization process, looking at the following feedstock options: (i) PE; (ii) PE + poly(ethylene terephthalate) (PET), where PET (e.g., soft-drink bottles) is one of the major non-PE plastics in municipal waste; (iii) PE + FT wax; and (iv) FT wax.

## Experimental Procedure

**Laboratory Pyrolysis Units.** Laboratory pyrolysis of HDPE was conducted using two different modes. Figure 2 is a schematic of the batch mode experimental setup. After placing HDPE in the reactor, and flushing the system with an inert gas, the reactor was lowered into the floor furnace. The furnace was heated from room temperature to the pyrolysis temperature within 15–20 min and held at that temperature for 1 h before cooling back to room temperature. In all our runs, there was complete conversion of all reactant HDPE and the reactor was clean at the end of the run. Several runs were performed to optimize the temperature and pressure conditions.

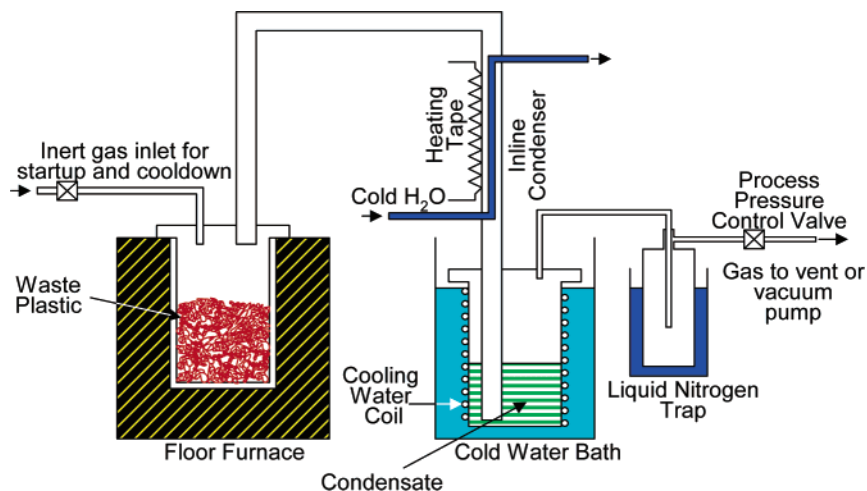
Because there is no control on the residence time in the batch pyrolysis setup, pyrolysis at higher temperature allows larger-molecular-weight species to leave quickly. At lower furnace temperatures, the larger HDPE molecules are not vaporized and spend more time in the furnace, to undergo further cracking. Figure 3 shows results for the simulated distillation of HDPE pyrolysis products at a reactor pressure

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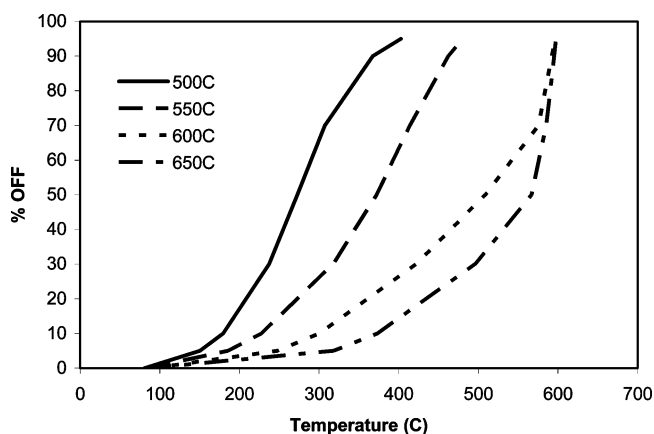
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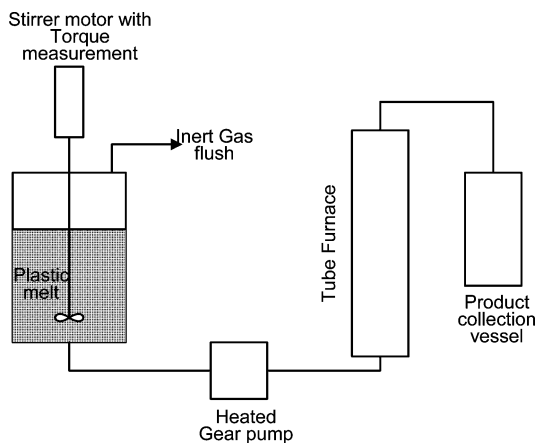
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**Figure 2.** Schematic of the batch-mode laboratory plastic pyrolysis experimental setup.



**Figure 3.** Simulated-distillation boiling-point distributions of HDPE pyrolysis condensates at a pressure of 0.1 atm.



**Figure 4.** Schematic of feed viscosity measurement and continuous pyrolysis of HDPE at ambient pressure.

of 0.1 atm and various furnace temperature settings. At higher (atmospheric) reactor pressures, the difference between the boiling-point distributions narrows.

A continuous process was considered to be more attractive for scaleup. To provide the information necessary for scaleup, and to better control residence time (space velocity) of the continuous process, a second pyrolysis unit was designed and used for laboratory pyrolysis at ambient pressure (Figure 4). The feed was placed in a melter/feed vessel and heated under a 4-psig argon blanket. The vessel was equipped with a stirrer motor with torque measurement. Melted feed went via 1/2-in. (outer diameter, OD) stainless-steel tubing to a heated Parker

Hannifin Zenith gear pump. This pump could deliver metered feeds at temperatures as high as 450 °C with little dead volume. The feed then travelled via 1/4-in. stainless-steel tubing to a 25 cm<sup>3</sup>, 1/2-in. (OD), upflow stainless-steel reactor in a tube furnace. Products were collected downstream in a water-cooled collection vessel.

The effect of pyrolysis at various residence times and temperatures on molecular weight is shown in Figure 5. Note that, at 700 °C and a residence time of 3 min, a considerable fraction of the pyrolyzed product was in the base oil range.

**One-Gallon-per-Day Pilot Plant.** A diagram of the 1 gal/day pyrolysis pilot plant is shown in Figure 6. Feedstock was melted at 260 °C in a 30-L feed pot that was equipped with an air-driven stirrer and had a 10-psi nitrogen blanket. Using a Parker Hannifin Zenith gear pump, the feed was pumped through a stainless-steel preheat coil at 370 °C and then upflowed through a 2.5-cm-diameter stainless-steel reactor that contained preheat and after-heat steel bars to reduce the reactor volume to 140 cm<sup>3</sup>. When plastic without FT wax was used, the feed was diluted to 50/50 (w/w) with a hydrocracked diesel having a boiling point range of 290–370 °C hydrocracked diesel, to lower the viscosity to a point at which the feed could be pumped. All pyrolysis runs were at atmospheric pressure and a residence time of ~1 h (based on plastic and/or wax), with no added gases.

Product from the reactor was sent to a still, which was set at ~230 °C, with nitrogen stripping gas to cut the effluent stream at ~340 °C. Both overhead and bottoms liquids were collected in cans on scales. Gas went through a gas meter and gas sampler for analysis.

**Hydrotreating.** Hydrotreatment of the pyrolyzer stripper bottoms was performed over a commercial nickel–tungsten compound on a silica–alumina hydrotreating catalyst at 300 °C, with a liquid hourly space velocity of 1.5 h<sup>-1</sup>, a total pressure of 13.4 MPa, and a once-through volume flow of 880 scm of H<sub>2</sub> per cubic meter of feed. (Note: scm denotes standard cubic centimeters.) Under these conditions, cracking of the feed was minimal.

**Hydroisomerization.** Isomerization of the waxy pyrolyzer stripper bottoms was performed over a proprietary wax hydroisomerization catalyst at a total pressure of 500 psig. A commercial Pt–Pd on a silica–alumina hydrofinishing catalyst was used at the same pressure in a second reactor downstream from the first, to hydrogenate any unsaturated compounds to improve thermal and oxidative stability.

**Feedstocks.** HDPE and LDPE were obtained from the Chevron Phillips Chemical Company. PET was obtained by cutting up soft-drink bottles. FT wax was obtained from Moore and Munger.

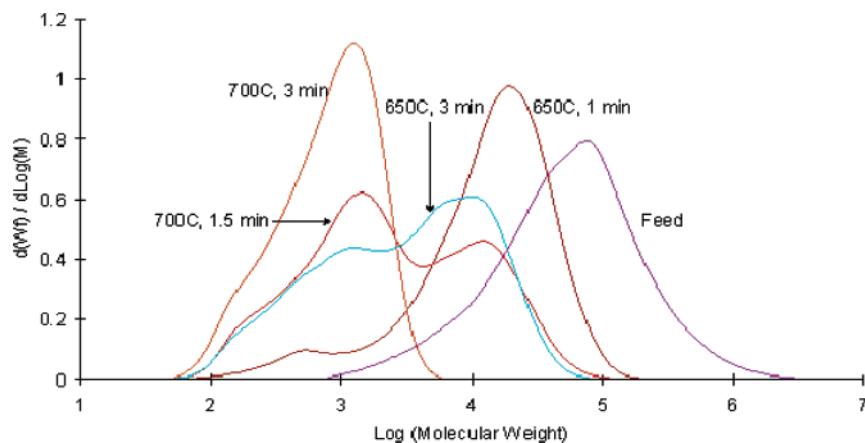


Figure 5. Molecular weight of pyrolyzed HDPE, as determined by gel permeation chromatography (GPC).

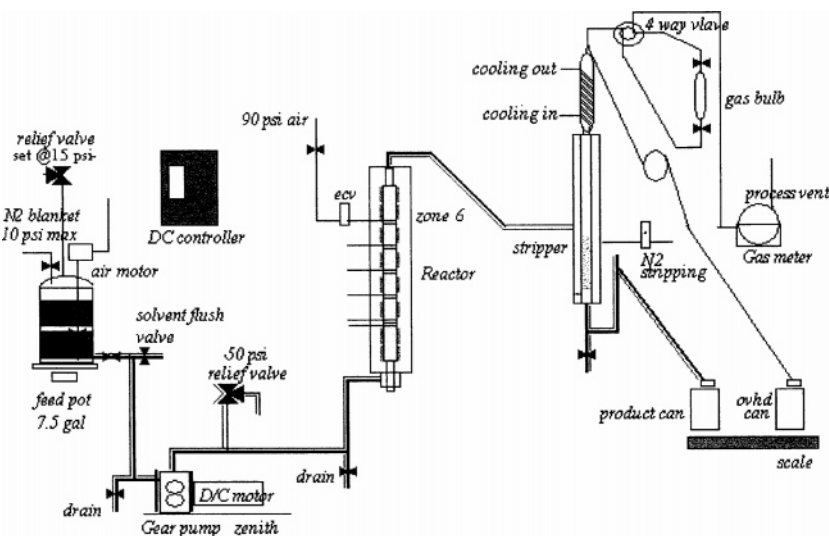


Figure 6. Depiction of the pyrolyzer pilot plant.

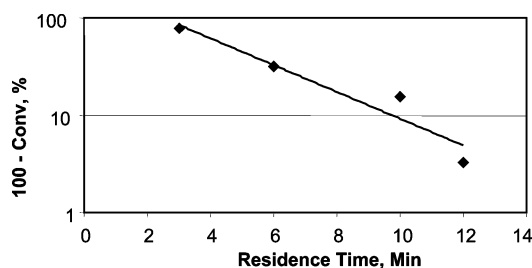


Figure 7. Conversion (to  $<538$  °C boiling fraction) of HDPE pyrolyzed at 650 °C at atmospheric pressure, as a function of residence time.

## Results and Discussion

The kinetics runs were performed in the continuous laboratory pyrolysis unit (Figure 4) with the melter/feed vessel temperature set at  $\sim 325$  °C and the pump temperature set at  $\sim 300$  °C. By varying the speed on the gear pump, residence times were set. Residence times used ranged from 1 min up to 12 min.

In all cases, gas makeup was low (not more than a few percent for the 600–650 °C pyrolysis runs). Simulated distillation results (by thermogravimetric analysis) on the collected products were used to determine the weight percent conversion below a boiling point of 538 °C. These showed the conversion to follow close to first-order kinetics (Figure 7). The apparent activation en-

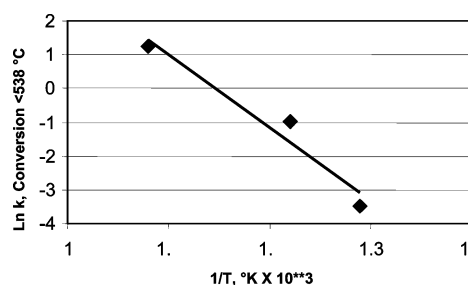


Figure 8. Plot of  $\ln k$  vs  $1/T$ , to determine the activation energy.

ergy for the process was  $42 \pm 20$  kcal/mol (Figure 8). This is within the range of values reported in the literature.<sup>15</sup>

The results of this study indicate that it should be possible to get substantial conversion, primarily to lube, at operating temperatures (500–550 °C) and residence times (30 min to 1 h) similar to that for several conventional refining processes, such as catalytic reforming, but at atmospheric pressure and without co-feeding hydrogen.

**One-Gallon-per-Day Pilot Plant.** Results obtained using the pilot plant shown in Figure 6 are summarized below.

**A. Polyethylene (PE).** Table 1 shows the yields and inspections from the pyrolysis run in the 1 gal/day pilot

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**Table 1. Pyrolysis of 50/50 (w/w) Plastic/Diesel at Atmospheric Pressure and a Residence Time of 1 h**

	Feed		
	HDPE <sup>a</sup>	HDPE	96/4 HDPE/PET
temperature (°C)	552	524	524
yield (wt %)			
C1	0.8	0.5	0.2
C2=	1.8	0.8	0.5
C2	0.9	0.6	0.4
C3=	2.4	1.2	0.6
C3	0.8	0.5	0.4
C4=	2.2	0.8	0.6
C4	0.4	0.5	0.2
C4-	9.3	4.9	2.9
C5–385 °C	69.6	69.4	75.9
385 °C+	21.1	25.7	21.2
385 °C+, based on plastic	42.2	51.4	42.4

<sup>a</sup> High-density polyethylene.

**Table 2. Hydroisomerization of Product from HDPE/Diesel Pyrolyzed at 524 °C**

	Feed	
	HDPE/diesel	HDPE/PET/diesel
385 °C+ yield	41.1	68.9
bottoms		
pour point (°C)	-37	-13
cloud point (°C)	+9	+6
viscosity @ 40 °C (cSt)	25.43	21.63
viscosity @ 100 °C (cSt)	5.416	4.920
viscosity index, VI	156	160
simulated distillation (wt %)		
10	357	371
30	396	400
50	451	432
70	496	467
90	566	515
overall mass of 385 °C+ <sup>a</sup>	21.3	25.3

<sup>a</sup> Based on plastic.

plant with HDPE. At 524 °C, the yield of 385 °C+ product, with an endpoint of about 593 °C, suitable for lubricating base oil, was 51.4 wt % based on plastic in the feed. Under the conditions of the run, there was only 6 wt % 538 °C+ in the product, yet only ~5 wt % of the low-valued C4- light ends. Minimizing both might be possible through further optimization.

The liquid bottoms collected from this run were then isomerized at 316 °C to produce an oil with a viscosity of 5.4 cSt, a pour point of -37 °C, and a VI value of 156 (Table 2). The overall 385 °C+ yield, based on plastic to the pyrolyzer, was 21 wt %. For this pure HDPE feed, no hydrotreatment was required ahead of the isomerization, which would lower cost substantially. Whether a real HDPE waste stream could be processed without hydrotreating would need to be confirmed.

**B. Polyethylene + Poly(ethylene terephthalate) (PE + PET).** Baled HDPE typically sells for approximately \$0.07–\$0.15 per pound, with an impurity limit of 2%. If the plastic used in the pyrolysis process did not require this limit, the cost could be considerably lower. (Unseparated waste plastic can be valued as low as -\$0.02 per pound, which accounts for landfilling costs.) Consequently, the run with HDPE was repeated, except the plastic was 96 wt % HDPE and 4 wt % waste PET from soft-drink bottles. Pyrolysis yields are given in Table 1, showing a 385 °C+ yield, based on plastic, of 42.4 wt %.

In the pyrolysis run, C4- was again quite low (~3 wt %), and the product contained no 538 °C+ in the

**Table 3. Pyrolysis of FT Wax Feeds at 524 °C, Atmospheric Pressure, and a Residence Time of 1 h**

	Feed	
	50/50 LDPE/FT wax	FT wax
yield (wt %)		
C1	0.2	1.0
C2=	0.6	0.6
C2	0.4	2.4
C3=	0.9	0.8
C3	0.7	1.8
C4=	0.9	1.6
C4	0.4	1.3
C4-	4.1	9.5
C5–177 °C	9.9	8.4
177–343 °C	20.0	21.4
343–385 °C	8.5	9.6
385 °C+	57.5	51.1
overhead		
wt% of feed	17.1	17.6
paraffins + naphthenes	22	20
olefins	76	79
aromatics	2	1
simulated distillation (wt %)		
10	215	231
30	307	331
50	378	382
70	455	454
90	550	545
bottoms		
wt% of feed	76.0	71.8
gravity, API	40.7	41.9
sulfur (ppm)	<4	<4
nitrogen (ppm)	7.9	2.2
simulated distillation (wt %)		
10	334	327
30	403	389
50	454	440
70	488	480
90	527	521

bottoms. Assuming that all the C4- came from the plastic would indicate that ~6 wt % of the plastic was converted to gas.

Table 2 gives yields and inspections for hydroisomerization of the pyrolysis bottoms. This gave an oil with a viscosity of 4.9 cSt, a pour point of -13 °C, and a viscosity index of 160. The overall 385 °C+ yield, based on plastic to the pyrolyzer, was 25 wt %. The results were promising in that VI value of the lube product was still exceptional at 4% PET, suggesting that higher PET levels and/or other plastics, such as polypropylene (PP) or even polystyrene (PS), might be co-processed, along with the PE. Because the pyrolysis overhead gas and liquid were highly olefinic (56 wt % olefins in the liquid overhead), oligomerization of these olefins in a separate process (e.g., acid catalysis) could produce additional low pour point lube base oil. Assuming all the olefins in the lights products from the pyrolysis unit were catalytically oligomerized to lube, this would give an additional 32 wt % lube, or ~57 wt % overall, based on plastic.

One reason the PET may have had negligible effect on lube quality is that it cracks more readily than PE, such that the PET-derived effluent will be mostly in the naphtha/diesel product fractions. The same should be true for polystyrene and polypropylene, based on previous pyrolysis kinetics studies.<sup>15</sup> While having a lesser affect on the lube, the impurity plastics would then likely have a greater affect on the properties of those lighter fractions. This was not investigated in this study.

**C. Polyethylene + Fischer–Tropsch (FT) Wax.** Pyrolysis was performed on a feed that was composed

**Table 4. Hydroisomerization of Pyrolyzed Product from FT Wax Feeds**

	Feed		
	pyrolyzed 50/50 LDPE/FT wax		pyrolyzed FT wax <sup>a</sup>
	without hydrotreatment	with hydrotreatment	
yield (wt %)			
C1–C2	0	0.1	0
C3	0.5	0.8	0.5
C4	0.9	1.7	1.0
C4–	1.4	2.6	1.5
C5–177 °C	8.7	13.7	10.2
177–343 °C	32.6	31.7	37.4
343–385 °C	11.5	11.0	12.4
385 °C+	45.8	41.0	38.5
bottoms			
wt% of feed	60.9	61.6	64.7
pour point (°C)	–22	–15	–14
cloud point (°C)	–2	–2	–1
viscosity @ 40 °C (cSt)	18.70	15.23	12.56
viscosity @ 100 °C (cSt)	4.416	3.829	3.380
viscosity index, VI	154	150	150
simulated distillation (wt %)			
10	353	329	319
30	396	377	363
50	437	426	407
70	474	470	449
90	516	517	491
overall 385 °C+	34.8	31.2	27.6
overall 343 °C+	43.7	39.7	36.5
total 343 °C+, including oligomers	59	55	52

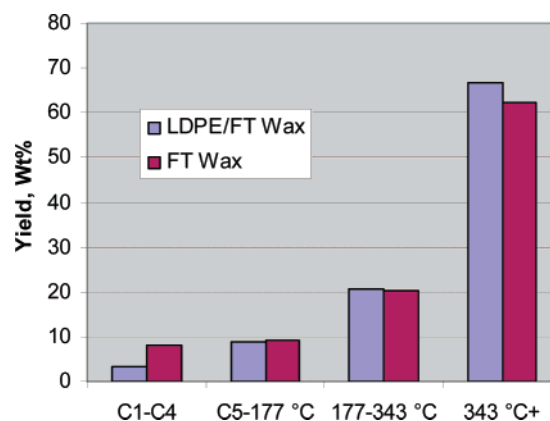
<sup>a</sup> The pyrolyzed FT wax was not subjected to hydrotreatment.

of a 50/50 mixture (w/w) of LDPE and hydrotreated FT wax. Yields are given in Table 3, which shows a 385 °C+ yield of 57.5 wt %. The yield for a broader lube feed, 343 °C+, was 66.0 wt %. Although there was considerable 538 °C+ in the feed to the pyrolyzer, there was little 538 °C+ in the product, which is believed here to be advantageous for obtaining a low cloud point. Olefinicity in the pyrolysis overhead was 76 wt %, by paraffins, olefins, naphthenes, and aromatics (PONA) analysis. The olefinic overhead liquids from the pyrolysis of both FT wax and LDPE/FT wax were analyzed using gas chromatography (GC). This showed the cracked product to be almost entirely 1-normal olefins and normal paraffins.

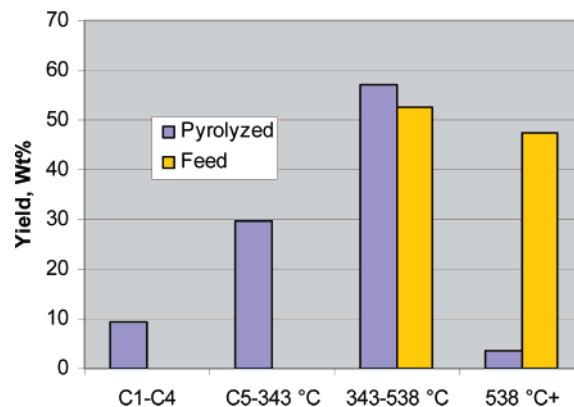
The pyrolysis bottoms were then hydroisomerized to give an oil with a viscosity of 4.4 cSt, a pour point of –22 °C, and a viscosity index of 154 (Table 4). The overall 343 °C+ yield, based on feed to the pyrolyzer, was 44 wt %. Adding the potential lube that would be possible from oligomerizing the lighter olefinic product from the pyrolyzer would increase the 343 °C+ yield to ~59 wt %. However, in this run, a significant amount of 343 °C– was in the feed to the hydroisomerization step (10 wt %, based on feed to the pyrolyzer). Had this been sent to an oligomerization process, the potential 343 °C+ would be 67 wt % (Figure 9), based on the PONA olefin analysis.

A portion of the pyrolysis bottoms was hydrotreated to reduce the nitrogen content from 8 ppm to <1 ppm. This was then hydroisomerized to give an oil with a viscosity of 3.8 cSt, a pour point of –15 °C, and a viscosity index of 150 (see Table 4). The overall 343 °C+ yield was 40 wt %, which is similar to that estimated for unhydrotreated feed at the same pour point.

**D. FT Wax.** FT wax was next tested without plastic. Yields through the pyrolyzer are given in Table 3,



**Figure 9.** Potential yields with isomerization/oligomerization.



**Figure 10.** Pyrolysis of FT wax at 524 °C and a residence time of 1 h.

showing a surprisingly similar product distribution and olefinicity to the run with a 50/50 mixture of LDPE and FT wax, indicating the minor effect of FT wax content on these key product properties from the pyrolyzer, and

suggesting that the molecular-weight distribution of the polymer feeds are not a major determinant on the distribution of the product. Again, there was little 538 °C+ in the product, which was mostly in the neutral oil boiling range, as shown in Figure 10. Hydroisomerization of the pyrolysis bottoms gave an oil with a viscosity of 3.4 cSt, a pour point of -14 °C, and a viscosity index of 150 (see Table 4). The overall 343 °C+ yield was 37 wt %. Adding the potential lube from oligomerizing the lighter olefinic product from the pyrolyzer would increase the 343 °C+ yield to ~52 wt %. Had all the 343 °C- from the pyrolyzer been sent to oligomerization, the potential 343 °C+ would be ~62 wt % (see Figure 9). Note that the product distribution in Figure 9 is approximately the same for either FT wax alone or FT wax plus plastic. This suggests, along with the similar properties found in the isomerized products, that a pyrolysis process could be developed with a wide flexibility in choice of feedstock mix.

### Conclusions

This report summarizes work that has been conducted on the investigation and development of a new process for the conversion of waste plastic and Fischer-Tropsch (FT) wax to lube range molecules, which can be hydroisomerized to low-pour-point base oils of unconventional base oil (UCBO) quality. The process uses pyrolysis, which is a thermal, noncatalytic, low-pressure reaction where high-molecular-weight molecules are cracked to form lower-molecular-weight molecules. The major byproduct is diesel, with slight production of C4- gas. The byproduct liquids are highly olefinic and could be separately oligomerized to provide additional base oil. The value of using waste plastic is in its availability, low cost, and the potential benefits in providing a means of addressing the growing environmental and political problems that are associated with landfilling.

A pilot-plant study was conducted in a 1 gal/day unit. The main findings included the following:

(1) Potential lube yields were in the 60–70 wt % range, assuming that all the olefins (almost all 1-olefins) could be upgraded to lube. Approximately half of this

yield would come from hydroisomerization and half from oligomerization.

(2) The product distribution and lube quality surprisingly showed little variation, whether the feed was polyethylene, FT wax, or a combination of the two.

(3) The pyrolysis process could be performed at atmospheric pressure, and at a temperature and residence time that is not atypical of refinery operations (i.e., 524 °C for 1 h), with total conversion of plastic to lube range and lighter product, almost all of which was 538 °C-.

(4) Hydrotreatment of the feed prior to the hydroisomerization step did not significantly affect lube yield or quality. Eliminating this step could benefit the overall process economics.

(5) When 4 wt % poly(ethylene terephthalate) (PET), from used soda bottles, was added to the polyethylene, no decline in lube quality was observed, with hydroisomerization giving oil with a viscosity of 5 cSt and a viscosity index of 160. This indicates a high degree of separation of the waste plastic may not be necessary, which would reduce the feedstock cost to the process.

In summary, we have shown that, by pyrolyzing waste polymers such as polyethylene (PE), waxy products similar to those from FT synthesis can be made, which can then be converted to high quality lubricant oils via wax hydroisomerization. This could have at least three important consequences:

(1) It offers a technology for reducing a growing waste stream problem, by converting the waste to an environmentally beneficial and valuable product.

(2) Waste PE and FT wax could be *co-processed* in the same plant, increasing product volume of lube and diesel, such that the economics of such a process appear more attractive than processing either stream separately.

(3) Because the major byproduct of the pyrolysis is olefins, olefins that boil at temperatures below the lube oil range might then be oligomerized up to lube, increasing overall lube yield.

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