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Gold et al.

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(54) **HYDROCARBON COMPOSITIONS DERIVED FROM PYROLYSIS OF POST-CONSUMER AND/OR POST-INDUSTRIAL PLASTICS AND METHODS OF MAKING AND USE THEREOF**

(71) Applicant: **Nexus Circular LLC**, Atlanta, GA (US)

(72) Inventors: **Jeffrey W. Gold**, Atlanta, GA (US); **Connor Cudney**, Atlanta, GA (US)

(73) Assignee: **Nexus Circular LLC**, Atlanta, GA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

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(51) **Int. Cl.**
C10L 1/04 (2006.01)
C10G 9/00 (2006.01)

(52) **U.S. Cl.**
CPC ***C10L 1/04*** (2013.01); ***C10G 9/00*** (2013.01); *C10G 2300/1003* (2013.01); *C10G 2300/202* (2013.01); *C10G 2300/205* (2013.01); *C10G 2300/301* (2013.01); *C10G 2300/304* (2013.01); *C10G 2400/02* (2013.01); *C10G 2400/04* (2013.01); *C10G 2400/08* (2013.01); *C10G 2400/10* (2013.01); *C10G 2400/14* (2013.01); *C10G 2400/20* (2013.01); *C10G 2400/22* (2013.01)

(58) **Field of Classification Search**
CPC C10L 1/04; C10L 9/00; C10L 2300/1003; C10L 2300/202; C10L 2300/205; C10L 2300/301; C10L 2300/304; C10L 2400/02; C10L 2400/04; C10L 2400/08; C10L 2400/10; C10L 2400/14; C10L 2400/20; C10L 2400/22
See application file for complete search history.

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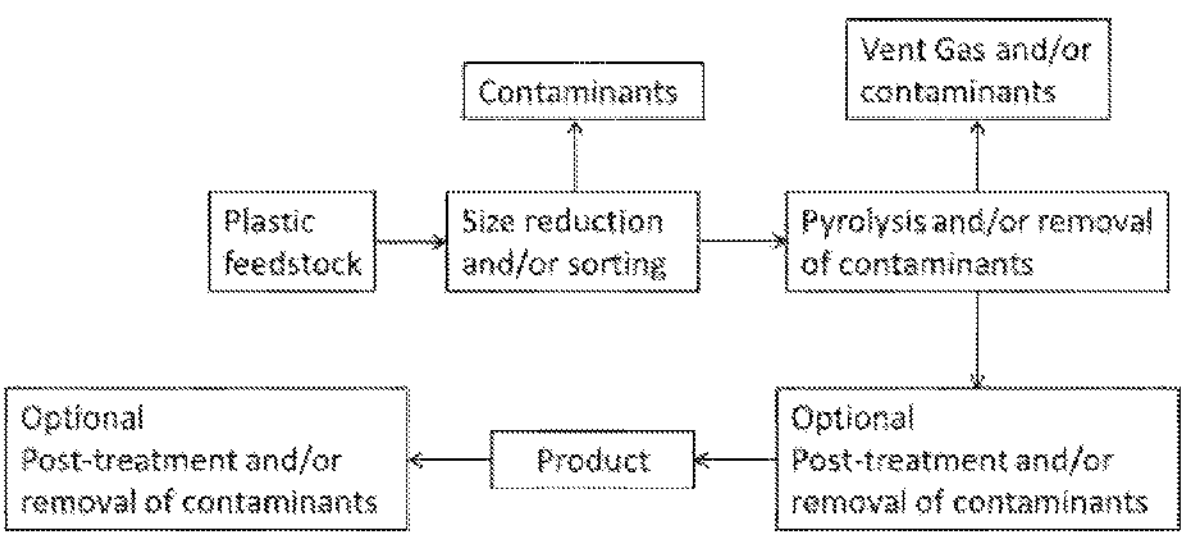
Primary Examiner — James C Goloboy
(74) *Attorney, Agent, or Firm* — Meunier Carlin & Curfman LLC

(57) **ABSTRACT**

Disclosed herein are hydrocarbon based compositions derived from pyrolysis of a feedstock comprising post-consumer and/or post-industrial plastics and methods of making and use thereof.

24 Claims, 18 Drawing Sheets



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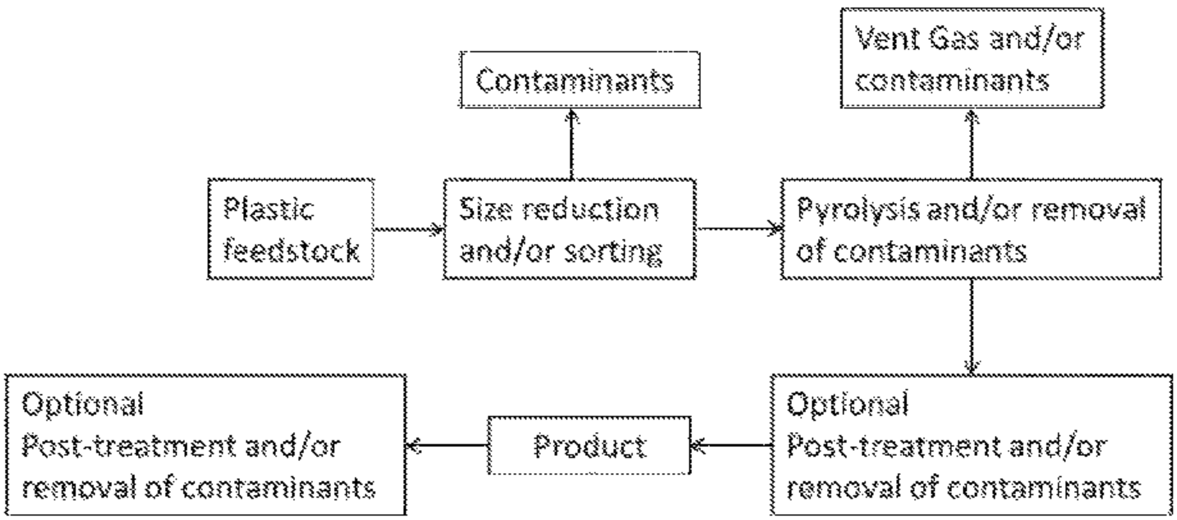


Figure 1

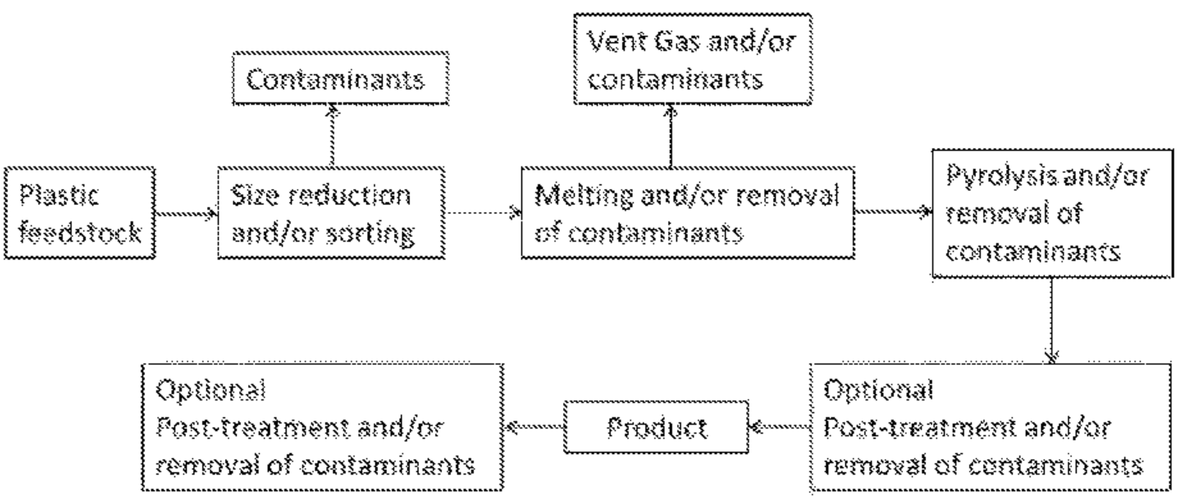


Figure 2

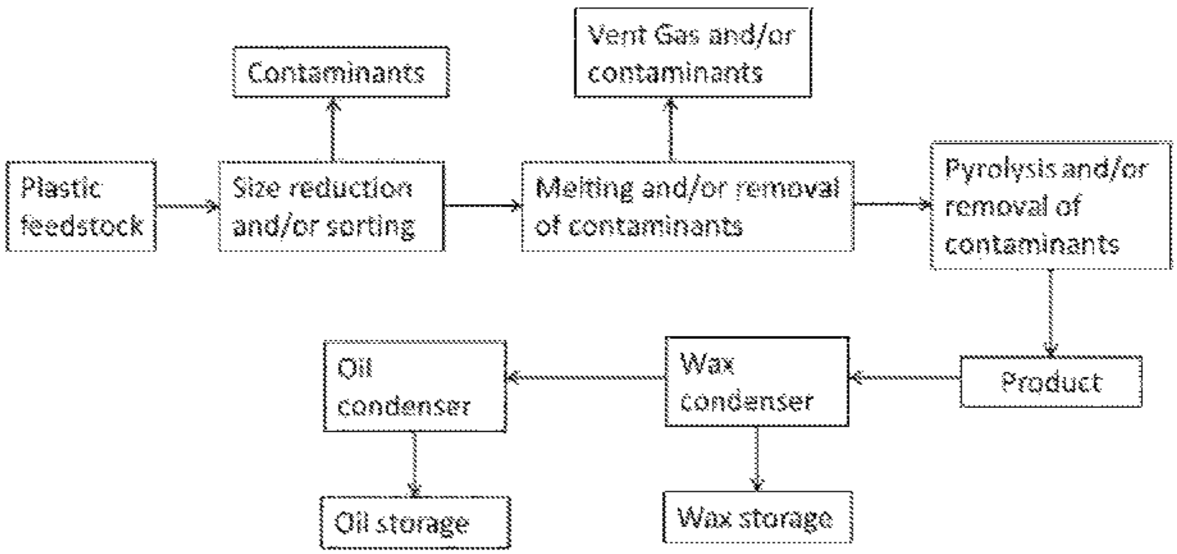


Figure 3

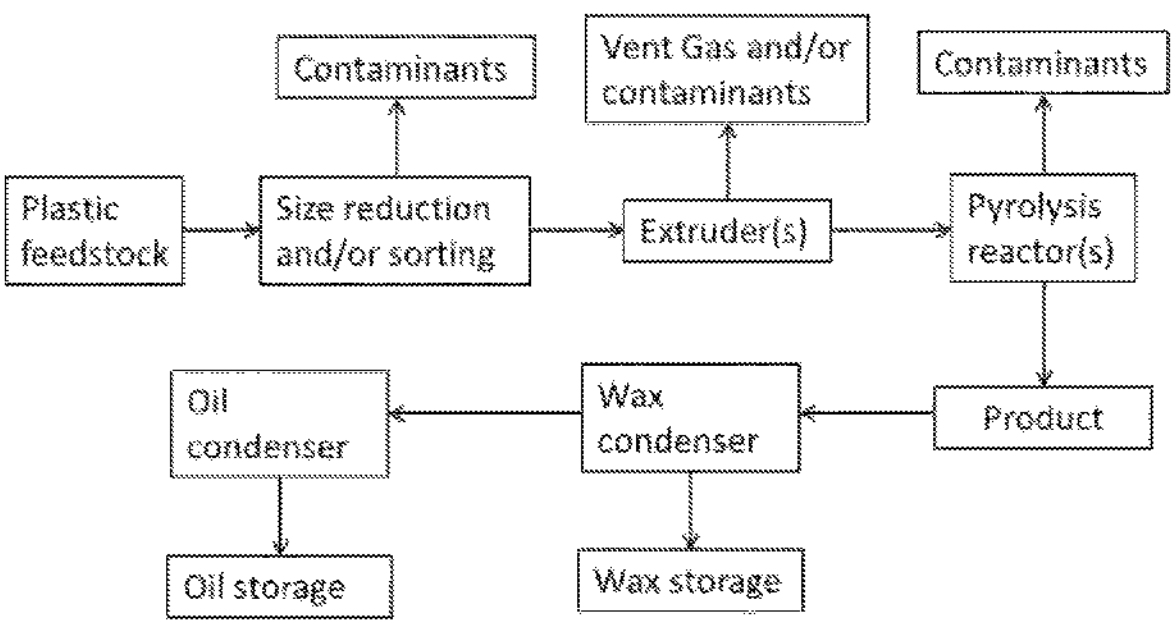


Figure 4

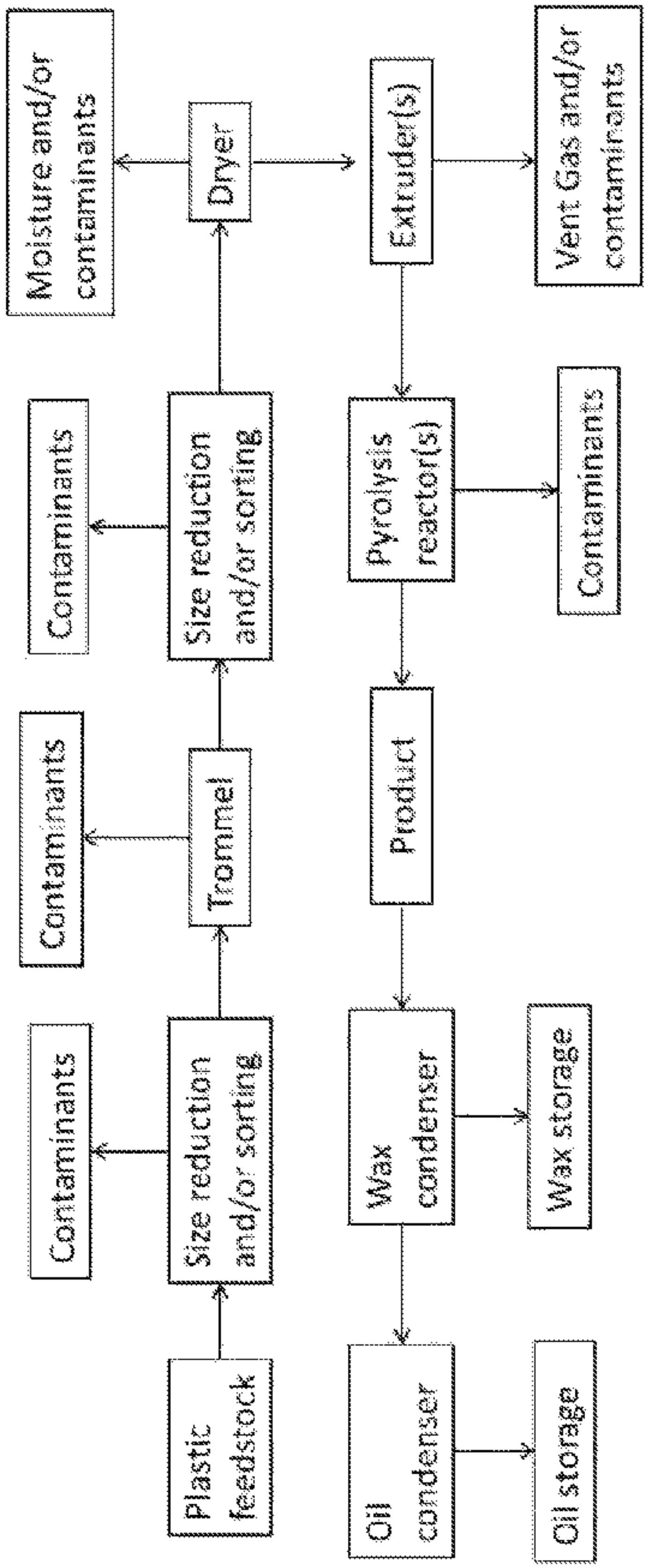

Plastic feedstock
Size reduction and/or sorting
Contaminants
Trommel
Contaminants
Size reduction and/or sorting
Contaminants
Dryer
Moisture and/or contaminants
Extruder(s)
Vent Gas and/or contaminants
Pyrolysis reactor(s)
Contaminants
Product
Wax condenser
Wax storage
Oil condenser
Oil storage

Figure 5

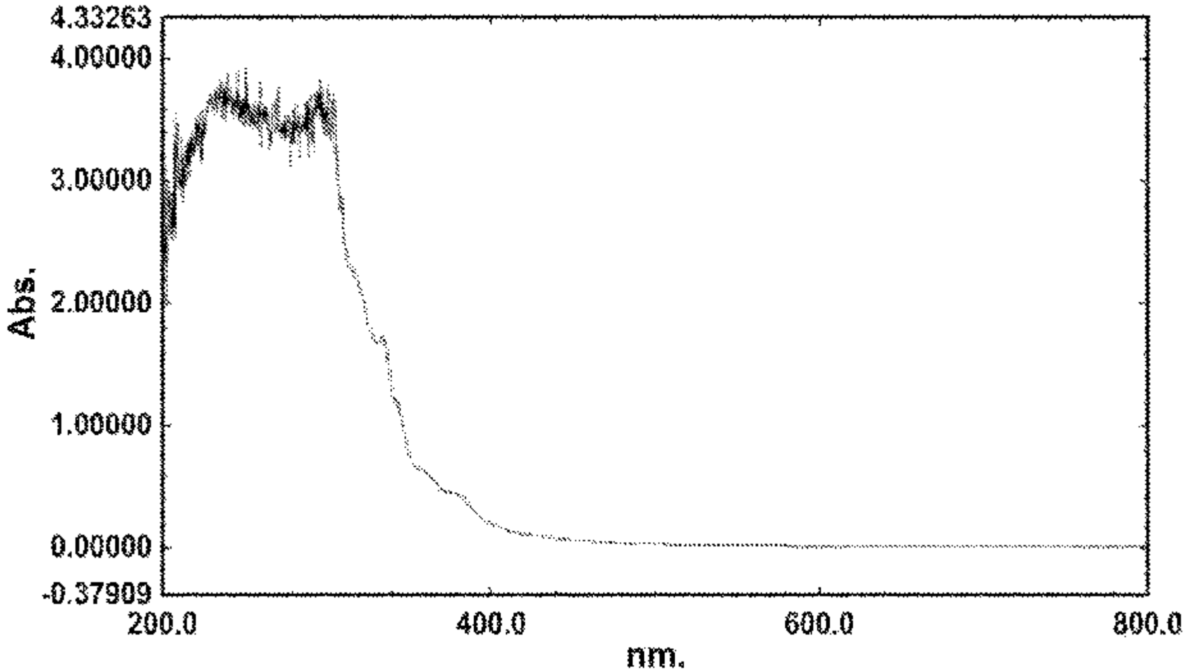


Figure 6

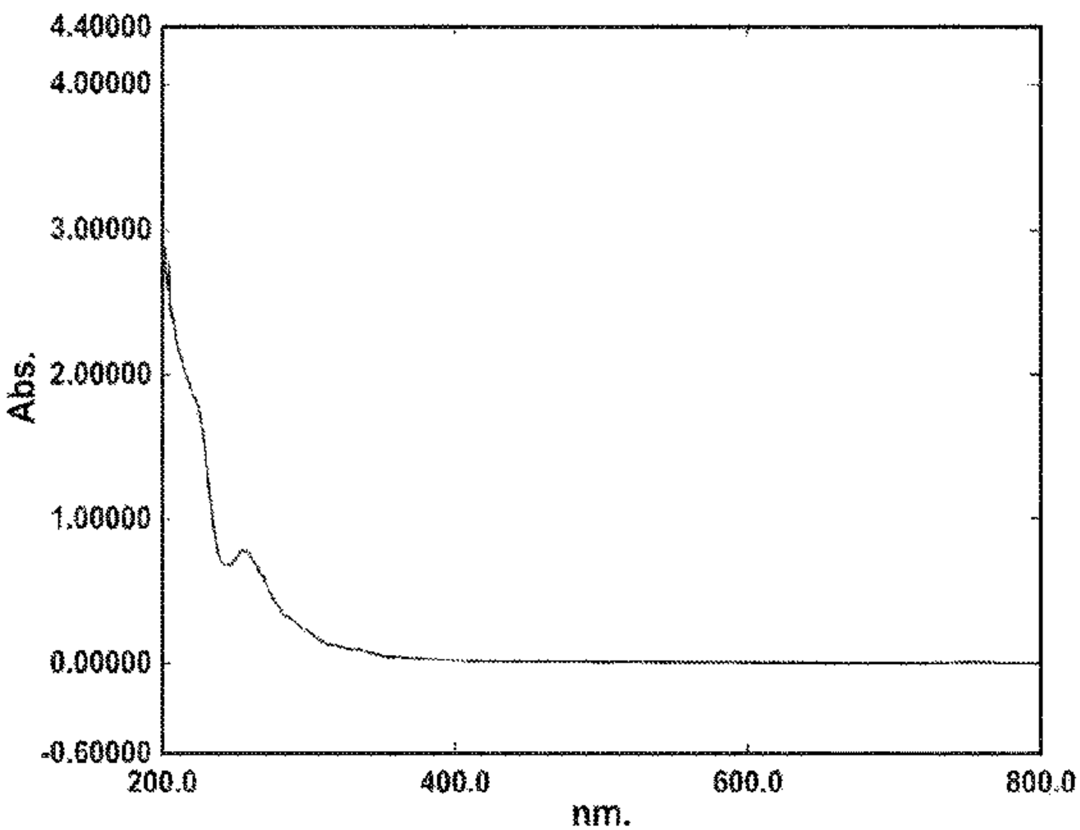


Figure 7

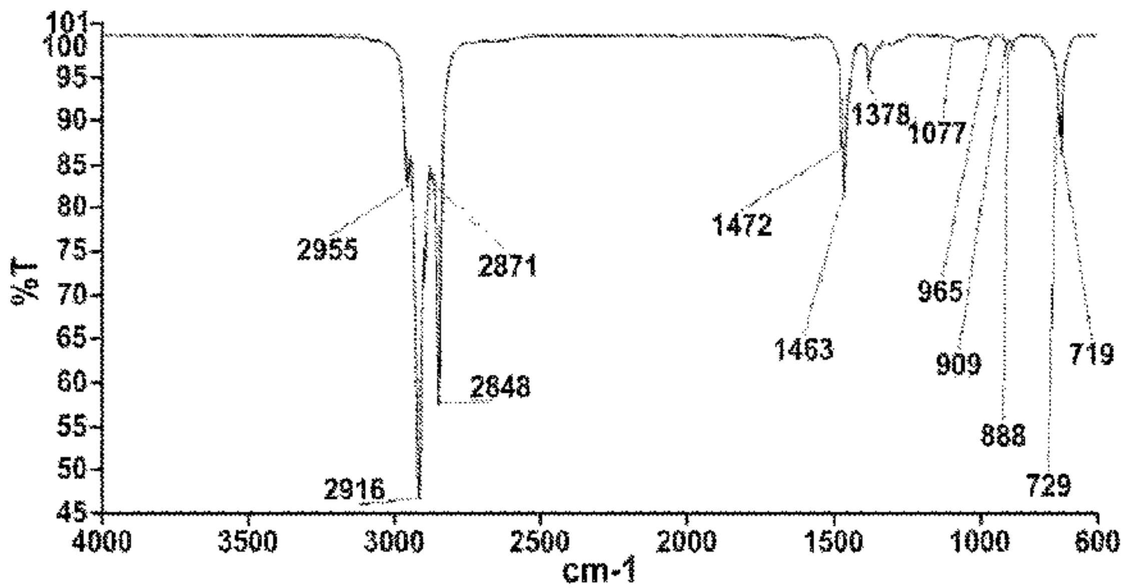


Figure 8

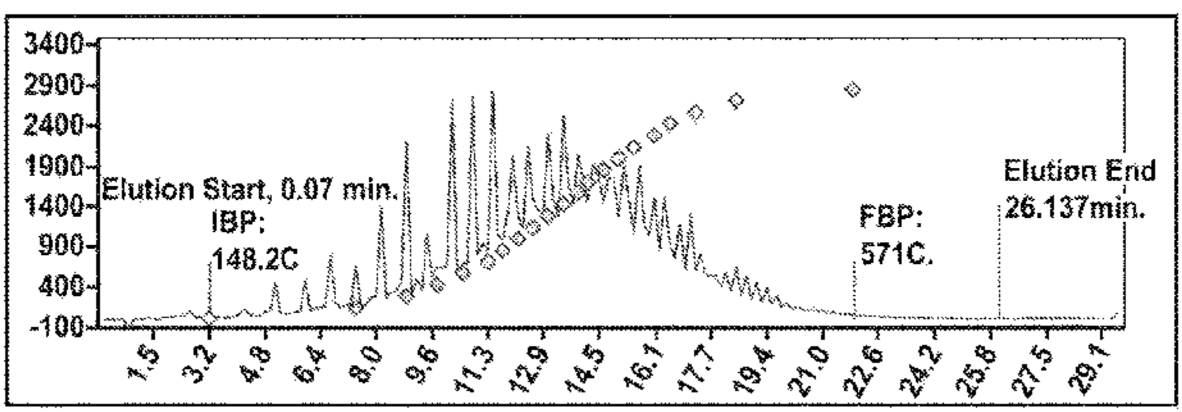


Figure 9

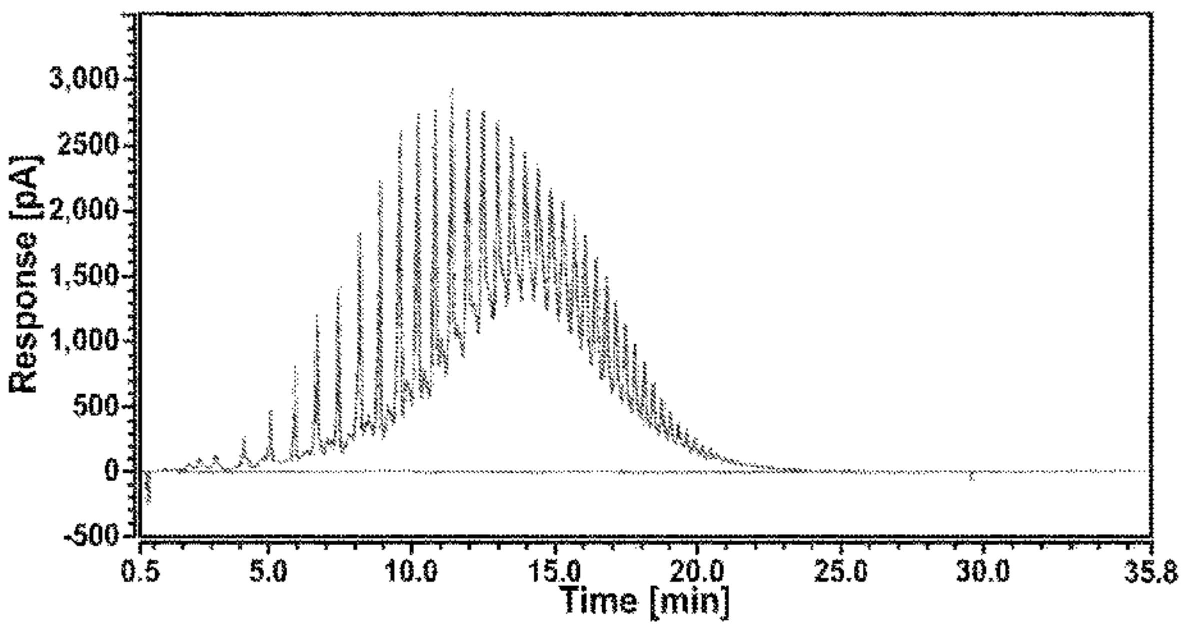


Figure 10

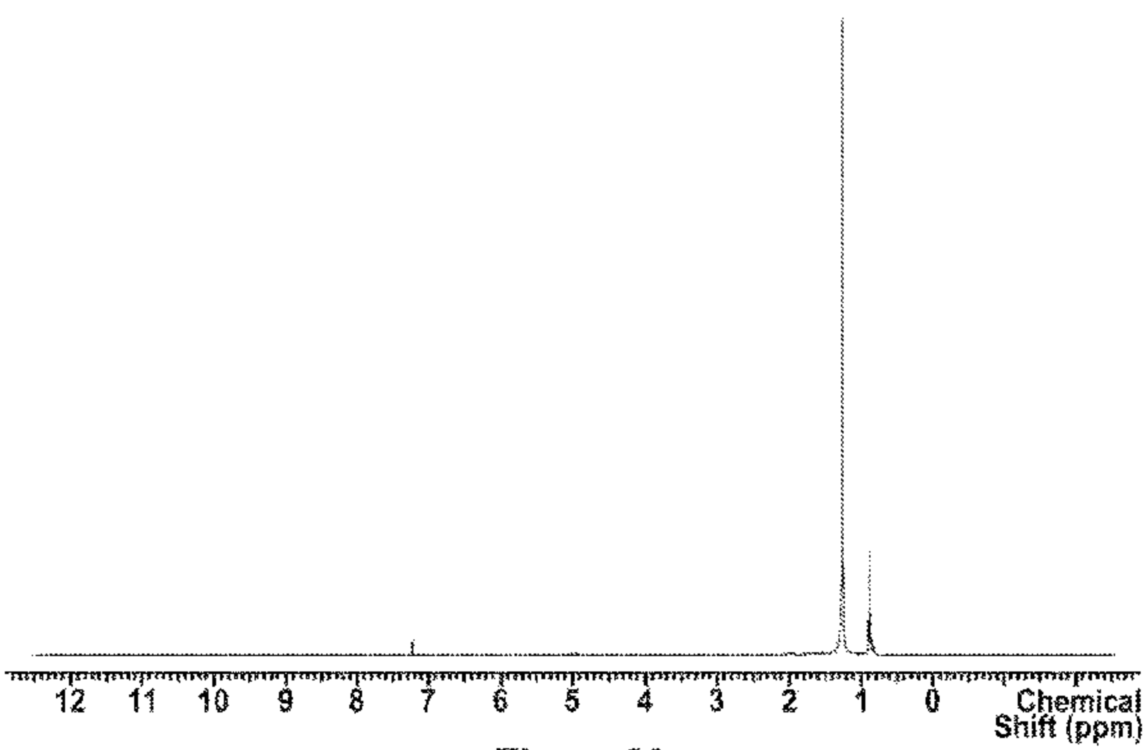


Figure 11

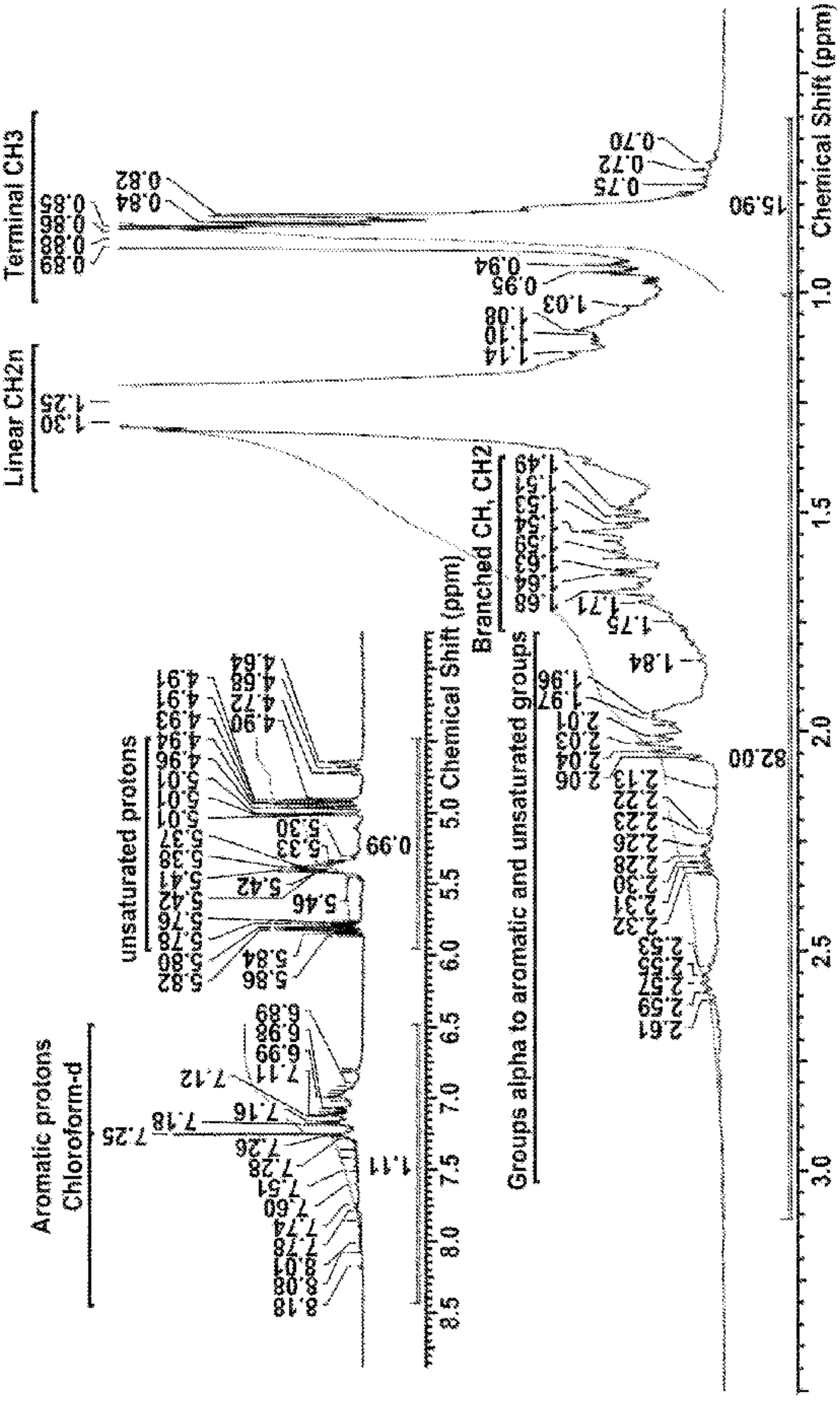

Terminal CH3
Linear CH2n
Branched CH, CH2
Groups alpha to aromatic and unsaturated groups
unsaturated protons
Aromatic protons
Chloroform-d
15.90
82.00
0.99
1.11
Chemical Shift (ppm)
Chemical Shift (ppm)

Figure 12

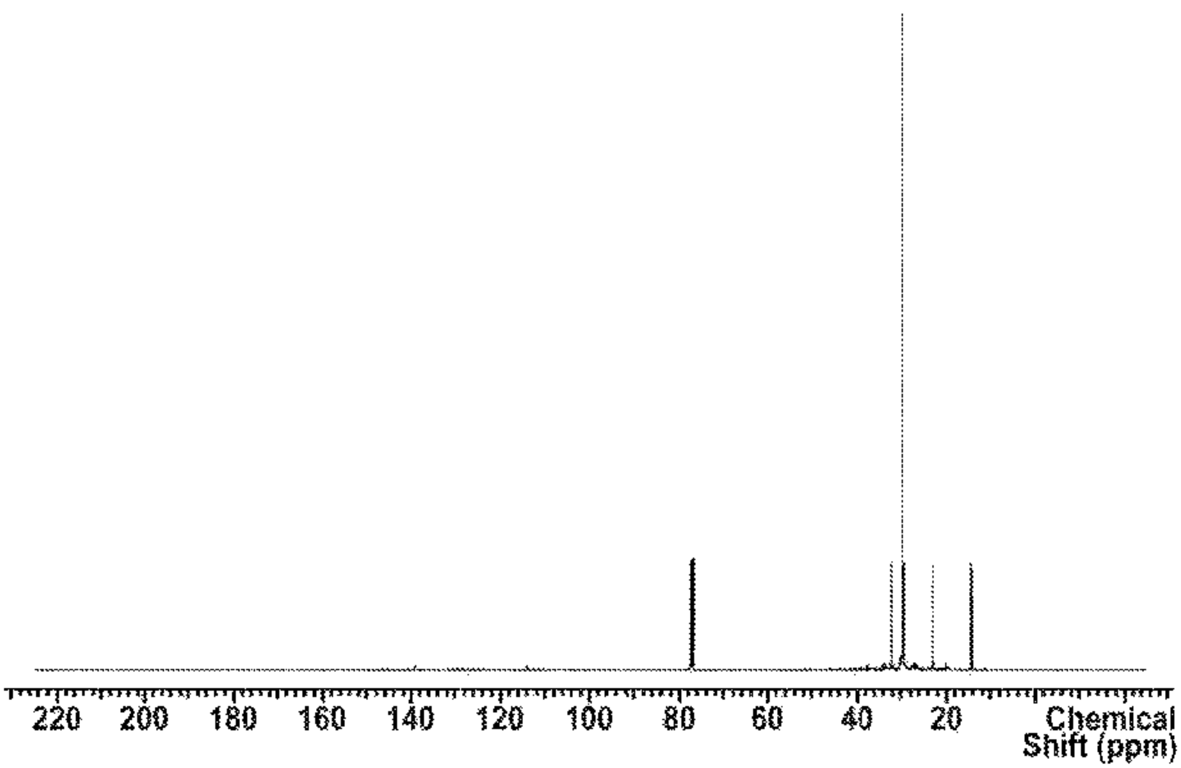


Figure 13

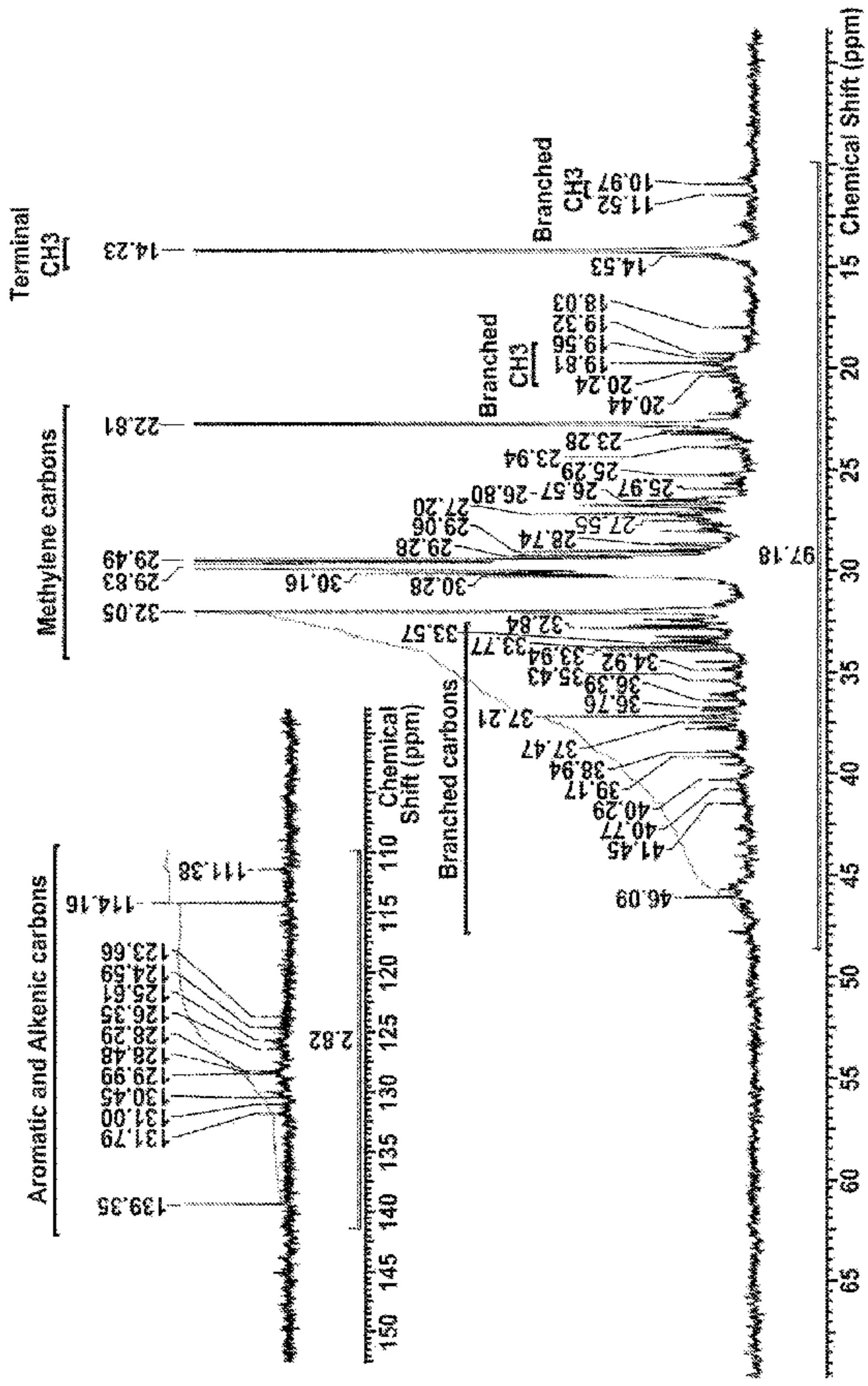

Terminal CH3
14.23
Methylene carbons
22.81
29.49
29.83
32.05
Aromatic and Alkenic carbons
111.38
114.16
123.66
124.59
125.61
126.35
128.29
128.48
129.99
130.45
131.00
131.79
139.35
2.82
150 145 140 135 130 125 120 115 110 Chemical Shift (ppm)
Branched carbons
Branched CH3
10.97
11.52
14.53
18.03
19.32
19.56
19.81
20.24
20.44
23.28
23.94
25.29
25.97
26.57
26.80
27.20
27.55
29.06
29.28
28.74
30.16
30.28
32.84
33.57
33.77
33.94
34.92
35.43
36.39
36.76
37.21
37.47
38.94
39.17
40.29
40.77
41.45
46.09
97.18
65 60 55 50 45 40 35 30 25 20 15 Chemical Shift (ppm)

Figure 14

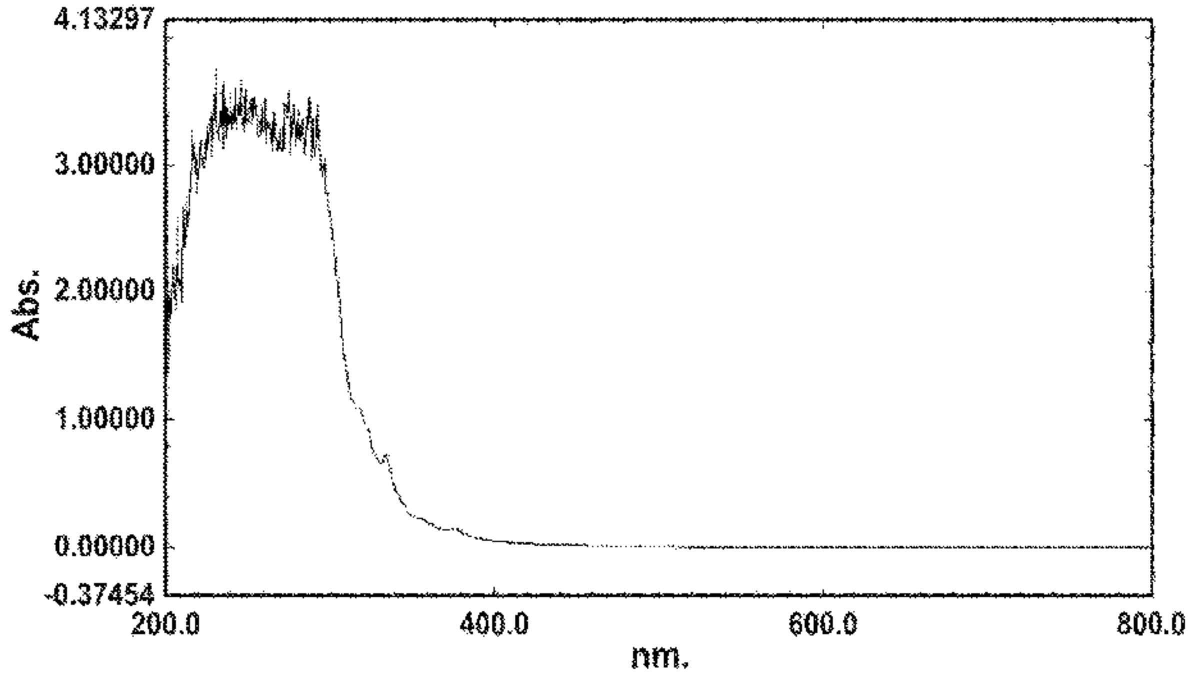


Figure 15

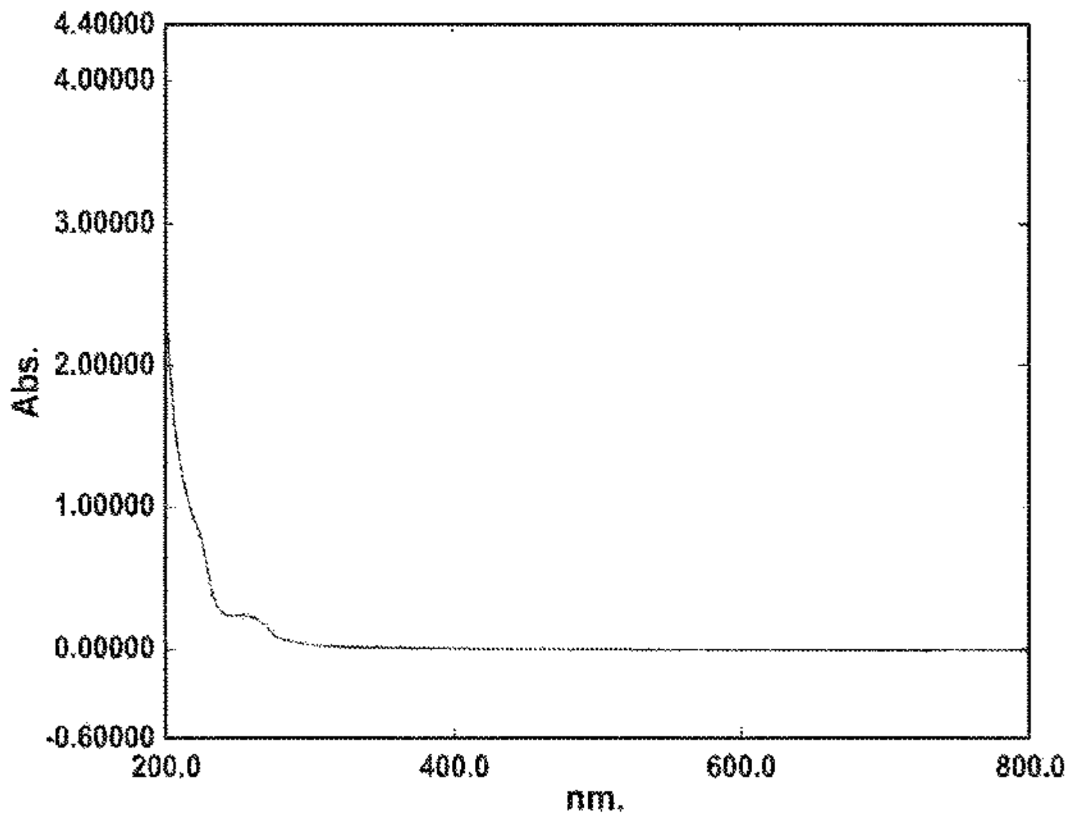
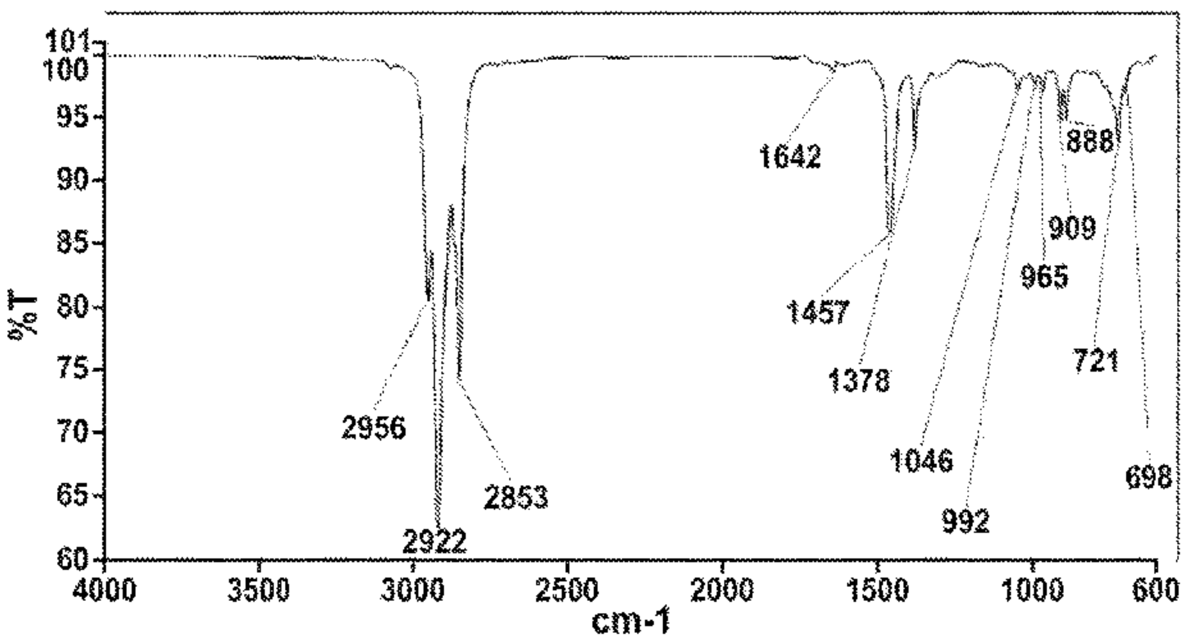


Figure 16



101
100
95
90
85
80
75
70
65
60
%T
4000
3500
3000
2500
2000
1500
1000
600
cm-1
2956
2922
2853
1642
1457
1378
1046
992
965
909
888
721
698

Figure 17

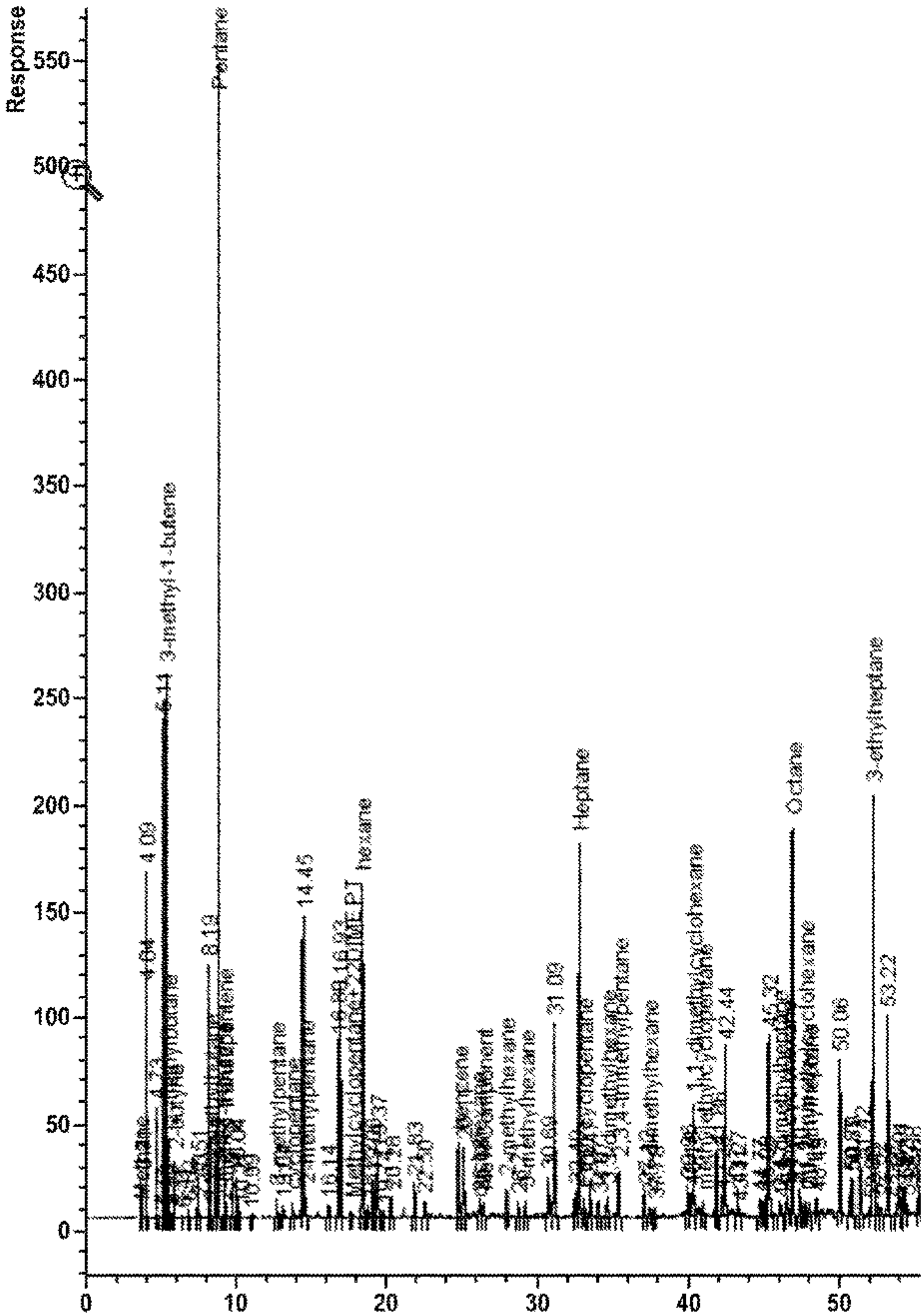

Response
550
500
450
400
350
300
250
200
150
100
50
0
Pentane
3-methyl-1-butene
4.09
14.45
hexane
Heptane
31.09
Octane
3-ethylheptane
53.22
50.06
42.44
1,1-dimethylcyclohexane
2,3,4-trimethylpentane
2-methylhexane
3-methylhexane
0
10
20
30
40
50

Figure 18

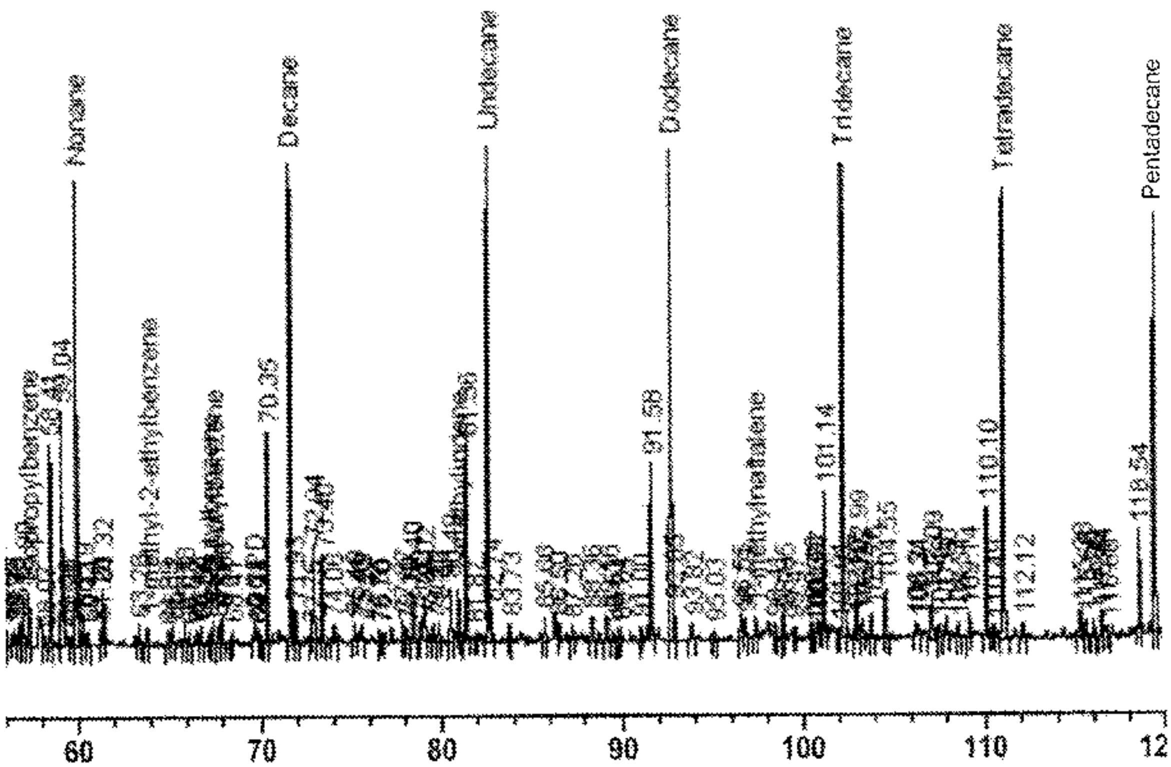


Figure 18 Cont.

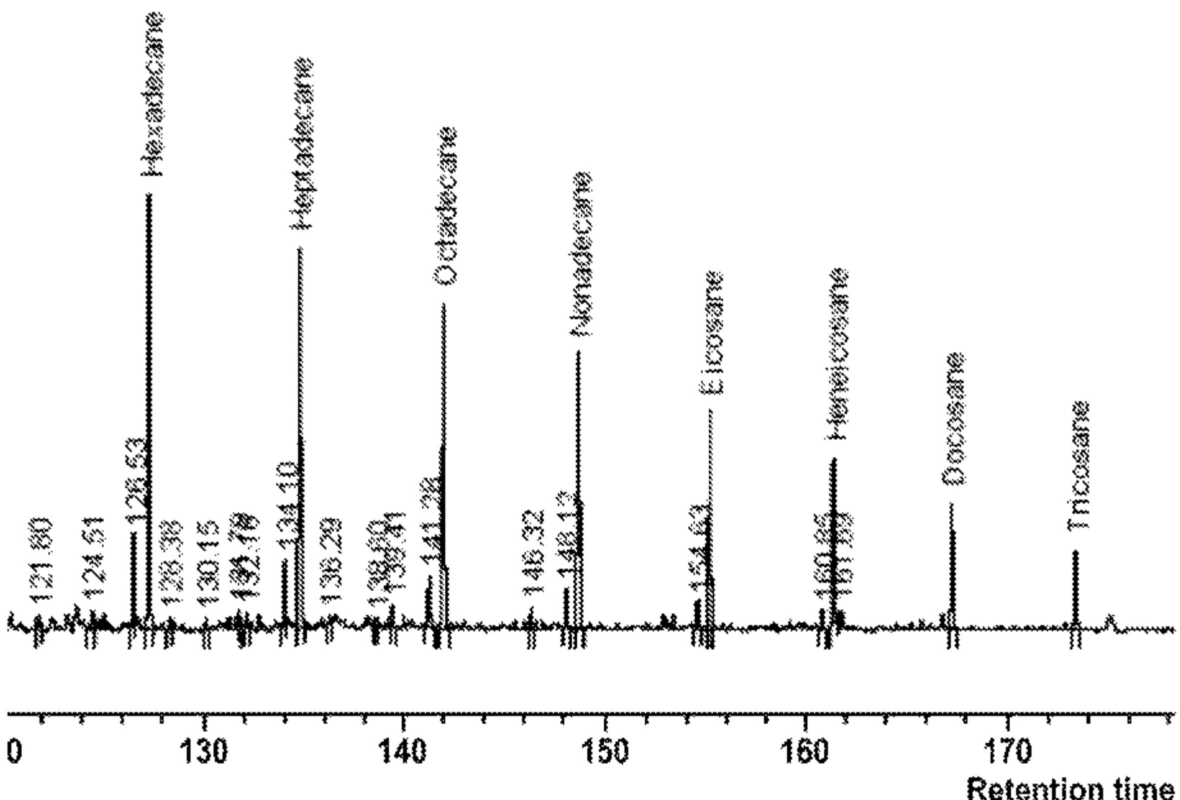


Figure 18 Cont.

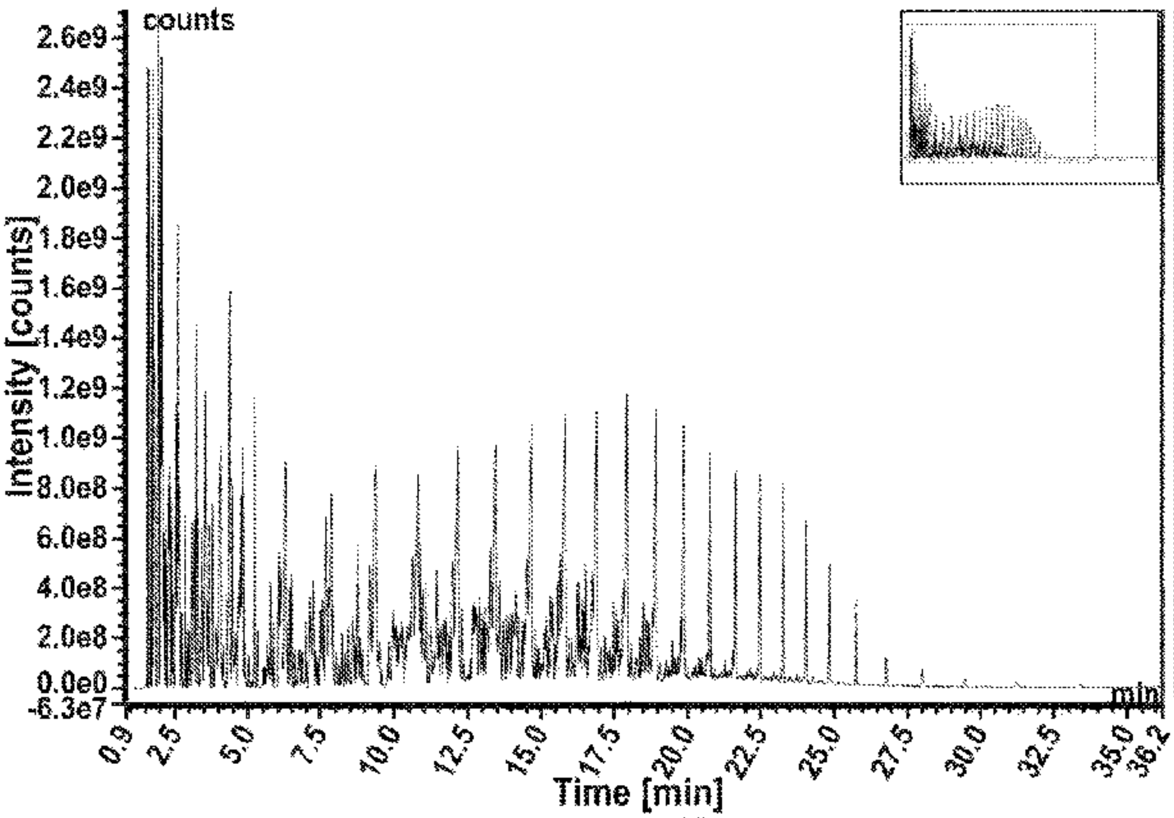


Figure 19

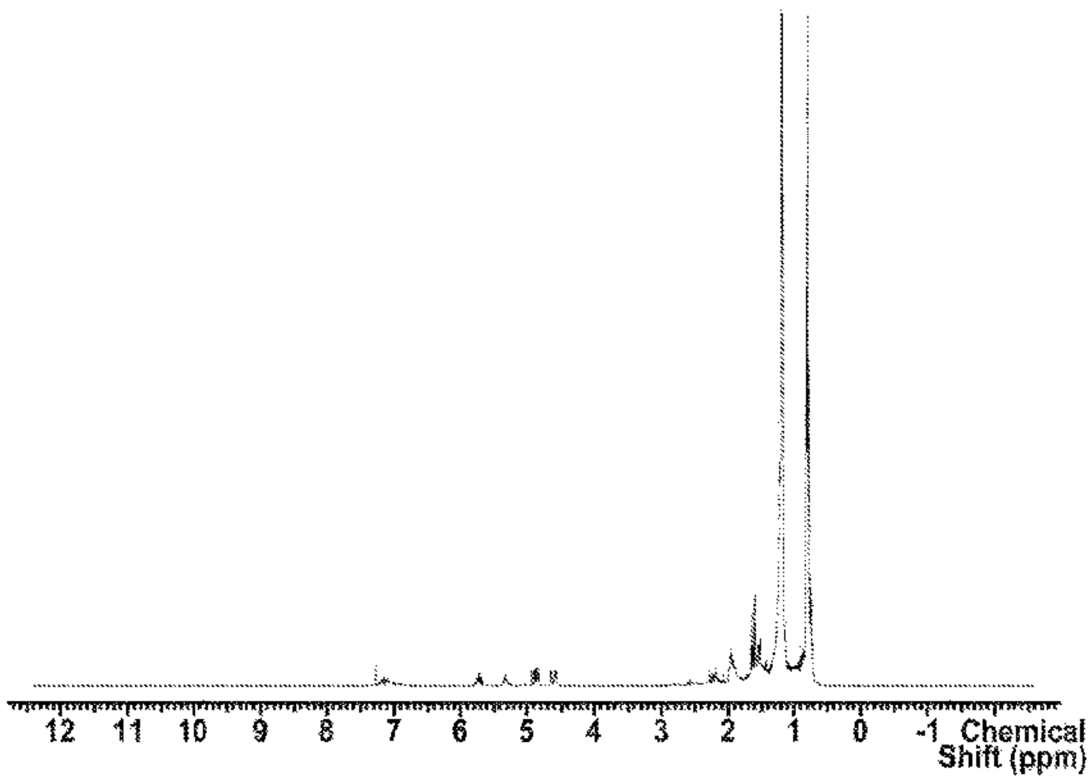
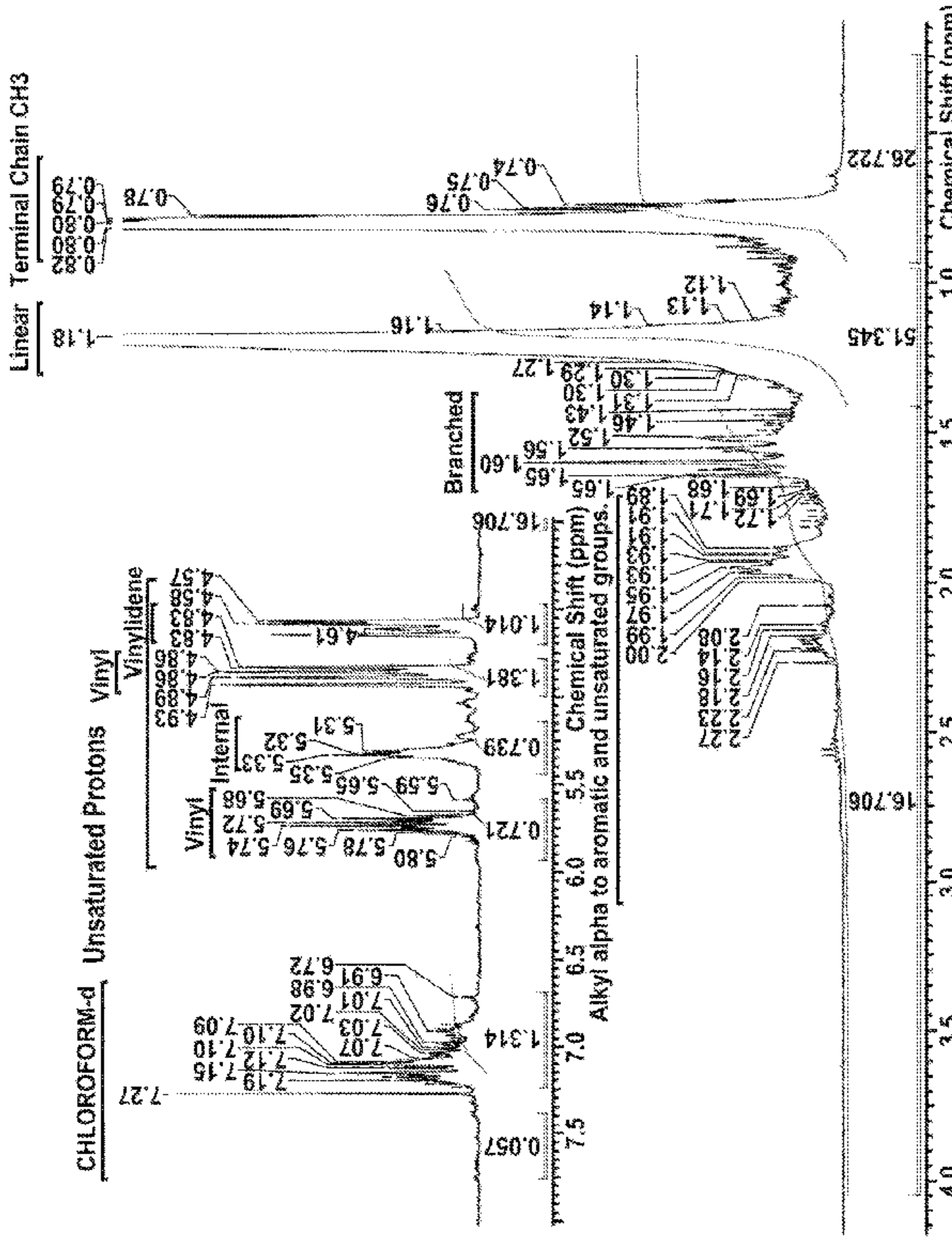


Figure 20



Terminal Chain CH3
Linear
Branched
Unsaturated Protons
Vinyl
Vinylidene
Internal
CHLOROFORM-d
Alkyl alpha to aromatic and unsaturated groups.
Chemical Shift (ppm)

Figure 21

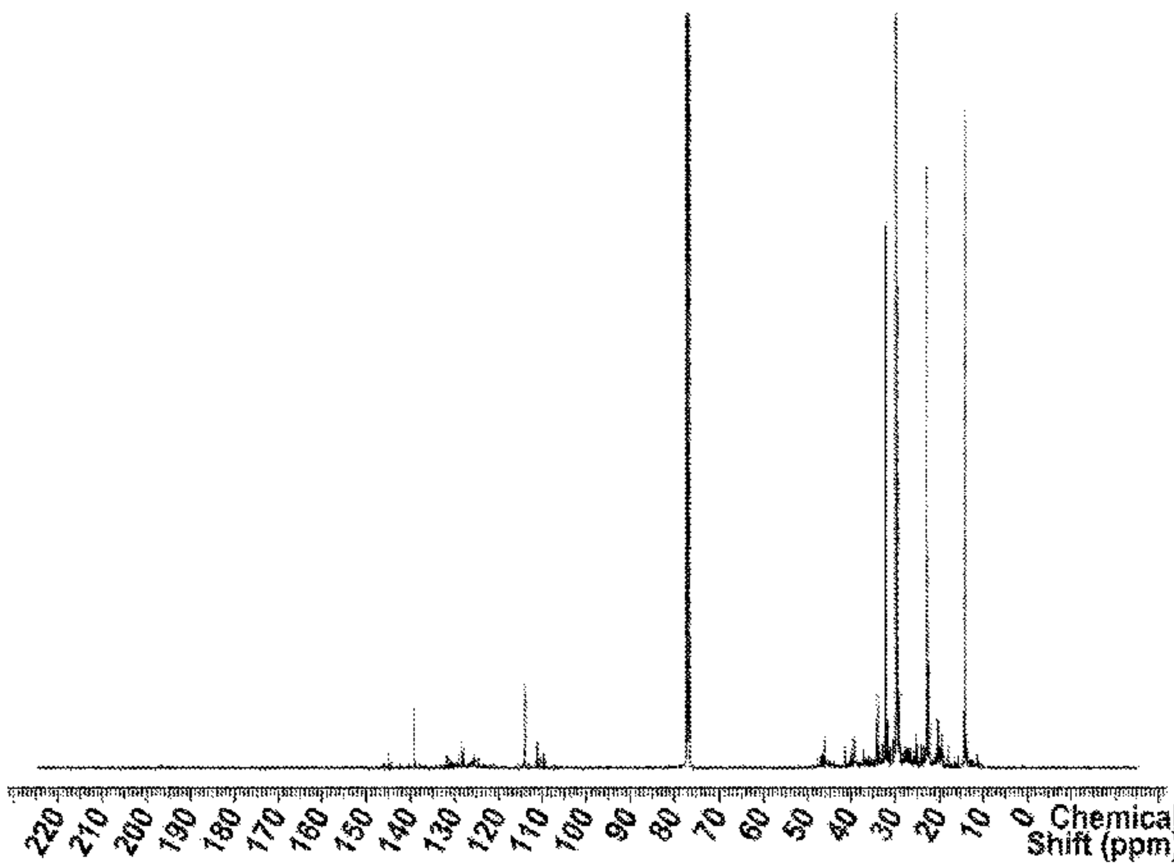

220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
Chemical Shift (ppm)

Figure 22

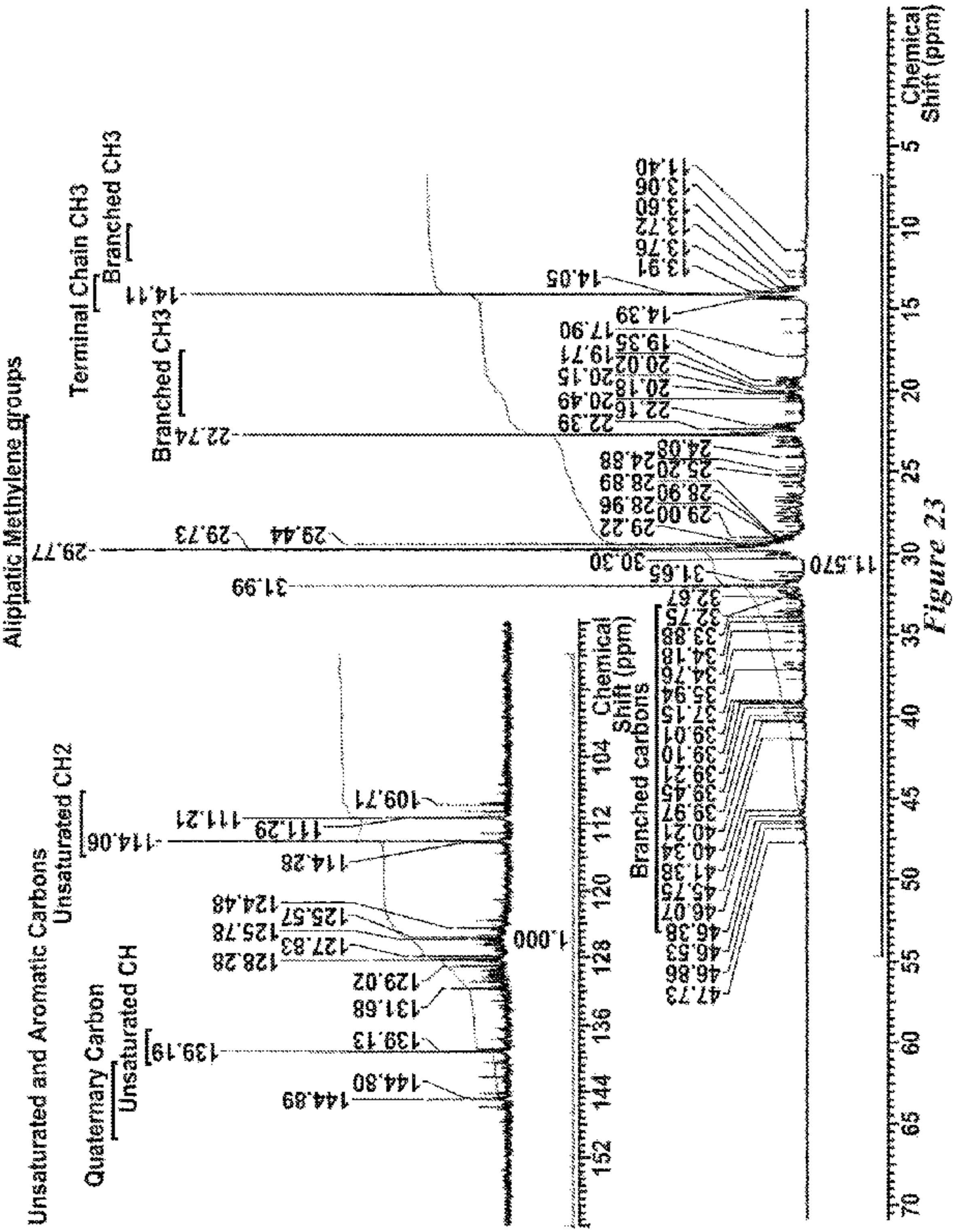

Unsaturated and Aromatic Carbons
Unsaturated CH2
Quaternary Carbon
Unsaturated CH
Aliphatic Methylene groups
Terminal Chain CH3
Branched CH3
Branched CH3
Branched carbons
Chemical Shift (ppm)
Chemical Shift (ppm)

Figure 23

HYDROCARBON COMPOSITIONS DERIVED FROM PYROLYSIS OF POST-CONSUMER AND/OR POST-INDUSTRIAL PLASTICS AND METHODS OF MAKING AND USE THEREOF

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of priority to U.S. Provisional Application No. 63/456,197 filed Mar. 31, 2023, which is hereby incorporated herein by reference in its entirety.

BACKGROUND

Single use plastic waste is a pressing environmental issue. There are currently few options for recycling a mixed polyolefin stream comprised of a broad range of compositions and physical forms of polyethylene, polypropylene, and polystyrene waste plastics to value-added chemical and refinery feedstock products. Improved processes are needed for recycling such plastics at an industrially significant scale and for producing improved products therefrom. The compositions and methods discussed herein address these and other needs.

SUMMARY

In accordance with the purposes of the disclosed compositions and methods as embodied and broadly described herein, the disclosed subject matter relates to hydrocarbon based compositions derived from pyrolysis of a feedstock comprising post-consumer and/or post-industrial plastics and methods of making and use thereof.

For example, disclosed herein is a wax derived from pyrolysis of a feedstock comprising post-consumer and/or post-industrial plastics. In some examples, the wax has a number average molecular weight and/or a weight average molecular weight of from 300 to 400 Daltons. In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, wherein from 60% to 80% of the mixture (w/w) comprises C_{20}-C_{45} hydrocarbons. In some examples, the wax has: a Reid Vapor Pressure of 12.5 psig or less; a final boiling point of 950° F. to 1300° F.; a pour point of 30° F. to 60° F.; a total chloride content of 50 ppm or less; a nitrogen content of 300 ppm or less; a silicon content of 125 ppm or less; a sodium content of 150 ppm or less; an iron content of 10 ppm or less; a phosphorus content of 50 ppm or less; a sulfur content of 500 ppm or less; a calcium content of 50 ppm or less; or a combination thereof.

In some examples of the wax, from 70% to 75% of the mixture (w/w) comprises C_{20}-C_{45} hydrocarbons. In some examples of the wax, from 80 to 90% of the mixture (w/w) comprises C_9-C_{33} hydrocarbons. In some examples of the wax, from 95 to 99% of the mixture (w/w) comprises C_9-C_{46} hydrocarbons. In some examples of the wax, the mixture comprises: 20-30% (e.g., 25-30%) C_9-C_{20} hydrocarbons, 20-30% (e.g., 20-25%) C_{20}-C_{24} hydrocarbons, 20-30% (e.g., 20-25%) C_{24}-C_{28} hydrocarbons, and 10-20% (e.g., 10-15%) C_{28}-C_{32} hydrocarbons.

In some examples of the wax, the mixture is substantially free of C_1-C_8 hydrocarbons.

In some examples of the wax, the mixture comprises: 80-10 wt. % unsaturated hydrocarbons (e.g., 85-90 wt. % or 95 to 99 wt. %); 0-5 wt. % unsaturated (non-aromatic) hydrocarbons (e.g., 0-2.5 wt. %, or 0-1.5 wt. %); and 0-15 wt. % aromatics (e.g., 0-2.5 wt. %, or 12-14 wt. %).

In some examples, the wax has a melting point of from 40° C. to 55° C. (e.g., from 40° C. to 50° C., or from 43° C. to 48° C.), for example as determined by ASTM D 127. In some examples, the wax has a congealing point of 40° C. to 55° C. (e.g., from 45° C. to 51° C.), for example as determined using ASTM D 938. In some examples, the wax has a final boiling point of 950° F. to 1300° F. (e.g., from 950° F. to 1250° F., from 1100° F. to 1250° F., or from 995° F. to 1235° F.), for example as determined using ASTM D 7169. In some examples, the wax has a pour point of from 30° F. to 60° F. (e.g., from 30° F. to 55° F., from 33° F. to 52° F., or from 45° F. to 60° F., for example as determined using ASTM D 97.

In some examples, the wax has a total chloride content of 50 ppm or less (e.g., 25 ppm or less, 10 ppm or less, 5 ppm or less, 1 ppm or less, 0.1 ppm or less, or 0.01 ppm or less), for example as determined according to ASTM D 7359. In some examples, the wax has a nitrogen content of 300 ppm or less (e.g., 250 ppm or less, 200 ppm or less, 150 ppm or less, 100 ppm or less, 50 ppm or less, 10 ppm or less, or 1 ppm or less), for example as determined according to ASTM D 4629. In some examples, the wax has a silicon content of 125 ppm or less (e.g., 100 ppm or less, 50 ppm or less, 25 ppm or less, 10 ppm or less, 5 ppm or less, or 1 ppm or less), for example as determined according to ASTM D 5185. In some examples, the wax has a sodium content of 150 ppm or less (e.g., 100 ppm or less, 50 ppm or less, 25 ppm or less, 10 ppm or less, 5 ppm or less, or 1 ppm or less), for example as determined according to ASTM D 5185. In some examples, the wax has an iron content of 10 ppm or less (e.g., 5 ppm or less, 1 ppm or less, 0.1 ppm or less, or 0.01 ppm or less), for example as determined according to ASTM D 5185. In some examples, the wax has a phosphorus content of 50 ppm or less (e.g., 30 ppm or less, 10 ppm or less, 5 ppm or less, or 1 ppm or less), for example as determined according to ASTM D 5185. In some examples, the wax has a sulfur content of 500 ppm or less (e.g., 250 ppm or less, 100 ppm or less, 10 ppm or less, or 1 ppm or less), for example as determined according to ASTM D 4294. In some examples, the wax has a calcium content of 50 ppm or less (e.g., 25 ppm or less, 10 ppm or less, 5 ppm or less, 1 ppm or less, 0.1 ppm or less, or 0.01 ppm or less), for example as determined according to ASTM D 5185. In some examples, the wax has a copper content of 10 ppm or less (e.g., 5 ppm or less, 1 ppm or less, 0.1 ppm or less, or 0.01 ppm or less), for example as determined according to ASTM D 5185. In some examples, the wax has a nickel content of 100 ppm or less (e.g., 50 ppm or less, 25 ppm or less, 10 ppm or less, 5 ppm or less, or 1 ppm or less), for example as determined according to ASTM D 5185. In some examples, the wax has a vanadium content of 25 ppm or less (e.g., 10 ppm or less, 5 ppm or less, or 1 ppm or less), for example as determined according to ASTM D 5185.

In some examples, the wax has: a total chloride content of 50 ppm or less; a nitrogen content of 300 ppm or less; and a silicon content of 125 ppm or less. In some examples, the wax has: a total chloride content of 50 ppm or less; a nitrogen content of 300 ppm or less; a silicon content of 125 ppm or less; and a sodium content of 150 ppm or less. In some examples, the wax has: a total chloride content of 50 ppm or less; a nitrogen content of 300 ppm or less; a silicon content of 125 ppm or less; a sodium content of 150 ppm or less; an iron content of 10 ppm or less; a sulfur content of 500 ppm or less; and a calcium content of 50 ppm or less. In some examples, the wax has: a total chloride content of

50 ppm or less; a nitrogen content of 300 ppm or less; a silicon content of 125 ppm or less: a sodium content of 150 ppm or less: an iron content of 10 ppm or less; a phosphorus content of 50 ppm or less: a sulfur content of 500 ppm or less; and a calcium content of 50 ppm or less. In some examples, the wax has: a total chloride content of 50 ppm or less: a nitrogen content of 300 ppm or less; a silicon content of 125 ppm or less; a sodium content of 150 ppm or less; an iron content of 10 ppm or less; a phosphorus content of 50 ppm or less; a sulfur content of 500 ppm or less; a calcium content of 50 ppm or less; a copper content of 10 ppm or less: a nickel content of 100 ppm or less: and a vanadium content of 25 ppm or less.

In some examples, the wax has: a total chloride content of 25 ppm or less; a nitrogen content of 300 ppm or less; and a silicon content of 100 ppm or less. In some examples. the wax has: a total chloride content of 25 ppm or less: a nitrogen content of 300 ppm or less: a silicon content of 100 ppm or less; and a sodium content of 10 ppm or less. In some examples, the wax has: a total chloride content of 25 ppm or less: a nitrogen content of 300 ppm or less; a silicon content of 100 ppm or less; a sodium content of 10 ppm or less: an iron content of 10 ppm or less; a sulfur content of 10 ppm or less; and a calcium content of 5 ppm or less. In some examples, the wax has: a total chloride content of 25 ppm or less: a nitrogen content of 300 ppm or less; a silicon content of 100 ppm or less; a sodium content of 10 ppm or less: an iron content of 10 ppm or less; a phosphorus content of 50 ppm or less; a sulfur content of 10 ppm or less; and a calcium content of 5 ppm or less. In some examples. the wax has: a total chloride content of 25 ppm or less: a nitrogen content of 300 ppm or less: a silicon content of 100 ppm or less: a sodium content of 10 ppm or less; an iron content of 10 ppm or less; a phosphorus content of 50 ppm or less; a sulfur content of 10 ppm or less: a calcium content of 5 ppm or less: a copper content of 10 ppm or less: a nickel content of 100 ppm or less; and a vanadium content of 25 ppm or less.

In some examples, the wax has a Gardner color of from 2 to 8 (e.g., from 2.5 to 8, or from 6.5 to 8), for example as determined according to ASTM D 1500. In some examples. the wax has an oil content of from 5-50% (e.g., from 25 to 45%, or from 40 to 45%) by weight, for example as determined according to ASTM D 721. In some examples, the wax has a Reid Vapor Pressure of 12.5 psig or less (e.g., 10 psig or less, or from 7 to 10 psig). for example as determined using ASTM D 5191. In some examples. the wax has a water by distillation amount of 0.5 vol. % or less (e.g., 0.1 vol. % or less, or 0.01 vol. % or less), for example as determined by ASTM D 95. In some examples, the wax has a total sediment content of 0.5 vol. % or less (e.g., 0.1 vol. % or less, or 0.01 vol. % or less). for example as determined by ASTM D 4870. In some examples, the wax has an n-heptane insoluble content of 0.5 wt. % or less (e.g., 0.1 wt. % or less, 0.05 wt. % or less, 0.01 wt. % or less), for example as determined by ASTM D 3279. In some examples, the wax has a total acid number of 1 mg KOH/g or less (e.g., 0.5 mg KOH/g or less, or 0.2 mg KOH/g or less), for example as determined according to ASTM D 664.

In some examples. the wax has: a Reid Vapor Pressure of 12.5 psig or less; a final boiling point of 950° F. to 1300° F.: and a pour point of 30° F. to 60° F. In some examples, the wax has: a Reid Vapor Pressure of from 7 to 10 psig; a final boiling point of from 995° F. to 1235° F.; and a pour point of from 33° F. to 52° F. In some examples. the wax has: a Reid Vapor Pressure of 12.5 psig or less; a final boiling point of 950° F. to 1300° F.; a pour point of 30° F. to 60° F.; a total chloride content of 50 ppm or less; a nitrogen content of 300 ppm or less; a silicon content of 125 ppm or less; a sodium content of 150 ppm or less: an iron content of 10 ppm or less; a phosphorus content of 50 ppm or less: a sulfur content of 500 ppm or less: and a calcium content of 50 ppm or less. In some examples, the wax has: a Reid Vapor Pressure of from 7 to 10 psig; a final boiling point of from 995° F. to 1235° F.; a pour point of from 33° F. to 52° F.; a total chloride content of 25 ppm or less; a nitrogen content of 300 ppm or less: a silicon content of 100 ppm or less: a sodium content of 10 ppm or less: an iron content of 10 ppm or less; a phosphorus content of 50 ppm or less; a sulfur content of 10 ppm or less; and a calcium content of 5 ppm or less.

In some examples, the wax is produced at an industrial scale. In some examples. the wax is produced via pyrolysis in a volume of from 10.000 to 1,000.000 gallons per 5 to 90 days.

Also disclosed herein is an oil derived from pyrolysis of a feedstock comprising post-consumer and/or post-industrial plastics. In some examples, the oil has a number average molecular weight and/or a weight average molecular weight of from 50 to 350 Daltons. In some examples. the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, wherein 90% to 100% of the mixture (w/w) comprises C_1-C_{20} hydrocarbons. In some examples, the oil comprises a mixture of different hydrocarbons. any of which can optionally be substituted. wherein 90% to 100% of the mixture (w/w) comprises C_4-C_{20} hydrocarbons. In some examples, the oil has: a Reid Vapor Pressure of 12.5 psig or less: a final boiling point of 750° F. to 1000° F.: a pour point of 0° F. to 20° F.: a total chloride content of 500 ppm or less: a nitrogen content of 600 ppm or less; a silicon content of 2000 ppm or less; a sodium content of 100 ppm or less; an iron content of 10 ppm or less; a phosphorus content of 25 ppm or less: a sulfur content of 250 ppm or less: a calcium content of 50 ppm or less: or a combination thereof.

In some examples of the oil, from 92% to 96% of the mixture (w/w) comprises C_1-C_{20} hydrocarbons. In some examples of the oil. 0-10% of the mixture (w/w) comprises C_{21}-C_{29} hydrocarbons. In some examples of the oil, the mixture comprises: 25-35% (e.g., 30-35%) C_1-C_5 hydrocarbons, 55-65% (e.g., 60-65%) C_9-C_{20} hydrocarbons, and 1-10% (e.g., 3-8%) C_{21}-C_{29} hydrocarbons. In some examples of the oil, the mixture is substantially free of hydrocarbons comprising 30 or more carbons.

In some examples of the oil, from 92% to 96% of the mixture (w/w) comprises C_4-C_{20} hydrocarbons. In some examples of the oil. 0-10% of the mixture (w/w) comprises C_{21}-C_{29} hydrocarbons. In some examples of the oil, the mixture comprises: 25-35% (e.g., 30-35%) C_4-C_5 hydrocarbons, 55-65% (e.g., 60-65%) C_9-C_{20} hydrocarbons, and 1-10% (e.g., 3-8%) C_{21}-C_{29} hydrocarbons. In some examples of the oil, the mixture is substantially free of hydrocarbons comprising 30 or more carbons.

In some examples of the oil, the mixture comprises: 90-100 wt. % unsaturated hydrocarbons (e.g., 94-96 wt. %); 0-5 wt. % unsaturated (non-aromatic) hydrocarbons (e.g., 3.5-4.5 wt. %); and 0-2.5 wt. % aromatic hydrocarbons (e.g., 1-2 wt. %).

In some examples, the oil has a final boiling point of from 750° F. to 1000° F. (e.g., from 900° F. to 950° F., from 920° F. to 950° F.. or from 935° F. to 950° F.), for example as determined using ASTM D 7169. In some examples. the oil has a pour point of from 0° F. to 20° F. (e.g.. from 5° F. to 15° F., from 8° F. to 15° F., or from 10° F. to 15° F.), for example as determined using ASTM D 97.

In some examples, the oil has a total chloride content of 500 ppm or less (e.g., 100 ppm or less. 50 ppm or less. 25 ppm or less, 10 ppm or less, 5 ppm or less, 1 ppm or less. 0.1 ppm or less. or 0.01 ppm or less). for example as determined according to ASTM D 7359. In some examples, the oil has a nitrogen content of 600 ppm or less (e.g., 250 ppm or less, 200 ppm or less, 150 ppm or less, 100 ppm or less, 50 ppm or less. 10 ppm or less, or 1 ppm or less), for example as determined according to ASTM D 4629. In some examples. the oil has a silicon content of 2000 ppm or less (e.g., 1000 ppm or less, 500 ppm or less, 250 ppm or less, 100 ppm or less, 50 ppm or less, 25 ppm or less, 10 ppm or less, 5 ppm or less, or 1 ppm or less), for example as determined according to ASTM D 5185. In some examples. the oil has a sodium content of 100 ppm or less. 50 ppm or less, 25 ppm or less, 10 ppm or less, 5 ppm or less, or 1 ppm or less for example as determined according to ASTM D 5185. In some examples, the oil has an iron content of 10 ppm or less (e.g., 5 ppm or less, 1 ppm or less, 0.1 ppm or less, or 0.01 ppm or less), for example as determined according to ASTM D 5185. In some examples, the oil has a phosphorus content of 25 ppm or less (e.g., 10 ppm or less, 5 ppm or less, or 1 ppm or less), for example as determined according to ASTM D 5185. In some examples, the oil has a sulfur content of 250 ppm or less (e.g., 100 ppm or less. 10 ppm or less. or 1 ppm or less). for example as determined according to ASTM D 4294. In some examples, the oil has a calcium content of 50 ppm or less, 25 ppm or less, 10 ppm or less, 5 ppm or less. 1 ppm or less, 0.1 ppm or less. or 0.01 ppm or less. for example as determined according to ASTM D 5185. In some examples, the oil has a copper content of 10 ppm or less (e.g., 5 ppm or less, 1 ppm or less, 0.1 ppm or less, or 0.01 ppm or less), for example as determined according to ASTM D 5185. In some examples, the oil has a nickel content of 250 ppm or less (e.g., 100 ppm or less. 50 ppm or less, 25 ppm or less. 10 ppm or less, 5 ppm or less. or 1 ppm or less), for example as determined according to ASTM D 5185. In some examples, the oil has a vanadium content of 25 ppm or less (e.g.. 10 ppm or less, 5 ppm or less. or 1 ppm or less). for example as determined according to ASTM D 5185.

In some examples, the oil has: a total chloride content of 500 ppm or less; a nitrogen content of 600 ppm or less; and a silicon content of 2000 ppm or less. In some examples, the oil has: a total chloride content of 500 ppm or less: a nitrogen content of 600 ppm or less; a silicon content of 2000 ppm or less; and a sodium content of 100 ppm or less. In some examples. the oil has: a total chloride content of 500 ppm or less: a nitrogen content of 600 ppm or less; a silicon content of 2000 ppm or less: a sodium content of 100 ppm or less: an iron content of 10 ppm or less; a sulfur content of 250 ppm or less; and a calcium content of 50 ppm or less. In some examples, the oil has: a total chloride content of 500 ppm or less; a nitrogen content of 600 ppm or less: a silicon content of 2000 ppm or less; a sodium content of 100 ppm or less; an iron content of 10 ppm or less; a phosphorus content of 25 ppm or less; a sulfur content of 250 ppm or less: and a calcium content of 50 ppm or less. In some examples. the oil has: a total chloride content of 500 ppm or less; a nitrogen content of 600 ppm or less; a silicon content of 2000 ppm or less; a sodium content of 100 ppm or less; an iron content of 10 ppm or less: a phosphorus content of 25 ppm or less; a sulfur content of 250 ppm or less; a calcium content of 50 ppm or less; a copper content of 10 ppm or less; a nickel content of 250 ppm or less; and a vanadium content of 25 ppm or less.

In some examples, the oil has: a total chloride content of 100 ppm or less; a nitrogen content of 600 ppm or less; and a silicon content of 250 ppm or less. In some examples, the oil has: a total chloride content of 100 ppm or less; a nitrogen content of 600 ppm or less; a silicon content of 250 ppm or less; and a sodium content of 25 ppm or less. In some examples, the oil has: a total chloride content of 100 ppm or less; a nitrogen content of 600 ppm or less: a silicon content of 250 ppm or less; a sodium content of 25 ppm or less; an iron content of 10 ppm or less; a sulfur content of 10 ppm or less; and a calcium content of 5 ppm or less. In some examples, the oil has: a total chloride content of 100 ppm or less; a nitrogen content of 600 ppm or less: a silicon content of 250 ppm or less; a sodium content of 25 ppm or less; an iron content of 10 ppm or less; a phosphorus content of 10 ppm or less: a sulfur content of 10 ppm or less; and a calcium content of 5 ppm or less. In some examples. the oil has: a total chloride content of 100 ppm or less: a nitrogen content of 600 ppm or less; a silicon content of 250 ppm or less; a sodium content of 25 ppm or less; an iron content of 10 ppm or less; a phosphorus content of 10 ppm or less; a sulfur content of 10 ppm or less; a calcium content of 5 ppm or less; a copper content of 1 ppm or less; a nickel content of 50 ppm or less; and a vanadium content of 1 ppm or less.

In some examples, the oil has a Reid Vapor Pressure of 12.5 psig or less (e.g.. 10 psig or less. or from 7-10 psig), for example as determined using ASTM D 5191. In some examples, the oil has a water by distillation amount of 0.5 vol. % or less (e.g., 0.1 vol. % or less, or 0.01 vol. % or less) for example as determined by ASTM D 95. In some examples, the oil has a total sediment content of 0.5 vol. % or less (e.g., 0.1 vol. % or less. or 0.01 vol. % or less), for example as determined by ASTM D 4870. In some examples, the oil has an n-heptane insoluble content of 0.1 wt. % or less (e.g., 0.05 wt. % or less. 0.01 wt. % or less), for example as determined by ASTM D 3279. In some examples, the oil has a total acid number of 1 mg KOH/g or less, 0.5 mg KOH/g or less, or 0.2 mg KOH/g or less, for example as determined according to ASTM D 664.

In some examples, the oil has: a Reid Vapor Pressure of 12.5 psig or less: a final boiling point of 750° F. to 1000° F.; and a pour point of 0° F. to 20° F. In some examples, the oil has: a Reid Vapor Pressure of from 7 to 10 psig; a final boiling point of from 935° F. to 950° F.; and a pour point of from 10° F. to 15° F. In some examples, the oil has: a Reid Vapor Pressure of 12.5 psig or less; a final boiling point of 750° F. to 1000° F.; a pour point of 0° F. to 20° F.; a total chloride content of 500 ppm or less; a nitrogen content of 600 ppm or less: a silicon content of 2000 ppm or less: a sodium content of 100 ppm or less; an iron content of 10 ppm or less; a phosphorus content of 25 ppm or less: a sulfur content of 250 ppm or less; and a calcium content of 50 ppm or less. In some examples, the oil has: a Reid Vapor Pressure of from 7 to 10 psig: a final boiling point of from 935° F. to 950° F.: a pour point of from 10° F. to 15° F.; a total chloride content of 100 ppm or less; a nitrogen content of 600 ppm or less; a silicon content of 250 ppm or less; a sodium content of 25 ppm or less; an iron content of 10 ppm or less; a phosphorus content of 10 ppm or less: a sulfur content of 10 ppm or less: and a calcium content of 5 ppm or less.

In some examples, the oil is produced at an industrial scale. In some examples, the oil is produced via pyrolysis in a volume of from 10.000 to 1,000,000 gallons per 5 to 90 days.

Also disclosed herein are compositions comprising any of waxes disclosed herein and any of the oils disclosed herein. In some examples, the composition comprises 50-70% of the oil and 30-50% of the wax by volume. In some examples, the composition comprises a blend of the wax and the oil. In some examples, the composition comprises 65% oil and 35% wax by volume. In some examples, the composition comprises 50% oil and 50% wax by volume.

Also disclosed herein are methods of making any of the waxes disclosed herein and/or any of the oils disclosed herein. In some examples, the method comprises pyrolysis of a feedstock comprising post-consumer and/or post-industrial plastics. In some examples, the method comprises thermal depolymerization of the feedstock. In some examples, the pyrolysis is substantially free of any added catalyst. In some examples, the method produces the oil and/or the wax at an industrial scale. In some examples, the method produces the oil and/or the wax in a volume of from 10,000 to 1,000,000 gallons per 5 to 90 days. In some examples, the method produces the oil and/or the wax at a yield of 75% or more, 80% or more, or 83% or more. In some examples, the oil and/or the wax produced by the method is a raw pyrolysis product, meaning method substantially excludes any hydrotreatment or further refining steps after the pyrolysis.

In some examples, the feedstock comprises 50% or more, 60% or more, or 70% or more by weight post-consumer plastics. In some examples, the post-consumer and/or post-industrial plastics comprise polyethylene (e.g., LDPE, LLDPE, HDPE), polypropylene, polystyrene, or a combination thereof. In some examples, the feedstock comprises 90% or more (e.g., 93% or more) by weight of polyethylene, polypropylene, polystyrene, or a combination thereof. In some examples, the feedstock comprises moisture at an amount of 20% or less (e.g., 10% or less, 15% or less, 5% or less, or 3% or less) by weight. In some examples, the feedstock comprises 5% or less (e.g., 2.5% or less, or 1% or less) by weight polyvinyl chloride (PVC), polyvinylidene chloride (PVDC), polyethylene terephthalate (PET), nylon, ethylene vinyl alcohol (EVOH), polycarbonate (PC), acrylonitrile butadiene styrene (ABS), rubber, thermosets, or a combination thereof. In some examples, the feedstock comprises 15% by weight or less (e.g., 10% by weight or less, 5% by weight or less, or 3% by weight or less) non-plastic materials such as metal, glass, wood, cotton, paper, cardboard, dirt, inorganics, etc. In some examples, the feedstock comprises films, such as single and/or multi-layered films. In some examples, the feedstock includes plastics with a plastic type classification #2, 4, 5, 6, or a combination thereof.

Also disclosed herein are compositions comprising any of the waxes disclosed herein, any of the oils disclosed herein, any of the blends disclosed herein, the product of any of the methods disclosed herein, or a combination thereof.

Also disclosed herein are methods of use of any of the waxes disclosed herein, any of the oils disclosed herein, any of the blends disclosed herein, the product of any of the methods disclosed herein, or a combination thereof.

Also disclosed herein are articles of manufacture comprising any of the waxes disclosed herein, any of the oils disclosed herein, any of the blends disclosed herein, the product of any of the methods disclosed herein, or a combination thereof.

Also disclosed herein are compositions derived from any of the waxes disclosed herein, any of the oils disclosed herein, any of the blends disclosed herein, the product of any of the methods disclosed herein, or a combination thereof. Also disclosed herein are methods of making said compositions. For example, the method can comprise additional processing of the composition, such as refining, filtering, cracking, hydrotreating, etc. In some examples, the composition comprises a lubricating oil, a mineral oil, a group III base oil, a fully refined paraffin wax, or a combination thereof. In some examples, the composition comprises a binder, a processing aid, or a combination thereof. In some examples, the composition comprises kerosene including cosmetic kerosene, white oils, high value paraffin and purified liquid fuels, or a combination thereof. In some examples, the composition comprises naphtha. In some examples, the composition comprises fuel. In some examples, the composition comprises liquefied petroleum gas (LPG), naphtha, kerosene, diesel and gas oil, or a combination thereof. In some examples, the composition comprises lube oil, gasoline, jet fuel, diesel fuel, or a combination thereof. Also disclosed here are articles of manufacture comprising any of the compositions. In some examples, the article comprises packaging, film, and/or fibers for carpets and clothing, molded articles, and extruded pipes, or a combination thereof. In some examples, the article comprises a medical device. In some examples, the article comprises lubricant, candles, adhesives, packaging, rubber, cosmetics, fire logs, bituminous mixtures, superficial wear coatings, asphalt, sealing coatings, or a combination thereof. In some examples, the composition or article comprises asphalt, automotive fuel, aviation fuels, base oil, bitumen, cadalene, cutting fluid, diesel fuel, fuel oil, gasoline, heating oil, heavy fuel oil, hydrocarbon solvents, jet fuel, kerosene, ligroin, lubricant, mazut, microcrystalline wax, mineral oil, motor fuel, motor oil, naphtha, naphthenic acid, paraffin wax, petroleum benzine, petroleum ether, petroleum jelly, petroleum naphtha, petroleum resin, retene, or a combination thereof. In some examples, the composition or article comprises gasoline, jet fuel, diesel and other fuels, asphalt, heavy fuel oil, lubricants, paraffin wax, tar, asphalt, fertilizer, flooring, perfume, insecticide, petroleum jelly, soap, vitamin, amino acid, or a combination thereof. In some examples, the composition or article comprises wood-based composites such as oriented-strand board (OSB), particleboard, hardboard, medium density fiberboard, gypsum board, or a combination thereof. In some examples, the composition or article comprises fully refined paraffin which is used to produce candles, cosmetics, crayons, food packaging, paper and carton coatings, or a combination thereof. In some examples, the composition or article comprises a hydrocarbon feedstock for a petroleum refinery, a catalytic cracking system, a thermal cracking system, a polymerization system, or a combination thereof. Also disclosed herein are methods of use of any of the compositions disclosed herein, for example, wherein the method comprises using the composition as a hydrocarbon feedstock for a petroleum refinery, a catalytic cracking system, a thermal cracking system, a polymerization system, or a combination thereof.

Additional advantages of the disclosed compositions and methods will be set forth in part in the description which follows, and in part will be obvious from the description. The advantages of the disclosed compositions and methods will be realized and attained by means of the elements and combinations particularly pointed out in the appended claims. It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the disclosed systems and methods, as claimed.

The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF THE FIGURES

The accompanying figures, which are incorporated in and constitute a part of this specification, illustrate several aspects of the disclosure, and together with the description, serve to explain the principles of the disclosure.

FIG. 1. Schematic diagram of an example system and/or method as disclosed herein according to one implementation.

FIG. 2. Schematic diagram of an example system and/or method as disclosed herein according to one implementation.

FIG. 3. Schematic diagram of an example system and/or method as disclosed herein according to one implementation.

FIG. 4. Schematic diagram of an example system and/or method as disclosed herein according to one implementation.

FIG. 5. Schematic diagram of an example system and/or method as disclosed herein according to one implementation.

FIG. 6. UV-Vis spectrum of wax product in hexane with a 100× dilution factor.

FIG. 7. UV-Vis spectrum of wax product in hexane with a 1000× dilution factor.

FIG. 8. FTIR-ATR spectrum of wax product.

FIG. 9. Gas chromatogram of wax product.

FIG. 10. Gas chromatogram of wax product.

FIG. 11. ^{1}H-NMR spectrum of wax product.

FIG. 12. ^{1}H-NMR spectrum of wax product with annotations.

FIG. 13. ^{13}C-NMR spectrum of wax product.

FIG. 14. ^{13}C-NMR spectrum of wax product with annotations.

FIG. 15. UV-Vis spectrum of oil product in hexane with a 100× dilution factor.

FIG. 16. UV-Vis spectrum of oil product in hexane with a 1000× dilution factor.

FIG. 17. FTIR-ATR spectrum of oil product.

FIG. 18. GC-FID chromatogram of oil product.

FIG. 19. GC-FID chromatogram of oil product.

FIG. 20. ^{1}H-NMR spectrum of oil product.

FIG. 21. ^{1}H-NMR spectrum of oil product with annotations.

FIG. 22. ^{13}C-NMR spectrum of oil product.

FIG. 23. ^{13}C-NMR spectrum of oil product with annotations.

DETAILED DESCRIPTION

The compositions, methods, and systems described herein may be understood more readily by reference to the following detailed description of specific aspects of the disclosed subject matter and the Examples included therein.

Before the present compositions, methods, and systems are disclosed and described, it is to be understood that the aspects described below are not limited to specific synthetic methods or specific reagents, as such may, of course, vary. It is also to be understood that the terminology used herein is for the purpose of describing particular aspects only and is not intended to be limiting.

Also, throughout this specification, various publications are referenced. The disclosures of these publications in their entireties are hereby incorporated by reference into this application in order to more fully describe the state of the art to which the disclosed matter pertains. The references disclosed are also individually and specifically incorporated by reference herein for the material contained in them that is discussed in the sentence in which the reference is relied upon.

General Definitions

In this specification and in the claims that follow, reference will be made to a number of terms, which shall be defined to have the following meanings.

Throughout the description and claims of this specification, the word "comprise" and other forms of the word, such as "comprising" and "comprises," means including but not limited to, and is not intended to exclude, for example, other additives, components, integers, or steps.

As used in the description and the appended claims, the singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to "a composition" includes mixtures of two or more such compositions, reference to "an agent" includes mixtures of two or more such agents, reference to "the component" includes mixtures of two or more such components, and the like.

"Optional" or "optionally" means that the subsequently described event or circumstance can or cannot occur, and that the description includes instances where the event or circumstance occurs and instances where it does not.

Ranges can be expressed herein as from "about" one particular value, and/or to "about" another particular value. By "about" is meant within 5% of the value, e.g., within 4, 3, 2, or 1% of the value. When such a range is expressed, another aspect includes from the one particular value and/or to the other particular value. Similarly, when values are expressed as approximations, by use of the antecedent "about," it will be understood that the particular value forms another aspect. It will be further understood that the endpoints of each of the ranges are significant both in relation to the other endpoint, and independently of the other endpoint.

Values can be expressed herein as an "average" value. "Average" generally refers to the statistical mean value.

By "substantially" is meant within 5%, e.g., within 4%, 3%, 2%, or 1%.

"Exemplary" means "an example of" and is not intended to convey an indication of a preferred or ideal embodiment. "Such as" is not used in a restrictive sense, but for explanatory purposes.

It is understood that throughout this specification the identifiers "first" and "second" are used solely to aid in distinguishing the various components and steps of the disclosed subject matter. The identifiers "first" and "second" are not intended to imply any particular order, amount, preference, or importance to the components or steps modified by these terms.

References in the specification and concluding claims to parts by weight of a particular element or component in a composition denotes the weight relationship between the element or component and any other elements or components in the composition or article for which a part by weight is expressed. Thus, in a compound containing 2 parts by weight of component X and 5 parts by weight component Y, X and Y are present at a weight ratio of 2:5, and are present in such ratio regardless of whether additional components are contained in the compound.

A weight percent (wt. %) of a component, unless specifically stated to the contrary, is based on the total weight of the formulation or composition in which the component is included.

The term "or combinations thereof" as used herein refers to all permutations and combinations of the listed items preceding the term. For example, "A, B, C, or combinations thereof" is intended to include at least one of: A, B, C, AB, AC, BC, or ABC, and if order is important in a particular context, also BA, CA, CB, CBA, BCA, ACB, BAC, or CAB. Continuing with this example, expressly included are combinations that contain repeats of one or more item or term, such as BB, AAA, AB, BBC, AAABCCCC, CBBAAA, CABABB, and so forth. The skilled artisan will understand that typically there is no limit on the number of items or terms in any combination, unless otherwise apparent from the context.

Chemical Definitions

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs.

The organic moieties mentioned when defining variable positions within the general formulae described herein (e.g., the term "halogen") are collective terms for the individual substituents encompassed by the organic moiety. The prefix C_n-C_m preceding a group or moiety indicates, in each case, the possible number of carbon atoms in the group or moiety that follows.

The term "ion," as used herein, refers to any molecule, portion of a molecule, cluster of molecules, molecular complex, moiety, or atom that contains a charge (positive, negative, or both at the same time within one molecule, cluster of molecules, molecular complex, or moiety (e.g., zwitterions)) or that can be made to contain a charge. Methods for producing a charge in a molecule, portion of a molecule, cluster of molecules, molecular complex, moiety, or atom are disclosed herein and can be accomplished by methods known in the art, e.g., protonation, deprotonation, oxidation, reduction, alkylation, acetylation, esterification, de-esterification, hydrolysis, etc.

The term "anion" is a type of ion and is included within the meaning of the term "ion." An "anion" is any molecule, portion of a molecule (e.g., zwitterion), cluster of molecules, molecular complex, moiety, or atom that contains a net negative charge or that can be made to contain a net negative charge. The term "anion precursor" is used herein to specifically refer to a molecule that can be converted to an anion via a chemical reaction (e.g., deprotonation).

The term "cation" is a type of ion and is included within the meaning of the term "ion." A "cation" is any molecule, portion of a molecule (e.g., zwitterion), cluster of molecules, molecular complex, moiety, or atom, that contains a net positive charge or that can be made to contain a net positive charge. The term "cation precursor" is used herein to specifically refer to a molecule that can be converted to a cation via a chemical reaction (e.g., protonation or alkylation).

As used herein, the term "substituted" is contemplated to include all permissible substituents of organic compounds. In a broad aspect, the permissible substituents include acyclic and cyclic, branched and unbranched, carbocyclic and heterocyclic, and aromatic and nonaromatic substituents of organic compounds. Illustrative substituents include, for example, those described below. The permissible substituents can be one or more and the same or different for appropriate organic compounds. For purposes of this disclosure, the heteroatoms, such as nitrogen, can have hydrogen substituents and/or any permissible substituents of organic compounds described herein which satisfy the valencies of the heteroatoms. This disclosure is not intended to be limited in any manner by the permissible substituents of organic compounds. Also, the terms "substitution" or "substituted with" include the implicit proviso that such substitution is in accordance with permitted valence of the substituted atom and the substituent, and that the substitution results in a stable compound, e.g., a compound that does not spontaneously undergo transformation such as by rearrangement, cyclization, elimination, etc.

"Z^1," "Z^2," "Z^3," and "Z^4" are used herein as generic symbols to represent various specific substituents. These symbols can be any substituent, not limited to those disclosed herein, and when they are defined to be certain substituents in one instance, they can, in another instance, be defined as some other substituents.

The term "aliphatic" as used herein refers to a non-aromatic hydrocarbon group and includes branched and unbranched, alkyl, alkenyl, or alkynyl groups.

As used herein, the term "alkyl" refers to saturated, straight-chained or branched saturated hydrocarbon moieties. Unless otherwise specified, C_1-C_{24} (e.g., C_1-C_{22}, C_1-C_{20}, C_1-C_{18}, C_1-C_{16}, C_1-C_{14}, C_1-C_{12}, C_1-C_{10}, C_1-C_8, C_1-C_6, or C_1-C_4) alkyl groups are intended. Examples of alkyl groups include methyl, ethyl, propyl, 1-methyl-ethyl, butyl, 1-methyl-propyl, 2-methyl-propyl, 1,1-dimethyl-ethyl, pentyl, 1-methyl-butyl, 2-methyl-butyl, 3-methyl-butyl, 2,2-dimethyl-propyl, 1-ethyl-propyl, hexyl, 1,1-dimethyl-propyl, 1,2-dimethyl-propyl, 1-methyl-pentyl, 2-methyl-pentyl, 3-methyl-pentyl, 4-methyl-pentyl, 1,1-dimethyl-butyl, 1,2-dimethyl-butyl, 1,3-dimethyl-butyl, 2,2-dimethyl-butyl, 2,3-dimethyl-butyl, 3,3-dimethyl-butyl, 1-ethyl-butyl, 2-ethyl-butyl, 1,1,2-trimethyl-propyl, 1,2,2-trimethyl-propyl, 1-ethyl-1-methyl-propyl, 1-ethyl-2-methyl-propyl, heptyl, octyl, nonyl, decyl, dodecyl, tetradecyl, hexadecyl, eicosyl, tetracosyl, and the like. Alkyl substituents may be unsubstituted or substituted with one or more chemical moieties. The alkyl group can be substituted with one or more groups including, but not limited to, hydroxyl, halogen, acyl, alkyl, alkoxy, alkenyl, alkynyl, aryl, heteroaryl, aldehyde, amino, cyano, carboxylic acid, ester, ether, ketone, nitro, phosphonyl, silyl, sulfo-oxo, sulfonyl, sulfone, sulfoxide, or thiol, as described below, provided that the substituents are sterically compatible and the rules of chemical bonding and strain energy are satisfied.

Throughout the specification "alkyl" is generally used to refer to both unsubstituted alkyl groups and substituted alkyl groups; however, substituted alkyl groups are also specifically referred to herein by identifying the specific substituent(s) on the alkyl group. For example, the term "halogenated alkyl" specifically refers to an alkyl group that is substituted with one or more halides (halogens; e.g., fluorine, chlorine, bromine, or iodine). The term "alkoxyalkyl" specifically refers to an alkyl group that is substituted with one or more alkoxy groups, as described below. The term "alkylamino" specifically refers to an alkyl group that is substituted with one or more amino groups, as described below, and the like. When "alkyl" is used in one instance and a specific term such as "alkylalcohol" is used in another, it is not meant to imply that the term "alkyl" does not also refer to specific terms such as "alkylalcohol" and the like.

This practice is also used for other groups described herein. That is, while a term such as "cycloalkyl" refers to both unsubstituted and substituted cycloalkyl moieties, the substituted moieties can, in addition, be specifically identified herein; for example, a particular substituted cycloalkyl can be referred to as, e.g., an "alkylcycloalkyl." Similarly, a substituted alkoxy can be specifically referred to as, e.g., a "halogenated alkoxy," a particular substituted alkenyl can be, e.g., an "alkenylalcohol," and the like. Again, the practice of using a general term, such as "cycloalkyl," and a specific term, such as "alkylcycloalkyl," is not meant to imply that the general term does not also include the specific term.

As used herein, the term "alkenyl" refers to unsaturated, straight-chained, or branched hydrocarbon moieties containing a double bond. Unless otherwise specified, C_2-C_{24} (e.g., C_2-C_{22}, C_2-C_{20}, C_2-C_{18}, C_2-C_{16}, C_2-C_{14}, C_2-C_{12}, C_2-C_{10}, C_2-C_8, C_2-C_6, or C_2-C_4) alkenyl groups are intended. Alkenyl groups may contain more than one unsaturated bond. Examples include ethenyl, 1-propenyl, 2-propenyl, 1-methylethenyl, 1-butenyl, 2-butenyl, 3-butenyl, 1-methyl-1-propenyl, 2-methyl-1-propenyl, 1-methyl-2-propenyl, 2-methyl-2-propenyl, 1-pentenyl, 2-pentenyl, 3-pentenyl, 4-pentenyl, 1-methyl-1-butenyl, 2-methyl-1-butenyl, 3-methyl-1-butenyl, 1-methyl-2-butenyl, 2-methyl-2-butenyl, 3-methyl-2-butenyl, 1-methyl-3-butenyl, 2-methyl-3-butenyl, 3-methyl-3-butenyl, 1,1-dimethyl-2-propenyl, 1,2-dimethyl-1-propenyl, 1,2-dimethyl-2-propenyl, 1-ethyl-1-propenyl, 1-ethyl-2-propenyl, 1-hexenyl, 2-hexenyl, 3-hexenyl, 4-hexenyl, 5-hexenyl, 1-methyl-1-pentenyl, 2-methyl-1-pentenyl, 3-methyl-1-pentenyl, 4-methyl-1-pentenyl, 1-methyl-2-pentenyl, 2-methyl-2-pentenyl, 3-methyl-2-pentenyl, 4-methyl-2-pentenyl, 1-methyl-3-pentenyl, 2-methyl-3-pentenyl, 3-methyl-3-pentenyl, 4-methyl-3-pentenyl, 1-methyl-4-pentenyl, 2-methyl-4-pentenyl, 3-methyl-4-pentenyl, 4-methyl-4-pentenyl, 1,1-dimethyl-2-butenyl, 1,1-dimethyl-3-butenyl, 1,2-dimethyl-1-butenyl, 1,2-dimethyl-2-butenyl, 1,2-dimethyl-3-butenyl, 1,3-dimethyl-1-butenyl, 1,3-dimethyl-2-butenyl, 1,3-dimethyl-3-butenyl, 2,2-dimethyl-3-butenyl, 2,3-dimethyl-1-butenyl, 2,3-dimethyl-2-butenyl, 2,3-dimethyl-3-butenyl, 3,3-dimethyl-1-butenyl, 3,3-dimethyl-2-butenyl, 1-ethyl-1-butenyl, 1-ethyl-2-butenyl, 1-ethyl-3-butenyl, 2-ethyl-1-butenyl, 2-ethyl-2-butenyl, 2-ethyl-3-butenyl, 1,1,2-trimethyl-2-propenyl, 1-ethyl-1-methyl-2-propenyl, 1-ethyl-2-methyl-1-propenyl, and 1-ethyl-2-methyl-2-propenyl. The term "vinyl" refers to a group having the structure —CH═CH$_2$; 1-propenyl refers to a group with the structure —CH═CH—CH$_3$; and 2-propenyl refers to a group with the structure —CH$_2$—CH═CH$_2$. Asymmetric structures such as $(Z^1Z^2)C{=}C(Z^3Z^4)$ are intended to include both the E and Z isomers. This can be presumed in structural formulae herein wherein an asymmetric alkene is present, or it can be explicitly indicated by the bond symbol C═C. Alkenyl substituents may be unsubstituted or substituted with one or more chemical moieties. Examples of suitable substituents include, for example, alkyl, alkoxy, alkenyl, alkynyl, aryl, heteroaryl, acyl, aldehyde, amino, cyano, carboxylic acid, ester, ether, halide, hydroxyl, ketone, nitro, phosphonyl, silyl, sulfo-oxo, sulfonyl, sulfone, sulfoxide, or thiol, as described below, provided that the substituents are sterically compatible and the rules of chemical bonding and strain energy are satisfied.

As used herein, the term "alkynyl" represents straight-chained or branched hydrocarbon moieties containing a triple bond. Unless otherwise specified, C_2-C_{24} (e.g., C_2-C_{24}, C_2-C_{20}, C_2-C_{18}, C_2-C_{16}, C_2-C_{14}, C_2-C_{12}, C_2-C_{10}, C_2-C_8, C_2-C_6, or C_2-C_4) alkynyl groups are intended. Alkynyl groups may contain more than one unsaturated bond. Examples include C_2-C_6-alkynyl, such as ethynyl, 1-propynyl, 2-propynyl (or propargyl), 1-butynyl, 2-butynyl, 3-butynyl, 1-methyl-2-propynyl, 1-pentynyl, 2-pentynyl, 3-pentynyl, 4-pentynyl, 3-methyl-1-butynyl, 1-methyl-2-butynyl, 1-methyl-3-butynyl, 2-methyl-3-butynyl, 1,1-dimethyl-2-propynyl, 1-ethyl-2-propynyl, 1-hexynyl, 2-hexynyl, 3-hexynyl, 4-hexynyl, 5-hexynyl, 3-methyl-1-pentynyl, 4-methyl-1-pentynyl, 1-methyl-2-pentynyl, 4-methyl-2-pentynyl, 1-methyl-3-pentynyl, 2-methyl-3-pentynyl, 1-methyl-4-pentynyl, 2-methyl-4-pentynyl, 3-methyl-4-pentynyl, 1,1-dimethyl-2-butynyl, 1,1-dimethyl-3-butynyl, 1,2-dimethyl-3-butynyl, 2,2-dimethyl-3-butynyl, 3,3-dimethyl-1-butynyl, 1-ethyl-2-butynyl, 1-ethyl-3-butynyl, 2-ethyl-3-butynyl, and 1-ethyl-1-methyl-2-propynyl. Alkynyl substituents may be unsubstituted or substituted with one or more chemical moieties. Examples of suitable substituents include, for example, alkyl, alkoxy, alkenyl, alkynyl, aryl, heteroaryl, acyl, aldehyde, amino, cyano, carboxylic acid, ester, ether, halide, hydroxyl, ketone, nitro, phosphonyl, silyl, sulfo-oxo, sulfonyl, sulfone, sulfoxide, or thiol, as described below.

As used herein, the term "aryl," as well as derivative terms such as aryloxy, refers to groups that include a monovalent aromatic carbocyclic group of from 3 to 50 carbon atoms. Aryl groups can include a single ring or multiple condensed rings. In some examples, aryl groups include C_6-C_{10} aryl groups. Examples of aryl groups include, but are not limited to, benzene, phenyl, biphenyl, naphthyl, tetrahydronaphthyl, phenylcyclopropyl, phenoxybenzene, and indanyl. The term "aryl" also includes "heteroaryl," which is defined as a group that contains an aromatic group that has at least one heteroatom incorporated within the ring of the aromatic group. Examples of heteroatoms include, but are not limited to, nitrogen, oxygen, sulfur, and phosphorus. The term "non-heteroaryl," which is also included in the term "aryl," defines a group that contains an aromatic group that does not contain a heteroatom. The aryl substituents may be unsubstituted or substituted with one or more chemical moieties. Examples of suitable substituents include, for example, alkyl, alkoxy, alkenyl, alkynyl, aryl, heteroaryl, acyl, aldehyde, amino, cyano, carboxylic acid, ester, ether, halide, hydroxyl, ketone, nitro, phosphonyl, silyl, sulfo-oxo, sulfonyl, sulfone, sulfoxide, or thiol as described herein. The term "biaryl" is a specific type of aryl group and is included in the definition of aryl. Biaryl refers to two aryl groups that are bound together via a fused ring structure, as in naphthalene, or are attached via one or more carbon-carbon bonds, as in biphenyl.

The term "cycloalkyl" as used herein is a non-aromatic carbon-based ring composed of at least three carbon atoms. Examples of cycloalkyl groups include, but are not limited to, cyclopropyl, cyclobutyl, cyclopentyl, cyclohexyl, etc. The term "heterocycloalkyl" is a cycloalkyl group as defined above where at least one of the carbon atoms of the ring is substituted with a heteroatom such as, but not limited to, nitrogen, oxygen, sulfur, or phosphorus. The cycloalkyl group and heterocycloalkyl group can be substituted or unsubstituted. The cycloalkyl group and heterocycloalkyl group can be substituted with one or more groups including, but not limited to, alkyl, alkoxy, alkenyl, alkynyl, aryl, heteroaryl, acyl, aldehyde, amino, cyano, carboxylic acid, ester, ether, halide, hydroxyl, ketone, nitro, phosphonyl, silyl, sulfo-oxo, sulfonyl, sulfone, sulfoxide, or thiol as described herein.

The term "cycloalkenyl" as used herein is a non-aromatic carbon-based ring composed of at least three carbon atoms and containing at least one double bound, i.e., C═C. Examples of cycloalkenyl groups include, but are not limited to, cyclopropenyl, cyclobutenyl, cyclopentenyl, cyclopentadienyl, cyclohexenyl, cyclohexadienyl, and the like. The term "heterocycloalkenyl" is a type of cycloalkenyl group as defined above and is included within the meaning of the term "cycloalkenyl," where at least one of the carbon atoms of the ring is substituted with a heteroatom such as, but not limited to, nitrogen, oxygen, sulfur, or phosphorus. The cycloalkenyl group and heterocycloalkenyl group can be substituted or unsubstituted. The cycloalkenyl group and heterocycloalkenyl group can be substituted with one or more groups including, but not limited to, alkyl, alkoxy, alkenyl, alkynyl, aryl, heteroaryl, acyl, aldehyde, amino, cyano, carboxylic acid, ester, ether, halide, hydroxyl, ketone, nitro, phosphonyl, silyl, sulfo-oxo, sulfonyl, sulfone, sulfoxide, or thiol as described herein.

The term "cyclic group" is used herein to refer to either aryl groups, non-aryl groups (i.e., cycloalkyl, heterocycloalkyl, cycloalkenyl, and heterocycloalkenyl groups), or both. Cyclic groups have one or more ring systems (e.g., monocyclic, bicyclic, tricyclic, polycyclic, etc.) that can be substituted or unsubstituted. A cyclic group can contain one or more aryl groups, one or more non-aryl groups, or one or more aryl groups and one or more non-aryl groups.

The term "acyl" as used herein is represented by the formula —C(O)Z^1 where Z^1 can be a hydrogen, hydroxyl, alkoxy, alkyl, alkenyl, alkynyl, aryl, heteroaryl, cycloalkyl, cycloalkenyl, heterocycloalkyl, or heterocycloalkenyl group described above. As used herein, the term "acyl" can be used interchangeably with "carbonyl." Throughout this specification "C(O)" or "CO" is a shorthand notation for C═O.

The term "acetal" as used herein is represented by the formula $(Z^1Z^2)C(—OZ^3)(—OZ^4)$, where Z^1, Z^2, Z^3, and Z^4 can be, independently, a hydrogen, halogen, hydroxyl, alkyl, alkenyl, alkynyl, aryl, heteroaryl, cycloalkyl, cycloalkenyl, heterocycloalkyl, or heterocycloalkenyl group described above.

The term "alkanol" as used herein is represented by the formula Z^1OH, where Z^1 can be an alkyl, alkenyl, alkynyl, aryl, heteroaryl, cycloalkyl, cycloalkenyl, heterocycloalkyl, or heterocycloalkenyl group described above.

As used herein, the term "alkoxy" as used herein is an alkyl group bound through a single, terminal ether linkage; that is, an "alkoxy" group can be defined as to a group of the formula Z^1—O—, where Z^1 is unsubstituted or substituted alkyl as defined above. Unless otherwise specified, alkoxy groups wherein Z^1 is a C_1-C_{24} (e.g., C_1-C_{22}, C_1-C_{20}, C_1-C_{18}, C_1-C_{16}, C_1-C_{14}, C_1-C_{12}, C_1-C_{10}, C_1-C_8, C_1-C_6, or C_1-C_4) alkyl group are intended. Examples include methoxy, ethoxy, propoxy, 1-methyl-ethoxy, butoxy, 1-methyl-propoxy, 2-methyl-propoxy, 1,1-dimethyl-ethoxy, pentoxy, 1-methyl-butyloxy, 2-methyl-butoxy, 3-methyl-butoxy, 2,2-di-methyl-propoxy, 1-ethyl-propoxy, hexoxy, 1,1-dimethyl-propoxy, 1,2-dimethyl-propoxy, 1-methyl-pentoxy, 2-methyl-pentoxy, 3-methyl-pentoxy, 4-methyl-penoxy, 1,1-dimethyl-butoxy, 1,2-dimethyl-butoxy, 1,3-dimethyl-butoxy, 2,2-dimethyl-butoxy, 2,3-dimethyl-butoxy, 3,3-dimethyl-butoxy, 1-ethyl-butoxy, 2-ethylbutoxy, 1,1,2-trimethyl-propoxy, 1,2,2-trimethyl-propoxy, 1-ethyl-1-methyl-propoxy, and 1-ethyl-2-methyl-propoxy.

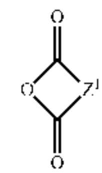
The term "aldehyde" as used herein is represented by the formula —C(O)H. Throughout this specification "C(O)" is a shorthand notation for C═O.

The term "amino" as used herein are represented by the formula —$NZ^1Z^2Z^3$, where Z^1, Z^2, and Z^3 can each be substitution group as described herein, such as hydrogen, an alkyl, alkenyl, alkynyl, aryl, heteroaryl, cycloalkyl, cycloalkenyl, heterocycloalkyl, or heterocycloalkenyl group described above.

The terms "amide" or "amido" as used herein are represented by the formula —$C(O)NZ^1Z^2$, where Z^1 and Z^2 can each be substitution group as described herein, such as hydrogen, an alkyl, alkenyl, alkynyl, aryl, heteroaryl, cycloalkyl, cycloalkenyl, heterocycloalkyl, or heterocycloalkenyl group described above.

The term "anhydride" as used herein is represented by the formula $Z^1C(O)OC(O)Z^2$ where Z^1 and Z^2, independently, can be an alkyl, alkenyl, alkynyl, aryl, heteroaryl, cycloalkyl, cycloalkenyl, heterocycloalkyl, or heterocycloalkenyl group described above.

The term "cyclic anhydride" as used herein is represented by the formula:



where Z^1 can be an alkyl, alkenyl, alkynyl, aryl, heteroaryl, cycloalkyl, cycloalkenyl, heterocycloalkyl, or heterocycloalkenyl group described above.

The term "azide" as used herein is represented by the formula —N═N═N.

The term "carboxylic acid" as used herein is represented by the formula —C(O)OH.

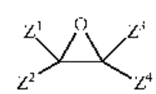
A "carboxylate" or "carboxyl" group as used herein is represented by the formula —C(O)O^-.

The term "cyano" as used herein is represented by the formula —CN.

The term "ester" as used herein is represented by the formula —$OC(O)Z^1$ or —$C(O)OZ^1$, where Z^1 can be an alkyl, alkenyl, alkynyl, aryl, heteroaryl, cycloalkyl, cycloalkenyl, heterocycloalkyl, or heterocycloalkenyl group described above.

The term "ether" as used herein is represented by the formula Z^1OZ^2, where Z^1 and Z^2 can be, independently, an alkyl, alkenyl, alkynyl, aryl, heteroaryl, cycloalkyl, cycloalkenyl, heterocycloalkyl, or heterocycloalkenyl group described above.

The term "epoxy" or "epoxide" as used herein refers to a cyclic ether with a three atom ring and can represented by the formula:



where Z^1, Z^2, Z^3, and Z^4 can be, independently, an alkyl, alkenyl, alkynyl, aryl, heteroaryl, cycloalkyl, cycloalkenyl, heterocycloalkyl, or heterocycloalkenyl group described above.

The term "ketone" as used herein is represented by the formula $Z^1C(O)Z^2$, where Z^1 and Z^2 can be, independently, an alkyl, alkenyl, alkynyl, aryl, heteroaryl, cycloalkyl, cycloalkenyl, heterocycloalkyl, or heterocycloalkenyl group described above.

The term "halide" or "halogen" or "halo" as used herein refers to fluorine, chlorine, bromine, and iodine.

The term "hydroxyl" as used herein is represented by the formula —OH.

The term "nitro" as used herein is represented by the formula —NO_2.

The term "phosphonyl" is used herein to refer to the phospho-oxo group represented by the formula —P(O)$(OZ^1)_2$, where Z^1 can be hydrogen, an alkyl, alkenyl, alkynyl, aryl, heteroaryl, cycloalkyl, cycloalkenyl, heterocycloalkyl, or heterocycloalkenyl group described above.

The term "silyl" as used herein is represented by the formula —$SiZ^1Z^2Z^3$, where Z^1, Z^2, and Z^3 can be, independently, hydrogen, alkyl, alkoxy, alkenyl, alkynyl, aryl, heteroaryl, cycloalkyl, cycloalkenyl, heterocycloalkyl, or heterocycloalkenyl group described above.

The term "sulfonyl" or "sulfone" is used herein to refer to the sulfo-oxo group represented by the formula —$S(O)_2Z^1$, where Z^1 can be hydrogen, an alkyl, alkenyl, alkynyl, aryl, heteroaryl, cycloalkyl, cycloalkenyl, heterocycloalkyl, or heterocycloalkenyl group described above.

The term "sulfide" as used herein comprises the formula —S—.

The term "thiol" as used herein is represented by the formula —SH.

"R^1," "R^2," "R^3," "R^n," etc., where n is some integer, as used herein can, independently, possess one or more of the groups listed above. For example, if R^1 is a straight chain alkyl group, one of the hydrogen atoms of the alkyl group can optionally be substituted with a hydroxyl group, an alkoxy group, an amino group, an alkyl group, a halide, and the like. Depending upon the groups that are selected, a first group can be incorporated within a second group or, alternatively, the first group can be pendant (i.e., attached) to the second group. For example, with the phrase "an alkyl group comprising an amino group," the amino group can be incorporated within the backbone of the alkyl group. Alternatively, the amino group can be attached to the backbone of the alkyl group. The nature of the group(s) that is (are) selected will determine if the first group is embedded or attached to the second group.

Unless stated to the contrary, a formula with chemical bonds shown only as solid lines and not as wedges or dashed lines contemplates each possible stereoisomer or mixture of stereoisomer (e.g., each enantiomer, each diastereomer, each meso compound, a racemic mixture, or scalemic mixture).

Compositions

Disclosed herein are hydrocarbon based compositions derived from pyrolysis of a feedstock comprising post-consumer and/or post-industrial plastics. Pyrolysis depolymerizes plastics into products comprised of building block molecules. Contaminants are introduced during plastic formulation and manufacturing processes during the first life of plastic in conjunction with the source and collection method of the plastics. Recycling of plastics via pyrolysis is a technology that generates products with a broad range of quality dependent upon a variety of factors, including the feedstock and manufacturing process.

"Post-industrial" or "Pre-consumer" plastics include materials derived from waste streams during a plastic manufacturing process.

"Post-consumer" plastics include materials generated by households or by commercial, industrial, and/or institutional facilities in their roles as end-users of the product which can no longer be used for its intended purpose. This includes returns of material from the distribution chain.

Sources of post-consumer and/or post-industrial plastics include, but are not limited to, plastic resin producers; packaging converters; industrial, commercial, retail, and institutional facilities; households; and waste collectors.

In some examples, the compositions disclosed herein can comprise a wax, an oil, or a combination thereof.

Wax

For example, disclosed herein are waxes derived from pyrolysis of a feedstock comprising post-consumer and/or post-industrial plastics. In some examples, the wax can be produced via pyrolysis at an industrial scale.

The wax can, for example, have a number average molecular weight and/or a weight average molecular weight of 300 Daltons or more (e.g., 305 Daltons or more, 310 Daltons or more, 315 Daltons or more, 320 Daltons or more, 325 Daltons or more, 330 Daltons or more, 335 Daltons or more, 340 Daltons or more, 345 Daltons or more, 350 Daltons or more, 355 Daltons or more, 360 Daltons or more, 365 Daltons or more, 370 Daltons or more, 375 Daltons or more, 380 Daltons or more, 385 Daltons or more, or 390 Daltons or more). In some examples, the wax can have a number average molecular weight and/or a weight average molecular weight of 400 Daltons or less (e.g., 395 Daltons or less, 390 Daltons or less, 385 Daltons or less, 380 Daltons or less, 375 Daltons or less, 370 Daltons or less, 365 Daltons or less, 360 Daltons or less, 355 Daltons or less, 350 Daltons or less, 345 Daltons or less, 340 Daltons or less, 335 Daltons or less, 330 Daltons or less, 325 Daltons or less, 320 Daltons or less, 315 Daltons or less, or 310 Daltons or less). The number average molecular weight and/or weight average molecular weight of the wax can range from any of the minimum values described above to any of the maximum values described above. For example, the wax can have a number average molecular weight and/or a weight average molecular weight of from 300 to 400 Daltons (e.g., from 300 to 350 Daltons, from 350 to 400 Daltons, from 300 to 320 Daltons, from 320 to 340 Daltons, from 340 to 360 Daltons, from 360 to 380 Daltons, from 380 to 400 Daltons, from 300 to 380 Daltons, from 300 to 360 Daltons, from 300 to 340 Daltons, from 320 to 400 Daltons, from 340 to 400 Daltons, from 360 to 400 Daltons, from 310 to 390 Daltons, from 320 to 380 Daltons, from 325 to 375 Daltons, or from 325 to 350 Daltons).

The wax comprises a mixture of different hydrocarbons (e.g., linear, branched, cyclic, acyclic, saturated, unsaturated, aromatic, non-aromatic, etc.), any of which can optionally be substituted. In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and 60% or more of the mixture (w/w) comprises C_{20}-C_{45} hydrocarbons (e.g., 61% or more, 62% or more, 63% or more, 64% or more, 65% or more, 66% or more, 67% or more, 68% or more, 69% or more, 70% or more, 71% or more, 72% or more, 73% or more, 74% or more, 75% or more, 76% or more, 77% or more, or 78% or more). In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and 80% or less of the mixture (w/w) comprises C_{20}-C_{45} hydrocarbons (e.g., 79% or less, 78% or less, 77% or less, 76% or less, 75% or less, 74% or less, 73% or less, 72% or less, 71% or less, 70% or less, 69% or less, 68% or less, 67% or less, 66% or less, 65% or less, 64% or less, 63% or less, or 62% or less). The amount of the mixture comprising C_{20}-C_{45} hydrocarbons can range from any of the minimum values described above to any of the maximum values described above. For example, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and from 60% to 80% of the mixture (w/w) comprises C_{20}-C_{45} hydrocarbons (e.g., from 60% to 70%, from 70% to 80%, from 60% to 65%, from 65% to 70%, from 70% to 75%, from 75% to 80%, from 60% to 75%, from 65% to 80%, or from 65% to 75%).

In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and 80% or more of the mixture (w/w) can comprise C_9-C_{33} hydrocarbons (e.g., 81% or more, 82% or more, 83% or more, 84% or more, 85% or more, 86% or more, 87% or more, or 88% or more). In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and 90% or less of the mixture (w/w) can comprise C_9-C_{33} hydrocarbons (e.g., 89% or less, 88% or less, 87% or less, 86% or less, 85% or less, 84% or less, 83% or less, or 82% or less). The amount of the mixture comprising C_9-C_{33} hydrocarbons can range from any of the minimum values described above to any of the maximum values described above. For example, the wax can comprise a mixture of different hydrocarbons, any of which can optionally be substituted, and from 80% to 90% of the mixture (w/w) can comprise C_9-C_{33} hydrocarbons (e.g., from 80% to 85%, from 85% to 90%, from 80% to 82%, from 82% to 84%, from 84% to 86%, from 86% to 88%, from 88% to 90%, from 80% to 88%, from 80% to 86%, from 80% to 84%, from 82% to 90%, from 84% to 90%, from 86% to 90%, from 81% to 89%, or from 82% to 88%).

In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and 95% or more of the mixture (w/w) comprises C_9-C_{46} hydrocarbons (e.g., 95.5% or more, 96% or more, 96.5% or more, 97% or more, 97.5% or more, or 98% or more). In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and 99% or less of the mixture (w/w) comprises C_9-C_{46} hydrocarbons (e.g., 98.5% or less, 98% or less, 97.5% or less, 97% or less, 96.5% or less, or 96% or less). The amount of the mixture comprising C_9-C_{46} hydrocarbons can range from any of the minimum values described above to any of the maximum values described above. For example, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and from 95% to 99% of the mixture (w/w) comprises C_9-C_{46} hydrocarbons (e.g., from 95% to 97%, from 97% to 99%, from 95% to 96%, from 96% to 97%, from 97% to 98%, from 98% to 99%, from 95% to 98%, from 96% to 99%, or from 96% to 98%).

In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and 20% or more of the mixture (w/w) comprises C_9-C_{20} hydrocarbons (e.g., 21% or more, 22% or more, 23% or more, 24% or more, 25% or more, 26% or more, 27% or more, or 28% or more). In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and 30% or less of the mixture (w/w) comprises C_9-C_{20} hydrocarbons (e.g., 29% or less, 28% or less, 27% or less, 26% or less, 25% or less, 24% or less, 23% or less, or 22% or less). The amount of the mixture comprising C_9-C_{20} hydrocarbons can range from any of the minimum values described above to any of the maximum values described above. For example, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and from 20% to 30% of the mixture (w/w) comprises C_9-C_{20} hydrocarbons (e.g., from 20% to 25%, from 25% to 30%, from 20% to 22%, from 22% to 24%, from 24% to 26%, from 26% to 28%, from 28% to 30%, from 20% to 28%, from 20% to 26%, from 20% to 24%, from 22% to 30%, from 24% to 30%, from 26% to 30%, from 21% to 29%, or from 22% to 28%).

In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and 20% or more of the mixture (w/w) comprises C_{20}-C_{24} hydrocarbons (e.g., 21% or more, 22% or more, 23% or more, 24% or more, 25% or more, 26% or more, 27% or more, or 28% or more). In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and 30% or less of the mixture (w/w) comprises C_{20}-C_{24} hydrocarbons (e.g., 29% or less, 28% or less, 27% or less, 26% or less, 25% or less, 24% or less, 23% or less, or 22% or less). The amount of the mixture comprising C_{20}-C_{24} hydrocarbons can range from any of the minimum values described above to any of the maximum values described above. For example, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and from 20% to 30% of the mixture (w/w) comprises C_{20}-C_{24} hydrocarbons (e.g., from 20% to 25%, from 25% to 30%, from 20% to 22%, from 22% to 24%, from 24% to 26%, from 26% to 28%, from 28% to 30%, from 20% to 28%, from 20% to 26%, from 20% to 24%, from 22% to 30%, from 24% to 30%, from 26% to 30%, from 21% to 29%, or from 22% to 28%).

In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and 20% or more of the mixture (w/w) comprises C_{24}-C_{28} hydrocarbons (e.g., 21% or more, 22% or more, 23% or more, 24% or more, 25% or more, 26% or more, 27% or more, or 28% or more). In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and 30% or less of the mixture (w/w) comprises C_{24}-C_{28} hydrocarbons (e.g., 29% or less, 28% or less, 27% or less, 26% or less, 25% or less, 24% or less, 23% or less, or 22% or less). The amount of the mixture comprising C_{24}-C_{28} hydrocarbons can range from any of the minimum values described above to any of the maximum values described above. For example, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and from 20% to 30% of the mixture (w/w) comprises C_{24}-C_{28} hydrocarbons (e.g., from 20% to 25%, from 25% to 30%, from 20% to 22%, from 22% to 24%, from 24% to 26%, from 26% to 28%, from 28% to 30%, from 20% to 28%, from 20% to 26%, from 20% to 24%, from 22% to 30%, from 24% to 30%, from 26% to 30%, from 21% to 29%, or from 22% to 28%).

In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and 10% or more of the mixture (w/w) comprises C_{28}-C_{32} hydrocarbons (e.g., 11% or more, 12% or more, 13% or more, 14% or more, 15% or more, 16% or more, 17% or more, or 18% or more). In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and 20% or less of the mixture (w/w) comprises C_{28}-C_{32} hydrocarbons (e.g., 19% or less, 18% or less, 17% or less, 16% or less, 15% or less, 14% or less, 13% or less, or 12% or less). The amount of the mixture comprising C_{28}-C_{32} hydrocarbons can range from any of the minimum values described above to any of the maximum values described above. For example, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and from 10% to 20% of the mixture (w/w) comprises C_{28}-C_{32} hydrocarbons (e.g., from 10% to 15%, from 15% to 20%, from 10% to 12%, from 12% to 14%, from 14% to 16%, from 16% to 18%, from 18% to 20%, from 10% to 18%, from 10% to 16%, from 10% to 14%, from 12% to 20%, from 14% to 20%, from 16% to 20%, from 11% to 19%, or from 12% to 18%).

In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture comprises: 20-30% (e.g., 25-30%) C_9-C_{20} hydrocarbons, 20-30% (e.g., 20-25%) C_{20}-C_{24} hydrocarbons, 20-30% (e.g., 20-25%) C_{24}-C_{28} hydrocarbons, and 10-20% (e.g., 10-15%) C_{28}-C_{32} hydrocarbons. In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture comprises: 25-30% C_9-C_{20} hydrocarbons, 20-25% C_{20}-C_{24} hydrocarbons, 20-25% C_{24}-C_{28} hydrocarbons, and 10-15% C_{28}-C_{32} hydrocarbons.

In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture is substantially free of C_1-C_5 hydrocarbons.

In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture comprises saturated hydrocarbons (e.g., linear, branched, and/or cyclic alkanes), unsaturated (non-aromatic) hydrocarbons (e.g., linear, branched, and/or cyclic alkenes and/or alkynes), and aromatic hydrocarbons. For example, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture comprises 80 wt. % or more saturated hydrocarbons (e.g., 81 wt. % or more, 82 wt. % or more, 83 wt. % or more, 84 wt. % or more, 85 wt. % or more, 86 wt. % or more, 87 wt. % or more, 88 wt. % or more, 89 wt. % or more, 90 wt. % or more, 91 wt. % or more, 92 wt. % or more, 93 wt. % or more, 94 wt. % or more, 95 wt. % or more, 96 wt. % or more, 97 wt. % or more, 98 wt. % or more, or 99 wt. % or more). In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture comprises 100 wt. % or less saturated hydrocarbons (e.g., 99 wt. % or less, 98 wt. % or less, 97 wt. % or less, 96 wt. % or less, 95 wt. % or less, 94 wt. % or less, 93 wt. % or less, 92 wt. % or less, 91 wt. % or less, 90 wt. % or less, 89 wt. % or less, 88 wt. % or less, 87 wt. % or less, 86 wt. % or less, 85 wt. % or less, 84 wt. % or less, 83 wt. % or less, or 82 wt. % or less). The amount of the mixture comprising saturated hydrocarbons can range from any of the minimum values described above to any of the maximum values described above. For example, the wax can comprise a mixture of different hydrocarbons, any of which can optionally be substituted, and from 80 wt. % to 100 wt. % of the mixture can comprise saturated hydrocarbons (e.g., from 80 wt. % to 90 wt. %, from 90 wt. % to 100 wt. %, from 80 wt. % to 85 wt. %, from 85 wt. % to 90 wt. %, from 90 wt. % to 95 wt. %, from 95 wt. % to 100 wt. %, from 80 wt. % to 98 wt. %, from 80 wt. % to 96 wt. %, from 80 wt. % to 94 wt. %, from 80 wt. % to 92 wt. %, from 80 wt. % to 88 wt. %, from 80 wt. % to 86 wt. %, from 80 wt. % to 84 wt. %, from 80 wt. % to 82 wt. %, from 82 wt. % to 100 wt. %, from 84 wt. % to 100 wt. %, from 86 wt. % to 100 wt. %, from 88 wt. % to 100 wt. %, from 92 wt. % to 100 wt. %, from 94 wt. % to 100 wt. %, from 96 wt. % to 100 wt. %, from 98 wt. % to 100 wt. %, from 82 wt. % to 98 wt. %, from 85 wt. % to 99 wt. %, from 85 wt. % to 87 wt. %, or from 97 wt. % to 99 wt. %).

In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture comprises 0 wt. % or more unsaturated (non-aromatic) hydrocarbons (e.g., 0.1 wt. % or more, 0.2 wt. % or more, 0.3 wt. % or more, 0.4 wt. % or more, 0.5 wt. % or more, 0.6 wt. % or more, 0.7 wt. % or more, 0.8 wt. % or more, 0.9 wt. % or more, 1 wt. % or more, 1.25 wt. % or more, 1.5 wt. % or more, 1.75 wt. % or more, 2 wt. % or more, 2.25 wt. % or more, 2.5 wt. % or more, 3 wt. % or more, 3.5 wt. % or more, or 4 wt. % or more). In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture comprises 5 wt. % or less unsaturated (non-aromatic) hydrocarbons (e.g., 4.5 wt. % or less, 4 wt. % or less, 3.5 wt. % or less, 3 wt. % or less, 2.5 wt. % or less, 2.25 wt. % or less, 2 wt. % or less, 1.75 wt. % or less, 1.5 wt. % or less, 1.25 wt. % or less, 1 wt. % or less, 0.9 wt. % or less, 0.8 wt. % or less, 0.7 wt. % or less, 0.6 wt. % or less, 0.5 wt. % or less, 0.4 wt. % or less, 0.3 wt. % or less, or 0.2 wt. % or less). The amount of the mixture comprising unsaturated (non-aromatic) hydrocarbons can range from any of the minimum values described above to any of the maximum values described above. For example, the wax can comprise a mixture of different hydrocarbons, any of which can optionally be substituted, and from 0 to 5 wt. % of the mixture can comprise unsaturated (non-aromatic) hydrocarbons (e.g., from 0 to 2.5 wt. %, from 2.5 to 5 wt. %, from 0 to 1 wt. %, from 1 to 2 wt. %, from 2 to 3 wt. %, from 3 to 4 wt. %, from 4 to 5 wt. %, from 0 to 4 wt. %, from 0 to 3 wt. %, from 0 to 2 wt. %, from 1 to 5 wt. %, from 2 to 5 wt. %, from 3 to 5 wt. %, from 0.5 to 4.5 wt. %, or from 0.5 to 1.5 wt. %).

In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture comprises 0 wt. % or more aromatic hydrocarbons (e.g., 0.1 wt. % or more, 0.2 wt. % or more, 0.3 wt. % or more, 0.4 wt. % or more, 0.5 wt. % or more, 0.6 wt. % or more, 0.7 wt. % or more, 0.8 wt. % or more, 0.9 wt. % or more, 1 wt. % or more, 1.25 wt. % or more, 1.5 wt. % or more, 1.75 wt. % or more, 2 wt. % or more, 2.25 wt. % or more, 2.5 wt. % or more, 3 wt. % or more, 3.5 wt. % or more, 4 wt. % or more, 4.5 wt. % or more, 5.5 wt. % or more, 6 wt. % or more, 6.5 wt. % or more, 7 wt. % or more, 7.5 wt. % or more, 8 wt. % or more, 8.5 wt. % or more, 9 wt. % or more, 9.5 wt. % or more, 10 wt. % or more, 10.5 wt. % or more, 11 wt. % or more, 11.5 wt. % or more, 12 wt. % or more, 12.5 wt. % or more, 13 wt. % or more, 13.5 wt. % or more, or 14 wt. % or more). In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture comprises 15 wt. % or less aromatic hydrocarbons (e.g., 14.5 wt. % or less, 14 wt. % or less, 13.5 wt. % or less, 13 wt. % or less, 12.5 wt. % or less, 12 wt. % or less, 11.5 wt. % or less, 11 wt. % or less, 10.5 wt. % or less, 10 wt. % or less, 9.5 wt. % or less, 9 wt. % or less, 8.5 wt. % or less, 8 wt. % or less, 7.5 wt. % or less, 7 wt. % or less, 6.5 wt. % or less, 6 wt. % or less, 5.5 wt. % or less, 5 wt. % or less, 4.5 wt. % or less, 4 wt. % or less, 3.5 wt. % or less, 3 wt. % or less, 2.5 wt. % or less, 2.25 wt. % or less, 2 wt. % or less, 1.75 wt. % or less, 1.5 wt. % or less, 1.25 wt. % or less, 1 wt. % or less, 0.9 wt. % or less, 0.8 wt. % or less, 0.7 wt. % or less, 0.6 wt. % or less, 0.5 wt. % or less, 0.4 wt. % or less, 0.3 wt. % or less, or 0.2 wt. % or less). The amount of the mixture comprising aromatic hydrocarbons can range from any of the minimum values described above to any of the maximum values described above. For example, the wax can comprise a mixture of different hydrocarbons, any of which can optionally be substituted, and from 0 to 15 wt. % of the mixture can comprise aromatic hydrocarbons (e.g., from 0 to 7.5 wt. %, from 7.5 to 15 wt. %, from 0 to 5 wt. %, from 5 to 10 wt. %, from 10 to 15 wt. %, from 0 to 14 wt. %, from 0 to 12 wt. %, from 0 to 10 wt. %, from 0 to 8 wt. %, from 0 to 6 wt. %, from 0 to 4 wt. %, from 0 to 2 wt. %, from 0 to 1 wt. %, from 1 to 15 wt. %, from 2 to 15 wt. %, from 4 to 15 wt. %, from 6 to 15 wt. %, from 8 to 15 wt. %, from 12 to 15 wt. %, from 0.5 to 14.5 wt. %, from 1 to 14 wt. %, or from 12 to 14 wt. %).

In some examples, the wax comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture comprises 80-100 wt. % saturated hydrocarbons (e.g., 85-90 wt. % or 95 to 99 wt. %); 0-5 wt. % unsaturated (non-aromatic) hydrocarbons (e.g., 0-2.5 wt. %, or 0-1.5 wt. %); and 0-15 wt. % aromatic hydrocarbons (e.g., 0-2.5 wt. %, or 12-14 wt. %). In some examples, the wax comprises a mixture of different hydrocarbons. any of which can optionally be substituted. and the mixture comprises 85-90 wt. % saturated hydrocarbons; 0-2.5 wt. % unsaturated (non-aromatic) hydrocarbons; and 12-14 wt. % aromatic hydrocarbons. In some examples, the wax comprises a mixture of different hydrocarbons. any of which can optionally be substituted. and the mixture comprises 95-99 wt. % saturated hydrocarbons; 0-1.5 wt. % unsaturated (non-aromatic) hydrocarbons; and 0-2.5 wt. % aromatic hydrocarbons.

The wax can. for example. have a melting point of 40° C. or more (e.g., 41° C. or more, 42° C. or more, 43° C. or more, 44° C. or more, 45° C. or more, 46° C. or more, 47° C. or more, 48° C. or more, 49° C. or more, 50° C. or more, 51° C. or more. 52° C. or more. or 53° C. or more). In some examples. the wax can have a melting point of 55° C. or less (e.g.. 54° C. or less. 53° C. or less, 52° C. or less, 51° C. or less, 50° C. or less, 49° C. or less, 48° C. or less, 47° C. or less, 46° C. or less, 45° C. or less, 44° C. or less, 43° C. or less, or 42° C. or less). The melting point of the wax can range from any of the minimum values described above to any of the maximum values described above. For example, the wax can have a melting point of from 40° C. to 55° C. (e.g., from 40° C. to 48° C., from 48° C. to 55° C., from 40° C. to 45° C., from 45° C. to 50° C., from 50° C. to 55° C.. from 40° C. to 54° C., from 40° C. to 52° C.. from 40° C. to 50° C., from 40° C. to 46° C., from 42° C. to 55° C., from 44° C. to 55° C., from 46° C. to 55° C., 41° C. to 54° C., from 42° C. to 50° C., or from 43° C. to 48° C.). The melting point of the wax can be determined by any suitable method. such as those known in the art. In some examples, the melting point of the wax is determined using ASTM D 127.

The wax can, for example, have a congealing point of 40° C. or more (e.g., 41° C. or more, 42° C. or more, 43° C. or more. 44° C. or more, 45° C. or more, 46° C. or more. 47° C. or more, 48° C. or more, 49° C. or more, 50° C. or more. 51° C. or more, 52° C. or more, or 53° C. or more). In some examples, the wax can have a congealing point of 55° C. or less (e.g., 54° C. or less. 53° C. or less. 52° C. or less. 51° C. or less, 50° C. or less. 49° C. or less, 48° C. or less, 47° C. or less, 46° C. or less, 45° C. or less, 44° C. or less, 43° C. or less, or 42° C. or less). The congealing point of the wax can range from any of the minimum values described above to any of the maximum values described above. For example. the wax can have a congealing point of from 40° C. to 55° C. (e.g., from 40° C. to 48° C., from 48° C. to 55° C., from 40° C. to 45° C., from 45° C. to 50° C., from 50° C. to 55° C., from 40° C. to 54° C., from 40° C. to 52° C.. from 40° C. to 50° C., from 40° C. to 46° C.. from 42° C. to 55° C., from 44° C. to 55° C.. from 46° C. to 55° C., 41° C. to 54° C., from 42° C. to 52° C., or from 45° C. to 51° C.). The congealing point of the wax can be determined by any suitable method. such as those known in the art. In some examples. the congealing point of the wax is determined using ASTM D 938.

The wax can, for example, have a final boiling point of 950° F. or more (e.g., 975° F. or more, 1000° F. or more, 1025° F. or more, 1050° F. or more, 1075° F. or more, 1100° F. or more. 1125° F. or more. 1150° F. or more, 1175° F. or more, 1200° F. or more, 1225° F. or more, or 1250° F. or more). In some examples, the wax can have a final boiling point of 1300° F. or less (e.g.. 1275° F. or less. 1250° F. or less, 1225° F. or less, 1200° F. or less, 1175° F. or less, 1150° F. or less, 1125° F. or less. 1100° F. or less, 1075° F. or less. 1050° F. or less, 1025° F. or less, or 1000° F. or less). The final boiling point of the wax can range from any of the minimum values described above to any of the maximum values described above. For example. the wax can have a final boiling point of from 950° F. to 1300° F. (e.g.. from 950° F. to 1125° F., from 1125° F. to 1300° F., from 950° F. to 1000° F., from 1000° F. to 1050° F., from 1050° F. to 1100° F., from 1100° F. to 1150° F., from 1150° F. to 1200° F., from 1200° F. to 1250° F.. from 1250° F. to 1300° F.. from 950° F. to 1250° F.. from 950° F. to 1200° F.. from 950° F. to 1150° F., from 950° F. to 1100° F., from 950° F. to 1050° F., from 1000° F. to 1300° F., from 1050° F. to 1300° F., from 1100° F. to 1300° F., from 1150° F. to 1300° F., from 1200° F. to 1300° F., from 975° F. to 1275° F.. from 950° F. to 1250° F., from 1100° F. to 1250° F.. or from 995° F. to 1235° F.). The final boiling point of the wax can be determined by any suitable method, such as those known in the art. In some examples, the final boiling point of the wax is determined using ASTM D 7169.

The wax can, for example, have a pour point of 30° F. or more (e.g., 31° F. or more, 32° F. or more, 33° F. or more, 34° F. or more, 35° F. or more, 36° F. or more, 37° F. or more, 38° F. or more. 39° F. or more. 40° F. or more, 41° F. or more. 42° F. or more. 43° F. or more. 44° F. or more, 45° F. or more, 46° F. or more, 47° F. or more, 48° F. or more, 49° F. or more, 50° F. or more, 51° F. or more, 52° F. or more, 53° F. or more, 54° F. or more, 55° F. or more, 56° F. or more, 57° F. or more. or 58° F. or more). In some examples, the wax can have a pour point of 60° F. or less (e.g., 59° F. or less, 58° F. or less, 57° F. or less, 56° F. or less, 55° F. or less, 54° F. or less, 53° F. or less, 52° F. or less, 51° F. or less, 50° F. or less, 49° F. or less. 48° F. or less. 47° F. or less, 46° F. or less, 45° F. or less, 44° F. or less. 43° F. or less, 42° F. or less. 41° F. or less, 40° F. or less. 39° F. or less, 38° F. or less, 37° F. or less, 36° F. or less, 35° F. or less, 34° F. or less, 33° F. or less, or 32° F. or less). The pour point of the wax can range from any of the minimum values described above to any of the maximum values described above. For example. the wax can have a pour point of from 30° F. to 60° F. (e.g., from 30° F. to 45° F., from 45° F. to 60° F., from 30° F. to 40° F., from 40° F. to 50° F., from 50° F. to 60° F.. from 30° F. to 55° F., from 30° F. to 50° F., from 35° F. to 60° F.. from 40° F. to 60° F.. from 32° F. to 58° F., from 33° F. to 52° F., or from 45° F. to 60° F.). The pour point of the wax can be determined by any suitable method, such as those known in the art. In some examples, the pour point of the wax is determined using ASTM D 97.

In some examples. the wax can include one or more contaminants. Contaminants can, for example, comprise an alkali metal, an alkaline earth metal, a transition metal, a basic metal. a semimetal. a nonmetal, a halogen, a salt or compound thereof. or a combination thereof. Examples of contaminants include, but are not limited to. lithium, sodium, beryllium, magnesium, calcium, strontium, titanium, vanadium, chromium, manganese, iron, cobalt, nickel, copper. zinc. molybdenum. cadmium, mercury. aluminum, titanium silicon, tin, lead, nitrogen. phosphorus, arsenic, antimony, oxygen, sulfur, selenium, fluorine, chlorine, bromine, compounds thereof, and combinations thereof. In some examples, the wax includes a contaminant comprising chloride, nitrogen. silicon, sodium. iron, phosphorus. sulfur, calcium. nickel, copper. vanadium. or a combination thereof.

Contaminants are introduced during plastic formulation and manufacturing processes during the first life of plastic in conjunction with the source and collection method of the plastics.

For example. chlorine sources in used plastics can comprise PVDC layers. PVDC is often used as a layer or coating in food and pharma packaging applications because it provides excellent barrier properties against moisture, UV light, acids, salts, and detergents as well as having good transparency. Despite design for recyclability formulation changes, PVDC is forecasted to increase at 3.2% annually through 2028 in the US. Packaging converters produce a range of monolayer and multi-layer packaging. Both types can become mixed in recycled streams. Post-consumer sources will contain higher volumes of materials containing chlorine sources that can be difficult to differentiate and remove through standard sorting techniques.

Nitrogen sources in used plastics can, for example, be derived from depolymerization of nylon (e.g., Nylon 6 (PA-6), Nylon-66 (PA-66) in used plastic sources, often from food and industrial packaging materials. Nylon is used in multi-layer flexible packing films to protect oxygen-sensitive foods or when excellent oil and grease resistance and high mechanical strength are required, such as for processed meats and fish, and cheese and other dairy products. Nylon also provides a wide cold to hot temperature range (e.g., −60° C. to 150° C.), which enables foods to move through freezer to the microwave/oven without packaging degradation. In industrial packaging, nylon is often used as a reinforcing layer to provide high mechanical strength and excellent abrasion and puncture resistance (for example, in polypropylene supersacks that contain a nylon interlayer or straps). Nitrogen can also come from protein (food) residue on plastics that arises from the amino acids in decomposed protein. Post-consumer sources will contain higher volumes of materials containing nitrogen sources that can be difficult to differentiate and remove through standard sorting techniques.

Silicon sources in used plastics can, for example, comprise silica desiccant packages. In food packaging and processing plants, silicon products are widely used as release agents in a wide variety of materials and equipment, leaving residue on plastic surfaces. Silicon is also an additive that can be added to a wide range of materials to change the appearance, extrusion properties, and/or end-product characteristics; this applied to films as well as two-dimensional plastics. Post-consumer sources will contain higher volumes of materials containing silicon sources that can be difficult to differentiate and remove through standard sorting techniques.

Silicon dioxide can be applied in a very thin coating to plastics, specifically polyethylene, polypropylene, and/or polystyrene, to act as a barrier layer to improve the shelf life of oxygen and moisture sensitive food. This thin coating can be applied by a vacuum or plasma deposition process; the barrier layer and the plastic forma covalent bond. The SiO_2 barrier coatings are chemically inert and enable benefits in rigid and flexible food packaging applications, including, but not limited to, reducing oxygen and moisture permeability of plastics, ensuring aroma protection and retention of the smell and taste of contents, not sensitive to fluctuations in temperature and humidity, well-suited for pasteurization and sterilization processes, ad can increase shelf life of foods without the addition of preservatives. The SiO_2 coatings are thin, e.g. significantly thinner than a human hair, and therefore have a negligible impact on the packing weight. For this reason, coated packaging is considered a mono-material that can be mechanically recycled. Recyclability initiatives are promoting the use of SiO_2 coatings as a replacement for PVDC and Nylon barriers in flexible and rigid packaging. Although these guidelines are intended for mechanically recycled plastics, several packaging forms and formulations are better suited for pyrolysis-based advanced recycling. SiO_2 coatings have the potential to be the "gift that keeps on giving", especially when used in rigid and flexible polyethylene and polypropylene plastics that are mechanically recycled initially, which, after a few cycles, will then eventually become the used plastic feedstocks for advanced recycling; the silicon is predicted to accumulate and carry forward into each successive application.

Phosphorus-containing flame retardants are widely used in plastics where its rapid oxidation consumes all the oxygen present, thereby stopping the fire. Plastics commonly containing these flame retardants include, but are not limited to, engineered plastics, polyurethane foams, polyamides (e.g., nylon) and glass-fiber reinforced nylon, polyethylene and EVA co-polymers, and intumescent coatings on foams and polypropylene textiles. Phosphate esters are also used as flame retardant plasticizers in PVC, high impact polystyrene (HIPS), polycarbonate (PC), and acrylonitrile butadiene styrene (ABS). Phosphorus sources also include agricultural applications, such as residual glyphosate in HDPE containers and residual phosphorus fertilizers on ground-level films (e.g., mulch films). Post-consumer sources will contain higher volumes of materials containing phosphorus sources that can be difficult to differentiate and remove through standard sorting techniques.

Sources of sulfur, calcium, sodium, iron, phosphorus, or a combination thereof are additives, surface residues, and residual contamination of the incoming post-consumer and/or post-industrial plastics. A wash step can potentially remove certain surface residues, but would add cost and complexity to the advanced (e.g., pyrolysis based) recycling process. Accordingly, post-consumer sources will contain higher volumes of materials containing sources of sulfur, calcium, sodium, iron, phosphorus, or a combination thereof that can be difficult to differentiate and remove through standard sorting techniques.

Copper alloys are commonly and increasingly used to create molds for plastic injection molding processes due to their high thermal conductivity that removes hot spots, reduces warpage and reduces cycle time, ease of machining by a variety of processes, and corrosion resistance to water, cooling fluids and the plastics being injected. Copper alloys often contain nickel and silicon. Plastics manufactured in copper alloy molds can have residual amounts of copper, nickel, and silicon on their surface. In addition, the plating of plastic with nickel and copper can be an effective means of protecting a substrate against corrosion from environmental exposure and make it more resistant to damage from chemicals used in the manufacturing process. In some instances, the plating on plastic can increase the hardness, strength, and wear resistance of the substrate. The presence of copper and nickel on the surface of both pre-consumer and post-consumer sources can be difficult to differentiate and remove through standard sorting techniques.

In some examples, the wax has a total chloride content of 50 ppm or less (e.g., 45 ppm or less, 40 ppm or less, 35 ppm or less, 30 ppm or less, 25 ppm or less, 20 ppm or less, 15 ppm or less, 10 ppm or less, 9 ppm or less, 8 ppm or less, 7 ppm or less, 6 ppm or less, 5 ppm or less, 4.5 ppm or less, 4 ppm or less, 3.5 ppm or less, 3 ppm or less, 2.5 ppm or less, 2 ppm or less, 1.5 ppm or less, 1 ppm or less, 0.75 ppm or less, 0.5 ppm or less, 0.25 ppm or less, 0.1 ppm or less, 0.075 ppm or less, 0.05 ppm or less, 0.025 ppm or less, 0.01 ppm or less, 0.0075 ppm or less, or 0.005 ppm or less). In some examples, the wax has a total chloride content of 0 ppm or more (e.g., 0.001 ppm or more, 0.0025 ppm or more, 0.005 ppm or more, 0.0075 ppm or more, 0.01 ppm or more, 0.025 ppm or more, 0.05 ppm or more, 0.075 ppm or more, 0.1 ppm or more, 0.25 ppm or more, 0.5 ppm or more, 0.75 ppm or more, 1 ppm or more, 1.5 ppm or more, 2 ppm or more, 2.5 ppm or more, 3 ppm or more, 3.5 ppm or more. 4 ppm or more. 4.5 ppm or more. 5 ppm or more, 6 ppm or more. 7 ppm or more. 8 ppm or more, 9 ppm or more. 10 ppm or more, 15 ppm or more, 20 ppm or more, 25 ppm or more, 30 ppm or more, 35 ppm or more, or 40 ppm or more). The total chloride content of the wax can range from any of the minimum values described above to any of the maximum values described above. For example, the wax can have a total chloride content of from 0 ppm to 50 ppm (e.g., from 0 to 25 ppm, from 25 to 50 ppm, from 0 to 10 ppm, from 10 to 20 ppm. from 20 to 30 ppm, from 30 to 40 ppm. from 40 to 50 ppm. from 0.001 to 50 ppm, from 0.001 to 45 ppm. from 0.001 to 40 ppm, from 0.001 to 35 ppm, from 0.001 to 30 ppm, from 0.001 to 25 ppm, from 0.001 to 20 ppm, from 0.001 to 15 ppm. from 0.001 to 10 ppm, from 0.001 to 5 ppm. from 0.001 to 1 ppm, from 0.001 to 0.1 ppm, from 0.001 to 0.01 ppm, from 0 to 45 ppm. from 0 to 40 ppm. from 0 to 35 ppm, from 0 to 30 ppm, from 0 to 25 ppm, from 0 to 20 ppm, from 0 to 15 ppm, from 0 to 10 ppm, from 0 to 5 ppm. from 0 to 1 ppm. from 0 to 0.1 ppm, or from 0 to 0.01 ppm). In some examples. the wax is substantially free of chlorides. The total chloride content of the wax can be determined by any suitable method, such as those known in the art. For example, the total chloride content of the wax can be determined using ASTM D 7359.

In some examples, the wax has a nitrogen content of 300 ppm or less (e.g., 275 ppm or less, 250 ppm or less, 225 ppm or less, 200 ppm or less, 175 ppm or less, 150 ppm or less, 125 ppm or less, 100 ppm or less. 75 ppm or less. 50 ppm or less. 45 ppm or less, 40 ppm or less. 35 ppm or less, 30 ppm or less. 25 ppm or less, 20 ppm or less, 15 ppm or less. 10 ppm or less, 9 ppm or less, 8 ppm or less, 7 ppm or less, 6 ppm or less, 5 ppm or less, 4.5 ppm or less, 4 ppm or less, 3.5 ppm or less, 3 ppm or less, 2.5 ppm or less, 2 ppm or less. 1.5 ppm or less. 1 ppm or less. 0.75 ppm or less, 0.5 ppm or less, 0.25 ppm or less, 0.1 ppm or less. 0.075 ppm or less. 0.05 ppm or less, 0.025 ppm or less, 0.01 ppm or less, 0.0075 ppm or less, or 0.005 ppm or less). In some examples, the wax has a nitrogen content of 0 ppm or more (e.g.. 0.001 ppm or more. 0.0025 ppm or more. 0.005 ppm or more. 0.0075 ppm or more, 0.01 ppm or more, 0.025 ppm or more, 0.05 ppm or more, 0.075 ppm or more, 0.1 ppm or more, 0.25 ppm or more, 0.5 ppm or more, 0.75 ppm or more, 1 ppm or more, 1.5 ppm or more, 2 ppm or more. 2.5 ppm or more. 3 ppm or more. 3.5 ppm or more, 4 ppm or more, 4.5 ppm or more, 5 ppm or more, 6 ppm or more, 7 ppm or more, 8 ppm or more, 9 ppm or more, 10 ppm or more, 15 ppm or more. 20 ppm or more, 25 ppm or more, 30 ppm or more. 35 ppm or more, 40 ppm or more. 45 ppm or more. 50 ppm or more, 75 ppm or more, 100 ppm or more, 125 ppm or more, 150 ppm or more, 175 ppm or more, 200 ppm or more, 225 ppm or more, or 250 ppm or more). The nitrogen content of the wax can range from any of the minimum values described above to any of the maximum values described above. For example, the wax can have a nitrogen content of from 0 to 300 ppm (e.g., from 0 to 150 ppm, from 150 to 300 ppm, from 0 to 100 ppm, from 100 to 200 ppm, from 200 to 300 ppm. from 0.001 to 275 ppm, from 0.001 to 250 ppm. from 0.001 to 225 ppm. from 0.001 to 200 ppm. from 0.001 to 175 ppm, from 0.001 to 150 ppm, from 0.001 to 125 ppm, from 0.001 to 100 ppm, from 0.001 to 75 ppm, from 0.001 to 50 ppm, from 0.001 to 45 ppm, from 0.001 to 40 ppm. from 0.001 to 35 ppm, from 0.001 to 30 ppm. from 0.001 to 25 ppm. from 0.001 to 20 ppm, from 0.001 to 15 ppm, from 0.001 to 10 ppm, from 0.001 to 5 ppm, from 0.001 to 1 ppm, from 0.001 to 0.1 ppm, from 0.001 to 0.01 ppm, from 0 to 275 ppm, from 0 to 250 ppm, from 0 to 225 ppm. from 0 to 200 ppm, from 0 to 175 ppm. from 0 to 150 ppm. from 0 to 125 ppm. from 0 to 100 ppm, from 0 to 75 ppm. from 0 to 50 ppm, from 0 to 45 ppm, from 0 to 40 ppm, from 0 to 35 ppm, from 0 to 30 ppm, from 0 to 25 ppm, from 0 to 20 ppm, from 0 to 15 ppm, from 0 to 10 ppm, from 0 to 5 ppm, from 0 to 1 ppm, from 0 to 0.1 ppm. or from 0 to 0.01 ppm). In some examples, the wax is substantially free of nitrogen. The nitrogen content of the wax can be determine using any suitable method, such as those known in the art. In some examples, the nitrogen content of the wax is determined using ASTM D 4629.

The wax can, for example, have a silicon content of 125 ppm or less (e.g., 100 ppm or less, 75 ppm or less, 50 ppm or less, 45 ppm or less, 40 ppm or less, 35 ppm or less, 30 ppm or less, 25 ppm or less, 20 ppm or less. 15 ppm or less, 10 ppm or less. 9 ppm or less. 8 ppm or less. 7 ppm or less, 6 ppm or less, 5 ppm or less, 4.5 ppm or less, 4 ppm or less, 3.5 ppm or less, 3 ppm or less, 2.5 ppm or less, 2 ppm or less, 1.5 ppm or less, 1 ppm or less, 0.75 ppm or less, 0.5 ppm or less. 0.25 ppm or less. 0.1 ppm or less. 0.075 ppm or less, 0.05 ppm or less. 0.025 ppm or less, 0.01 ppm or less. 0.0075 ppm or less, or 0.005 ppm or less). In some examples, the wax has a silicon content of 0 ppm or more (e.g., 0.001 ppm or more, 0.0025 ppm or more, 0.005 ppm or more, 0.0075 ppm or more. 0.01 ppm or more, 0.025 ppm or more, 0.05 ppm or more. 0.075 ppm or more. 0.1 ppm or more. 0.25 ppm or more, 0.5 ppm or more, 0.75 ppm or more, 1 ppm or more, 1.5 ppm or more, 2 ppm or more, 2.5 ppm or more, 3 ppm or more. 3.5 ppm or more. 4 ppm or more, 4.5 ppm or more, 5 ppm or more. 6 ppm or more. 7 ppm or more, 8 ppm or more. 9 ppm or more, 10 ppm or more. 15 ppm or more, 20 ppm or more, 25 ppm or more, 30 ppm or more, 35 ppm or more, 40 ppm or more, 45 ppm or more, 50 ppm or more. 75 ppm or more, or 100 ppm or more). The silicon content of the wax can range from any of the minimum values described above to any of the maximum values described above. For example, the wax can have a silicon content of from 0 to 125 ppm (e.g., from 0 to 60 ppm, from 60 ppm to 125 ppm. from 0 to 25 ppm. from 25 to 50 ppm, from 50 to 75 ppm. from 75 to 100 ppm, from 100 to 125 ppm, from 0.001 to 100 ppm, from 0.001 to 75 ppm, from 0.001 to 50 ppm, from 0.001 to 45 ppm, from 0.001 to 40 ppm, from 0.001 to 35 ppm, from 0.001 to 30 ppm, from 0.001 to 25 ppm. from 0.001 to 20 ppm. from 0.001 to 15 ppm. from 0.001 to 10 ppm, from 0.001 to 5 ppm, from 0.001 to 1 ppm, from 0.001 to 0.1 ppm, from 0.001 to 0.01 ppm, from 0 to 100 ppm, from 0 to 75 ppm, from 0 to 50 ppm. from 0 to 45 ppm, from 0 to 40 ppm, from 0 to 35 ppm, from 0 to 30 ppm, from 0 to 25 ppm, from 0 to 20 ppm. from 0 to 15 ppm, from 0 to 10 ppm, from 0 to 5 ppm, from 0 to 1 ppm, from 0 to 0.1 ppm, or from 0 to 0.01 ppm). In some examples, the wax is substantially free of silicon. The silicon content of the wax can be determine using any suitable method. such as those known in the art. For example, the silicon content of the wax can be determined using ASTM D 5185.

The wax can, for example, have a sodium content of 150 ppm or less (e.g., 125 ppm or less, 100 ppm or less, 75 ppm or less, 50 ppm or less. 45 ppm or less, 40 ppm or less. 35 ppm or less, 30 ppm or less, 25 ppm or less, 20 ppm or less, 15 ppm or less, 10 ppm or less, 9 ppm or less, 8 ppm or less, 7 ppm or less, 6 ppm or less, 5 ppm or less, 4.5 ppm or less, 4 ppm or less, 3.5 ppm or less. 3 ppm or less. 2.5 ppm or less, 2 ppm or less, 1.5 ppm or less, 1 ppm or less, 0.75 ppm or less, 0.5 ppm or less, 0.25 ppm or less, 0.1 ppm or less, 0.075 ppm or less, 0.05 ppm or less, 0.025 ppm or less, 0.01 ppm or less, 0.0075 ppm or less, or 0.005 ppm or less). In some examples, the wax has a sodium content of 0 ppm or more (e.g., 0.001 ppm or more, 0.0025 ppm or more, 0.005 ppm or more, 0.0075 ppm or more, 0.01 ppm or more, 0.025 ppm or more, 0.05 ppm or more, 0.075 ppm or more, 0.1 ppm or more, 0.25 ppm or more, 0.5 ppm or more, 0.75 ppm or more, 1 ppm or more, 1.5 ppm or more, 2 ppm or more, 2.5 ppm or more, 3 ppm or more, 3.5 ppm or more, 4 ppm or more, 4.5 ppm or more, 5 ppm or more, 6 ppm or more, 7 ppm or more, 8 ppm or more, 9 ppm or more, 10 ppm or more, 15 ppm or more, 20 ppm or more, 25 ppm or more, 30 ppm or more, 35 ppm or more, 40 ppm or more, 45 ppm or more, 50 ppm or more, 75 ppm or more, 100 ppm or more, or 125 ppm or more). The sodium content can range from any of the minimum values described above to any of the maximum values described above. For example, the wax can have a sodium content of from 0 to 150 ppm (e.g., from 0 to 75 ppm, from 75 to 150 ppm, from 0 to 50 ppm, from 50 to 100 ppm, from 100 to 150 ppm, from 0.001 to 150 ppm, from 0.001 to 125 ppm, from 0.001 to 100 ppm, from 0.001 to 75 ppm, from 0.001 to 50 ppm, from 0.001 to 45 ppm, from 0.001 to 40 ppm, from 0.001 to 35 ppm, from 0.001 to 30 ppm, from 0.001 to 25 ppm, from 0.001 to 20 ppm, from 0.001 to 15 ppm, from 0.001 to 10 ppm, from 0.001 to 5 ppm, from 0.001 to 1 ppm, from 0.001 to 0.1 ppm, from 0.001 to 0.01 ppm, from 0 to 125 ppm, from 0 to 100 ppm, from 0 to 75 ppm, from 0 to 50 ppm, from 0 to 45 ppm, from 0 to 40 ppm, from 0 to 35 ppm, from 0 to 30 ppm, from 0 to 25 ppm, from 0 to 20 ppm, from 0 to 15 ppm, from 0 to 10 ppm, from 0 to 5 ppm, from 0 to 1 ppm, from 0 to 0.1 ppm, or from 0 to 0.01 ppm). In some examples, the wax is substantially free of sodium. The sodium content of the wax can be determined by any suitable method, such as those known in the art. For example, the sodium content of the wax can be determined using ASTM D 5185.

The wax can, for example, have an iron content of 10 ppm or less (e.g., 9 ppm or less, 8 ppm or less, 7 ppm or less, 6 ppm or less, 5 ppm or less, 4.5 ppm or less, 4 ppm or less, 3.5 ppm or less, 3 ppm or less, 2.5 ppm or less, 2 ppm or less, 1.5 ppm or less, 1 ppm or less, 0.75 ppm or less, 0.5 ppm or less, 0.25 ppm or less, 0.1 ppm or less, 0.075 ppm or less, 0.05 ppm or less, 0.025 ppm or less, 0.01 ppm or less, 0.0075 ppm or less, or 0.005 ppm or less). In some examples, the wax can have an iron content of 0 ppm or more (e.g., 0.001 ppm or more, 0.0025 ppm or more, 0.005 ppm or more, 0.0075 ppm or more, 0.01 ppm or more, 0.025 ppm or more, 0.05 ppm or more, 0.075 ppm or more, 0.1 ppm or more, 0.25 ppm or more, 0.5 ppm or more, 0.75 ppm or more, 1 ppm or more, 1.5 ppm or more, 2 ppm or more, 2.5 ppm or more, 3 ppm or more, 3.5 ppm or more, 4 ppm or more, 4.5 ppm or more, 5 ppm or more, 6 ppm or more, 7 ppm or more, 8 ppm or more, or 9 ppm or more). The iron content of the wax can range from any of the minimum values described above to any of the maximum values described above. For example, the wax can have an iron content of from 0 to 10 ppm (e.g., from 0 to 5 ppm, from 5 to 10 ppm, from 1 to 2 ppm, from 2 to 4 ppm, from 4 to 6 ppm, from 6 to 8 ppm, from 8 to 10 ppm, from 0.001 to 10 ppm, from 0.001 to 9 ppm, from 0.001 to 8 ppm, from 0.001 to 7 ppm, from 0.001 to 6 ppm, from 0.001 to 5 ppm, from 0.001 to 4 ppm, from 0.001 to 3 ppm, from 0.001 to 2 ppm, from 0.001 to 1 ppm, from 0.001 to 0.1 ppm, from 0.001 to 0.01 ppm, from 0 to 9 ppm, from 0 to 8 ppm, from 0 to 7 ppm, from 0 to 6 ppm, from 0 to 5 ppm, from 0 to 4 ppm, from 0 to 3 ppm, from 0 to 1 ppm, from 0 to 0.1 ppm, or from 0 to 0.01 ppm). In some examples, the wax is substantially free of iron. The iron content of the wax can be determined using any suitable method, such as those known in the art. For example, the iron content of the wax can be determined using ASTM D 5185.

The wax can, for example, have a phosphorus content of 50 ppm or less (e.g., 45 ppm or less, 40 ppm or less, 35 ppm or less, 30 ppm or less, 25 ppm or less, 20 ppm or less, 15 ppm or less, 10 ppm or less, 9 ppm or less, 8 ppm or less, 7 ppm or less, 6 ppm or less, 5 ppm or less, 4.5 ppm or less, 4 ppm or less, 3.5 ppm or less, 3 ppm or less, 2.5 ppm or less, 2 ppm or less, 1.5 ppm or less, 1 ppm or less, 0.75 ppm or less, 0.5 ppm or less, 0.25 ppm or less, 0.1 ppm or less, 0.075 ppm or less, 0.05 ppm or less, 0.025 ppm or less, 0.01 ppm or less, 0.0075 ppm or less, or 0.005 ppm or less). In some examples, the wax can have a phosphorus content of 0 ppm or more (e.g., 0.001 ppm or more, 0.0025 ppm or more, 0.005 ppm or more, 0.0075 ppm or more, 0.01 ppm or more, 0.025 ppm or more, 0.05 ppm or more, 0.075 ppm or more, 0.1 ppm or more, 0.25 ppm or more, 0.5 ppm or more, 0.75 ppm or more, 1 ppm or more, 1.5 ppm or more, 2 ppm or more, 2.5 ppm or more, 3 ppm or more, 3.5 ppm or more, 4 ppm or more, 4.5 ppm or more, 5 ppm or more, 6 ppm or more, 7 ppm or more, 8 ppm or more, 9 ppm or more, 10 ppm or more, 15 ppm or more, 20 ppm or more, 25 ppm or more, 30 ppm or more, 35 ppm or more, 40 ppm or more, or 45 ppm or more). The phosphorus content of the wax can range from any of the minimum values described above to any of the maximum values described above. For example, the wax can have a phosphorus content of from 0 ppm to 50 ppm (e.g., from 0 to 25 ppm, from 25 to 50 ppm, from 0 to 10 ppm, from 10 to 20 ppm, from 20 to 30 ppm, from 30 to 40 ppm, from 40 to 50 ppm, from 0.001 to 50 ppm, from 0.001 to 45 ppm, from 0.001 to 40 ppm, from 0.001 to 35 ppm, from 0.001 to 30 ppm, from 0.001 to 25 ppm, from 0.001 to 20 ppm, from 0.001 to 15 ppm, from 0.001 to 10 ppm, from 0.001 to 5 ppm, from 0.001 to 1 ppm, from 0.001 to 0.1 ppm, from 0.001 to 0.01 ppm, from 0 to 45 ppm, from 0 to 40 ppm, from 0 to 35 ppm, from 0 to 30 ppm, from 0 to 25 ppm, from 0 to 20 ppm, from 0 to 15 ppm, from 0 to 10 ppm, from 0 to 5 ppm, from 0 to 1 ppm, from 0 to 0.1 ppm, or from 0 to 0.01 ppm). In some examples, the wax can be substantially free of phosphorus. The phosphorus content of the wax can be determined using any suitable method, such as those known in the art. In some examples, the nitrogen content of the wax is determined using ASTM D 5185.

The wax can, for example, have a sulfur content of 500 ppm or less (e.g., 475 ppm or less, 450 ppm or less, 425 ppm or less, 400 ppm or less, 375 ppm or less, 350 ppm or less, 325 ppm or less, 300 ppm or less, 275 ppm or less, 250 ppm or less, 225 ppm or less, 200 ppm or less, 175 ppm or less, 150 ppm or less, 125 ppm or less, 100 ppm or less, 75 ppm or less, 50 ppm or less, 45 ppm or less, 40 ppm or less, 35 ppm or less, 30 ppm or less, 25 ppm or less, 20 ppm or less, 15 ppm or less, 10 ppm or less, 9 ppm or less, 8 ppm or less, 7 ppm or less, 6 ppm or less, 5 ppm or less, 4.5 ppm or less, 4 ppm or less, 3.5 ppm or less, 3 ppm or less, 2.5 ppm or less, 2 ppm or less, 1.5 ppm or less, 1 ppm or less, 0.75 ppm or less, 0.5 ppm or less, 0.25 ppm or less, 0.1 ppm or less, 0.075 ppm or less, 0.05 ppm or less, 0.025 ppm or less, 0.01 ppm or less, 0.0075 ppm or less, or 0.005 ppm or less). In some examples, the wax can have a sulfur content of 0 ppm or more (e.g., 0.001 ppm or more, 0.0025 ppm or more, 0.005 ppm or more, 0.0075 ppm or more, 0.01 ppm or more, 0.025 ppm or more, 0.05 ppm or more, 0.075 ppm or more, 0.1 ppm or more, 0.25 ppm or more, 0.5 ppm or more, 0.75 ppm or more, 1 ppm or more, 1.5 ppm or more, 2 ppm or more, 2.5 ppm or more, 3 ppm or more, 3.5 ppm or more, 4 ppm or more, 4.5 ppm or more, 5 ppm or more, 6 ppm or more, 7 ppm or more. 8 ppm or more, 9 ppm or more. 10 ppm or more. 15 ppm or more, 20 ppm or more, 25 ppm or more. 30 ppm or more, 35 ppm or more. 40 ppm or more. 45 ppm or more, 50 ppm or more, 75 ppm or more, 100 ppm or more, 125 ppm or more, 150 ppm or more, 175 ppm or more, 200 ppm or more. 225 ppm or more, 250 ppm or more, 275 ppm or more, 300 ppm or more. 325 ppm or more, 350 ppm or more, 375 ppm or more, 400 ppm or more, 425 ppm or more, or 450 ppm or more). The sulfur content of the wax can range from any of the minimum values described above to any of the maximum values described above. For example. the wax can have a sulfur content of from 0 to 500 ppm (e.g.. from 0 to 250 ppm, from 250 to 500 ppm, from 0 to 100 ppm, from 100 to 200 ppm, from 200 to 300 ppm, from 300 to 400 ppm. from 400 to 500 ppm. from 0.001 to 500 ppm. from 0.001 to 475 ppm. from 0.001 to 450 ppm. from 0.001 to 425 ppm. from 0.001 to 400 ppm. from 0.001 to 375 ppm. from 0.001 to 350 ppm, from 0.001 to 325 ppm, from 0.001 to 300 ppm, from 0.001 to 275 ppm, from 0.001 to 250 ppm, from 0.001 to 225 ppm. from 0.001 to 200 ppm. from 0.001 to 175 ppm. from 0.001 to 150 ppm. from 0.001 to 125 ppm. from 0.001 to 100 ppm, from 0.001 to 75 ppm, from 0.001 to 50 ppm, from 0.001 to 45 ppm, from 0.001 to 40 ppm, from 0.001 to 35 ppm, from 0.001 to 30 ppm, from 0.001 to 25 ppm. from 0.001 to 20 ppm, from 0.001 to 15 ppm. from 0.001 to 10 ppm. from 0.001 to 5 ppm, from 0.001 to 1 ppm. from 0.001 to 0.1 ppm, from 0.001 to 0.01 ppm, from 0 to 475 ppm, from 0 to 450 ppm, from 0 to 425 ppm, from 0 to 400 ppm. from 0 to 375 ppm. from 0 to 350 ppm, from 0 to 325 ppm. from 0 to 300 ppm. from 0 to 275 ppm, from 0 to 250 ppm. from 0 to 225 ppm. from 0 to 200 ppm, from 0 to 175 ppm, from 0 to 150 ppm, from 0 to 125 ppm, from 0 to 100 ppm, from 0 to 75 ppm, from 0 to 50 ppm, from 0 to 45 ppm. from 0 to 40 ppm. from 0 to 35 ppm. from 0 to 30 ppm. from 0 to 25 ppm, from 0 to 20 ppm. from 0 to 15 ppm, from 0 to 10 ppm. from 0 to 5 ppm, from 0 to 1 ppm. from 0 to 0.1 ppm, or from 0 to 0.01 ppm). In some examples, the wax can be substantially free of sulfur. The sulfur content of the wax can be determined by any suitable methods. such as those known in the art. In some examples. the sulfur content of the wax is determined using ASTM D 4294.

The wax can, for example, have a calcium content of 50 ppm or less (e.g., 45 ppm or less, 40 ppm or less, 35 ppm or less, 30 ppm or less. 25 ppm or less, 20 ppm or less. 15 ppm or less, 10 ppm or less. 9 ppm or less. 8 ppm or less. 7 ppm or less, 6 ppm or less, 5 ppm or less, 4.5 ppm or less, 4 ppm or less, 3.5 ppm or less, 3 ppm or less, 2.5 ppm or less, 2 ppm or less. 1.5 ppm or less. 1 ppm or less, 0.75 ppm or less. 0.5 ppm or less, 0.25 ppm or less. 0.1 ppm or less, 0.075 ppm or less. 0.05 ppm or less, 0.025 ppm or less. 0.01 ppm or less, 0.0075 ppm or less, or 0.005 ppm or less). In some examples, the wax can have a calcium content of 0 ppm or more (e.g., 0.001 ppm or more. 0.0025 ppm or more, 0.005 ppm or more, 0.0075 ppm or more. 0.01 ppm or more, 0.025 ppm or more, 0.05 ppm or more, 0.075 ppm or more, 0.1 ppm or more, 0.25 ppm or more, 0.5 ppm or more, 0.75 ppm or more, 1 ppm or more, 1.5 ppm or more, 2 ppm or more, 2.5 ppm or more, 3 ppm or more, 3.5 ppm or more. 4 ppm or more. 4.5 ppm or more. 5 ppm or more, 6 ppm or more. 7 ppm or more, 8 ppm or more, 9 ppm or more, 10 ppm or more, 15 ppm or more, 20 ppm or more, 25 ppm or more, 30 ppm or more. 35 ppm or more. or 40 ppm or more). The calcium content of the wax can range from any of the minimum values described above to any of the maximum values described above. For example, the wax can have a calcium content of from 0 to 50 ppm (e.g., from 0 to 25 ppm, from 25 to 50 ppm, from 0 to 10 ppm, from 10 to 20 ppm, from 20 to 30 ppm, from 30 to 40 ppm. from 40 to 50 ppm, from 0.001 to 50 ppm. from 0.001 to 45 ppm. from 0.001 to 40 ppm, from 0.001 to 35 ppm. from 0.001 to 30 ppm, from 0.001 to 25 ppm, from 0.001 to 20 ppm, from 0.001 to 15 ppm, from 0.001 to 10 ppm, from 0.001 to 5 ppm, from 0.001 to 1 ppm, from 0.001 to 0.1 ppm. from 0.001 to 0.01 ppm. from 0 to 45 ppm, from 0 to 40 ppm, from 0 to 35 ppm, from 0 to 30 ppm, from 0 to 25 ppm, from 0 to 20 ppm, from 0 to 15 ppm, from 0 to 10 ppm, from 0 to 5 ppm, from 0 to 1 ppm, from 0 to 0.1 ppm, or from 0 to 0.01 ppm). In some examples, the wax can be substantially free of calcium. The calcium content of the wax can be determined using any suitable methods, such as those known in the art. In some examples, the calcium content of the wax can be determined using ASTM D 5185.

The wax can. for example. have a copper content of 10 ppm or less (e.g., 9 ppm or less, 8 ppm or less. 7 ppm or less, 6 ppm or less, 5 ppm or less, 4.5 ppm or less, 4 ppm or less, 3.5 ppm or less, 3 ppm or less, 2.5 ppm or less, 2 ppm or less, 1.5 ppm or less, 1 ppm or less, 0.75 ppm or less. 0.5 ppm or less. 0.25 ppm or less. 0.1 ppm or less. 0.075 ppm or less, 0.05 ppm or less, 0.025 ppm or less, 0.01 ppm or less, 0.0075 ppm or less, or 0.005 ppm or less). In some examples, the wax can have a copper content of 0 ppm or more (e.g., 0.001 ppm or more. 0.0025 ppm or more, 0.005 ppm or more, 0.0075 ppm or more, 0.01 ppm or more. 0.025 ppm or more, 0.05 ppm or more, 0.075 ppm or more, 0.1 ppm or more, 0.25 ppm or more, 0.5 ppm or more, 0.75 ppm or more, 1 ppm or more. 1.5 ppm or more. 2 ppm or more, 2.5 ppm or more, 3 ppm or more, 3.5 ppm or more. 4 ppm or more. 4.5 ppm or more. 5 ppm or more, 6 ppm or more. 7 ppm or more, or 8 ppm or more). The copper content of the wax can range from any of the minimum values described above to any of the maximum values described above. For example. the wax can have a copper content of from 0 ppm to 10 ppm (e.g., from 0 to 5 ppm, from 5 to 10 ppm. from 1 to 2 ppm, from 2 to 4 ppm, from 4 to 6 ppm, from 6 to 8 ppm, from 8 to 10 ppm, from 0.001 to 10 ppm, from 0.001 to 9 ppm, from 0.001 to 8 ppm. from 0.001 to 7 ppm. from 0.001 to 6 ppm, from 0.001 to 5 ppm. from 0.001 to 4 ppm, from 0.001 to 3 ppm, from 0.001 to 2 ppm, from 0.001 to 1 ppm, from 0.001 to 0.1 ppm, from 0.001 to 0.01 ppm, from 0 to 9 ppm, from 0 to 8 ppm, from 0 to 7 ppm, from 0 to 6 ppm, from 0 to 5 ppm. from 0 to 4 ppm, from 0 to 3 ppm, from 0 to 1 ppm, from 0 to 0.1 ppm. or from 0 to 0.01 ppm). In some examples, the wax can be substantially free of copper. The copper content of the wax can be determine using any suitable method, such as those known in the art. For example, the copper content of the wax can be determined using ASTM D 5185.

The wax can, for example, have a nickel content of 100 ppm or less (e.g., 95 ppm or less, 90 ppm or less, 85 ppm or less. 80 ppm or less, 75 ppm or less. 70 ppm or less, 65 ppm or less, 60 ppm or less. 55 ppm or less, 50 ppm or less. 45 ppm or less, 40 ppm or less, 35 ppm or less, 30 ppm or less, 25 ppm or less, 20 ppm or less, 15 ppm or less, 10 ppm or less, 9 ppm or less, 8 ppm or less, 7 ppm or less, 6 ppm or less. 5 ppm or less. 4.5 ppm or less, 4 ppm or less, 3.5 ppm or less, 3 ppm or less, 2.5 ppm or less. 2 ppm or less. 1.5 ppm or less, 1 ppm or less, 0.75 ppm or less, 0.5 ppm or less, 0.25 ppm or less, 0.1 ppm or less, 0.075 ppm or less, 0.05 ppm or less. 0.025 ppm or less, 0.01 ppm or less, 0.0075 ppm or less. or 0.005 ppm or less). In some examples. the wax can have a nickel content of 0 ppm or more (e.g., 0.001 ppm or more, 0.0025 ppm or more, 0.005 ppm or more, 0.0075 ppm or more, 0.01 ppm or more, 0.025 ppm or more, 0.05 ppm or more, 0.075 ppm or more, 0.1 ppm or more, 0.25 ppm or more. 0.5 ppm or more. 0.75 ppm or more. 1 ppm or more. 1.5 ppm or more, 2 ppm or more, 2.5 ppm or more. 3 ppm or more. 3.5 ppm or more, 4 ppm or more, 4.5 ppm or more. 5 ppm or more, 6 ppm or more, 7 ppm or more, 8 ppm or more, 9 ppm or more, 10 ppm or more, 15 ppm or more, 20 ppm or more, 25 ppm or more, 30 ppm or more, 35 ppm or more. 40 ppm or more, 45 ppm or more, 50 ppm or more. 55 ppm or more, 60 ppm or more. 65 ppm or more. 70 ppm or more. 75 ppm or more, 80 ppm or more, 85 ppm or more. or 90 ppm or more). The nickel content of the wax can range from any of the minimum values described above to any of the maximum values described above. For example, the wax can have a nickel content of from 0 to 100 ppm (e.g.. from 0 to 50 ppm, from 50 to 100 ppm, from 0 to 20 ppm. from 20 to 40 ppm. from 40 to 60 ppm. from 60 to 80 ppm, from 80 to 100 ppm, from 0.001 to 100 ppm, from 0.001 to 75 ppm, from 0.001 to 50 ppm, from 0.001 to 45 ppm, from 0.001 to 40 ppm, from 0.001 to 35 ppm, from 0.001 to 30 ppm. from 0.001 to 25 ppm. from 0.001 to 20 ppm, from 0.001 to 15 ppm. from 0.001 to 10 ppm, from 0.001 to 5 ppm, from 0.001 to 1 ppm, from 0.001 to 0.1 ppm, from 0.001 to 0.01 ppm, from 0 to 75 ppm, from 0 to 50 ppm, from 0 to 45 ppm, from 0 to 40 ppm, from 0 to 35 ppm, from 0 to 30 ppm. from 0 to 25 ppm. from 0 to 20 ppm, from 0 to 15 ppm, from 0 to 10 ppm, from 0 to 5 ppm. from 0 to 1 ppm, from 0 to 0.1 ppm, or from 0 to 0.01 ppm). In some examples, the wax can be substantially free of nickel. The nickel content of the wax can be determined using any suitable method. such as those known in the art. For example. the nickel content can be determined using ASTM D 5185.

The wax can, for example, have a vanadium content of 25 ppm or less (e.g.. 20 ppm or less. 15 ppm or less. 10 ppm or less, 9 ppm or less, 8 ppm or less. 7 ppm or less, 6 ppm or less, 5 ppm or less, 4.5 ppm or less. 4 ppm or less. 3.5 ppm or less, 3 ppm or less, 2.5 ppm or less, 2 ppm or less, 1.5 ppm or less, 1 ppm or less, 0.75 ppm or less, 0.5 ppm or less, 0.25 ppm or less, 0.1 ppm or less. 0.075 ppm or less. 0.05 ppm or less, 0.025 ppm or less. 0.01 ppm or less. 0.0075 ppm or less, or 0.005 ppm or less). In some examples, the wax can have a vanadium content of 0 ppm or more (e.g., 0.001 ppm or more, 0.0025 ppm or more, 0.005 ppm or more, 0.0075 ppm or more. 0.01 ppm or more, 0.025 ppm or more. 0.05 ppm or more, 0.075 ppm or more. 0.1 ppm or more, 0.25 ppm or more, 0.5 ppm or more, 0.75 ppm or more, 1 ppm or more, 1.5 ppm or more, 2 ppm or more, 2.5 ppm or more, 3 ppm or more, 3.5 ppm or more, 4 ppm or more. 4.5 ppm or more. 5 ppm or more, 6 ppm or more. 7 ppm or more. 8 ppm or more. 9 ppm or more. 10 ppm or more, 15 ppm or more, or 20 ppm or more). The vanadium content of the wax can range from any of the minimum values described above to any of the maximum values described above. For example. the wax can have a vanadium content of from 0 to 20 ppm (e.g., from 0 to 10 ppm, from 10 to 20 ppm, from 0 to 5 ppm, from 5 to 10 ppm, from 10 to 15 ppm, from 15 to 20 ppm, from 0.001 to 20 ppm, from 0.001 to 15 ppm, from 0.001 to 10 ppm, from 0.001 to 5 ppm, from 0.001 to 1 ppm. from 0.001 to 0.1 ppm. from 0.001 to 0.01 ppm, from 0 to 15 ppm, from 0 to 10 ppm, from 0 to 5 ppm, from 0 to 1 ppm, from 0 to 0.1 ppm, or from 0 to 0.01 ppm). In some examples. the wax can be substantially free of vanadium. The vanadium content of the wax can be determined using any suitable method. such as those known in the art. For example, the vanadium content of the wax can be determined using ASTM D 5185.

In some examples, the wax has a total chloride content of 50 ppm or less; a nitrogen content of 300 ppm or less; and a silicon content of 125 ppm or less. In some examples, the wax has a total chloride content of 50 ppm or less; a nitrogen content of 300 ppm or less; a silicon content of 125 ppm or less; and a sodium content of 150 ppm or less. In some examples, the wax has a total chloride content of 50 ppm or less; a nitrogen content of 300 ppm or less: a silicon content of 125 ppm or less: a sodium content of 150 ppm or less: an iron content of 10 ppm or less; a sulfur content of 500 ppm or less; and a calcium content of 50 ppm or less. In some examples, the wax has a total chloride content of 50 ppm or less; a nitrogen content of 300 ppm or less; a silicon content of 125 ppm or less: a sodium content of 150 ppm or less: an iron content of 10 ppm or less; a phosphorus content of 50 ppm or less: a sulfur content of 500 ppm or less; and a calcium content of 50 ppm or less. In some examples, the wax has a total chloride content of 50 ppm or less; a nitrogen content of 300 ppm or less; a silicon content of 125 ppm or less; a sodium content of 150 ppm or less: an iron content of 10 ppm or less; a phosphorus content of 50 ppm or less: a sulfur content of 500 ppm or less; a calcium content of 50 ppm or less; a copper content of 10 ppm or less; a nickel content of 100 ppm or less; and a vanadium content of 25 ppm or less.

In some examples. the wax has a total chloride content of 25 ppm or less; a nitrogen content of 300 ppm or less; and a silicon content of 100 ppm or less. In some examples, the wax has a total chloride content of 25 ppm or less; a nitrogen content of 300 ppm or less: a silicon content of 100 ppm or less; and a sodium content of 10 ppm or less. In some examples, the wax has: a total chloride content of 25 ppm or less; a nitrogen content of 300 ppm or less; a silicon content of 100 ppm or less: a sodium content of 10 ppm or less; an iron content of 10 ppm or less; a sulfur content of 10 ppm or less; and a calcium content of 5 ppm or less. In some examples, the wax has a total chloride content of 25 ppm or less; a nitrogen content of 300 ppm or less; a silicon content of 100 ppm or less: a sodium content of 10 ppm or less; an iron content of 10 ppm or less; a phosphorus content of 50 ppm or less; a sulfur content of 10 ppm or less; and a calcium content of 5 ppm or less. In some examples, the wax has a total chloride content of 25 ppm or less; a nitrogen content of 300 ppm or less; a silicon content of 100 ppm or less: a sodium content of 10 ppm or less: an iron content of 10 ppm or less; a phosphorus content of 50 ppm or less; a sulfur content of 10 ppm or less; a calcium content of 5 ppm or less; a copper content of 10 ppm or less; a nickel content of 100 ppm or less: and a vanadium content of 25 ppm or less.

The wax can. for example, have a Gardner color of 2 or more (e.g., 2.5 or more, 3 or more, 3.5 or more, 4 or more, 4.5 or more, 5 or more, 5.5 or more, 6 or more, 6.5 or more, 7 or more, or 7.5 or more). In some examples, the wax can have a Gardner color of 8 or less (e.g.. 7.5 or less, 7 or less, 6.5 or less, 6 or less, 5.5 or less, 5 or less, 4.5 or less, 4 or less, 3.5 or less, 3 or less, or 2.5 or less). The Gardner color of the wax can range from any of the minimum values described above to any of the maximum values described above. For example. the wax can have a Gardner color of from 2 to 8 (e.g., from 2 to 5, from 5 to 8, from 2 to 4, from 4 to 6, from 6 to 8, from 2 to 7, from 2 to 6, from 3 to 8, from 4 to 8, from 2.5 to 7.5. from 2.5 to 8. or from 6.5 to 8). The Gardner color of the wax can be determine using any suitable method, such as those known in the art. For example, the Gardner color of the wax can be determined using ASTM D 1500.

The wax can, for example, have an oil content of 5% or more by weight (e.g., 10% or more, 15% or more, 20% or more, 25% or more, 30% or more, 35% or more, or 40% or more). In some examples, the wax can have an oil content of 50% or less (e.g., 45% or less, 40% or less, 35% or less, 30% or less, 25% or less, 20% or less, 15% or less, or 10% or less). The oil content of the wax can range from any of the minimum values described above to any of the maximum values described above. For example, the wax can have an oil content of from 5% to 50% (e.g., from 5% to 25%, from 25% to 50%, from 5% to 15%, from 10% to 15%, from 15% to 20%, from 20% to 25%, from 25% to 30%, from 30% to 35%, from 35% to 40%, from 40% to 45%, from 45% to 50%, from 5% to 45%, from 5% to 40%, from 5% to 35%, from 5% to 30%, from 5% to 20%, from 5% to 15%, from 10% to 50%, from 15% to 50%, from 20% to 50%, from 30% to 50%, from 35% to 50%, from 40% to 50%, from 10% to 45%, or from 25% to 45%). The oil content of the wax can be determined using any suitable method, for example those known in the art. For example, the oil content of the wax can be determined using ASTM D 721.

The wax can, for example, have a Reid Vapor Pressure of 12.5 psig or less (e.g., 12 psig or less, 11.5 psig or less, 11 psig or less, 10.5 psig or less, 10 psig or less, 9.5 psig or less, 9 psig or less, 8.5 psig or less, 8 psig or less, 7.5 psig or less, 7 psig or less, 6.5 psig or less, 6 psig or less, 5.5 psig or less, 5 psig or less, 4.5 psig or less, 4 psig or less, 3.5 psig or less, 3 psig or less, or 2.5 psig or less). In some examples, the wax can have a Reid Vapor Pressure of 2 psig or more (e.g., 2.5 psig or more, 3 psig or more, 3.5 psig or more, 4 psig or more, 4.5 psig or more, 5 psig or more, 5.5 psig or more, 6 psig or more, 6.5 psig or more, 7 psig or more, 7.5 psig or more, 8 psig or more, 8.5 psig or more, 9 psig or more, 9.5 psig or more, 10 psig or more, 10.5 psig or more, or 11 psig or more). The Reid Vapor Pressure of the wax can range from any of the minimum values described above to any of the maximum values described above. For example, the wax can have a Reid Vapor Pressure of from 2 to 12.5 psig (e.g., from 5 to 7 psig, from 7 to 12.5 psig, from 2 to 4 psig, from 4 to 6 psig, from 6 to 8 psig, from 8 to 10 psig, from 10 to 12.5 psig, from 2 to 12 psig, from 2 to 11 psig, from 2 to 10 psig, from 2 to 9 psig, from 2 to 8 psig, from 2 to 6 psig, from 2 to 5 psig, from 3 to 12.5 psig, from 4 to 12.5 psig, from 5 to 12.5 psig, from 6 to 12.5 psig, from 7 to 12.5 psig, from 8 to 12.5 psig, from 9 to 12.5 psig, from 3 to 12 psig, from 5 to 11 psig, or from 7 to 10 psig). The Reid Vapor Pressure of the wax can be determined using any suitable method, such as those known in the art. For example, the Reid Vapor Pressure of the wax can be determined using ASTM D 5191.

The wax can, for example, have a water by distillation amount of 0.5 vol. % or less (e.g., 0.45 vol. % or less, 0.4 vol. % or less, 0.35 vol. % or less, 0.3 vol. % or less, 0.25 vol. % or less, 0.2 vol. % or less, 0.15 vol. % or less, 0.1 vol. % or less, 0.075 vol. % or less, 0.05 vol. % or less, 0.025 vol. % or less, or 0.01 vol. % or less). In some examples, the wax can have a water by distillation amount of 0 vol. % or more (e.g., 0.01 vol. % or more, 0.025 vol. % or more, 0.05 vol. % or more, 0.075 vol. % or more, 0.1 vol. % or more, 0.15 vol. % or more, 0.2 vol. % or more, 0.25 vol. % or more, 0.3 vol. % or more, 0.35 vol. % or more, or 0.4 vol. % or more). The amount of water by distillation in the wax can range from any of the minimum values described above to any of the maximum values described above. For example, the wax can have a water by distillation amount of from 0 to 0.5 vol. % (e.g., from 0 to 0.25 vol. %, from 0.25 to 0.5 vol. %, from 0 to 0.1 vol. %, from 0.1 to 0.2 vol. %, from 0.2 to 0.3 vol. %, from 0.3 to 0.4 vol. %, from 0.4 to 0.5 vol. %, from 0 to 0.4 vol. %, from 0 to 0.3 vol. %, from 0 to 0.2 vol. %, from 0 to 0.05 vol. %, or from 0 to 0.01 vol. %). The amount of water by distillation in the wax can be determined by any suitable method, such as those known in the art. For example, the water by distillation amount in the wax can be determined using ASTM D 95.

The wax can, for example, have a total sediment content of 0.5 vol. % or less (e.g., 0.45 vol. % or less, 0.4 vol. % or less, 0.35 vol. % or less, 0.3 vol. % or less, 0.25 vol. % or less, 0.2 vol. % or less, 0.15 vol. % or less, 0.1 vol. % or less, 0.075 vol. % or less, 0.05 vol. % or less, 0.025 vol. % or less, or 0.01 vol. % or less). In some examples, the wax can have a total sediment content of 0 vol. % or more (e.g., 0.01 vol. % or more, 0.025 vol. % or more, 0.05 vol. % or more, 0.075 vol. % or more, 0.1 vol. % or more, 0.15 vol. % or more, 0.2 vol. % or more, 0.25 vol. % or more, 0.3 vol. % or more, 0.35 vol. % or more, or 0.4 vol. % or more). The total sediment content of the wax can range from any of the minimum values described above to any of the maximum values described above. For example, the wax can have a total sediment content of from 0 to 0.5 vol. % (e.g., from 0 to 0.25 vol. %, from 0.25 to 0.5 vol. %, from 0 to 0.1 vol. %, from 0.1 to 0.2 vol. %, from 0.2 to 0.3 vol. %, from 0.3 to 0.4 vol. %, from 0.4 to 0.5 vol. %, from 0 to 0.4 vol. %, from 0 to 0.3 vol. %, from 0 to 0.2 vol. %, from 0 to 0.05 vol. %, or from 0 to 0.01 vol. %). The total sediment content of the wax can be determined by any suitable method, such as those known in the art. For example, the total sediment content of the wax can be determined using ASTM D 4870.

The wax can, for example, have an n-heptane insoluble content of 0.5 wt. % or less (e.g., 0.45 wt. % or less, 0.4 wt. % or less, 0.35 wt. % or less, 0.3 wt. % or less, 0.25 wt. % or less, 0.2 wt. % or less, 0.15 wt. % or less, 0.1 wt. % or less, 0.075 wt. % or less, 0.05 wt. % or less, 0.025 wt. % or less, or 0.01 wt. % or less). In some examples, the wax can have an n-heptane insoluble content of 0 wt. % or more (e.g., 0.01 wt. % or more, 0.025 wt. % or more, 0.05 wt. % or more, 0.075 wt. % or more, 0.1 wt. % or more, 0.15 wt. % or more, 0.2 wt. % or more, 0.25 wt. % or more, 0.3 wt. % or more, 0.35 wt. % or more, or 0.4 wt. % or more). The n-heptane insoluble content of the wax can range from any of the minimum values described above to any of the maximum values described above. For example, the wax can have an n-heptane insoluble content of from 0 to 0.5 wt. % (e.g., from 0 to 0.25 wt. %, from 0.25 to 0.5 wt. %, from 0 to 0.1 wt. %, from 0.1 to 0.2 wt. %, from 0.2 to 0.3 wt. %, from 0.3 to 0.4 wt. %, from 0.4 to 0.5 wt. %, from 0 to 0.4 wt. %, from 0 to 0.3 wt. %, from 0 to 0.2 wt. %, from 0 to 0.05 wt. %, or from 0 to 0.01 wt. %). The n-heptane insoluble content of the wax can be determined by any suitable method, such as those known in the art. For example, the n-heptane insoluble content of the wax can be determined using ASTM D 3279.

The wax can, for example, have a total acid number of 1 mg KOH/g or less (e.g., 0.9 mg KOH/g or less, 0.8 mg KOH/g or less, 0.7 mg KOH/g or less, 0.6 mg KOH/g or less, 0.5 mg KOH/g or less, 0.4 mg KOH/g or less, 0.3 mg KOH/g or less, 0.2 mg KOH/g or less, or 0.1 mg KOH/g or less). In some examples, the wax can have a total acid number of 0 mg KOH/g or more (e.g., 0.1 mg KOH/g or more, 0.2 mg KOH/g or more, 0.3 mg KOH/g or more, 0.4 mg KOH/g or more, 0.5 mg KOH/g or more, 0.6 mg KOH/g or more, 0.7 mg KOH/g or more, 0.8 mg KOH/g or more, or 0.9 mg KOH/g or more). The total acid number of the wax can range from any of the minimum values described above to any of the maximum values described above. For example, the wax can have a total acid number of from 0 to

1 mg KOH/g (e.g., from 0 to 0.5 mg KOH/g, from 0.5 to 1 mg KOH/g, from 0 to 0.2 mg KOH/g, from 0.2 to 0.4 mg KOH/g, from 0.4 to 0.6 mg KOH/g, from 0.6 to 0.8 mg KOH/g, from 0.8 to 1 mg KOH/g, from 0 to 0.8 mg KOH/g, from 0 to 0.6 mg KOH/g, from 0 to 0.4 mg KOH/g, or from 0 to 0.1 mg KOH/g). The total acid number of the wax can be determined using any suitable method, such as those known in the art. For example, the total acid number of the wax can be determined using ASTM D 664.

In some examples, the wax has a Reid Vapor Pressure of 12.5 psig or less; and a final boiling point of 950° F. to 1300° F. In some examples, the wax has a Reid Vapor Pressure of from 7 to 10 psig; and a final boiling point of from 995° F. to 1235° F.

In some examples, the wax has a Reid Vapor Pressure of 12.5 psig or less; and a pour point of 30° F. to 60° F. In some examples, the wax has a Reid Vapor Pressure of from 7 to 10 psig; and a pour point of from 33° F. to 52° F.

In some examples, the wax has a final boiling point of 950° F. to 1300° F.; and a pour point of 30° F. to 60° F. In some examples, the wax has a final boiling point of from 995° F. to 1235° F.; and a pour point of from 33° F. to 52° F.

In some examples, the wax has a Reid Vapor Pressure of 12.5 psig or less; a final boiling point of 950° F. to 1300° F.; and a pour point of 30° F. to 60° F. In some examples, the wax has a Reid Vapor Pressure of from 7 to 10 psig; a final boiling point of from 995° F. to 1235° F.; and a pour point of from 33° F. to 52° F.

In some examples, the wax has a Reid Vapor Pressure of 12.5 psig or less; a final boiling point of 950° F. to 1300° F.; a pour point of 30° F. to 60° F.; a total chloride content of 50 ppm or less; a nitrogen content of 300 ppm or less; a silicon content of 125 ppm or less; a sodium content of 150 ppm or less; an iron content of 10 ppm or less; a phosphorus content of 50 ppm or less; a sulfur content of 500 ppm or less; and a calcium content of 50 ppm or less. In some examples, the wax has a Reid Vapor Pressure of from 7 to 10 psig; a final boiling point of from 995° F. to 1235° F.; a pour point of from 33° F. to 52° F.; a total chloride content of 25 ppm or less; a nitrogen content of 300 ppm or less; a silicon content of 100 ppm or less; a sodium content of 10 ppm or less; an iron content of 10 ppm or less; a phosphorus content of 50 ppm or less; a sulfur content of 10 ppm or less; and a calcium content of 5 ppm or less.

In some examples, the wax is a raw pyrolysis product, meaning the wax is produced by a method that substantially excludes any hydrotreatment or further refining steps after pyrolysis.

Oil

Also disclosed herein are oils derived from pyrolysis of a feedstock comprising post-consumer and/or post-industrial plastics. In some examples, the oil can be produced via pyrolysis at an industrial scale.

The oil can, for example, have a number average molecular weight and/or a weight average molecular weight of 50 Daltons or more (e.g., 55 Daltons or more, 60 Daltons or more, 65 Daltons or more, 70 Daltons or more, 75 Daltons or more, 80 Daltons or more, 85 Daltons or more, 90 Daltons or more, 95 Daltons or more, 100 Daltons or more, 110 Daltons or more, 120 Daltons or more, 130 Daltons or more, 140 Daltons or more, 150 Daltons or more, 160 Daltons or more, 170 Daltons or more, 180 Daltons or more, 190 Daltons or more, 200 Daltons or more, 225 Daltons or more, 250 Daltons or more, 275 Daltons or more, 300 Daltons or more, or 325 Daltons or more). In some examples, the oil can have a number average molecular weight and/or a weight average molecular weight of 350 Daltons or less (e.g., 325 Daltons or less, 300 Daltons or less, 275 Daltons or less, 250 Daltons or less, 225 Daltons or less, 200 Daltons or less, 190 Daltons or less, 180 Daltons or less, 170 Daltons or less, 160 Daltons or less, 150 Daltons or less, 140 Daltons or less, 130 Daltons or less, 120 Daltons or less, 110 Daltons or less, 100 Daltons or less, 95 Daltons or less, 90 Daltons or less, 85 Daltons or less, 80 Daltons or less, 75 Daltons or less, 70 Daltons or less, 65 Daltons or less, or 60 Daltons or less). The number average molecular weight and/or a weight average molecular weight of the oil can range from any of the minimum values described above to any of the maximum values described above. For example, the oil have a number average molecular weight and/or a weight average molecular weight of from 50 to 350 Daltons (e.g., from 50 to 200 Daltons, from 200 to 350 Daltons, from 50 to 150 Daltons, from 150 to 250 Daltons, from 250 to 350 Daltons, from 50 to 300 Daltons, from 50 to 250 Daltons, from 50 to 100 Daltons, from 75 to 350 Daltons, from 100 to 350 Daltons, from 150 to 350 Daltons, from 300 to 350 Daltons, from 75 to 325 Daltons, or from 100 to 300 Daltons).

The oil comprises a mixture of different hydrocarbons (e.g., linear, branched, cyclic, acyclic, saturated, unsaturated, aromatic, non-aromatic, etc.), any of which can optionally be substituted. In some examples, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and 90% or more of the mixture (w/w) comprises C_1-C_{20} hydrocarbons (e.g., 90.5% or more, 91% or more, 91.5% or more, 92% or more, 92.5% or more, 93% or more, 93.5% or more, 94% or more, 94.5% or more, 95% or more, 95.5% or more, 96% or more, 96.5% or more, 97% or more, 97.5% or more, 98% or more, 98.5% or more, or 99% or more). In some examples, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and 100% or less of the mixture (w/w) comprises C_1-C_{20} hydrocarbons (e.g., 99.5% or less, 99% or less, 98.5% or less, 98% or less, 97.5% or less, 97% or less, 96.5% or less, 96% or less, 95.5% or less, 95% or less, 94.5% or less, 94% or less, 93.5% or less, 93% or less, 92.5% or less, 92% or less, 91.5% or less, or 91% or less). The amount of the mixture comprising C_1-C_{20} hydrocarbons can range from any of the minimum values described above to any of the maximum values described above. For example, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and from 90% to 100% of the mixture (w/w) can comprise C_1-C_{20} hydrocarbons (e.g., from 90% to 95%, from 95% to 100%, from 90% to 92%, from 92% to 94%, from 94% to 96%, from 96% to 98%, from 98% to 100%, from 90% to 98%, from 90% to 96%, from 90% to 94%, from 92% to 100%, from 94% to 100%, from 96% to 100%, from 91% to 99%, from 92% to 98%, or from 92% to 96%).

The oil comprises a mixture of different hydrocarbons (e.g., linear, branched, cyclic, acyclic, saturated, unsaturated, aromatic, non-aromatic, etc.), any of which can optionally be substituted. In some examples, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and 90% or more of the mixture (w/w) comprises C_4-C_{20} hydrocarbons (e.g., 90.5% or more, 91% or more, 91.5% or more, 92% or more, 92.5% or more, 93% or more, 93.5% or more, 94% or more, 94.5% or more, 95% or more, 95.5% or more, 96% or more, 96.5% or more, 97% or more, 97.5% or more, 98% or more, 98.5% or more, or 99% or more). In some examples, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and 100% or less of the mixture (w/w) comprises C_4-C_{20} hydrocarbons (e.g., 99.5% or less, 99% or less, 98.5% or less, 98% or less, 97.5% or less, 97% or less, 96.5% or less. 96% or less, 95.5% or less, 95% or less. 94.5% or less. 94% or less, 93.5% or less, 93% or less. 92.5% or less. 92% or less. 91.5% or less, or 91% or less). The amount of the mixture comprising C_4-C_{20} hydrocarbons can range from any of the minimum values described above to any of the maximum values described above. For example. the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and from 90% to 100% of the mixture (w/w) can comprise C_4-C_{20} hydrocarbons (e.g., from 90% to 95%, from 95% to 100%, from 90% to 92%. from 92% to 94%. from 94% to 96%. from 96% to 98%, from 98% to 100%, from 90% to 98%. from 90% to 96%, from 90% to 94%, from 92% to 100%, from 94% to 100%, from 96% to 100%, from 91% to 99%, from 92% to 98%, or from 92% to 96%).

In some examples. the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted. and 0% or more of the mixture (w/w) can comprise C_{12}-C_{29} hydrocarbons (e.g., 0.5% or more, 1% or more, 1.5% or more. 2% or more. 2.5% or more, 3% or more, 3.5% or more. 4% or more. 4.5% or more, 5% or more, 5.5% or more, 6% or more, 6.5% or more, 7% or more, 7.5% or more, 8% or more, 8.5% or more, or 9% or more). In some examples, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and 10% or less of the mixture (w/w) can comprise C_{12}-C_{29} hydrocarbons (e.g., 9.5% or less, 9% or less, 8.5% or less, 8% or less, 7.5% or less, 7% or less, 6.5% or less, 6% or less, 5.5% or less, 5% or less, 4.5% or less. 4% or less. 3.5% or less, 3% or less. 2.5% or less. 2% or less, 1.5% or less. or 1% or less). The amount of the mixture comprising C_{12}-C_{29} hydrocarbons can range from any of the minimum values described above to any of the maximum values described above. For example, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted. and from 0% to 10% of the mixture (w/w) can comprise C_{12}-C_{29} hydrocarbons (e.g., from 0% to 5%, from 5% to 10%, from 0% to 2%, from 2% to 4%, from 4% to 6%, from 6% to 8%, from 8% to 10%. from 0% to 8%. from 0% to 6%. from 0% to 4%, from 1% to 10%, from 2% to 10%, from 4% to 10%, from 6% to 10%, from 0.5% to 9.5%, from 1% to 9%, or from 2% to 8%).

In some examples, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted. and 25% or more of the mixture (w/w) comprises C_1-C_8 hydrocarbons (e.g., 25.5% or more, 26% or more, 26.5% or more, 27% or more, 27.5% or more, 28% or more, 28.5% or more. 29% or more, 29.5% or more, 30% or more. 30.5% or more. 31% or more, 31.5% or more, 32% or more. 32.5% or more. 33% or more, 33.5% or more. or 34% or more). In some examples, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and 35% or less of the mixture (w/w) comprises C_1-C_8 hydrocarbons (e.g.. 34.5% or less, 34% or less, 33.5% or less, 33% or less, 32.5% or less, 32% or less, 31.5% or less, 31% or less, 30.5% or less, 30% or less, 29.5% or less, 29% or less, 28.5% or less, 28% or less, 27.5% or less, 27% or less, 26.5% or less, or 26% or less). The amount of the mixture comprising C_1-C_5 hydrocarbon can range from any of the minimum values described above to any of the maximum values described above. For example, the oil comprises a mixture of different hydrocarbons. any of which can optionally be substituted. and from 25% to 35% of the mixture (w/w) can comprise C_1-C_5 hydrocarbons (e.g., from 25% to 30%, from 30% to 35%, from 25% to 27%, from 27% to 29%, from 29% to 31%, from 31% to 33%, from 33% to 35%, from 25% to 33%, from 25% to 31%, from 25% to 29%. from 27% to 35%. from 29% to 35%. from 31% to 35%, from 25.5% to 34.5%, or from 26% to 34%).

In some examples, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and 25% or more of the mixture (w/w) comprises C_4-C_8 hydrocarbons (e.g.. 25.5% or more, 26% or more, 26.5% or more, 27% or more. 27.5% or more. 28% or more, 28.5% or more, 29% or more, 29.5% or more, 30% or more, 30.5% or more, 31% or more, 31.5% or more, 32% or more, 32.5% or more, 33% or more, 33.5% or more, or 34% or more). In some examples. the oil comprises a mixture of different hydrocarbons. any of which can optionally be substituted, and 35% or less of the mixture (w/w) comprises C_4-C_8 hydrocarbons (e.g., 34.5% or less, 34% or less, 33.5% or less. 33% or less. 32.5% or less. 32% or less, 31.5% or less, 31% or less, 30.5% or less. 30% or less, 29.5% or less, 29% or less. 28.5% or less, 28% or less, 27.5% or less. 27% or less, 26.5% or less, or 26% or less). The amount of the mixture comprising C_4-C_5 hydrocarbon can range from any of the minimum values described above to any of the maximum values described above. For example, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and from 25% to 35% of the mixture (w/w) can comprise C_4-C_5 hydrocarbons (e.g., from 25% to 30%. from 30% to 35%. from 25% to 27%. from 27% to 29%. from 29% to 31%. from 31% to 33%. from 33% to 35%, from 25% to 33%, from 25% to 31%, from 25% to 29%, from 27% to 35%, from 29% to 35%, from 31% to 35%, from 25.5% to 34.5%, or from 26% to 34%).

In some examples, the oil comprises a mixture of different hydrocarbons. any of which can optionally be substituted, and 55% or more of the mixture (w/w) can comprise C_9-C_{20} hydrocarbons (e.g., 55.5% or more, 56% or more, 56.5% or more, 57% or more. 57.5% or more. 58% or more, 58.5% or more, 59% or more. 59.5% or more. 60% or more, 60.5% or more, 61% or more. 61.5% or more. 62% or more, 62.5% or more, 63% or more, 63.5% or more, or 64% or more). In some examples, the oil comprises a mixture of different hydrocarbons. any of which can optionally be substituted, and 65% or less of the mixture (w/w) can comprise C_9-C_{20} hydrocarbons (e.g., 64.5% or less, 64% or less, 63.5% or less, 63% or less, 62.5% or less, 62% or less, 61.5% or less, 61% or less, 60.5% or less, 60% or less, 59.5% or less, 59% or less. 58.5% or less, 58% or less, 57.5% or less. 57% or less. 56.5% or less. or 56% or less). The amount of the mixture comprising C_9-C_{20} hydrocarbons can range from any of the minimum values described above to any of the maximum values described above. For example, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted. and from 55% to 65% of the mixture (w/w) can comprise C_9-C_{20} hydrocarbons (e.g., from 55% to 60%, from 60% to 65%, from 55% to 57%, from 57% to 59%, from 59% to 61%, from 61% to 63%, from 63% to 65%, from 55% to 63%, from 55% to 61%, from 55% to 59%, from 57% to 65%, from 59% to 65%, from 61% to 65%, from 55.5% to 64.5%, or from 56% to 64%).

In some examples, the oil comprises a mixture of different hydrocarbons. any of which can optionally be substituted, and 1% or more of the mixture (w/w) can comprise C_{21}-C_{29} hydrocarbons (e.g., 1.5% or more, 2% or more, 2.5% or more, 3% or more, 3.5% or more. 4% or more. 4.5% or more, 5% or more, 5.5% or more. 6% or more. 6.5% or more, 7% or more, 7.5% or more. 8% or more. 8.5% or more, or 9% or more). In some examples, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and 10% or less of the mixture (w/w) can comprise C_{21}-C_{29} hydrocarbons (e.g., 9.5% or less, 9% or less, 8.5% or less, 8% or less, 7.5% or less, 7% or less, 6.5% or less, 6% or less, 5.5% or less, 5% or less, 4.5% or less, 4% or less, 3.5% or less, 3% or less, 2.5% or less, or 2% or less). The amount of the mixture comprising C_{21}-C_{29} hydrocarbons can range from any of the minimum values described above to any of the maximum values described above. For example, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and from 1% to 10% of the mixture (w/w) can comprise C_{21}-C_{29} hydrocarbons (e.g., from 1% to 4.5%, from 4.5% to 10%, from 1% to 4%, from 4% to 7%, from 7% to 10%, from 1% to 9%, from 1% to 8%, from 1% to 7%, from 1% to 6%, from 1% to 5%, from 1% to 3%, from 2% to 10%, from 3% to 10%, from 4% to 10%, from 5% to 10%, from 6% to 10%, from 8% to 10%, from 1.5% to 9.5%, from 2% to 9%, or from 3% to 8%).

In some examples, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture comprises: 25-35% (e.g., 30-35%) C_1-C_8 hydrocarbons, 55-65% (e.g., 60-65%) C_9-C_{20} hydrocarbons, and 1-10% (e.g., 3-8%) C_{21}-C_{29} hydrocarbons. In some examples, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture comprises: 30-35% C_1-C_8 hydrocarbons, 60-65% C_9-C_{20} hydrocarbons, and 3-8% C_{21}-C_{29} hydrocarbons.

In some examples, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture comprises: 25-35% (e.g., 30-35%) C_4-C_5 hydrocarbons, 55-65% (e.g., 60-65%) C_9-C_{20} hydrocarbons, and 1-10% (e.g., 3-8%) C_{21}-C_{29} hydrocarbons. In some examples, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture comprises: 30-35% C_4-C_5 hydrocarbons, 60-65% C_9-C_{20} hydrocarbons, and 3-8% C_{21}-C_{29} hydrocarbons.

In some examples, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture is substantially free of hydrocarbons comprising 30 or more carbons.

In some examples, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture comprises saturated hydrocarbons (e.g., linear, branched, and/or cyclic alkanes), unsaturated (non-aromatic) hydrocarbons (e.g., linear, branched, and/or cyclic alkenes and/or alkynes), and aromatic hydrocarbons. For example, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture comprises 90 wt. % or more unsaturated hydrocarbons (e.g., 90.5 wt. % or more, 91 wt. % or more, 91.5 wt. % or more, 92 wt. % or more, 92.5 wt. % or more, 93 wt. % or more, 93.5 wt. % or more, 94 wt. % or more, 94.5 wt. % or more, 95 wt. % or more, 95.5 wt. % or more, 96 wt. % or more, 96.5 wt. % or more, 97 wt. % or more, 97.5 wt. % or more, 98 wt. % or more, 98.5 wt. % or more, or 99 wt. % or more). In some examples, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture comprises 100 wt. % or less unsaturated hydrocarbons (e.g., 99.5 wt. % or less, 99 wt. % or less, 98.5 wt. % or less, 98 wt. % or less, 97.5 wt. % or less, 97 wt. % or less, 96.5 wt. % or less, 96 wt. % or less, 95.5 wt. % or less, 95 wt. % or less, 94.5 wt. % or less, 94 wt. % or less, 93.5 wt. % or less, 93 wt. % or less, 92.5 wt. % or less, 92 wt. % or less, 91.5 wt. % or less, or 91 wt. % or less). The amount of the mixture comprising unsaturated hydrocarbons can range from any of the minimum values described above to any of the maximum values described above. For example, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture comprises from 90 wt. % to 100 wt. % unsaturated hydrocarbons (e.g., from 90 to 95 wt. %, from 95 to 100 wt. %, from 90 to 92 wt. %, from 92 to 94 wt. %, from 94 to 96 wt. %, from 96 to 98 wt. %, from 98 to 100 wt. %, from 90 to 98 wt. %, from 90 to 96 wt. %, from 90 to 94 wt. %, from 92 to 100 wt. %, from 94 to 100 wt. %, from 96 to 100 wt. %, from 91 to 99 wt. %, from 92 to 98 wt. %, or from 94 to 96 wt. %).

In some examples, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture comprises 0 wt. % or more unsaturated (non-aromatic) hydrocarbons (e.g., 0.25 wt. % or more, 0.5 wt. % or more, 0.75 wt. % or more, 1 wt. % or more, 1.25 wt. % or more, 1.5 wt. % or more, 1.75 wt. % or more, 2 wt. % or more, 2.25 wt. % or more, 2.5 wt. % or more, 3 wt. % or more, 3.5 wt. % or more, or 4 wt. % or more). In some examples, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture comprises 5 wt. % or less unsaturated (non-aromatic) hydrocarbons (e.g., 4.5 wt. % or less, 4 wt. % or less, 3.5 wt. % or less, 3 wt. % or less, 2.5 wt. % or less, 2.25 wt. % or less, 2 wt. % or less, 1.75 wt. % or less, 1.5 wt. % or less, 1.25 wt. % or less, 1 wt. % or less, 0.75 wt. % or less, or 0.5 wt. % or less). The amount of unsaturated (non-aromatic) hydrocarbons in the mixture can range from any of the minimum values described above to any of the maximum values described above. For example, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture can comprise from 0 wt. % to 5 wt. % unsaturated (non-aromatic) hydrocarbons (e.g., from 0 to 2.5 wt. %, from 2.5 to 5 wt. %, from 0 to 1 wt. %, from 1 to 2 wt. %, from 2 to 3 wt. %, from 3 to 4 wt. %, from 4 to 5 wt. %, from 0 to 4 wt. %, from 0 to 3 wt. %, from 0 to 2 wt. %, from 1 to 5 wt. %, from 2 to 5 wt. %, from 3 to 5 wt. %, from 0.5 to 4.5 wt. %, or from 3.5 to 4.5 wt. %).

In some examples, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture comprises 0 wt. % or more aromatic hydrocarbons (e.g., 0.25 wt. % or more, 0.5 wt. % or more, 0.75 wt. % or more, 1 wt. % or more, 1.25 wt. % or more, 1.5 wt. % or more, 1.75 wt. % or more, or 2 wt. % or more). In some examples, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture comprises 2.5 wt. % or less aromatic hydrocarbons (e.g., 2.25 wt. % or less, 2 wt. % or less, 1.75 wt. % or less, 1.5 wt. % or less, 1.25 wt. % or less, 1 wt. % or less, 0.75 wt. % or less, or 0.5 wt. % or less). The amount of the mixture comprising aromatic hydrocarbons can range from any of the minimum values described above to any of the maximum values described above. For example, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture can comprise from 0 wt. % to 2.5 wt. % aromatic hydrocarbons (e.g., from 0 to 1.25 wt. %, from 1.25 to 2.5 wt. %, from 0 to 0.5 wt. %, from 0.5 to 1 wt. %, from 1 to 1.5 wt. %, from 1.5 to 2 wt. %, from 2 to 2.5 wt. %, from 0 to 2 wt. %, from 0 to 1.5 wt. %, from 0 to 1 wt. %, from 0.5 to 2.5 wt. %, from 1 to 2.5 wt. %, from 1.5 to 2.5 wt. %, from 0.5 to 2 wt. %, or from 1 to 2 wt. %).

In some examples, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture comprises: 90-100 wt. % saturated hydrocarbons (e.g., 94-96 wt. %); 0-5 wt. % unsaturated (non-aromatic) hydrocarbons (e.g., 3.5-4.5 wt. %); and 0-2.5 wt.

% aromatic hydrocarbons (e.g., 1-2 wt. %). In some examples, the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the mixture comprises: 94-96 wt. % saturated hydrocarbons: 3.5-4.5 wt. % unsaturated (non-aromatic) hydrocarbons; and 1-2 wt. % aromatic hydrocarbons.

The oil can, for example, have a final boiling point of 750° F. or more (e.g., 760° F. or more, 770° F. or more, 780° F. or more, 790° F. or more, 800° F. or more, 810° F. or more, 820° F. or more, 830° F. or more, 840° F. or more, 850° F. or more, 860° F. or more, 870° F. or more, 880° F. or more, 890° F. or more, 900° F. or more, 910° F. or more, 920° F. or more, 930° F. or more, 940° F. or more, 950° F. or more, 960° F. or more, 970° F. or more, or 980° F. or more). In some examples, the oil can have a final boiling point of 1000° F. or less (e.g., 990° F. or less, 980° F. or less, 970° F. or less, 960° F. or less, 950° F. or less, 940° F. or less, 930° F. or less, 920° F. or less, 910° F. or less, 900° F. or less, 890° F. or less, 880° F. or less, 870° F. or less, 860° F. or less, 850° F. or less, 840° F. or less, 830° F. or less, 820° F. or less, 810° F. or less, 800° F. or less, 790° F. or less, 780° F. or less, or 770° F. or less). The final boiling point of the oil can range from any of the minimum values described above to any of the maximum values described above. For example, the oil can have a final boiling point of from 750° F. to 1000° F. (e.g., from 750° F. to 875° F., from 875° F. to 1000° F., from 750° F. to 800° F., from 800° F. to 850° F., from 850° F. to 900° F., from 900° F. to 950° F., from 950° F. to 1000° F., from 750° F. to 975° F., from 750° F. to 950° F., from 750° F. to 925° F., from 750° F. to 900° F., from 750° F. to 850° F., from 750° F. to 825° F., from 775° F. to 1000° F., from 800° F. to 1000° F., from 825° F. to 1000° F., from 850° F. to 1000° F., from 900° F. to 1000° F., from 925° F. to 1000° F., from 775° F. to 975° F., from 800° F. to 950° F., from 850° F. to 950° F., from 920° F. to 950° F., or from 935° F. to 950° F.). The final boiling point of the oil can be determined using any suitable method, such as those known in the art. For example, the final boiling point of the oil can be determined using ASTM D 7169.

The oil can, for example, have a pour point of 0° F. or more (e.g., 1° F. or more, 2° F. or more, 3° F. or more, 4° F. or more, 5° F. or more, 6° F. or more, 7° F. or more, 8° F. or more, 9° F. or more, 10° F. or more, 11° F. or more, 12° F. or more, 13° F. or more, 14° F. or more, 15° F. or more, 16° F. or more, 17° F. or more, or 18° F. or more). In some examples, the oil can have a pour point of 20° F. or less (e.g., 19° F. or less, 18° F. or less, 17° F. or less, 16° F. or less, 15° F. or less, 14° F. or less, 13° F. or less, 12° F. or less, 11° F. or less, 10° F. or less, 9° F. or less, 8° F. or less, 7° F. or less, 6° F. or less, 5° F. or less, 4° F. or less, 3° F. or less, or 2° F. or less). The pour point of the oil can range from any of the minimum values described above to any of the maximum values described above. For example, the oil can have a pour point of from 0° F. to 20° F. (e.g., from 0° F. to 10° F., from 10° F. to 20° F., from 0° F. to 5° F., from 5° F. to 10° F., from 10° F. to 15° F., from 15° F. to 20° F., from 0° F. to 15° F., from 5° F. to 20° F., from 5° F. to 15° F., or from 8° F. to 15° F.). The pour point of the oil can be determined using any suitable method, such as those known in the art. For example, the pour point of the oil can be determined using ASTM D 97.

In some examples, the oil can include one or more contaminants. Contaminants can for example, comprise an alkali metal, an alkaline earth metal, a transition metal, a basic metal, a semimetal, a nonmetal, a halogen, a salt or compound thereof, or a combination thereof. Examples of contaminants include, but are not limited to, lithium, sodium, beryllium, magnesium, calcium, strontium, titanium, vanadium, chromium, manganese, iron, cobalt, nickel, copper, zinc, molybdenum, cadmium, mercury, aluminum, titanium silicon, tin, lead, nitrogen, phosphorus, arsenic, antimony, oxygen, sulfur, selenium, fluorine, chlorine, bromine, compounds thereof, and combinations thereof. In some examples, the oil includes a contaminant comprising chloride, nitrogen, silicon, sodium, iron, phosphorus, sulfur, calcium, nickel, copper, vanadium, or a combination thereof.

Contaminants are introduced during plastic formulation and manufacturing processes during the first life of plastic in conjunction with the source and collection method of the plastics.

For example, chlorine sources in used plastics can comprise PVDC layers. PVDC is often used as a layer or coating in food and pharma packaging applications because it provides excellent barrier properties against moisture, UV light, acids, salts, and detergents as well as having good transparency. Despite design for recyclability formulation changes, PVDC is forecasted to increase at 3.2% annually through 2028 in the US. Packaging converters produce a range of monolayer and multi-layer packaging. Both types can become mixed in recycled streams. Post-consumer sources will contain higher volumes of materials containing chlorine sources that can be difficult to differentiate and remove through standard sorting techniques.

Nitrogen sources in used plastics can, for example, be derived from depolymerization of nylon (e.g., Nylon 6 (PA-6), Nylon-66 (PA-66) in used plastic sources, often from food and industrial packaging materials. Nylon is used in multi-layer flexible packing films to protect oxygen-sensitive foods or when excellent oil and grease resistance and high mechanical strength are required, such as for processed meats and fish, and cheese and other dairy products. Nylon also provides a wide cold to hot temperature range (e.g., −60° C. to 150° C.), which enables foods to move through freezer to the microwave/oven without packaging degradation. In industrial packaging, nylon is often used as a reinforcing layer to provide high mechanical strength and excellent abrasion and puncture resistance (for example, in polypropylene supersacks that contain a nylon interlayer or straps). Nitrogen can also come from protein (food) residue on plastics that arises from the amino acids in decomposed protein. Post-consumer sources will contain higher volumes of materials containing nitrogen sources that can be difficult to differentiate and remove through standard sorting techniques.

Silicon sources in used plastics can, for example, comprise silica desiccant packages. In food packaging and processing plants, silicon products are widely used as release agents in a wide variety of materials and equipment, leaving residue on plastic surfaces. Silicon is also an additive that can be added to a wide range of materials to change the appearance, extrusion properties, and/or end-product characteristics; this applied to films as well as two-dimensional plastics. Post-consumer sources will contain higher volumes of materials containing silicon sources that can be difficult to differentiate and remove through standard sorting techniques.

Silicon dioxide can be applied in a very thin coating to plastics, specifically polyethylene, polypropylene, and/or polystyrene, to act as a barrier layer to improve the shelf life of oxygen and moisture sensitive food. This thin coating can be applied by a vacuum or plasma deposition process: the barrier layer and the plastic forma covalent bond. The SiO_2 barrier coatings are chemically inert and enable benefits in rigid and flexible food packaging applications, including, but not limited to, reducing oxygen and moisture permeability of plastics, ensuring aroma protection and retention of the smell and taste of contents, not sensitive to fluctuations in temperature and humidity, well-suited for pasteurization and sterilization processes, ad can increase shelf life of foods without the addition of preservatives. The SiO_2 coatings are thin, e.g. significantly thinner than a human hair, and therefore have a negligible impact on the packing weight. For this reason, coated packaging is considered a mono-material that can be mechanically recycled. Recyclability initiatives are promoting the use of SiO_2 coatings as a replacement for PVDC and Nylon barriers in flexible and rigid packaging. Although these guidelines are intended for mechanically recycled plastics, several packaging forms and formulations are better suited for pyrolysis-based advanced recycling. SiO_2 coatings have the potential to be the "gift that keeps on giving", especially when used in rigid and flexible polyethylene and polypropylene plastics that are mechanically recycled initially, which, after a few cycles, will then eventually become the used plastic feedstocks for advanced recycling; the silicon is predicted to accumulate and carry forward into each successive application.

Phosphorus-containing flame retardants are widely used in plastics where its rapid oxidation consumes all the oxygen present, thereby stopping the fire. Plastics commonly containing these flame retardants include, but are not limited to, engineered plastics, polyurethane foams, polyamides (e.g., nylon) and glass-fiber reinforced nylon, polyethylene and EVA co-polymers, and intumescent coatings on foams and polypropylene textiles. Phosphate esters are also used as flame retardant plasticizers in PVC, high impact polystyrene (HIPS), polycarbonate (PC), and acrylonitrile butadiene styrene (ABS). Phosphorus sources also include agricultural applications, such as residual glyphosate in HDPE containers and residual phosphorus fertilizers on ground-level films (e.g., mulch films). Post-consumer sources will contain higher volumes of materials containing phosphorus sources that can be difficult to differentiate and remove through standard sorting techniques.

Sources of sulfur, calcium, sodium, iron, phosphorus, or a combination thereof are additives, surface residues, and residual contamination of the incoming post-consumer and/or post-industrial plastics. A wash step can potentially remove certain surface residues, but would add cost and complexity to the advanced (e.g., pyrolysis based) recycling process. Accordingly, post-consumer sources will contain higher volumes of materials containing sources of sulfur, calcium, sodium, iron, phosphorus, or a combination thereof that can be difficult to differentiate and remove through standard sorting techniques.

Copper alloys are commonly and increasingly used to create molds for plastic injection molding processes due to their high thermal conductivity that removes hot spots, reduces warpage and reduces cycle time, ease of machining by a variety of processes, and corrosion resistance to water, cooling fluids and the plastics being injected. Copper alloys often contain nickel and silicon. Plastics manufactured in copper alloy molds can have residual amounts of copper, nickel, and silicon on their surface. In addition, the plating of plastic with nickel and copper can be an effective means of protecting a substrate against corrosion from environmental exposure and make it more resistant to damage from chemicals used in the manufacturing process. In some instances, the plating on plastic can increase the hardness, strength, and wear resistance of the substrate. The presence of copper and nickel on the surface of both pre-consumer and post-consumer sources can be difficult to differentiate and remove through standard sorting techniques.

In some examples, the oil has a total chloride content of 500 ppm or less (e.g., 475 ppm or less, 450 ppm or less, 425 ppm or less, 400 ppm or less, 375 ppm or less, 350 ppm or less, 325 ppm or less, 300 ppm or less, 275 ppm or less, 250 ppm or less, 225 ppm or less, 200 ppm or less, 175 ppm or less, 150 ppm or less, 125 ppm or less, 100 ppm or less, 75 ppm or less, 50 ppm or less, 45 ppm or less, 40 ppm or less, 35 ppm or less, 30 ppm or less, 25 ppm or less, 20 ppm or less, 15 ppm or less, 10 ppm or less, 9 ppm or less, 8 ppm or less, 7 ppm or less, 6 ppm or less, 5 ppm or less, 4.5 ppm or less, 4 ppm or less, 3.5 ppm or less, 3 ppm or less, 2.5 ppm or less, 2 ppm or less, 1.5 ppm or less, 1 ppm or less, 0.75 ppm or less, 0.5 ppm or less, 0.25 ppm or less, 0.1 ppm or less, 0.075 ppm or less, 0.05 ppm or less, 0.025 ppm or less, 0.01 ppm or less, 0.0075 ppm or less, or 0.005 ppm or less). In some examples, the oil has a total chloride content of 0 ppm or more (e.g., 0.001 ppm or more, 0.0025 ppm or more, 0.005 ppm or more, 0.0075 ppm or more, 0.01 ppm or more, 0.025 ppm or more, 0.05 ppm or more, 0.075 ppm or more, 0.1 ppm or more, 0.25 ppm or more, 0.5 ppm or more, 0.75 ppm or more, 1 ppm or more, 1.5 ppm or more, 2 ppm or more, 2.5 ppm or more, 3 ppm or more, 3.5 ppm or more, 4 ppm or more, 4.5 ppm or more, 5 ppm or more, 6 ppm or more, 7 ppm or more, 8 ppm or more, 9 ppm or more, 10 ppm or more, 15 ppm or more, 20 ppm or more, 25 ppm or more, 30 ppm or more, 35 ppm or more, 40 ppm or more, 45 ppm or more, 50 ppm or more, 75 ppm or more, 100 ppm or more, 125 ppm or more, 150 ppm or more, 175 ppm or more, 200 ppm or more, 225 ppm or more, 250 ppm or more, 275 ppm or more, 300 ppm or more, 325 ppm or more, 350 ppm or more, 375 ppm or more, 400 ppm or more, 425 ppm or more, or 450 ppm or more). The total chloride content of the oil can range from any of the minimum values described above to any of the maximum values described above. For example, the oil can have a total chloride content of from 0 to 500 ppm (e.g., from 0 to 250 ppm, from 250 to 500 ppm, from 0 to 100 ppm, from 100 to 200 ppm, from 200 to 300 ppm, from 300 to 400 ppm, from 400 to 500 ppm, from 0.001 to 500 ppm, from 0.001 to 475 ppm, from 0.001 to 450 ppm, from 0.001 to 425 ppm, from 0.001 to 400 ppm, from 0.001 to 375 ppm, from 0.001 to 350 ppm, from 0.001 to 325 ppm, from 0.001 to 300 ppm, from 0.001 to 275 ppm, from 0.001 to 250 ppm, from 0.001 to 225 ppm, from 0.001 to 200 ppm, from 0.001 to 175 ppm, from 0.001 to 150 ppm, from 0.001 to 125 ppm, from 0.001 to 100 ppm, from 0.001 to 75 ppm, from 0.001 to 50 ppm, from 0.001 to 45 ppm, from 0.001 to 40 ppm, from 0.001 to 35 ppm, from 0.001 to 30 ppm, from 0.001 to 25 ppm, from 0.001 to 20 ppm, from 0.001 to 15 ppm, from 0.001 to 10 ppm, from 0.001 to 5 ppm, from 0.001 to 1 ppm, from 0.001 to 0.1 ppm, from 0.001 to 0.01 ppm, from 0 to 475 ppm, from 0 to 450 ppm, from 0 to 425 ppm, from 0 to 400 ppm, from 0 to 375 ppm, from 0 to 350 ppm, from 0 to 325 ppm, from 0 to 300 ppm, from 0 to 275 ppm, from 0 to 250 ppm, from 0 to 225 ppm, from 0 to 200 ppm, from 0 to 175 ppm, from 0 to 150 ppm, from 0 to 125 ppm, from 0 to 100 ppm, from 0 to 75 ppm, from 0 to 50 ppm, from 0 to 45 ppm, from 0 to 40 ppm, from 0 to 35 ppm, from 0 to 30 ppm, from 0 to 25 ppm, from 0 to 20 ppm, from 0 to 15 ppm, from 0 to 10 ppm, from 0 to 5 ppm, from 0 to 1 ppm, from 0 to 0.1 ppm, or from 0 to 0.01 ppm). In some examples, the oil is substantially free of chlorides. The total chloride content of the oil can be determined using any suitable method. For example, the total chloride content of the oil can be determined using ASTM D 7359.

The oil can, for example, have a nitrogen content of 600 ppm or less (e.g., 575 ppm or less. 550 ppm or less, 525 ppm or less, 500 ppm or less, 475 ppm or less. 450 ppm or less. 425 ppm or less. 400 ppm or less. 375 ppm or less, 350 ppm or less, 325 ppm or less, 300 ppm or less, 275 ppm or less, 250 ppm or less, 225 ppm or less, 200 ppm or less, 175 ppm or less, 150 ppm or less, 125 ppm or less. 100 ppm or less. 75 ppm or less, 50 ppm or less. 45 ppm or less. 40 ppm or less, 35 ppm or less, 30 ppm or less, 25 ppm or less, 20 ppm or less, 15 ppm or less, 10 ppm or less, 9 ppm or less, 8 ppm or less, 7 ppm or less, 6 ppm or less, 5 ppm or less, 4.5 ppm or less. 4 ppm or less. 3.5 ppm or less, 3 ppm or less, 2.5 ppm or less. 2 ppm or less. 1.5 ppm or less, 1 ppm or less, 0.75 ppm or less, 0.5 ppm or less, 0.25 ppm or less, 0.1 ppm or less, 0.075 ppm or less, 0.05 ppm or less, 0.025 ppm or less, 0.01 ppm or less. 0.0075 ppm or less. or 0.005 ppm or less). In some examples. the oil can have a nitrogen content of 0 ppm or more (e.g., 0.001 ppm or more, 0.0025 ppm or more. 0.005 ppm or more, 0.0075 ppm or more, 0.01 ppm or more, 0.025 ppm or more, 0.05 ppm or more, 0.075 ppm or more, 0.1 ppm or more, 0.25 ppm or more, 0.5 ppm or more. 0.75 ppm or more, 1 ppm or more. 1.5 ppm or more. 2 ppm or more, 2.5 ppm or more, 3 ppm or more, 3.5 ppm or more, 4 ppm or more, 4.5 ppm or more, 5 ppm or more, 6 ppm or more, 7 ppm or more, 8 ppm or more, 9 ppm or more, 10 ppm or more, 15 ppm or more. 20 ppm or more, 25 ppm or more. 30 ppm or more, 35 ppm or more, 40 ppm or more. 45 ppm or more, 50 ppm or more, 75 ppm or more, 100 ppm or more, 125 ppm or more, 150 ppm or more, 175 ppm or more. 200 ppm or more, 225 ppm or more, 250 ppm or more. 275 ppm or more. 300 ppm or more, 325 ppm or more. 350 ppm or more. 375 ppm or more, 400 ppm or more, 425 ppm or more, 450 ppm or more, 475 ppm or more, 500 ppm or more, 525 ppm or more, or 550 ppm or more). The nitrogen content of the oil can range from any of the minimum values described above to any of the maximum values described above. For example. the oil can have a sulfur content of from 0 to 600 ppm (e.g., from 0 to 300 ppm, from 300 to 600 ppm, from 0 to 100 ppm, from 100 to 200 ppm, from 200 to 300 ppm. from 300 to 400 ppm, from 400 to 500 ppm. from 500 to 600 ppm. from 0.001 to 600 ppm. from 0.001 to 575 ppm. from 0.001 to 550 ppm, from 0.001 to 525 ppm, from 0.001 to 500 ppm, from 0.001 to 475 ppm, from 0.001 to 450 ppm, from 0.001 to 425 ppm, from 0.001 to 400 ppm, from 0.001 to 375 ppm. from 0.001 to 350 ppm. from 0.001 to 325 ppm. from 0.001 to 300 ppm. from 0.001 to 275 ppm. from 0.001 to 250 ppm, from 0.001 to 225 ppm, from 0.001 to 200 ppm, from 0.001 to 175 ppm, from 0.001 to 150 ppm, from 0.001 to 125 ppm, from 0.001 to 100 ppm, from 0.001 to 75 ppm. from 0.001 to 50 ppm, from 0.001 to 45 ppm, from 0.001 to 40 ppm. from 0.001 to 35 ppm, from 0.001 to 30 ppm. from 0.001 to 25 ppm, from 0.001 to 20 ppm, from 0.001 to 15 ppm, from 0.001 to 10 ppm, from 0.001 to 5 ppm, from 0.001 to 1 ppm. from 0.001 to 0.1 ppm, from 0.001 to 0.01 ppm. from 0 to 575 ppm. from 0 to 550 ppm, from 0 to 525 ppm, from 0 to 500 ppm, from 0 to 475 ppm, from 0 to 450 ppm, from 0 to 425 ppm, from 0 to 400 ppm, from 0 to 375 ppm, from 0 to 350 ppm, from 0 to 325 ppm, from 0 to 300 ppm. from 0 to 275 ppm. from 0 to 250 ppm, from 0 to 225 ppm. from 0 to 200 ppm. from 0 to 175 ppm, from 0 to 150 ppm, from 0 to 125 ppm, from 0 to 100 ppm, from 0 to 75 ppm, from 0 to 50 ppm, from 0 to 45 ppm, from 0 to 40 ppm, from 0 to 35 ppm, from 0 to 30 ppm. from 0 to 25 ppm, from 0 to 20 ppm. from 0 to 15 ppm. from 0 to 10 ppm, from 0 to 5 ppm. from 0 to 1 ppm. from 0 to 0.1 ppm, or from 0 to 0.01 ppm). In some examples, the oil can be substantially free of nitrogen. The nitrogen content of the oil can be determined using any suitable method, such as those known in the art. For example. the nitrogen content of the oil can be determined using ASTM D 4629.

The oil can, for example. have a silicon content of 2000 ppm or less (e.g., 1900 ppm or less, 1800 ppm or less, 1700 ppm or less, 1600 ppm or less, 1500 ppm or less, 1400 ppm or less. 1300 ppm or less. 1200 ppm or less, 1100 ppm or less. 1000 ppm or less, 950 ppm or less, 900 ppm or less, 850 ppm or less, 800 ppm or less, 750 ppm or less, 700 ppm or less, 650 ppm or less, 600 ppm or less, 550 ppm or less, 500 ppm or less, 475 ppm or less, 450 ppm or less, 425 ppm or less. 400 ppm or less. 375 ppm or less. 350 ppm or less, 325 ppm or less. 300 ppm or less, 275 ppm or less. 250 ppm or less, 225 ppm or less, 200 ppm or less, 175 ppm or less, 150 ppm or less, 125 ppm or less, 100 ppm or less, 75 ppm or less. 50 ppm or less, 45 ppm or less. 40 ppm or less, 35 ppm or less, 30 ppm or less. 25 ppm or less, 20 ppm or less. 15 ppm or less. 10 ppm or less, 9 ppm or less. 8 ppm or less, 7 ppm or less, 6 ppm or less, 5 ppm or less, 4.5 ppm or less, 4 ppm or less, 3.5 ppm or less, 3 ppm or less, 2.5 ppm or less, 2 ppm or less, 1.5 ppm or less, 1 ppm or less, 0.75 ppm or less. 0.5 ppm or less, 0.25 ppm or less. 0.1 ppm or less, 0.075 ppm or less, 0.05 ppm or less, 0.025 ppm or less, 0.01 ppm or less, 0.0075 ppm or less, or 0.005 ppm or less). In some examples, the oil can have a silicon content of 0 ppm or more (e.g.. 0.001 ppm or more, 0.0025 ppm or more. 0.005 ppm or more. 0.0075 ppm or more. 0.01 ppm or more. 0.025 ppm or more, 0.05 ppm or more, 0.075 ppm or more, 0.1 ppm or more, 0.25 ppm or more, 0.5 ppm or more, 0.75 ppm or more, 1 ppm or more. 1.5 ppm or more. 2 ppm or more, 2.5 ppm or more. 3 ppm or more. 3.5 ppm or more, 4 ppm or more, 4.5 ppm or more. 5 ppm or more. 6 ppm or more, 7 ppm or more, 8 ppm or more, 9 ppm or more, 10 ppm or more, 15 ppm or more, 20 ppm or more, 25 ppm or more, 30 ppm or more. 35 ppm or more, 40 ppm or more, 45 ppm or more. 50 ppm or more, 75 ppm or more, 100 ppm or more, 125 ppm or more, 150 ppm or more. 175 ppm or more. 200 ppm or more, 225 ppm or more, 250 ppm or more, 275 ppm or more, 300 ppm or more, 325 ppm or more, 350 ppm or more, 375 ppm or more, 400 ppm or more. 425 ppm or more, 450 ppm or more, 475 ppm or more. 500 ppm or more. 550 ppm or more, 600 ppm or more, 650 ppm or more, 700 ppm or more, 750 ppm or more, 800 ppm or more, 850 ppm or more, 900 ppm or more, 950 ppm or more, 1000 ppm or more, 1100 ppm or more, 1200 ppm or more, 1300 ppm or more, 1400 ppm or more. 1500 ppm or more, 1600 ppm or more, 1700 ppm or more, or 1800 ppm or more). The silicon content of the oil can range from any of the minimum values described above to any of the maximum values described above. For example, the oil can have a silicon content of from 0 to 2000 ppm (e.g., from 0 to 1000 ppm. from 1000 to 2000 ppm, from 0 to 500 ppm, from 500 to 1000 ppm, from 1000 to 1500 ppm, from 1500 to 2000 ppm, from 0.001 to 2000 ppm. from 0.001 to 1750 ppm. from 0.001 to 1500 ppm. from 0.001 to 1250 ppm. from 0.001 to 1000 ppm, from 0.001 to 750 ppm, from 0.001 to 500 ppm, from 0.001 to 475 ppm, from 0.001 to 450 ppm, from 0.001 to 425 ppm, from 0.001 to 400 ppm, from 0.001 to 375 ppm, from 0.001 to 350 ppm, from 0.001 to 325 ppm, from 0.001 to 300 ppm, from 0.001 to 275 ppm, from 0.001 to 250 ppm, from 0.001 to 225 ppm, from 0.001 to 200 ppm, from 0.001 to 175 ppm, from 0.001 to 150 ppm, from 0.001 to 125 ppm, from 0.001 to 100 ppm, from 0.001 to 75 ppm. from 0.001 to 50 ppm, from 0.001 to 45 ppm. from 0.001 to 40 ppm. from 0.001 to 35 ppm, from 0.001 to 30 ppm. from 0.001 to 25 ppm, from 0.001 to 20 ppm, from 0.001 to 15 ppm, from 0.001 to 10 ppm, from 0.001 to 5 ppm, from 0.001 to 1 ppm, from 0.001

to 0.1 ppm, from 0.001 to 0.01 ppm, from 0 to 1750 ppm, from 0 to 1500 ppm. from 0 to 1250 ppm, from 0 to 1000 ppm. from 0 to 750 ppm. from 0 to 500 ppm, from 0 to 475 ppm. from 0 to 450 ppm. from 0 to 425 ppm, from 0 to 400 ppm, from 0 to 375 ppm, from 0 to 350 ppm, from 0 to 325 ppm, from 0 to 300 ppm, from 0 to 275 ppm, from 0 to 250 ppm. from 0 to 225 ppm. from 0 to 200 ppm, from 0 to 175 ppm. from 0 to 150 ppm. from 0 to 125 ppm, from 0 to 100 ppm, from 0 to 75 ppm, from 0 to 50 ppm, from 0 to 45 ppm, from 0 to 40 ppm, from 0 to 35 ppm, from 0 to 30 ppm, from 0 to 25 ppm, from 0 to 20 ppm, from 0 to 15 ppm, from 0 to 10 ppm. from 0 to 5 ppm. from 0 to 1 ppm, from 0 to 0.1 ppm. or from 0 to 0.01 ppm). In some examples, the oil can be substantially free of silicon. The silicon content of the oil can be determined using any suitable method, such as those known in the art. For example. the silicon content of the oil can be determined using ASTM D 5185.

The oil can. for example, have a sodium content of 100 ppm or less (e.g., 95 ppm or less, 90 ppm or less, 85 ppm or less, 80 ppm or less, 75 ppm or less, 70 ppm or less, 65 ppm or less. 60 ppm or less, 55 ppm or less. 50 ppm or less, 45 ppm or less. 40 ppm or less, 35 ppm or less, 30 ppm or less. 25 ppm or less, 20 ppm or less, 15 ppm or less, 10 ppm or less, 9 ppm or less, 8 ppm or less, 7 ppm or less, 6 ppm or less, 5 ppm or less, 4.5 ppm or less, 4 ppm or less, 3.5 ppm or less. 3 ppm or less. 2.5 ppm or less, 2 ppm or less, 1.5 ppm or less, 1 ppm or less, 0.75 ppm or less, 0.5 ppm or less. 0.25 ppm or less, 0.1 ppm or less, 0.075 ppm or less, 0.05 ppm or less, 0.025 ppm or less, 0.01 ppm or less, 0.0075 ppm or less, or 0.005 ppm or less). In some examples. the oil can have a sodium content of 0 ppm or more (e.g., 0.001 ppm or more. 0.0025 ppm or more. 0.005 ppm or more, 0.0075 ppm or more, 0.01 ppm or more, 0.025 ppm or more, 0.05 ppm or more, 0.075 ppm or more, 0.1 ppm or more, 0.25 ppm or more. 0.5 ppm or more. 0.75 ppm or more. 1 ppm or more. 1.5 ppm or more, 2 ppm or more, 2.5 ppm or more. 3 ppm or more. 3.5 ppm or more, 4 ppm or more, 4.5 ppm or more. 5 ppm or more, 6 ppm or more, 7 ppm or more, 8 ppm or more, 9 ppm or more, 10 ppm or more, 15 ppm or more, 20 ppm or more, 25 ppm or more. 30 ppm or more, 35 ppm or more. 40 ppm or more, 45 ppm or more, 50 ppm or more. 55 ppm or more, 60 ppm or more, 65 ppm or more, 70 ppm or more, 75 ppm or more, 80 ppm or more, 85 ppm or more, or 90 ppm or more). The sodium content of the oil can range from any of the minimum values described above to any of the maximum values described above. For example. the oil can have a sodium content of from 0 to 100 ppm (e.g., from 0 to 50 ppm, from 50 to 100 ppm, from 0 to 20 ppm, from 20 to 40 ppm. from 40 to 60 ppm. from 60 to 80 ppm, from 80 to 100 ppm. from 0.001 to 100 ppm. from 0.001 to 75 ppm. from 0.001 to 50 ppm. from 0.001 to 45 ppm, from 0.001 to 40 ppm, from 0.001 to 35 ppm, from 0.001 to 30 ppm, from 0.001 to 25 ppm, from 0.001 to 20 ppm, from 0.001 to 15 ppm. from 0.001 to 10 ppm, from 0.001 to 5 ppm. from 0.001 to 1 ppm, from 0.001 to 0.1 ppm, from 0.001 to 0.01 ppm, from 0 to 75 ppm, from 0 to 50 ppm, from 0 to 45 ppm, from 0 to 40 ppm, from 0 to 35 ppm, from 0 to 30 ppm, from 0 to 25 ppm, from 0 to 20 ppm, from 0 to 15 ppm, from 0 to 10 ppm, from 0 to 5 ppm. from 0 to 1 ppm, from 0 to 0.1 ppm, or from 0 to 0.01 ppm). In some examples, the oil can be substantially free of sodium. The sodium content of the oil can be determined using any suitable method. such as those known in the art. For example. the sodium content of the oil can be determined using ASTM D 5185.

The oil can, for example, have an iron content of 10 ppm or less (e.g., 9 ppm or less, 8 ppm or less, 7 ppm or less, 6 ppm or less, 5 ppm or less, 4.5 ppm or less, 4 ppm or less, 3.5 ppm or less, 3 ppm or less. 2.5 ppm or less. 2 ppm or less, 1.5 ppm or less, 1 ppm or less, 0.75 ppm or less. 0.5 ppm or less. 0.25 ppm or less. 0.1 ppm or less. 0.075 ppm or less, 0.05 ppm or less, 0.025 ppm or less, 0.01 ppm or less, 0.0075 ppm or less, or 0.005 ppm or less). In some examples, the oil can have an iron content of 0 ppm or more (e.g.. 0.001 ppm or more. 0.0025 ppm or more. 0.005 ppm or more. 0.0075 ppm or more, 0.01 ppm or more, 0.025 ppm or more, 0.05 ppm or more, 0.075 ppm or more, 0.1 ppm or more, 0.25 ppm or more, 0.5 ppm or more, 0.75 ppm or more, 1 ppm or more, 1.5 ppm or more. 2 ppm or more. 2.5 ppm or more, 3 ppm or more. 3.5 ppm or more. 4 ppm or more, 4.5 ppm or more, 5 ppm or more, 6 ppm or more, 7 ppm or more, or 8 ppm or more). The iron content of the oil can range from any of the minimum values above to any of the maximum values described above. For example. the oil can have an iron content of from 0 ppm to 10 ppm (e.g., from 0 to 5 ppm, from 5 to 10 ppm, from 1 to 2 ppm, from 2 to 4 ppm, from 4 to 6 ppm, from 6 to 8 ppm, from 8 to 10 ppm, from 0.001 to 10 ppm. from 0.001 to 9 ppm, from 0.001 to 8 ppm, from 0.001 to 7 ppm. from 0.001 to 6 ppm. from 0.001 to 5 ppm, from 0.001 to 4 ppm, from 0.001 to 3 ppm, from 0.001 to 2 ppm, from 0.001 to 1 ppm, from 0.001 to 0.1 ppm, from 0.001 to 0.01 ppm, from 0 to 9 ppm, from 0 to 8 ppm, from 0 to 7 ppm. from 0 to 6 ppm. from 0 to 5 ppm. from 0 to 4 ppm. from 0 to 3 ppm, from 0 to 1 ppm. from 0 to 0.1 ppm, or from 0 to 0.01 ppm). In some examples, the oil can be substantially free of iron. The iron content of the oil can be determined using any suitable method. such as those known in the art. For example. the iron content of the oil can be determined using ASTM D 5185.

The oil can, for example, have a phosphorus content of 25 ppm or less (e.g., 20 ppm or less, 15 ppm or less, 10 ppm or less. 9 ppm or less, 8 ppm or less, 7 ppm or less. 6 ppm or less. 5 ppm or less. 4.5 ppm or less, 4 ppm or less, 3.5 ppm or less, 3 ppm or less, 2.5 ppm or less. 2 ppm or less. 1.5 ppm or less, 1 ppm or less, 0.75 ppm or less, 0.5 ppm or less, 0.25 ppm or less, 0.1 ppm or less, 0.075 ppm or less, 0.05 ppm or less. 0.025 ppm or less, 0.01 ppm or less, 0.0075 ppm or less. or 0.005 ppm or less). In some examples. the oil can have a phosphorus content of 0 ppm or more (e.g., 0.001 ppm or more, 0.0025 ppm or more, 0.005 ppm or more, 0.0075 ppm or more, 0.01 ppm or more, 0.025 ppm or more, 0.05 ppm or more, 0.075 ppm or more, 0.1 ppm or more, 0.25 ppm or more, 0.5 ppm or more. 0.75 ppm or more, 1 ppm or more, 1.5 ppm or more, 2 ppm or more, 2.5 ppm or more, 3 ppm or more, 3.5 ppm or more, 4 ppm or more, 4.5 ppm or more. 5 ppm or more, 6 ppm or more. 7 ppm or more, 8 ppm or more. 9 ppm or more. 10 ppm or more. 15 ppm or more, or 20 ppm or more). The phosphorus content of the oil can range from any of the minimum values described above to any of the maximum values described above. For example, the oil can have a phosphorus content of from 0 to 25 ppm (e.g.. from 0 to 12.5 ppm. from 12.5 to 25 ppm. from 0 to 5 ppm, from 5 to 10 ppm, from 10 to 15 ppm, from 15 to 20 ppm, from 20 to 25 ppm, from 0.001 to 25 ppm, from 0.001 to 20 ppm, from 0.001 to 15 ppm, from 0.001 to 10 ppm. from 0.001 to 5 ppm. from 0.001 to 1 ppm. from 0.001 to 0.1 ppm. from 0.001 to 0.01 ppm. from 0 to 20 ppm, from 0 to 15 ppm, from 0 to 10 ppm, from 0 to 5 ppm, from 0 to 1 ppm, from 0 to 0.1 ppm, or from 0 to 0.01 ppm). In some examples, the oil can be substantially free of phosphorus. The phosphorus content of the oil can be determined using any suitable method, such as those known in the art. For example, the phosphorus content of the oil can be determined using ASTM D 5185.

The oil can, for example, have a sulfur content of 250 ppm or less (e.g., 225 ppm or less. 200 ppm or less, 175 ppm or less, 150 ppm or less, 125 ppm or less. 100 ppm or less. 75 ppm or less. 50 ppm or less, 45 ppm or less, 40 ppm or less. 35 ppm or less, 30 ppm or less, 25 ppm or less, 20 ppm or less, 15 ppm or less, 10 ppm or less, 9 ppm or less, 8 ppm or less. 7 ppm or less. 6 ppm or less. 5 ppm or less, 4.5 ppm or less. 4 ppm or less. 3.5 ppm or less, 3 ppm or less, 2.5 ppm or less, 2 ppm or less, 1.5 ppm or less, 1 ppm or less, 0.75 ppm or less, 0.5 ppm or less, 0.25 ppm or less, 0.1 ppm or less, 0.075 ppm or less, 0.05 ppm or less, 0.025 ppm or less, 0.01 ppm or less. 0.0075 ppm or less. or 0.005 ppm or less). In some examples. the oil has a sulfur content of 0 ppm or more (e.g., 0.001 ppm or more, 0.0025 ppm or more, 0.005 ppm or more, 0.0075 ppm or more, 0.01 ppm or more, 0.025 ppm or more, 0.05 ppm or more, 0.075 ppm or more, 0.1 ppm or more, 0.25 ppm or more. 0.5 ppm or more, 0.75 ppm or more. 1 ppm or more, 1.5 ppm or more, 2 ppm or more. 2.5 ppm or more, 3 ppm or more, 3.5 ppm or more, 4 ppm or more, 4.5 ppm or more, 5 ppm or more, 6 ppm or more, 7 ppm or more. 8 ppm or more, 9 ppm or more. 10 ppm or more. 15 ppm or more, 20 ppm or more, 25 ppm or more. 30 ppm or more, 35 ppm or more, 40 ppm or more, 45 ppm or more, 50 ppm or more, 75 ppm or more, 100 ppm or more, 125 ppm or more, 150 ppm or more, 175 ppm or more, or 200 ppm or more). The sulfur content of the oil can range from any of the minimum values described above to any of the maximum values described above. For example, the oil can have a sulfur content of from 0 ppm to 250 ppm (e.g., from 0 to 125 ppm, from 125 to 250 ppm, from 0 to 50 ppm. from 50 to 100 ppm, from 100 to 150 ppm. from 150 to 200 ppm. from 200 to 250 ppm. from 0.001 to 250 ppm. from 0.001 to 225 ppm, from 0.001 to 200 ppm, from 0.001 to 175 ppm, from 0.001 to 150 ppm, from 0.001 to 125 ppm, from 0.001 to 100 ppm. from 0.001 to 75 ppm, from 0.001 to 50 ppm. from 0.001 to 45 ppm. from 0.001 to 40 ppm, from 0.001 to 35 ppm. from 0.001 to 30 ppm, from 0.001 to 25 ppm, from 0.001 to 20 ppm, from 0.001 to 15 ppm, from 0.001 to 10 ppm, from 0.001 to 5 ppm, from 0.001 to 1 ppm, from 0.001 to 0.1 ppm. from 0.001 to 0.01 ppm. from 0 to 225 ppm. from 0 to 200 ppm. from 0 to 175 ppm, from 0 to 150 ppm, from 0 to 125 ppm, from 0 to 100 ppm, from 0 to 75 ppm, from 0 to 50 ppm, from 0 to 45 ppm, from 0 to 40 ppm, from 0 to 35 ppm, from 0 to 30 ppm, from 0 to 25 ppm, from 0 to 20 ppm, from 0 to 15 ppm. from 0 to 10 ppm, from 0 to 5 ppm, from 0 to 1 ppm, from 0 to 0.1 ppm. or from 0 to 0.01 ppm). In some examples, the oil can be substantially free of sulfur. The sulfur content of the oil can be determined by any suitable method. such as those known in the art. For example. the sulfur content of the oil can be determined using ASTM D 4294.

The oil can, for example, have a calcium content of 50 ppm or less (e.g., 45 ppm or less, 40 ppm or less, 35 ppm or less, 30 ppm or less. 25 ppm or less, 20 ppm or less. 15 ppm or less, 10 ppm or less. 9 ppm or less. 8 ppm or less. 7 ppm or less, 6 ppm or less, 5 ppm or less, 4.5 ppm or less, 4 ppm or less, 3.5 ppm or less, 3 ppm or less, 2.5 ppm or less, 2 ppm or less, 1.5 ppm or less, 1 ppm or less, 0.75 ppm or less, 0.5 ppm or less, 0.25 ppm or less. 0.1 ppm or less, 0.075 ppm or less. 0.05 ppm or less, 0.025 ppm or less. 0.01 ppm or less, 0.0075 ppm or less, or 0.005 ppm or less). In some examples, the oil can have a calcium content of 0 ppm or more (e.g., 0.001 ppm or more. 0.0025 ppm or more, 0.005 ppm or more, 0.0075 ppm or more. 0.01 ppm or more, 0.025 ppm or more, 0.05 ppm or more, 0.075 ppm or more, 0.1 ppm or more, 0.25 ppm or more, 0.5 ppm or more, 0.75 ppm or more, 1 ppm or more, 1.5 ppm or more, 2 ppm or more, 2.5 ppm or more, 3 ppm or more, 3.5 ppm or more, 4 ppm or more, 4.5 ppm or more. 5 ppm or more. 6 ppm or more, 7 ppm or more. 8 ppm or more, 9 ppm or more. 10 ppm or more, 15 ppm or more, 20 ppm or more. 25 ppm or more, 30 ppm or more, 35 ppm or more, or 40 ppm or more). The calcium content of the oil can range from any of the minimum values described above to any of the maximum values described above. For example. the oil can have a calcium content of from 0 to 50 ppm (e.g., from 0 to 25 ppm, from 25 to 50 ppm, from 0 to 10 ppm, from 10 to 20 ppm, from 20 to 30 ppm, from 30 to 40 ppm, from 40 to 50 ppm, from 0.001 to 50 ppm. from 0.001 to 45 ppm. from 0.001 to 40 ppm, from 0.001 to 35 ppm. from 0.001 to 30 ppm, from 0.001 to 25 ppm, from 0.001 to 20 ppm, from 0.001 to 15 ppm, from 0.001 to 10 ppm, from 0.001 to 5 ppm, from 0.001 to 1 ppm, from 0.001 to 0.1 ppm. from 0.001 to 0.01 ppm. from 0 to 45 ppm, from 0 to 40 ppm, from 0 to 35 ppm, from 0 to 30 ppm, from 0 to 25 ppm, from 0 to 20 ppm. from 0 to 15 ppm, from 0 to 10 ppm, from 0 to 5 ppm, from 0 to 1 ppm, from 0 to 0.1 ppm, or from 0 to 0.01 ppm). In some examples, the oil can be substantially free of calcium. The calcium content of the oil can be determined using any suitable methods, such as those known in the art. In some examples, the calcium content of the oil can be determined using ASTM D 5185.

The oil can, for example, have a copper content of 10 ppm or less (e.g.. 9 ppm or less. 8 ppm or less, 7 ppm or less, 6 ppm or less, 5 ppm or less, 4.5 ppm or less, 4 ppm or less, 3.5 ppm or less, 3 ppm or less, 2.5 ppm or less, 2 ppm or less, 1.5 ppm or less, 1 ppm or less, 0.75 ppm or less. 0.5 ppm or less. 0.25 ppm or less. 0.1 ppm or less. 0.075 ppm or less, 0.05 ppm or less. 0.025 ppm or less, 0.01 ppm or less. 0.0075 ppm or less, or 0.005 ppm or less). In some examples, the oil can have a copper content of 0 ppm or more (e.g., 0.001 ppm or more. 0.0025 ppm or more. 0.005 ppm or more. 0.0075 ppm or more. 0.01 ppm or more, 0.025 ppm or more, 0.05 ppm or more. 0.075 ppm or more. 0.1 ppm or more. 0.25 ppm or more, 0.5 ppm or more, 0.75 ppm or more, 1 ppm or more, 1.5 ppm or more, 2 ppm or more, 2.5 ppm or more, 3 ppm or more. 3.5 ppm or more. 4 ppm or more, 4.5 ppm or more. 5 ppm or more, 6 ppm or more. 7 ppm or more, or 8 ppm or more). The copper content of the oil can range from any of the minimum values described above to any of the maximum values described above. For example, the oil can have a copper content of from 0 ppm to 10 ppm (e.g., from 0 to 5 ppm, from 5 to 10 ppm. from 1 to 2 ppm, from 2 to 4 ppm, from 4 to 6 ppm, from 6 to 8 ppm, from 8 to 10 ppm, from 0.001 to 10 ppm, from 0.001 to 9 ppm, from 0.001 to 8 ppm. from 0.001 to 7 ppm. from 0.001 to 6 ppm, from 0.001 to 5 ppm. from 0.001 to 4 ppm, from 0.001 to 3 ppm. from 0.001 to 2 ppm. from 0.001 to 1 ppm. from 0.001 to 0.1 ppm, from 0.001 to 0.01 ppm, from 0 to 9 ppm, from 0 to 8 ppm, from 0 to 7 ppm, from 0 to 6 ppm, from 0 to 5 ppm. from 0 to 4 ppm, from 0 to 3 ppm, from 0 to 1 ppm, from 0 to 0.1 ppm. or from 0 to 0.01 ppm). In some examples, the oil can be substantially free of copper. The copper content of the oil can be determine using any suitable method, such as those known in the art. For example, the copper content of the oil can be determined using ASTM D 5185.

The oil can, for example, have a nickel content of 250 ppm or less (e.g., 225 ppm or less, 200 ppm or less, 175 ppm or less. 150 ppm or less. 125 ppm or less, 100 ppm or less, 75 ppm or less. 50 ppm or less. 45 ppm or less, 40 ppm or less. 35 ppm or less, 30 ppm or less. 25 ppm or less, 20 ppm or less, 15 ppm or less, 10 ppm or less, 9 ppm or less, 8 ppm or less, 7 ppm or less, 6 ppm or less, 5 ppm or less, 4.5 ppm or less, 4 ppm or less, 3.5 ppm or less, 3 ppm or less, 2.5 ppm or less. 2 ppm or less. 1.5 ppm or less, 1 ppm or less, 0.75 ppm or less. 0.5 ppm or less, 0.25 ppm or less. 0.1 ppm or less, 0.075 ppm or less, 0.05 ppm or less. 0.025 ppm or less. 0.01 ppm or less, 0.0075 ppm or less, or 0.005 ppm or less). In some examples, the oil can have a nickel content of 0 ppm or more (e.g., 0.001 ppm or more, 0.0025 ppm or more. 0.005 ppm or more, 0.0075 ppm or more. 0.01 ppm or more. 0.025 ppm or more, 0.05 ppm or more, 0.075 ppm or more, 0.1 ppm or more, 0.25 ppm or more, 0.5 ppm or more, 0.75 ppm or more, 1 ppm or more, 1.5 ppm or more, 2 ppm or more. 2.5 ppm or more. 3 ppm or more. 3.5 ppm or more. 4 ppm or more. 4.5 ppm or more. 5 ppm or more. 6 ppm or more, 7 ppm or more, 8 ppm or more, 9 ppm or more, 10 ppm or more, 15 ppm or more, 20 ppm or more, 25 ppm or more. 30 ppm or more, 35 ppm or more, 40 ppm or more. 45 ppm or more, 50 ppm or more. 75 ppm or more. 100 ppm or more, 125 ppm or more. 150 ppm or more, 175 ppm or more, or 200 ppm or more). The nickel content of the oil can range from any of the minimum values described above to any of the maximum values described above. For example. the oil can have a nickel content of from 0 ppm to 250 ppm (e.g., from 0 to 125 ppm, from 125 to 250 ppm, from 0 to 50 ppm, from 50 to 100 ppm, from 100 to 150 ppm, from 150 to 200 ppm, from 200 to 250 ppm, from 0.001 to 250 ppm. from 0.001 to 225 ppm, from 0.001 to 200 ppm, from 0.001 to 175 ppm. from 0.001 to 150 ppm, from 0.001 to 125 ppm, from 0.001 to 100 ppm, from 0.001 to 75 ppm, from 0.001 to 50 ppm, from 0.001 to 45 ppm, from 0.001 to 40 ppm. from 0.001 to 35 ppm. from 0.001 to 30 ppm, from 0.001 to 25 ppm. from 0.001 to 20 ppm, from 0.001 to 15 ppm. from 0.001 to 10 ppm. from 0.001 to 5 ppm. from 0.001 to 1 ppm, from 0.001 to 0.1 ppm, from 0.001 to 0.01 ppm, from 0 to 225 ppm, from 0 to 200 ppm, from 0 to 175 ppm. from 0 to 150 ppm. from 0 to 125 ppm, from 0 to 100 ppm. from 0 to 75 ppm. from 0 to 50 ppm. from 0 to 45 ppm. from 0 to 40 ppm, from 0 to 35 ppm. from 0 to 30 ppm, from 0 to 25 ppm, from 0 to 20 ppm, from 0 to 15 ppm, from 0 to 10 ppm, from 0 to 5 ppm, from 0 to 1 ppm, from 0 to 0.1 ppm. or from 0 to 0.01 ppm). In some examples, the oil can be substantially fee of nickel. The nickel content of the oil can be determined using any suitable method, such as those known in the art. For example, the nickel content of the oil can be determined using ASTM D 5185.

The oil can. for example, have a vanadium content of 25 ppm or less (e.g.. 20 ppm or less. 15 ppm or less. 10 ppm or less, 9 ppm or less, 8 ppm or less, 7 ppm or less, 6 ppm or less, 5 ppm or less, 4.5 ppm or less, 4 ppm or less, 3.5 ppm or less. 3 ppm or less. 2.5 ppm or less, 2 ppm or less, 1.5 ppm or less, 1 ppm or less, 0.75 ppm or less, 0.5 ppm or less. 0.25 ppm or less, 0.1 ppm or less. 0.075 ppm or less. 0.05 ppm or less, 0.025 ppm or less, 0.01 ppm or less, 0.0075 ppm or less, or 0.005 ppm or less). In some examples, the oil can have a vanadium content of 0 ppm or more (e.g., 0.001 ppm or more, 0.0025 ppm or more, 0.005 ppm or more, 0.0075 ppm or more, 0.01 ppm or more, 0.025 ppm or more, 0.05 ppm or more, 0.075 ppm or more, 0.1 ppm or more, 0.25 ppm or more, 0.5 ppm or more, 0.75 ppm or more, 1 ppm or more. 1.5 ppm or more, 2 ppm or more, 2.5 ppm or more. 3 ppm or more, 3.5 ppm or more, 4 ppm or more. 4.5 ppm or more, 5 ppm or more, 6 ppm or more, 7 ppm or more, 8 ppm or more, 9 ppm or more, 10 ppm or more, 15 ppm or more. or 20 ppm or more). The vanadium content of the oil can range from any of the minimum values described above to any of the maximum values described above. For example, the oil can have a vanadium content of from 0 to 25 ppm (e.g., from 0 to 12.5 ppm, from 12.5 to 25 ppm, from 0 to 5 ppm, from 5 to 10 ppm, from 10 to 15 ppm, from 15 to 20 ppm, from 20 to 25 ppm. from 0.001 to 25 ppm. from 0.001 to 20 ppm. from 0.001 to 15 ppm. from 0.001 to 10 ppm. from 0.001 to 5 ppm. from 0.001 to 1 ppm. from 0.001 to 0.1 ppm, from 0.001 to 0.01 ppm, from 0 to 20 ppm, from 0 to 15 ppm, from 0 to 10 ppm, from 0 to 5 ppm, from 0 to 1 ppm. from 0 to 0.1 ppm. or from 0 to 0.01 ppm). In some examples, the oil can be substantially free of vanadium. The vanadium content of the oil can be determined using any suitable method, such as those known in the art. For example, the vanadium content of the oil can be determined using ASTM D 5185.

In some examples. the oil has a total chloride content of 500 ppm or less; a nitrogen content of 600 ppm or less; and a silicon content of 2000 ppm or less. In some examples, the oil has a total chloride content of 500 ppm or less; a nitrogen content of 600 ppm or less: a silicon content of 2000 ppm or less; and a sodium content of 100 ppm or less. In some examples, the oil has a total chloride content of 500 ppm or less; a nitrogen content of 600 ppm or less; a silicon content of 2000 ppm or less; a sodium content of 100 ppm or less; an iron content of 10 ppm or less; a sulfur content of 250 ppm or less; and a calcium content of 50 ppm or less. In some examples, the oil has a total chloride content of 500 ppm or less; a nitrogen content of 600 ppm or less; a silicon content of 2000 ppm or less; a sodium content of 100 ppm or less: an iron content of 10 ppm or less: a phosphorus content of 25 ppm or less; a sulfur content of 250 ppm or less; and a calcium content of 50 ppm or less. In some examples, the oil has a total chloride content of 500 ppm or less; a nitrogen content of 600 ppm or less: a silicon content of 2000 ppm or less; a sodium content of 100 ppm or less; an iron content of 10 ppm or less; a phosphorus content of 25 ppm or less; a sulfur content of 250 ppm or less; a calcium content of 50 ppm or less: a copper content of 10 ppm or less; a nickel content of 250 ppm or less: and a vanadium content of 25 ppm or less.

In some examples, the oil has a total chloride content of 100 ppm or less; a nitrogen content of 600 ppm or less; and a silicon content of 250 ppm or less. In some examples, the oil has a total chloride content of 100 ppm or less; a nitrogen content of 600 ppm or less; a silicon content of 250 ppm or less; and a sodium content of 25 ppm or less. In some examples, the oil has a total chloride content of 100 ppm or less; a nitrogen content of 600 ppm or less: a silicon content of 250 ppm or less: a sodium content of 25 ppm or less; an iron content of 10 ppm or less; a sulfur content of 10 ppm or less; and a calcium content of 5 ppm or less. In some examples, the oil has: a total chloride content of 100 ppm or less; a nitrogen content of 600 ppm or less: a silicon content of 250 ppm or less: a sodium content of 25 ppm or less; an iron content of 10 ppm or less; a phosphorus content of 10 ppm or less; a sulfur content of 10 ppm or less; and a calcium content of 5 ppm or less. In some examples, the oil has a total chloride content of 100 ppm or less: a nitrogen content of 600 ppm or less; a silicon content of 250 ppm or less; a sodium content of 25 ppm or less; an iron content of 10 ppm or less; a phosphorus content of 10 ppm or less; a sulfur content of 10 ppm or less; a calcium content of 5 ppm or less; a copper content of 1 ppm or less; a nickel content of 50 ppm or less; and a vanadium content of 1 ppm or less.

The oil can, for example, have a Reid Vapor Pressure of 12.5 psig or less (e.g.. 12 psig or less, 11.5 psig or less, 11 psig or less. 10.5 psig or less. 10 psig or less, 9.5 psig or less, 9 psig or less, 8.5 psig or less, 8 psig or less. 7.5 psig or less, 7 psig or less, 6.5 psig or less, 6 psig or less, 5.5 psig or less, 5 psig or less, 4.5 psig or less, 4 psig or less, 3.5 psig or less, 3 psig or less, or 2.5 psig or less). In some examples, the oil can have a Reid Vapor Pressure of 2 psig or more (e.g., 2.5 psig or more, 3 psig or more, 3.5 psig or more, 4 psig or more, 4.5 psig or more, 5 psig or more, 5.5 psig or more, 6 psig or more, 6.5 psig or more, 7 psig or more, 7.5 psig or more, 8 psig or more, 8.5 psig or more, 9 psig or more, 9.5 psig or more, 10 psig or more, 10.5 psig or more, or 11 psig or more). The Reid Vapor Pressure of the oil can range from any of the minimum values described above to any of the maximum values described above. For example, the oil can have a Reid Vapor Pressure of from 2 to 12.5 psig (e.g., from 5 to 7 psig, from 7 to 12.5 psig, from 2 to 4 psig, from 4 to 6 psig, from 6 to 8 psig, from 8 to 10 psig, from 10 to 12.5 psig, from 2 to 12 psig, from 2 to 11 psig, from 2 to 10 psig, from 2 to 9 psig, from 2 to 8 psig, from 2 to 6 psig, from 2 to 5 psig, from 3 to 12.5 psig, from 4 to 12.5 psig, from 5 to 12.5 psig, from 6 to 12.5 psig, from 7 to 12.5 psig, from 8 to 12.5 psig, from 9 to 12.5 psig, from 3 to 12 psig, from 5 to 11 psig, or from 7 to 10 psig). The Reid Vapor Pressure of the oil can be determined using any suitable method, such as those known in the art. For example, the Reid Vapor Pressure of the oil can be determined using ASTM D 5191.

The oil can, for example, have a water by distillation amount of 0.5 vol. % or less (e.g., 0.45 vol. % or less, 0.4 vol. % or less, 0.35 vol. % or less, 0.3 vol. % or less, 0.25 vol. % or less, 0.2 vol. % or less, 0.15 vol. % or less, 0.1 vol. % or less, 0.075 vol. % or less, 0.05 vol. % or less, 0.025 vol. % or less, or 0.01 vol. % or less). In some examples, the oil can have a water by distillation amount of 0 vol. % or more (e.g., 0.01 vol. % or more, 0.025 vol. % or more, 0.05 vol. % or more, 0.075 vol. % or more, 0.1 vol. % or more, 0.15 vol. % or more, 0.2 vol. % or more, 0.25 vol. % or more, 0.3 vol. % or more, 0.35 vol. % or more, or 0.4 vol. % or more). The amount of water by distillation in the oil can range from any of the minimum values described above to any of the maximum values described above. For example, the oil can have a water by distillation amount of from 0 to 0.5 vol. % (e.g., from 0 to 0.25 vol. %, from 0.25 to 0.5 vol. %, from 0 to 0.1 vol. %, from 0.1 to 0.2 vol. %, from 0.2 to 0.3 vol. %, from 0.3 to 0.4 vol. %, from 0.4 to 0.5 vol. %, from 0 to 0.4 vol. %, from 0 to 0.3 vol. %, from 0 to 0.2 vol. %, from 0 to 0.05 vol. %, or from 0 to 0.01 vol. %). The amount of water by distillation in the oil can be determined by any suitable method, such as those known in the art. For example, the water by distillation amount in the oil can be determined using ASTM D 95.

The oil can, for example, have a total sediment content of 0.5 vol. % or less (e.g., 0.45 vol. % or less, 0.4 vol. % or less, 0.35 vol. % or less, 0.3 vol. % or less, 0.25 vol. % or less, 0.2 vol. % or less, 0.15 vol. % or less, 0.1 vol. % or less, 0.075 vol. % or less, 0.05 vol. % or less, 0.025 vol. % or less, or 0.01 vol. % or less). In some examples, the oil can have a total sediment content of 0 vol. % or more (e.g., 0.01 vol. % or more, 0.025 vol. % or more, 0.05 vol. % or more, 0.075 vol. % or more, 0.1 vol. % or more, 0.15 vol. % or more, 0.2 vol. % or more, 0.25 vol. % or more, 0.3 vol. % or more, 0.35 vol. % or more, or 0.4 vol. % or more). The total sediment content of the oil can range from any of the minimum values described above to any of the maximum values described above. For example, the oil can have a total sediment content of from 0 to 0.5 vol. % (e.g., from 0 to 0.25 vol. %, from 0.25 to 0.5 vol. %, from 0 to 0.1 vol. %, from 0.1 to 0.2 vol. %, from 0.2 to 0.3 vol. %, from 0.3 to 0.4 vol. %, from 0.4 to 0.5 vol. %, from 0 to 0.4 vol. %, from 0 to 0.3 vol. %, from 0 to 0.2 vol. %, from 0 to 0.05 vol. %, or from 0 to 0.01 vol. %). The total sediment content of the oil can be determined by any suitable method, such as those known in the art. For example, the total sediment content of the oil can be determined using ASTM D 4870.

The oil can, for example, have an n-heptane insoluble content of 0.1 wt. % or less (e.g., 0.09 wt. % or less, 0.08 wt. % or less, 0.07 wt. % or less, 0.06 wt. % or less, 0.05 wt. % or less, 0.04 wt. % or less, 0.03 wt. % or less, 0.02 wt. % or less, or 0.01 wt. % or less). In some examples, the oil can have an n-heptane insoluble content of 0 wt. % or more (e.g., 0.01 wt. % or more, 0.02 wt. % or more, 0.03 wt. % or more, 0.04 wt. % or more, 0.05 wt. % or more, 0.06 wt. % or more, 0.07 wt. % or more, or 0.08 wt. % or more). The n-heptane insoluble content of the oil can range from any of the minimum values described above to any of the maximum values described above. For example, the oil can have an n-heptane insoluble content of from 0 to 0.1 wt. % (e.g., from 0 to 0.05 wt. %, from 0.05 to 0.1 wt. %, from 0 to 0.02 wt. %, from 0.02 to 0.04 wt. %, from 0.04 to 0.06 wt. %, from 0.06 to 0.08 wt. %, from 0.08 to 0.1 wt. %, from 0 to 0.09 wt. %, from 0 to 0.08 wt. %, from 0 to 0.07 wt. %, from 0 to 0.06 wt. %, from 0 to 0.04 wt. %, from 0 to 0.03 wt. %, or from 0 to 0.01 wt. %). The n-heptane insoluble content of the oil can be determined using any suitable method, such as those known in the art. For example, the n-heptane insoluble content of the oil can be determined using ASTM D 3279.

The oil can, for example, have a total acid number of 1 mg KOH/g or less (e.g., 0.9 mg KOH/g or less, 0.8 mg KOH/g or less, 0.7 mg KOH/g or less, 0.6 mg KOH/g or less, 0.5 mg KOH/g or less, 0.4 mg KOH/g or less, 0.3 mg KOH/g or less, 0.2 mg KOH/g or less, or 0.1 mg KOH/g or less). In some examples, the oil can have a total acid number of 0 mg KOH/g or more (e.g., 0.1 mg KOH/g or more, 0.2 mg KOH/g or more, 0.3 mg KOH/g or more, 0.4 mg KOH/g or more, 0.5 mg KOH/g or more, 0.6 mg KOH/g or more, 0.7 mg KOH/g or more, 0.8 mg KOH/g or more, or 0.9 mg KOH/g or more). The total acid number of the oil can range from any of the minimum values described above to any of the maximum values described above. For example, the oil can have a total acid number of from 0 to 1 mg KOH/g (e.g., from 0 to 0.5 mg KOH/g, from 0.5 to 1 mg KOH/g, from 0 to 0.2 mg KOH/g, from 0.2 to 0.4 mg KOH/g, from 0.4 to 0.6 mg KOH/g, from 0.6 to 0.8 mg KOH/g, from 0.8 to 1 mg KOH/g, from 0 to 0.8 mg KOH/g, from 0 to 0.6 mg KOH/g, from 0 to 0.4 mg KOH/g, or from 0 to 0.1 mg KOH/g). The total acid number of the oil can be determined using any suitable method, such as those known in the art. For example, the total acid number of the oil can be determined using ASTM D 664.

In some examples, the oil has a Reid Vapor Pressure of 12.5 psig or less; and a final boiling point of 750° F. to 1000° F. In some examples, the oil has a Reid Vapor Pressure of from 7 to 10 psig; and a final boiling point of from 935° F. to 950° F.

In some examples, the oil has a Reid Vapor Pressure of 12.5 psig or less; and a pour point of 0° F. to 20° F. In some examples, the oil has a Reid Vapor Pressure of from 7 to 10 psig; and a pour point of from 10° F. to 15° F.

In some examples, the oil has a final boiling point of 750° F. to 1000° F.; and a pour point of 0° F. to 20° F. In some examples, the oil has a final boiling point of from 935° F. to 950° F.; and a pour point of from 10° F. to 15° F.

In some examples, the oil has a Reid Vapor Pressure of 12.5 psig or less; a final boiling point of 750° F. to 1000° F.; and a pour point of 0° F. to 20° F. In some examples, the oil has a Reid Vapor Pressure of from 7 to 10 psig; a final boiling point of from 935° F. to 950° F.; and a pour point of from 10° F. to 15° F.; In some examples, the oil has a Reid Vapor Pressure of 12.5 psig or less; a final boiling point of

750° F. to 1000° F.; a pour point of 0° F. to 20° F.; a total chloride content of 500 ppm or less; a nitrogen content of 600 ppm or less; a silicon content of 2000 ppm or less: a sodium content of 100 ppm or less: an iron content of 10 ppm or less; a phosphorus content of 25 ppm or less; a sulfur content of 250 ppm or less; and a calcium content of 50 ppm or less. In some examples, the oil has a Reid Vapor Pressure of from 7 to 10 psig; a final boiling point of from 935° F. to 950° F.; a pour point of from 10° F. to 15° F.; a total chloride content of 100 ppm or less; a nitrogen content of 600 ppm or less; a silicon content of 250 ppm or less; a sodium content of 25 ppm or less: an iron content of 10 ppm or less: a phosphorus content of 10 ppm or less; a sulfur content of 10 ppm or less; and a calcium content of 5 ppm or less.

In some examples, the oil is a raw pyrolysis product, meaning the oil is produced by a method that substantially excludes any hydrotreatment or further refining steps after pyrolysis.

Compositions Comprising the Oil and the Wax, Such as Blends

Also disclosed herein are compositions comprising any of waxes disclosed herein and any of the oils disclosed herein.

For example, the composition can comprise 50% or more of the oil by volume (e.g., 51% or more, 52% or more, 53% or more, 54% or more, 55% or more, 56% or more, 57% or more. 58% or more. 59% or more. 60% or more. 61% or more. 62% or more. 63% or more. 64% or more. 65% or more, 66% or more, 67% or more, 68% or more, or 69% or more). In some examples, the composition can comprise 70% or less of the oil by volume (e.g., 69% or less, 68% or less, 67% or less. 66% or less, 65% or less. 64% or less, 63% or less, 62% or less, 61% or less, 60% or less. 59% or less. 58% or less, 57% or less, 56% or less, 55% or less, 54% or less, 53% or less, 52% or less, or 51% or less). The amount of oil by volume in the composition can range from any of the minimum values described above to any of the maximum values described above. For example, the composition can comprise from 50% to 70% of the oil by volume (e.g., from 50% to 60%, from 60% to 70%, from 50% to 55%, from 55% to 60%. from 60% to 65%. from 65% to 70%. from 50% to 65%, from 55% to 70%. or from 55% to 65%).

In some examples, the composition can comprise 30% or more of the wax by volume (e.g., 31% or more, 32% or more, 33% or more, 34% or more, 35% or more, 36% or more. 37% or more. 38% or more. 39% or more. 40% or more. 41% or more. 42% or more. 43% or more. 44% or more, 45% or more, 46% or more, 47% or more, 48% or more, or 49% or more). In some examples, the composition can comprise 50% or less of the wax by volume (e.g.. 49% or less, 48% or less, 47% or less, 46% or less. 45% or less. 44% or less. 43% or less, 42% or less. 41% or less, 40% or less, 39% or less, 38% or less, 37% or less, 36% or less, 35% or less, 34% or less, 33% or less, 32% or less, or 31% or less). The amount of wax by volume in the composition can range from any of the minimum values described above to any of the maximum values described above. For example, the composition can comprise from 30% to 50% of the wax by volume (e.g., from 30% to 40%, from 40% to 50%, from 30% to 35%, from 35% to 40%, from 40% to 45%, from 45% to 50%. from 30% to 45%, from 35% to 50%. or from 35% to 45%).

For example, the composition can comprise 50-70% of the oil and 30-50% of the wax by volume. For example. the composition can comprise 65% oil and 35% wax by volume. In some examples. the composition comprises 50% oil and 50% wax by volume. In some examples, the composition comprises a blend of the wax and the oil.

Systems and Methods of Making

Also disclosed herein are methods of making any of the compositions (e.g., waxes. oil. blends, etc.) described herein.

For example. disclosed herein are systems and methods for making hydrocarbon based compositions derived from pyrolysis of a feedstock comprising post-consumer and/or post-industrial plastics, such as any of the compositions described herein above. In some examples, the compositions disclosed herein can comprise a wax, an oil, or a combination thereof.

Recycling of plastics via pyrolysis is a technology that generates products with a broad range of quality dependent upon a variety of factors. including the feedstock and manufacturing process. Pyrolysis depolymerizes plastics into products comprised of building block molecules. Contaminants are introduced during plastic formulation and manufacturing processes during the first life of plastic in conjunction with the source and collection method of the plastics.

For example, described herein are systems and methods for plastic to liquids conversion that can accept. for example, polyethylene, polypropylene, and/or polystyrene plastics that are neither suitable nor desirable for conventional (mechanical) plastic recycling. The plastic is thermally converted to liquid (e.g., oil) and wax hydrocarbon products. The hydrocarbon products can. for example, be used in the production of new plastics through conventional hydrocarbon cracking units. The hydrocarbon products can, for example, also be used as an alternative for naphtha, fuel, etc. The systems and methods herein can also produce char/coke and combustible gases, e.g. as products or byproducts.

Plastics that are typically received would have otherwise been destined for disposal at a landfill or waste to energy plant because of their physical form and/or make-up prevents them from being effectively recycled by current conventional (mechanical) recycling means. Most film plastics fall into this category, as do others that have intermixed types of plastic resins or simply have contaminants (such as paper labels, organic food residue, functional additives, colorants, etc.) that make conventional (mechanical) recycling uneconomical.

The systems and/or methods described herein can, for example, operate on an industrial scale.

In some examples, the systems and/or methods described herein can process 5 metric tons or more of plastic feedstock per day (e.g.. 5.5 metric tons or more, 6 metric tons or more, 6.5 metric tons or more, 7 metric tons or more, 7.5 metric tons or more, 8 metric tons or more, 8.5 metric tons or more, 9 metric tons or more, 9.5 metric tons or more, 10 metric tons or more. 11 metric tons or more, 12 metric tons or more, 13 metric tons or more. 14 metric tons or more. 15 metric tons or more, 20 metric tons or more, 25 metric tons or more, 30 metric tons or more, 35 metric tons or more, 40 metric tons or more. 45 metric tons or more, 50 metric tons or more, 60 metric tons or more. 70 metric tons or more. 80 metric tons or more, 90 metric tons or more, 100 metric tons or more, 125 metric tons or more, 150 metric tons or more, 175 metric tons or more, 200 metric tons or more, 225 metric tons or more. 250 metric tons or more. 300 metric tons or more, 350 metric tons or more, 400 metric tons or more. 450 metric tons or more, 500 metric tons or more, 600 metric tons or more, 700 metric tons or more, 800 metric tons or more, or 900 metric tons or more). In some examples. the systems and methods described herein can process 1000 metric tons or less of plastic feedstock per day (e.g.. 900 metric tons or less, 800 metric tons or less, 700 metric tons or less, 600 metric tons or less, 500 metric tons or less, 450 metric tons or less, 400 metric tons or less, 350 metric tons or less, 300 metric tons or less, 250 metric tons or less, 225 metric tons or less, 200 metric tons or less, 175 metric tons or less, 150 metric tons or less, 125 metric tons or less, 100 metric tons or less, 90 metric tons or less, 80 metric tons or less, 70 metric tons or less, 60 metric tons or less, 50 metric tons or less, 45 metric tons or less. 40 metric tons or less, 35 metric tons or less. 30 metric tons or less. 25 metric tons or less, 20 metric tons or less, 15 metric tons or less, 14 metric tons or less, 13 metric tons or less, 12 metric tons or less, 11 metric tons or less, 10 metric tons or less, 9.5 metric tons or less, 9 metric tons or less. 8.5 metric tons or less. 8 metric tons or less, 7.5 metric tons or less, 7 metric tons or less. 6.5 metric tons or less, or 6 metric tons or less). The amount of plastic feedstock processed by the systems and/or methods herein can range from any of the minimum values described above to any of the maximum values described above. For example. the systems and/or methods described herein can process from 5 to 1000 metric tons of plastic feedstock per day (e.g., from 5 to 500 metric tons, from 500 to 1000 metric tons, from 5 to 200 metric tons. from 200 to 400 metric tons. from 400 to 600 metric tons, from 600 to 800 metric tons. from 800 to 1000 metric tons, from 5 to 800 metric tons, from 5 to 600 metric tons, from 5 to 400 metric tons, from 5 to 100 metric tons, from 5 to 50 metric tons, from 5 to 25 metric tons, from 10 to 1000 metric tons, from 25 to 1000 metric tons. from 50 to 1000 metric tons, from 100 to 1000 metric tons, from 200 to 1000 metric tons, from 400 to 1000 metric tons, from 600 to 1000 metric tons, from 10 to 900 metric tons, from 15 to 800 metric tons. from 25 to 750 metric tons. or from 50 to 500 metric tons).

In some examples. the systems and/or methods described herein can produce 10,000 gallons of pyrolysis product (e.g., oil and/or wax, etc.) or more in an amount of time (e.g., 11,000 gallons or more; 12,000 gallons or more: 13.000 gallons or more: 14.000 gallons or more: 15.000 gallons or more; 20,000 gallons or more: 25.000 gallons or more: 30,000 gallons or more; 35,000 gallons or more; 40,000 gallons or more; 45,000 gallons or more; 50,000 gallons or more; 60,000 gallons or more: 70.000 gallons or more: 80,000 gallons or more; 90,000 gallons or more: 100.000 gallons or more; 125,000 gallons or more; 150,000 gallons or more; 175,000 gallons or more; 200,000 gallons or more; 225,000 gallons or more; 250,000 gallons or more; 300,000 gallons or more: 350,000 gallons or more; 400.000 gallons or more; 450.000 gallons or more; 500,000 gallons or more: 600,000 gallons or more; 700,000 gallons or more; 800,000 gallons or more; or 900,000 gallons or more). In some examples. the systems and/or methods described herein can produce 1.000,000 gallons of pyrolysis product (e.g., oil and/or wax, etc.) or more in an amount of time (e.g.. 900.000 gallons or less; 800,000 gallons or less; 700,000 gallons or less; 600,000 gallons or less; 500,000 gallons or less; 450,000 gallons or less; 400,000 gallons or less; 350.000 gallons or less; 300.000 gallons or less: 250,000 gallons or less; 225,000 gallons or less; 200,000 gallons or less; 175,000 gallons or less; 150,000 gallons or less; 125,000 gallons or less; 100,000 gallons or less; 90,000 gallons or less: 80,000 gallons or less: 70.000 gallons or less; 60.000 gallons or less: 50,000 gallons or less; 45,000 gallons or less: 40,000 gallons or less; 35,000 gallons or less; 30,000 gallons or less; 25,000 gallons or less; 20,000 gallons or less; 15,000 gallons or less: 14,000 gallons or less; 13,000 gallons or less: or 12.000 gallons or less). The amount of pyrolysis product produced in the amount of time by the systems and/or methods described herein can range from any of the minimum values described above to any of the maximum values described above. For example, the systems and/or methods described herein can produce from 10,000 to 1,000,000 gallons of pyrolysis product (e.g.. oil and/or wax. etc.) or more in an amount of time (e.g., from 10,000 to 500,000 gallons; from 500,000 to 1,000,000 gallons; from 10,000 to 200,000 gallons; from 200,000 to 400,000 gallons; from 400,000 to 600,000 gallons; from 600,000 to 800,000 gallons; from 800.000 to 1,000,000 gallons: from 10,000 to 800.000 gallons; from 10.000 to 600,000 gallons: from 10,000 to 400.000 gallons; from 10,000 to 200.000 gallons; from 10,000 to 100,000 gallons; from 10,000 to 50,000 gallons; from 10,000 to 25,000 gallons; from 25,000 to 1,000,000 gallons; from 50,000 to 1,000,000 gallons; from 100.000 to 1.000,000 gallons; from 200,000 to 1,000,000 gallons; from 400,000 to 1,000.000 gallons; from 600,000 to 1,000.000 gallons; from 15,000 to 900.000 gallons: or from 20,000 to 800,000 gallons).

The amount of time in which the pyrolysis product is produced by the systems and/or methods can, for example, be 5 days or more (e.g.. 6 days or more, 7 days or more. 8 days or more, 9 days or more. 10 days or more, 11 days or more, 12 days or more, 13 days or more. 14 days or more, 15 days or more, 16 days or more, 17 days or more, 18 days or more, 19 days or more, 20 days or more, 21 days or more, 22 days or more. 23 days or more, 24 days or more. 25 days or more. 26 days or more. 27 days or more, 28 days or more, 29 days or more. 30 days or more, 35 days or more. 40 days or more, 45 days or more, 50 days or more, 60 days or more, 70 days or more, or 80 days or more). In some examples, the amount of time in which the pyrolysis product is produced by the systems and/or methods can be 90 days or less (e.g., 80 days or less. 70 days or less. 60 days or less, 50 days or less. 45 days or less, 40 days or less, 35 days or less. 30 days or less, 29 days or less, 28 days or less, 27 days or less, 26 days or less, 25 days or less, 24 days or less, 23 days or less, 22 days or less, 21 days or less, 20 days or less, 19 days or less. 18 days or less, 17 days or less, 16 days or less. 15 days or less. 14 days or less. 13 days or less. 12 days or less, 11 days or less, 10 days or less. 9 days or less. 8 days or less, or 7 days or less). The amount of time in which the pyrolysis product is produced by the systems and/or methods can range from any of the minimum values described above to any of the maximum values described above. For example, the amount of time in which the pyrolysis product is produced by the systems and/or methods can be from 5 to 90 days (e.g., from 4 to 45 days, from 45 to 90 days, from 5 to 30 days, from 30 to 60 days. from 60 to 90 days, from 5 to 80 days. from 5 to 70 days, from 5 to 60 days. from 5 to 50 days, from 5 to 40 days. from 5 to 21 days, from 5 to 14 days, from 5 to 10 days, from 7 to 90 days, from 10 to 90 days, from 14 to 90 days, from 21 to 90 days, from 30 to 90 days, from 40 to 90 days. from 50 to 90 days. from 70 to 90 days, from 7 to 80 days. or from 10 to 60 days).

In some examples, the systems and/or methods described herein can process from 5 to 1000 metric tons per day of plastic feedstock and produce from 10,000 to 1,000,000 gallons of pyrolysis product (e.g., oil. wax, or a combination thereof) per 5 to 90 days.

FIG. **1**-FIG. **5** are block flow diagrams of example systems and methods described herein.

The systems and methods can, for example. include intake of plastic feedstock. sorting and/or reducing the size of the plastic feedstock. followed by pyrolysis and/or removal of contaminants to produce the hydrocarbon product, which can optionally be post-treated.

Feedstock

The feedstock comprises post-consumer and/or post-industrial plastics. "Post-industrial" or "Pre-consumer" plastics include materials derived from waste streams during a plastic manufacturing process. "Post-consumer" plastics include materials generated by households or by commercial, industrial, and/or institutional facilities in their roles as end-users of the product which can no longer be used for its intended purpose. This includes returns of material from the distribution chain.

In some examples, the feedstock comprises 50% or more by weight post-consumer plastics (e.g., 51% or more, 52% or more, 53% or more, 54% or more, 55% or more, 56% or more, 57% or more, 58% or more, 59% or more, 60% or more, 61% or more, 62% or more, 63% or more, 64% or more, 65% or more, 66% or more, 67% or more, 68% or more, 69% or more, 70% or more, 71% or more, 72% or more, 73% or more, 74% or more, 75% or more, 76% or more, 77% or more, 78% or more, 79% or more, 80% or more, 81% or more, 82% or more, 83% or more, 84% or more, 85% or more, 86% or more, 87% or more, 88% or more, 89% or more, 90% or more, 91% or more, 92% or more, 93% or more, 94% or more, 95% or more, 96% or more, 97% or more, 98% or more, or 99% or more). In some examples, the feedstock comprises 100% or less by weight post-consumer plastics (e.g., 99% or less, 98% or less, 97% or less, 96% or less, 95% or less, 94% or less, 93% or less, 92% or less, 91% or less, 90% or less, 89% or less, 88% or less, 87% or less, 86% or less, 85% or less, 84% or less, 83% or less, 82% or less, 81% or less, 80% or less, 79% or less, 78% or less, 77% or less, 76% or less, 75% or less, 74% or less, 73% or less, 72% or less, 71% or less, 70% or less, 69% or less, 68% or less, 67% or less, 66% or less, 65% or less, 64% or less, 63% or less, 62% or less, 61% or less, 60% or less, 59% or less, 58% or less, 57% or less, 56% or less, 55% or less, 54% or less, 53% or less, or 52% or less). The percent by weight of the feedstock that is post-consumer plastics can range from any of the minimum values described above to any of the maximum values described above. For example, the feedstock can comprise from 50% to 100% by weight post-consumer plastics (e.g., from 50% to 75%, from 75% to 100%, from 50% to 60%, from 60% to 70%, from 70% to 80%, from 80% to 90%, from 90 to 100%, from 50 to 99%, from 50 to 95%, from 50 to 90%, from 50% to 80%, from 50% to 70%, from 55% to 100%, from 60% to 100%, from 70% to 100%, from 75 to 100%, from 80 to 100%, from 95 to 100%, from 55% to 99%, from 70% to 99%, or from 75 to 95%).

Plastic feedstock can be provided in any suitable form, such as, for example, loose film, baled film, rigids, thermoforms, sheets, foams, non-wovens, strips, pellets, powder, purge patties, densified, shredded, etc. In some examples, the feedstock comprises films, such as single and/or multi-layered films.

In some examples, the plastic feedstock can be packaged, e.g. in bales, boxes, drums, etc.

The feedstock can, for example, comprise polyethylene (e.g., LDPE, LLDPE, VLDPE, MDPE, HDPE, UHMWPE, PEX, etc.), polypropylene, polystyrene, or a combination thereof. In some examples, the feedstock includes plastics with a plastic type classification #2, 4, 5, 6, or a combination thereof.

In some examples, a majority of the plastic that is processed by the systems and methods described herein comprises low-density or linear-low density polyethylene (LDPE-#4) and high-density polyethylene (HDPE-#2), in particular film plastic, and the systems and methods described herein are optimized to effectively process these materials.

A substantial portion of polyethylene and polypropylene polymers are used in single use plastics and get discarded after its use. Polyethylene is used widely in various consumer and industrial products. Polyethylene is the most common plastic, over 100 million tons of polyethylene resins are produced annually. Its primary use is in packaging (plastic bags, plastic films, geomembranes, containers including bottles, etc.). Polyethylene is produced in a variety of forms (e.g., ultra-high molecular weight polyethylene (UHMWPE), high-density polyethylene (HDPE), medium density polyethylene (MDPE), linear low-density polyethylene (LLDPE), low-density polyethylene (LDPE), very low density polyethylene (VLDPE), crosslinked polyethylene (PEX)) with the same chemical formula $(C_2H_4)_n$ but different molecular structure. HDPE has a low degree of branching with short side chains while LDPE has a very high degree of branching with long side chains. LLDPE is a substantially linear polymer with significant numbers of short branches, commonly made by copolymerization of ethylene with short-chain alpha-olefins.

The feedstock can, for example, comprise polyethylene, polypropylene, polystyrene, or a combination thereof in an amount of 90% or more by weight (e.g., 91% or more, 92% or more, 93% or more, 94% or more, 95% or more, 96% or more, 97% or more, 98% or more, or 99% or more). In some examples, the feedstock comprises polyethylene, polypropylene, polystyrene, or a combination thereof in an amount of 100% or less by weight (e.g., 99% or less, 98% or less, 97% or less, 96% or less, 95% or less, 94% or less, 93% or less, 92% or less, or 91% or less). The amount of polyethylene, polypropylene, polystyrene, or a combination thereof in the feedstock can range from any of the minimum values described above to any of the maximum values described above. For example, the feedstock can comprise polyethylene, polypropylene, polystyrene, or a combination thereof in an amount of from 90% to 100% by weight (e.g., from 90% to 95%, from 95% to 100%, from 90% to 92%, from 92% to 94%, from 94% to 96%, from 96% to 98%, from 98% to 100%, from 90% to 98%, from 90% to 96%, from 90% to 94%, from 92% to 100%, from 94% to 100%, from 96% to 100%, from 91% to 99%, from 92% to 98%, or from 93% to 97%).

In some examples, the feedstock comprises moisture (e.g., water) in an amount of 20% or less by weight (e.g., 19.5% or less, 19% or less, 18.5% or less, 18% or less, 17.5% or less, 17% or less, 16.5% or less, 16% or less, 15.5% or less, 15% or less, 14.5% or less, 14% or less, 13.5% or less, 13% or less, 12.5% or less, 12% or less, 11.5% or less, 11% or less, 10.5% or less, 10% or less, 9.5% or less, 9% or less, 8.5% or less, 8% or less, 7.5% or less, 7% or less, 6.5% or less, 6% or less, 5.5% or less, 5% or less, 4.5% or less, 4% or less, 3.5% or less, 3% or less, 2.5% or less, 2% or less, 1.5% or less, 1% or less, or 0.5% or less). In some examples, the feedstock comprises moisture in an amount of 0% or more by weight (e.g., 0.5% or more, 1% or more, 1.5% or more, 2% or more, 2.5% or more, 3% or more, 3.5% or more, 4% or more, 4.5% or more, 5% or more, 5.5% or more, 6% or more, 6.5% or more, 7% or more, 7.5% or more, 8% or more, 8.5% or more, 9% or more, 9.5% or more, 10% or more, 10.5% or more, 11% or more, 11.5% or more, 12% or more, 12.5% or more, 13% or more, 13.5% or more, 14% or more, 14.5% or more, 15% or more, 15.5% or more, 16% or more, 16.5% or more, 17% or more, 17.5% or more, 18% or more, 18.5% or more, or 19% or more). The amount of moisture in the feedstock can range from any of the minimum values described above to any of the maximum values described above. For example, the feedstock can comprise moisture in an amount of from 0% to 20% by weight (e.g., from 0% to 10%, from 10% to 20%, from 0% to 5%, from 5% to 10%, from 5% to 15%, from 15% to 20%, from 0% to 2.5%, 2.5% to 5%, from 5% to 7.5%, from 7.5% to 10%, from 10% to 12.5%, from 12.5% to 15%, from 15% to 17.5%, from 17.5% to 20.%, from 0% to 19%, from 0% to 18%, from 0% to 17%, from 0% to 16%, from 0% to 15%, from 0% to 14%, from 0% to 13%, from 0% to 12%, from 0% to 11%, from 0% to 9%, from 0% to 8%, from 0% to 7%, from 0% to 6%, from 0% to 4%, from 0% to 3%, from 0% to 2%, from 0% to 1%, from 1% to 20%, from 2% to 20%, from 3% to 20%, from 4% to 20%, from 6% to 20%, from 7% to 20%, from 8% to 20%, from 9% to 20%, from 11% to 20%, from 12% to 20%, from 13% to 20%, from 14% to 20%, from 16% to 20%, from 17% to 20%, from 18% to 20%, from 0.5% to 19.5%, from 1% to 19%, from 1% to 15%, from 1% to 10%, or from 1% to 5%).

Polyvinyl chlorine (PVC), polyvinylidene chloride (PVDC), polyethylene terephthalate (PET) (commonly used for plastic bottles), nylon, ethylene vinyl alcohol (EVOH), polycarbonate (PC), acrylonitrile butadiene styrene (ABS), rubber, thermosets, and non-plastic components (e.g., metal, glass, wood, cotton, paper, cardboard, dirt, inorganics, etc.) are not desirable and their presence should be minimized.

In some examples, the feedstock comprises 5% or less by weight polyvinyl chloride (PVC), polyvinylidene chloride (PVDC), polyethylene terephthalate (PET), nylon, ethylene vinyl alcohol (EVOH), polycarbonate (PC), acrylonitrile butadiene styrene (ABS), rubber, thermosets, or a combination thereof (e.g., 4.5% or less, 4% or less, 3.5% or less, 3% or less, 2.5% or less, 2% or less, 1.75% or less, 1.5% or less, 1.25% or less, 1% or less, 0.9% or less, 0.8% or less, 0.7% or less, 0.6% or less, 0.5% or less, 0.4% or less, 0.3% or less, 0.2% or less, or 0.1% or less). In some examples, the feedstock comprises 0% or more by weight polyvinyl chloride (PVC), polyvinylidene chloride (PVDC), polyethylene terephthalate (PET), nylon, ethylene vinyl alcohol (EVOH), polycarbonate (PC), acrylonitrile butadiene styrene (ABS), rubber, thermosets, or a combination thereof (e.g., 0.1% or more, 0.2% or more, 0.3% or more, 0.4% or more, 0.5% or more, 0.6% or more, 0.7% or more, 0.8% or more, 0.9% or more, 1% or more, 1.25% or more, 1.5% or more, 1.75% or more, 2% or more, 2.5% or more, 3% or more, 3.5% or more, or 4% or more). The amount of polyvinyl chloride (PVC), polyvinylidene chloride (PVDC), polyethylene terephthalate (PET), nylon, ethylene vinyl alcohol (EVOH), polycarbonate (PC), acrylonitrile butadiene styrene (ABS), rubber, thermosets, or a combination thereof in the feedstock can range from any of the minimum values described above to any of the maximum values described above. For example, the feedstock can comprise from 0% to 5% by weight polyvinyl chloride (PVC), polyvinylidene chloride (PVDC), polyethylene terephthalate (PET), nylon, ethylene vinyl alcohol (EVOH), polycarbonate (PC), acrylonitrile butadiene styrene (ABS), rubber, thermosets, or a combination thereof (e.g., from 0% to 2.5%, from 2.5% to 5%, from 0% to 1%, from 1% to 2%, from 2% to 3%, from 3% to 4%, from 4% to 5%, from 0% to 4.5%, from 0% to 4%, from 0% to 3.5%, from 0% to 3%, from 0% to 2%, from 0% to 1.5%, from 0% to 0.5%, from 0.5% to 5%, from 1% to 5%, from 1.5% to 5%, from 2% to 5%, from 3% to 5%, from 3.5% to 5%, from 0.1% to 4.5%, from 0.2% to 4%, or from 0.3% to 3%).

The feedstock can, for example, comprise 15% by weight or less non-plastic materials, such as metal, glass, wood, cotton, paper, cardboard, dirt, inorganics, etc., or a combination thereof (e.g., 14.5% or less, 14% or less, 13.5% or less, 13% or less, 12.5% or less, 12% or less, 11.5% or less, 11% or less, 10.5% or less, 10% or less, 9.5% or less, 9% or less, 8.5% or less, 8% or less, 7.5% or less, 7% or less, 6.5% or less, 6% or less, 5.5% or less, 5% or less, 4.5% or less, 4% or less, 3.5% or less, 3% or less, 2.5% or less, 2% or less, 1.5% or less, 1% or less, or 0.5% or less). In some examples, the feedstock comprises 0% or more by weight non-plastic materials (e.g., 0.5% or more, 1% or more, 1.5% or more, 2% or more, 2.5% or more, 3% or more, 3.5% or more, 4% or more, 4.5% or more, 5% or more, 5.5% or more, 6% or more, 6.5% or more, 7% or more, 7.5% or more, 8% or more, 8.5% or more, 9% or more, 9.5% or more, 10% or more, 10.5% or more, 11% or more, 11.5% or more, 12% or more, 12.5% or more, 13% or more, 13.5% or more, or 14% or more). The amount of non-plastic materials in the feedstock can range from any of the minimum values described above to any of the maximum values described above. For example, the feedstock can comprise non-plastic materials in an amount of from 0% to 15% by weight (e.g., from 0% to 7.5%, from 7.5% to 15%, from 0% to 5%, from 5% to 10%, from 10% to 15%, from 0% to 2.5%, 2.5% to 5%, from 5% to 7.5%, from 7.5% to 10%, from 10% to 12.5%, from 12.5% to 15%, from 0% to 14%, from 0% to 13%, from 0% to 12%, from 0% to 11%, from 0% to 10%, from 0% to 9%, from 0% to 8%, from 0% to 7%, from 0% to 6%, from 0% to 4%, from 0% to 3%, from 0% to 2%, from 1% to 15%, from 2% to 15%, from 3% to 15%, from 4% to 15%, from 5% to 15%, from 6% to 15%, from 7% to 15%, from 8% to 15%, from 9% to 15%, from 11% to 15%, from 12% to 15%, from 15% to 15%, from 0.5% to 14.5%, from 1% to 14%, or from 1% to 10%).

In some examples, the feedstock can initially be manually, visually, and/or automatically (e.g., by an automated system/component) checked to ensure it contains the correct material and does not contain an inordinate amount of obvious contamination. During the manual/visual/automated inspection of the feedstock, the feedstock is inspected for large contaminant items, such as metal, glass, PVC, paper, wood, PET plastics, and cardboard, which are removed when identified.

In some examples, the feedstock can further be assessed, e.g. for chemical and/or physical properties. This can include, for example, assessing at least a representative sample portion of each feedstock via infrared analysis (e.g., portable infrared analyzer), gas chromatography-mass spectrometry (GC-MS), a bench-scale pyrolysis test, ASTM testing for specific contaminants and physical properties, melt-index test, ash test, or a combination thereof.

Feedstock that fail to meet the initial inspection criteria is not further processed by the systems or methods described herein.

After the initial inspection is complete, the acceptable feedstock can be stored for future use (e.g., in a stockpile, a hopper, etc.) and/or loaded into the system for processing.

Infeed

In some examples, the feedstock can be loaded into the system via an infeed conveyor. The rate at which the infeed conveyor provides feedstock to the system (e.g., the feed rate) can, for example, be 500 pounds per hour (lb./hr.) or more (e.g., 550 lb./hr. or more; 600 lb./hr. or more; 650 lb./hr. or more; 700 lb./hr. or more; 750 lb./hr. or more; 800 lb./hr. or more; 850 lb./hr. or more; 900 lb./hr. or more; 950 lb./hr. or more; 1000 lb./hr. or more; 1100 lb./hr. or more;

1200 lb./hr. or more; 1300 lb./hr. or more; 1400 lb./hr. or more; 1500 lb./hr. or more; 1750 lb./hr. or more: 2000 lb./hr. or more; 2250 lb./hr. or more; 2500 lb./hr. or more; 2750 lb./hr. or more: 3000 lb./hr. or more; 3250 lb./hr. or more: 3500 lb./hr. or more; 3750 lb./hr. or more; 4000 lb./hr. or more; 4250 lb./hr. or more; 4500 lb./hr. or more; 4750 lb./hr. or more; 5000 lb./hr. or more; 5500 lb./hr. or more; 6000 lb./hr. or more: 6500 lb./hr. or more; 7000 lb./hr. or more: 7500 lb./hr. or more; 8000 lb./hr. or more; 8500 lb./hr. or more; 9000 lb./hr. or more; 9500 lb./hr. or more; 10,000 lb./hr. or more; 11,000 lb./hr. or more; 12,000 lb./hr. or more; 13,000 lb./hr. or more; 14,000 lb./hr. or more: 15.000 lb./hr. or more: 16,000 lb./hr. or more; 17.000 lb./hr. or more: 18,000 lb./hr. or more; or 19,000 lb./hr. or more). In some examples, the rate at which the infeed conveyor provides feedstock to the system (e.g.. the feed rate) can be 20.000 lb./hr. or less (e.g.. 19.000 lb./hr. or less; 18.000 lb./hr. or less: 17.000 lb./hr. or less: 16.000 lb./hr. or less: 15.000 lb./hr. or less; 14,000 lb./hr. or less; 13,000 lb./hr. or less; 12,000 lb./hr. or less; 11,000 lb./hr. or less; 10,000 lb./hr. or less: 9500 lb./hr. or less; 9000 lb./hr. or less: 8500 lb./hr. or less: 8000 lb./hr. or less; 7500 lb./hr. or less: 7000 lb./hr. or less; 6500 lb./hr. or less; 6000 lb./hr. or less; 5500 lb./hr. or less; 5000 lb./hr. or less; 4750 lb./hr. or less; 4500 lb./hr. or less; 4250 lb./hr. or less; 4000 lb./hr. or less; 3750 lb./hr. or less: 3500 lb./hr. or less; 3250 lb./hr. or less: 3000 lb./hr. or less: 2750 lb./hr. or less; 2500 lb./hr. or less: 2250 lb./hr. or less; 2000 lb./hr. or less; 1750 lb./hr. or less; 1500 lb./hr. or less; 1400 lb./hr. or less; 1300 lb./hr. or less; 1200 lb./hr. or less: 1100 lb./hr. or less; 1000 lb./hr. or less; 950 lb./hr. or less: 900 lb./hr. or less; 850 lb./hr. or less; 800 lb./hr. or less: 750 lb./hr. or less; 700 lb./hr. or less: 650 lb./hr. or less; or 600 lb./hr. or less). The rate at which the infeed conveyor provides feedstock to the system can range from any of the minimum values described above to any of the maximum values described above. For example, the rate at which the infeed conveyor provides feedstock to the system can be from 500 pounds per hour (lb./hr.) to 20,000 lb./hr. (e.g., from 500 to 5,000 lb./hr.; from 5,000 to 20,000 lb./hr.; from 500 to 4000 lb./hr.; from 4000 to 8000 lb./hr.: from 8000 to 12,000 lb./hr.: from 12,000 to 16.000 lb./hr.: from 16,000 to 20,000 lb./hr.; from 500 to 15,000 lb./hr.; from 500 to 10,000 lb./hr.; from 500 to 9000 lb./hr.; from 500 to 8000 lb./hr.; from 500 to 7000 lb./hr.; from 500 to 6000 lb./hr.; from 500 to 2500 lb./hr.: from 1000 to 20.000 lb./hr.: from 2500 to 20,000 lb./hr.: from 6000 to 20.000 lb./hr.; from 7000 to 20,000 lb./hr.; from 8000 to 20,000 lb./hr.; from 9000 to 20,000 lb./hr.; from 10,000 to 20,000 lb./hr.; from 550 to 19,000 lb./hr.; from 600 to 19,000 lb./hr.: or from 1000 to 15,000 lb./hr.).

Sorting

In some examples, feedstock loaded into the system can undergo additional sorting.

In some examples, the plastic feedstock can be deposited onto a conveyor and/or further processed to remove contaminants. This can, for example, include visual inspection and manual removal, automated inspection and removal, positioning one or more magnets to magnetically remove ferrous contaminants (e.g., various components such as nuts. bolts. screws, small pieces of wire, etc. comprising ferrous metals and/or alloys), washing and/or drying, size based separation (e.g., screening, sifting, etc.), air jets, sink float, etc.

In some examples. the feedstock can be transported to a trommel. such as a screen trommel. The screened trommel can, for example, be used to remove fine dust, particles, and other contaminants from the incoming feedstock stream, for example before and/or after it has passed through a shredder. The trommel can receive feedstock and trommel rotation can agitate incoming feedstock and promote removal of granular materials (e.g.. sand, pigment, binder, food particulates, dirt, etc.) in the feedstock through the trommel screen. The remaining oversized material from the trommel can be deposited, for example. onto a conveyor for further inspection and/or sorting.

In some examples, visual inspection and manual sorting and/or automated inspection and sorting is used to remove contaminants from the plastic feedstock, e.g., before and/or after passing through the trommel and/or shredder. Contaminants to be removed can. for example, include undesirable plastic (such as PET, PVC, nylon, and thermosets) as well as other materials that can damage downstream equipment or degrade the quality of the finished products such as strapping. paper, cardboard. rope. batteries. beverage bottles still containing liquid. glass, wood, metal. electronics. and a wide range of other non-plastic materials.

Size Reduction

In some examples, feedstock loaded into the system can undergo one or more size reductions. The size reduction can be accomplished by any suitable means, such as those known in the art. For example, the feedstock can be shredded, pelletized, densified, or a combination thereof. For example, the system can include one or more size reduction components, such as a chipper, granulator. grinder. hammermill, shredder (e.g., a shear shredder), pelletizer, densifier, agglomerator, or a combination thereof.

In some examples, the feedstock can be shredded. for example using one or more shredders. Each shredder can comprise any suitable type of shredder. such as those known in the art. In some examples, the system can include one or more shear shredders.

The shredder can perform a size reduction on incoming plastic. for example to a range of 0.25 to 36 inches (longest dimension). For example. the shredder can reduce the average initial size of the incoming plastic to 0.25 inches or more (longest dimension) (e.g., 0.5 inches or more, 1 inch or more, 1.5 inches or more. 2 inches or more. 3 inches or more, 4 inches or more, 5 inches or more. 6 inches or more, 7 inches or more, 8 inches or more, 9 inches or more, 10 inches or more, 11 inches or more, 12 inches or more, 13 inches or more, 14 inches or more, 15 inches or more, 16 inches or more. 17 inches or more. 18 inches or more. 20 inches or more. 22 inches or more. 24 inches or more. 26 inches or more, 28 inches or more, 30 inches or more, 32 inches or more, or 34 inches or more). In some examples, the shredder can reduce the average initial size of the incoming plastic to 36 inches or less (longest dimension) (e.g., 34 inches or less. 32 inches or less, 30 inches or less, 28 inches or less, 26 inches or less, 24 inches or less, 22 inches or less, 20 inches or less, 18 inches or less, 17 inches or less, 16 inches or less. 15 inches or less, 14 inches or less, 13 inches or less. 12 inches or less, 11 inches or less. 10 inches or less, 9 inches or less, 8 inches or less, 7 inches or less, 6 inches or less, 5 inches or less, 4 inches or less, 3 inches or less, 2 inches or less, or 1 inch or less). The average longest dimension of the plastic processed by the shredder can range from any of the minimum values described above to any of the maximum values described above. For example, the shredder can reduce the average initial size of the incoming plastic to from 0.25 inches to 36 inches (longest dimension) (e.g.. from 0.25 to 18 inches, from 18 to 36 inches, from 0.25 to 6 inches, from 6 to 12 inches, from 12 to 18 inches. from 18 to 24 inches, from 24 to 30 inches, from 30 to 36 inches, from 0.25 to 30 inches, from 0.25 to 24 inches, from 0.25 to

18 inches, from 0.25 to 16 inches, from 0.25 to 14 inches, from 0.25 to 12 inches, from 0.25 to 10 inches, from 0.25 to 8 inches, from 0.25 to 4 inches. from 0.25 to 2 inches, from 0.25 inches to 1 inch. from 1 to 36 inches. from 2 to 36 inches, from 4 to 36 inches, from 6 to 36 inches, from 8 to 36 inches, from 10 to 36 inches, from 12 to 36 inches, from 14 to 36 inches. from 16 to 36 inches. from 18 to 36 inches. from 1 to 30 inches. or from 2 to 18 inches).

Plastic feedstock that passes through the shredder can then be stored in a hopper and/or transported for further processing.

In some examples, the shredded feedstock can go through a second size reduction process using any suitable size reduction technique.

Drying Component

In some examples, the systems and methods can further include washing and/or drying the feedstock.

For example, the systems and methods can further comprise drying the feedstock, for example to remove at least a portion of the moisture or other liquids comprising a contaminant within the feedstock.

In some examples. the feedstock can be deposited onto a conveyor which passes the feedstock through a dryer before depositing the feedstock in a storage bunker and/or transporting the feedstock to a further system component for further processing.

The dryer can comprise any suitable equipment. such as a rotary dryer. Heated air can be directed through the dryer across the feedstock to remove moisture from the feedstock. The surface area exposed can allow the heated air flow to remove moisture or free water that may be present in the feedstock. The moist air along with small. entrained particles from the dryer can be exhausted using any suitable means. The required air can be heated by any suitable means, such as electrically heated. The maximum air temperature will be below the softening point of any of the plastics. Using an effective drying solution upstream of the extruders and/or reactors can reduce the problems of vent flow at downstream extrusion equipment and water intrusion to the reactors.

Storage Bunker

In some examples, the system can further include a storage bunker, for example to store feedstock before undergoing melting, removal of contaminants, pyrolysis, or a combination thereof.

In some examples. the system includes a storage bunker that receives the feedstock from the infeed conveyor, the shredder (when present), the dryer (when present), the trommel (when present), etc. or a combination thereof.

The storage bunker can, for example. have the capacity to store enough feedstock to provide an uninterrupted supply of plastic to the downstream components (e.g., extruder(s)) for a period of time (e.g., up to two hours), for example if any of the upstream equipment has to be shut down briefly for maintenance or repair.

Feedstock levels inside the storage bunker can be monitored, for example using one or more cameras or other feedback mechanisms.

Metals Detection and Removal

In some examples. feedstock loaded into the system can undergo additional metals detection and removal. In some examples, the plastic feedstock can be deposited onto a conveyor and/or further processed to metal contaminants. This can, for example, include visual inspection and manual removal. automated inspection and removal, positioning one or more magnets to magnetically remove ferrous contaminants (e.g., various components such as nuts, bolts, screws, small pieces of wire, etc. comprising ferrous metals and/or alloys). washing and/or drying. size based separation (e.g., screening, sifting, etc.). air jets. sink float, etc.

For example. at one or more points in any of the systems or methods described herein, there can be one or more additional magnetic components to magnetically remove ferrous contaminants from the feedstock, for example before the shredder, after the shredder. before the trommel. after the trommel, before the dryer, after the dryer, before the storage bunker, after the storage bunker, before the components for melting, removal of contaminants, and/or pyrolysis, or a combination thereof. For example. the system can include magnets positioned before. after. or as part of each of the one or more conveyors that transport the feedstock between each system location/component. The strength of the magnets can be selected based on the location in the system and/or the throughput of feedstock processed.

In addition. the system can further include a metal detection and rejection system to eliminate further metal contaminants, such as non-ferrous metals (e.g., copper, brass, bronze. stainless steel. aluminum and other non-ferrous alloys). Non-ferrous metals can be present in a variety of forms, such as, for example, nuts, bolts, screws, washers, batteries, machine parts, tools, etc. The additional metal and detection system can be included in the system, for example, on the conveyors feeding the storage bunkers. This additional metal and detection system can detect non-ferrous metals and then trigger a quick-acting diverter gate that moves this metal off the conveyor and into a collection bin. While aluminum is the primary target of this system, copper, stainless steel, and brass can also be detected and rejected.

Conveyors

In the system described herein, each of the conveyors can comprise any suitable type of conveyor. Examples of conveyors include. but are not limited to. belt conveyors, roller conveyors. slat conveyors, apron conveyors, ball transfer conveyors. magnetic conveyors. bucket conveyors. chute conveyors, chain conveyors, pneumatic conveyors, vacuum conveyors, screw conveyors, vibrating conveyors, wheel conveyors. sandwich conveyors. and combinations thereof. In some examples, each of the conveyors can comprise a screw conveyor, a belt conveyor, or a combination thereof. In some examples, the system can include a plurality of belt conveyors. The belt conveyors can, for example, be designed with side walls. The belt conveyors can include any type of belt conveyor, such as standard flat belts. cleated belts, semi-trough belts, compound belts (e.g., hockey stick configurations), or a combination thereof.

The dimensions and/or speed of any of the conveyors can be selected in view of a variety of factors. For example, the dimensions and/or speed of the conveyor can be selected to regulate the flow of materials at a desired rate.

Melting, Removal of Contaminants, and/or Pyrolysis

In some examples. the systems can include one or more components for melting the feedstock, volatilizing various contaminants in the feedstock, pyrolyzing the feedstock, or a combination thereof.

While some contaminants can be physically removed by one or more of the processes discussed above, for certain feedstock components. such as multilayer films, it is difficult to physically remove the contaminants and instead they can be removed by heating the feedstock to a temperature sufficient to volatilize said contaminant.

For example. the systems and methods can comprise pyrolyzing the feedstock, wherein the pyrolysis reactor and method includes a component or step for removal of volatile contaminants. The pyrolysis can be accomplished using any suitable pyrolysis reactor, such as, for example, an auger pyrolysis reactor. a rotary kiln pyrolysis reactor, a drum pyrolysis reactor. a tubular pyrolysis reactor. a fluidized bed reactor, a spouted bed reactor, a molten salt reactor, a fixed-bed reactor, a continuously stirred reactor, a Heinz Retort Pyrolysis reactor, a vortex pyrolysis reactor, a batch pyrolysis reactor, a semi-batch pyrolysis reactor. or a combination thereof.

In some examples, the systems and methods can comprise heating and/or melting the feedstock before introducing the melted feedstock into a pyrolysis reactor, wherein the feedstock is heated and/or melted at a temperature sufficient to volatilize a contaminant and the systems and methods can further include removing said volatilized contaminants. Any suitable component for heating and/or melting can be used, such as those known in the art. In some examples, the systems and methods can include one or more extruders. wherein the feedstock is heated and/or melted within the extruder and optionally wherein the extruder includes one or more vents for removing volatile contaminants from the heated and/or melted feedstock.

Extruders

In some examples, plastic feedstock (e.g., optionally shredded plastic feedstock) from the storage bunker is conveyed separately to one or more extruders (e.g., two or more). for example using a conveyor. The extruders can, for example, be designed to heat the plastic and convert it into semi-molten plastic that is moved to the reactors. In some examples. the systems includes two or more extruders and the two or more extruders can be in operation simultaneously.

In some examples, the system includes a plurality of extruders and each extruder is configured to process a portion of normal throughput, for example so as to allow plastic flow to and operation of the reactors to continue when one of the extruders is taken out of service for repair or maintenance. In some examples, the system can include three extruders, with two extruders being in operation simultaneously and the third extruder being a redundancy, for example the third extruder can be operated while one of the other extruders is taken out of service for repair or maintenance.

Each extruder can, for example, use an internal pneumatically operated ram to increase the density of the plastic in order to achieve the desired throughput rate. The ram can also move the plastic from the extruder inlet into the extruder's screw mechanism.

In some examples, the extruder barrel can include one or more openings (e.g. one or more vents or ports) at one or more positions along the length of the extruder barrel. In some examples, each extruder barrel can include a plurality of vents (e.g., two or more vents) along the length of the extruder barrel. The vent(s) can allow vapors and/or gases produced from the plastic feedstock during the heating process to escape from the extruder. Moisture in the feedstock is converted to steam at the high temperatures created in the extruder and this steam typically exits at the vent. Other gaseous material such as volatile inks from plastic labels. various lipids and fats from food contamination on the plastic, and decomposed PVC and PET polymers can also exit at the vent along with gas made up of entrained fine particulates. This system allows removal of significant amounts of chlorine and other undesirable elements that otherwise would end up in the reactor and potentially affect the quality of both oil and wax products and/or corrode the processing equipment.

In some examples, each extruder comprises a two or more vents (e.g., wherein the extruder includes at least a first vent and a second vent). In some examples. the first vent of the extruder comprises an ambient pressure vent. In some examples, the second vent of the extruder comprises a vacuum vent, for example where a vacuum is applied through the vent to pull gases and/or contaminants out of the semi-molten feedstock.

In some examples, a vent feeding device can be used at one or more of the extruder vents to prevent expulsion of melted plastic from that vent. The vent feeder can force any plastic that is flowing or being expelled from the vent back into the barrel where it is then carried forward down the extruder. This feeder can be equipped with a vent section that can allow steam and other volatiles to pass by the feeder.

In some examples. the barrel of the extruder can be heated. for example by one or more externally mounted heaters. In some examples, the barrel of the extruder can be heated by a plurality of externally mounted heaters. The heaters can be any suitable type of heater, such as resistive electric heaters and/or inductive heaters. Additional heating can. for example. be provided by friction as the plastic is forced through the internal geometry of the extruder barrel by the screw. Multiple zones along the length of the extruder can, in some examples, be independently heated and cooled using barrel heaters and/or cooling fans to achieve a pre-set temperature profile that varies depending on the type of material being fed into the extruder.

In some examples, the barrel of the extruder can be heated such that the feedstock within the extruder has a temperature of 20° C. or more at the first of the one or more vents (e.g., 25° C. or more, 50° C. or more, 75° C. or more. 100° C. or more, 125° C. or more, 150° C. or more, 175° C. or more, 200° C. or more, 225° C. or more, 250° C. or more, 275° C. or more, 280° C. or more. 285° C. or more, 290° C. or more, 295° C. or more. 300° C. or more, 305° C. or more. 310° C. or more, 315° C. or more. 320° C. or more, 325° C. or more, 350° C. or more, 375° C. or more, 400° C. or more, or 425° C. or more). In some examples, the barrel of the extruder can be heated such that the feedstock within the extruder has a temperature of 450° C. or less at the first of the one or more vents (e.g., 425° C. or less, 400° C. or less, 375° C. or less, 350° C. or less, 325° C. or less, 320° C. or less, 315° C. or less, 310° C. or less, 305° C. or less, 300° C. or less, 295° C. or less, 290° C. or less, 285° C. or less, 285° C. or less, 280° C. or less. 275° C. or less. 250° C. or less, 225° C. or less, 200° C. or less, 175° C. or less, 150° C. or less, 125° C. or less, 100° C. or less, 75° C. or less, or 50° C. or less). The temperature of the feedstock within the extruder at the first vent can range from any of the minimum values described above to any of the maximum values described above. For example, the barrel of the extruder can be heated such that the feedstock within the extruder has a temperature of from 20° C. to 450° C. at the first of the one or more vents (e.g.. from 20° C. to 225° C., from 225° C. to 450° C.. from 20° C. to 125° C., from 125° C. to 225° C., from 225° C. to 325° C., from 325° C. to 450° C., from 20° C. to 400° C., from 20° C. to 350° C., from 20° C. to 300° C., from 20° C. to 250° C.. from 20° C. to 200° C.. from 20° C. to 250° C., from 20° C. to 100° C.. from 20° C. to 50° C., from 50° C. to 450° C., from 100° C. to 450° C., from 150° C. to 450° C., from 200° C. to 250° C., from 250° C. to 250° C., from 300° C. to 450° C., from 350° C. to 450° C., from 50° C. to 400° C.. from 100° C. to 375° C.. from 250° C. to 350° C., or from 275° C. to 325° C.).

In some examples, each extruder includes a screw with multiple zones, such as a pumping section, a compression section, a decompression section, a mixing section, or a combination thereof. In some examples, each extruder screw includes a decompression section at or before the first vent, for example to promote expulsion of entrained air, moisture, and/or other gases (e.g., volatiles) from the feedstock at the first vent.

The residence time of the feedstock within each extruder can be selected in view of a variety of factors. For example, the residence time of the feedstock within each extruder can be selected in view of the speed at which the extruder is run (which in turn can be selected based on the throughput rate of the reactor(s) that the extruder is feeding), the identity of the plastics within the feedstock, or a combination thereof.

In some examples, the residence time of the feedstock within the extruder can be 30 seconds or more (e.g., 1 minute or more, 1.5 minutes or more, 2 minutes or more, 2.5 minutes or more, 3 minutes or more, 3.5 minutes or more, 4 minutes or more, 5 minutes or more, 5.5 minutes or more, 6 minutes or more, 6.5 minutes or more, 7 minutes or more, 7.5 minutes or more, 8 minutes or more, 8.5 minutes or more, or 9 minutes or more). In some examples, the residence time of the feedstock within the extruder can be 10 minutes or less (e.g., 9.5 minutes or less, 9 minutes or less, 8.5 minutes or less, 8 minutes or less, 7.5 minutes or less, 7 minutes or less, 6.5 minutes or less, 6 minutes or less, 5.5 minutes or less, 5 minutes or less, 4.5 minutes or less, 4 minutes or less, 3.5 minutes or less, 3 minutes or less, 2.5 minutes or less, 2 minutes or less, 1.5 minutes or less, or 1 minute or less). The residence time of the feedstock within the extruder can range from any of the minimum values described above to any of the maximum values described above. For example, the residence time of the feedstock within the extruder can be from 30 seconds to 10 minutes (e.g., from 30 seconds to 5 minutes, from 5 minutes to 10 minutes, from 30 seconds to 2.5 minutes, from 2.5 to 5 minutes, from 5 to 7.5 minutes, from 7.5 minutes to 10 minutes, from 30 seconds to 9 minutes, from 30 seconds to 8 minutes, from 30 seconds to 7 minutes, from 30 seconds to 6 minutes, from 30 seconds to 4 minutes, from 30 seconds to 3 minutes, from 30 seconds to 2 minutes, from 1 minute to 10 minutes, from 2 to 10 minutes, from 3 to 10 minutes, from 4 to 10 minutes, from 6 to 10 minutes, from 7 to 10 minutes, from 8 to 10 minutes, from 1 minute to 9 minutes, or from 1.5 minutes to 5 minutes).

Feedstock material subsequently enters the extruder screw's pumping section where it is propelled out of the extruder and into the pyrolysis reactor, for example via a heated transfer pipe. A rupture disk can be provided for emergency pressure relief to prevent down-stream damage to piping and equipment.

Pyrolysis Reactors

The hydrocarbons that make up the feedstock plastic polymers include chains and rings of hydrocarbon molecules linked together to form the solid materials with some additives to the structures to adjust properties such as plasticity, stabilization against ultraviolet light degradation, and extrusion slip.

Oil and wax production is accomplished by heating the incoming stream of plastic (e.g., raw feedstock, melted feedstock, semi-molten plastic from the extruders, etc.) in an oxygen-free environment to the point where the plastic is a fully molten liquid and the polymers "depolymerize". During the conversion process, the hydrocarbon plastic chains and groups of rings are split apart by the heating process into smaller segments until they are small and light enough to exit the reactor as a vapor.

For example, the systems and methods can include one or more pyrolysis reactors (e.g., two or more, or three or more) for pyrolyzing the feedstock. The pyrolysis can be accomplished using any suitable pyrolysis reactor, such as, for example, an auger pyrolysis reactor, a rotary kiln pyrolysis reactor, a drum pyrolysis reactor, a tubular pyrolysis reactor, a fluidized bed reactor, a spouted bed reactor, a molten salt reactor, a fixed-bed reactor, a continuously stirred reactor, a Heinz Retort Pyrolysis reactor, a vortex pyrolysis reactor, a batch pyrolysis reactor, a semi-batch pyrolysis reactor, or a combination thereof. In some examples, the system and methods can include one or more batch pyrolysis reactors, semi-batch pyrolysis reactors, a continuously stirred reactor, or a combination thereof. The reactors can have any suitable orientation, such as horizontal or vertical. In some examples, the reactors are vertical reactors.

Each reactor can receive feedstock from one or more upstream components (e.g., storage bunker, extruder, etc.).

In some examples, the system includes one or more reactors (e.g., two or more, or three or more) configured to receive the semi-molten plastic feedstock from the extruder(s). In some examples, the system can include a plurality of reactors. Each reactor can, for example, process the output of one or more extruders.

The volume of each reactor can be selected, for example, in view of the throughput of the system.

In some examples, the volume of each reactor can independently be 1 cubic foot (ft^3) or more (e.g., 2 ft^3 or more, 3 ft^3 or more, 4 ft^3 or more, 5 ft^3 or more, 10 ft^3 or more, 15 ft^3 or more, 20 ft^3 or more, 25 ft^3 or more, 30 ft^3 or more, 35 ft^3 or more, 40 ft^3 or more, 45 ft^3 or more, 50 ft^3 or more, 60 ft^3 or more, 70 ft^3 or more, 80 ft^3 or more, 90 ft^3 or more, 100 ft^3 or more, 125 ft^3 or more, 150 ft^3 or more, 175 ft^3 or more, 200 ft^3 or more, 225 ft^3 or more, 250 ft^3 or more, 300 ft^3 or more, 350 ft^3 or more, 400 ft^3 or more, 450 ft^3 or more, 500 ft^3 or more, 600 ft^3 or more, 700 ft^3 or more, 800 ft^3 or more, 900 ft^3 or more, 1000 ft^3 or more, 1100 ft^3 or more, 1200 ft^3 or more, 1300 ft^3 or more, or 1400 ft^3 or more). In some examples, the volume of each reactor can independently be 1500 ft^3 or less (e.g., 1400 ft^3 or less, 1300 ft^3 or less, 1200 ft^3 or less, 1100 ft^3 or less, 1000 ft^3 or less, 900 ft^3 or less, 800 ft^3 or less, 700 ft^3 or less, 600 ft^3 or less, 500 ft^3 or less, 450 ft^3 or less, 400 ft^3 or less, 350 ft^3 or less, 300 ft^3 or less, 250 ft^3 or less, 225 ft^3 or less, 200 ft^3 or less, 175 ft^3 or less, 150 ft^3 or less, 125 ft^3 or less, 100 ft^3 or less, 90 ft^3 or less, 80 ft^3 or less, 70 ft^3 or less, 60 ft^3 or less, 50 ft^3 or less, 45 ft^3 or less, 40 ft^3 or less, 35 ft^3 or less, 30 ft^3 or less, 25 ft^3 or less, 20 ft^3 or less, 15 ft^3 or less, 10 ft^3 or less, 5 ft^3 or less, 4 ft^3 or less, 3 ft^3 or less, or 2 ft^3 or less). The volume of each reactor can independently range from any of the minimum values described above to any of the maximum values described above. For example, the volume of each reactor can independently be from 1 ft^3 to 1500 ft^3 (e.g., from 1 to 750 ft^3, from 750 to 1500 ft^3, from 1 to 500 ft^3, from 500 to 1000 ft^3, from 1000 to 1500 ft^3, from 1 to 1400 ft^3, from 1 to 1300 ft^3, from 1 to 1200 ft^3, from 1 to 1100 ft^3, from 1 to 1000 ft^3, from 1 to 900 ft^3, from 1 to 800 ft^3, from 1 to 700 ft^3, from 1 to 600 ft^3, from 1 to 400 ft^3, from 1 to 300 ft^3, from 1 to 200 ft^3, from 1 to 100 ft^3, from 1 to 50 ft^3, from 1 to 25 ft^3, from 1 to 10 ft^3, from 10 to 1500 ft^3, from 25 to 1500 ft^3, from 50 to 1500 ft^3, from 100 to 1500 ft^3, from 200 to 1500 ft^3, from 300 to 1500 ft^3, from 400 to 1500 ft^3, from 500 to 1500 ft^3, from 600 to 1500 ft^3, from 700 to 1500 ft^3, from 800 to 1500 ft^3, from 900 to 1500 ft^3, from 1200 to 1500 ft^3, from 1300 to 1500 ft^3, from 10 to 1400 ft^3, from 100 to 1000 ft^3, or from 500 to 750 ft^3).

In some examples, the volume of each reactor can independently be 100 gallons or more (e.g., 250 gallons or more, 500 gallons or more, 750 gallons or more, 1000 gallons or more, 1500 gallons or more, 2000 gallons or more, 2500 gallons or more, 3000 gallons or more, 3500 gallons or more, 4000 gallons or more, 4500 gallons or more, 5000 gallons or more, 5500 gallons or more, 6000 gallons or more, 6500 gallons or more, 7000 gallons or more, 7500 gallons or more, 8000 gallons or more, 8500 gallons or more, or 9000 gallons or more). In some examples, the volume of each reactor can independently be 10,000 gallons or less (e.g., 9500 gallons or less, 9000 gallons or less, 8500 gallons or less, 8000 gallons or less, 7500 gallons or less, 7000 gallons or less, 6500 gallons or less, 6000 gallons or less, 5500 gallons or less, 5000 gallons or less, 4500 gallons or less, 4000 gallons or less, 3500 gallons or less, 3000 gallons or less, 2500 gallons or less, 2000 gallons or less, 1500 gallons or less, 1000 gallons or less, 750 gallons or less, 500 gallons or less, or 250 gallons or less). The volume of each reactor can independently range from any of the minimum values described above to any of the maximum values described above. For example, the volume of each reactor can independently be from 100 gallons to 10,000 gallons (e.g., from 100 to 1000 gallons; from 1000 to 10,000 gallons; from 100 to 500 gallons; from 500 to 1000 gallons; from 1000 to 5000 gallons; from 5000 to 10,000 gallons; from 100 to 9000 gallons; from 100 to 8000 gallons; from 100 to 8000 gallons; from 100 to 7000 gallons; from 100 to 6000 gallons; from 100 to 5000 gallons; from 100 to 4000 gallons; from 100 to 3000 gallons; from 100 to 2000 gallons; from 500 to 10,000 gallons; from 1000 to 10,000 gallons; from 2000 to 10,000 gallons; from 3000 to 10,000 gallons; from 4000 to 10,000 gallons; from 6000 to 10,000 gallons; from 7000 to 10,000 gallons; from 8000 to 10,000 gallons; from 500 to 9000 gallons; or from 1000 to 7500 gallons).

Each reactor is equipped with heaters, for example internal and/or external heaters. The heaters can be any suitable type of heaters, such as electric, microwave, and/or gas heaters. The heaters provide the heat needed to raise temperatures inside the reactor to a point where the depolymerization process takes place. In some examples, a plurality of heaters can be arrayed on the reactor's exterior and/or within its interior.

In some examples, the heaters are gas heaters (e.g., gas powered heaters), which can be fed from commercial gas fuel and/or recycled hydrocarbon gases recovered from the reactor products (e.g., propane, butane, and/or pentane). In some examples, the heaters are electric heaters (e.g., electrically powered heaters, resistive heaters, inductive heaters, etc.). In some examples, the electric heaters can be powered by a generator, which in turn can be gas powered and which can be fed from commercial gas fuel and/or recycled hydrocarbon gases recovered from the reactor products (e.g., propane, butane, and/or pentane).

In some examples, the reactors are equipped with a plurality of internal electric heaters, e.g. a plurality of electric heaters disposed within the reactor (e.g., 2 or more, 3 or more, 4 or more, 5 or more, 6 or more 7 or more, 8 or more, 9 or more, 10 or more, 11 or more, 12 or more, 13 or more, 14 or more, or 15 or more). The electric heaters can, for example, be oriented in any suitable direction (e.g., horizontally, vertically, angled) within each reactor inside dry wells. The electric heater temperature can be controlled to provide a prescribed temperature and energy density to the dry well walls which in turn provide a controlled heat flux into the plastics bath to drive the reactions and minimizing char formation. The number of internal heaters can, for example, be selected based on the size of the reactor and/or the size of the heaters. Supplemental electric heaters on the outer surface of the reactors can also be provided that operate at the same temperatures and energy density as the internal heaters, as necessary.

The energy density applied by each of the internal and/or external heaters can, for example, independently be 5 watts per square inch (W/in^2) or more (e.g., 6 W/in^2 or more, 7 W/in^2 or more, 8 W/in^2 or more, 9 W/in^2 or more, 10 W/in^2 or more, 11 W/in^2 or more, 12 W/in^2 or more, 13 W/in^2 or more, 14 W/in^2 or more, 15 W/in^2 or more, 16 W/in^2 or more, 17 W/in^2 or more, 18 W/in^2 or more, 19 W/in^2 or more, 20 W/in^2 or more, 21 W/in^2 or more, 22 W/in^2 or more, 23 W/in^2 or more, 24 W/in^2 or more, 25 W/in^2 or more, 26 W/in^2 or more, 27 W/in^2 or more, 28 W/in^2 or more, 29 W/in^2 or more, 30 W/in^2 or more, 31 W/in^2 or more, 32 W/in^2 or more, 33 W/in^2 or more, 34 W/in^2 or more, 35 W/in^2 or more, 36 W/in^2 or more, 37 W/in^2 or more, 38 W/in^2 or more, 39 W/in^2 or more, 40 W/in^2 or more, 41 W/in^2 or more, 42 W/in^2 or more, or 43 W/in^2 or more). In some examples, the energy density applied by each of the internal and/or external heaters can independently be 45 W/in^2 or less (e.g., 44 W/in^2 or less, 43 W/in^2 or less, 42 W/in^2 or less, 41 W/in^2 or less, 40 W/in^2 or less, 39 W/in^2 or less, 38 W/in^2 or less, 37 W/in^2 or less, 36 W/in^2 or less, 35 W/in^2 or less, 34 W/in^2 or less, 33 W/in^2 or less, 32 W/in^2 or less, 31 W/in^2 or less, 30 W/in^2 or less, 29 W/in^2 or less, 28 W/in^2 or less, 27 W/in^2 or less, 26 W/in^2 or less, 25 W/in^2 or less, 24 W/in^2 or less, 23 W/in^2 or less, 22 W/in^2 or less, 21 W/in^2 or less, 20 W/in^2 or less, 19 W/in^2 or less, 18 W/in^2 or less, 17 W/in^2 or less, 16 W/in^2 or less, 15 W/in^2 or less, 14 W/in^2 or less, 13 W/in^2 or less, 12 W/in^2 or less, 11 W/in^2 or less, 10 W/in^2 or less, 9 W/in^2 or less, 8 W/in^2 or less, or 7 W/in^2 or less). The energy density applied by each of the internal and/or external heaters can independently range from any of the minimum values described above to any of the maximum values described above. For example, the energy density applied by each of the internal and/or external heaters can independently be from 5 to 45 W/in^2 (e.g., from 5 to 25 W/in^2, from 25 to 45 W/in^2, from 5 to 15 W/in^2, from 15 to 25 W/in^2, from 25 to 35 W/in^2, from 35 to 45 W/in^2, from 5 to 40 W/in^2, from 5 to 35 W/in^2, from 5 to 30 W/in^2, from 5 to 20 W/in^2, from 10 to 45 W/in^2, from 15 to 45 W/in^2, from 20 to 45 W/in^2, from 30 to 45 W/in^2, from 10 to 40 W/in^2, from 15 to 35 W/in^2, from 12 to 30 W/in^2, or from 16 to 24 W/in^2).

The depolymerization process can produce light hydrocarbon gases (e.g., propane, butane, and/or pentane) which can be separated from the oil and wax product streams and used as an energy source, fuel, or chemical feedstock.

Localized overheating and/or high temperatures can result in solid char (coke) formation. Char buildup can require periodic clean out of a reactor for char removal from heating surfaces. Loose char can also be formed by any wood, cardboard, or paper materials that enter the system as part of the plastic feedstock. Reactor temperature monitoring, accurate and precise individual heater control, and good heat transfer from the heaters into the liquid plastic can, for example, be selected to control and limit the amount and/or rate of char formation.

The feedstock can, for example, be heated to a temperature of 200° C. or more within the reactor (e.g., 225° C. or more, 250° C. or more, 275° C. or more, 300° C. or more, 325° C. or more, 350° C. or more, 375° C. or more, 400° C. or more, 425° C. or more, 450° C. or more, 475° C. or more, 500° C. or more, 550° C. or more, 600° C. or more, 650° C. or more, 700° C. or more, or 750° C. or more). In some examples, the feedstock can be heated to a temperature of 800° C. or less within the reactor (e.g., 750° C. or less, 700° C. or less, 650° C. or less, 600° C. or less, 550° C. or less, 500° C. or less, 475° C. or less, 450° C. or less, 425° C. or less, 400° C. or less, 375° C. or less, 350° C. or less, 325° C. or less, 300° C. or less, 275° C. or less, or 250° C. or less). The temperature to which the feedstock is heated within the reactor can range from any of the minimum values described above to any of the maximum values described above. For example, the feedstock can be heated to a temperature of from 200° C. to 800° C. within the reactor (e.g., from 200° C. to 500° C., from 500° C. to 800° C., from 200° C. to 300° C., from 300° C. to 400° C., from 400° C. to 500° C., from 500° C. to 600° C., from 600° C. to 700° C., from 700° C. to 800° C., from 200° C. to 700° C., from 200° C. to 600° C., from 200° C. to 400° C., from 300° C. to 800° C., from 400° C. to 800° C., from 600° C. to 800° C., from 250° C. to 750° C., from 300° C. to 700° C., from 350° C. to 500° C., from 375° C. to 425° C., or from 385° C. to 415° C.).

The liquid and/or vapor phase plastic inside a reactor can be agitated. For example, the pyrolysis reactor can comprise an auger pyrolysis reactor, a rotary kiln pyrolysis reactor, a fluidized bed reactor, a continuously stirred reactor, or a combination thereof, wherein the reactor agitates the liquid and/or vapor phase plastic.

In some examples, the liquid and/or vapor phase plastic inside a reactor can be kept in continuous motion using an agitator that circulates the liquid and/or vapor phase plastic inside the reactor. For example, the liquid plastic can be agitated in a manner that fosters heat transfer from the internal and/or external heaters to the liquid. Liquid plastic is a good insulator (i.e., has a low thermal conductivity) and the ability to get heat into it in a way that does not lead to charring but still provides enough heat to promote depolymerization can be an important factor.

For example, each reactor can include an agitator, for example a mixer or stirrer comprising one or more blades. The agitator can be configured so that it can produce liquid flow velocities inside the reactor such that the bath acquires the necessary heat and also avoids long residence times at the heated surfaces. For example, the agitator can be configured such that the entire liquid bath is agitated, e.g. substantially none of the liquid bath is static.

The agitator can, for example, be operated at a speed of 20 RPM or more (e.g., 25 RPM or more, 30 RPM or more, 35 RPM or more, 40 RPM or more, 45 RPM or more, 50 RPM or more, 55 RPM or more, 60 RPM or more, 65 RPM or more, 70 RPM or more, 75 RPM or more, 80 RPM or more, 85 RPM or more, 90 RPM or more, 95 RPM or more, 100 RPM or more, 105 RPM or more, 110 RPM or more, 115 RPM or more, 120 RPM or more, 125 RPM or more, 130 RPM or more, 135 RPM or more, 140 RPM or more, 145 RPM or more, 150 RPM or more, 155 RPM or more, 160 RPM or more, 165 RPM or more, 170 RPM or more, 175 RPM or more, 180 RPM or more, 185 RPM or more, or 190 RPM or more). In some examples, the agitator can be operated at a speed of 200 RPM or less (e.g., 195 RPM or less, 190 RPM or less, 185 RPM or less, 180 RPM or less, 175 RPM or less, 170 RPM or less, 165 RPM or less, 160 RPM or less, 155 RPM or less, 150 RPM or less, 145 RPM or less, 140 RPM or less, 135 RPM or less, 130 RPM or less, 125 RPM or less, 120 RPM or less, 115 RPM or less, 110 RPM or less, 105 RPM or less, 100 RPM or less, 95 RPM or less, 90 RPM or less, 85 RPM or less, 80 RPM or less, 75 RPM or less, 70 RPM or less, 65 RPM or less, 60 RPM or less, 55 RPM or less, 50 RPM or less, 45 RPM or less, 40 RPM or less, 35 RPM or less, or 30 RPM or less). The speed at which the agitator is operated can range from any of the minimum values described above to any of the maximum values described above. For example, the agitator can be operated at a speed of from 20 to 200 RPM (e.g., from 20 to 125 RPM, from 125 to 200 RPM, from 20 to 60 RPM, from 60 to 100 RPM, from 100 RPM to 140 RPM, from 140 to 200 RPM, from 20 to 180 RPM, from 20 to 160 RPM, from 20 to 140 RPM, from 20 to 120 RPM, from 20 to 100 RPM, from 20 to 80 RPM, from 20 to 40 RPM, from 40 to 200 RPM, from 60 to 200 RPM, from 80 to 200 RPM, from 100 to 200 RPM, from 120 to 200 RPM, from 140 to 200 RPM, from 160 to 200 RPM, from 25 to 195 RPM, from 30 to 190 RPM, from 50 to 175 RPM, from 75 to 150 RPM, or from 120 to 160 RPM).

The agitator can be configured to produce homogeneous or inhomogeneous fluid (e.g., liquid and/or vapor) flow inside the reactor. In some examples, the agitator is configured to produce fluid flow velocities inside the reactor of greater than 0 meters per second (m/s) (e.g., 0.05 m/s or more, 0.1 m/s or more, 0.15 m/s or more, 0.2 m/s or more, 0.25 m/s or more, 0.3 m/s or more, 0.35 m/s or more, 0.4 m/s or more, 0.45 m/s or more, 0.5 m/s or more, 0.6 m/s or more, 0.7 m/s or more, 0.8 m/s or more, 0.9 m/s or more, 1 m/s or more, 1.25 m/s or more, 1.5 m/s or more, 1.75 m/s or more, 2 m/s or more, 2.25 m/s or more, 2.5 m/s or more, 2.75 m/s or more, 3 m/s or more, 3.5 m/s or more, 4 m/s or more, 4.5 m/s or more, 5 m/s or more, 5.5 m/s or more, 6 m/s or more, 6.5 m/s or more, 7 m/s or more, 7.5 m/s or more, 8 m/s or more, 8.5 m/s or more, or 9 m/s or more). In some examples, the agitator is configured to produce fluid flow velocities inside the reactor of 10 m/s or less (e.g., 9.5 m/s or less, 9 m/s or less, 8.5 m/s or less, 8 m/s or less, 7.5 m/s or less, 7 m/s or less, 6.5 m/s or less, 6 m/s or less, 5.5 m/s or less, 5 m/s or less, 4.5 m/s or less, 4 m/s or less, 3.5 m/s or less, 3 m/s or less, 2.75 m/s or less, 2.5 m/s or less, 2.25 m/s or less, 2 m/s or less, 1.75 m/s or less, 1.5 m/s or less, 1.25 m/s or less, 1 m/s or less, 0.9 m/s or less, 0.8 m/s or less, 0.7 m/s or less, 0.6 m/s or less, 0.5 m/s or less, 0.45 m/s or less, 0.4 m/s or less, 0.35 m/s or less, 0.3 m/s or less, 0.25 m/s or less, 0.2 m/s or less, 0.15 m/s or less, or 0.1 m/s or less). The fluid flow velocity inside the reactor produced by the agitator can range from any of the minimum values described above to any of the maximum values described above. For example, the agitator can be configured to produce fluid flow velocities inside the reactor of from greater than 0 m/s to 10 m/s (e.g., from greater than 0 to 5 m/s, from 5 to 10 m/s, from greater than 0 to 2.5 m/s, from 2.5 to 5 m/s, from 5 to 7.5 m/s, from 7.5 to 10 m/s, from greater than 0 to 2 m/s, from 2 to 4 m/s, from 4 to 6 m/s, from 6 to 8 m/s, from 8 to 10 m/s, from greater than 0 to 9 m/s, from greater than 0 to 8 m/s, from greater than 0 to 7 m/s, from greater than 0 to 6 m/s, from greater than 0 to 4.5 m/s, from greater than 0 to 4 m/s, from greater than 0 to 3.5 m/s, from greater than 0 to 3 m/s, from greater than 0 to 2.5 m/s, from greater than 0 to 1.5 m/s, from 0.05 to 10 m/s, from 0.1 to 10 m/s, from 0.5 to 10 m/s, from 1 to 10 m/s, from 1.5 to 10 m/s, from 2 to 10 m/s, from 3 to 10 m/s, from 4 to 10 m/s, from 6 to 10 m/s, from 7 to 10 m/s, from 9 to 10 m/s, from 0.05 to 9.5 m/s, from 0.1 to 9 m/s, or from 0.25 to 5 m/s).

Liquid level inside the reactors can be monitored using any suitable means, for example using one or more (e.g., a series of) thermocouples arranged along the internal reactor wall or through non-contact means, such as radar or ultrasonic sensors. For example, a plurality of thermocouples can be arranged vertically along the internal reactor wall. The liquid bath is typically hotter than the vapor in the headspace above it. As the liquid bath level inside a reactor changes, the change can be seen by changing temperatures. Feedstock input and product output can be monitored and/or adjusted based on the observed variations in the liquid bath level.

The liquid volume in each reactor can, for example, comprise 40% or more of the volume of the reactor (e.g., 41% or more, 42% or more, 43% or more, 44% or more, 45% or more, 46% or more, 47% or more, 48% or more, 49% or more, 50% or more, 51% or more, 52% or more, 53% or more, 54% or more, 55% or more, 56% or more, 57% or more, 58% or more, 59% or more, 60% or more, 61% or more, 62% or more, 63% or more, 64% or more, 65% or more, 66% or more, 67% or more, 68% or more, 69% or more, 70% or more, 71% or more, 72% or more, 73% or more, 74% or more, 75% or more, 76% or more, 77% or more, or 78% or more). In some examples, the liquid volume in the reactor can comprise 80% or less of the volume of the reactor (e.g., 79% or less, 78% or less, 77% or less, 76% or less, 75% or less, 74% or less, 73% or less, 72% or less, 71% or less, 70% or less, 69% or less, 68% or less, 67% or less, 66% or less, 65% or less, 64% or less, 63% or less, 62% or less, 61% or less, 60% or less, 59% or less, 58% or less, 57% or less, 56% or less, 55% or less, 54% or less, 53% or less, 52% or less, 51% or less, 50% or less, 49% or less, 48% or less, 47% or less, 46% or less, 45% or less, 44% or less, 43% or less, or 42% or less). The liquid volume in the reactor can range from any of the minimum values described above to any of the maximum values described above. For example, the liquid volume in the reactor can comprise from 40% to 80% of the volume of the reactor (e.g., from 40% to 60%, from 60% to 80%, from 40% to 50%, from 50% to 60%, from 60% to 70%, from 70% to 80%, from 40% to 75%, from 40% to 70%, from 40% to 65%, from 40% to 55%, from 40% to 45%, from 45% to 80%, from 50% to 80%, from 55% to 80%, from 65% to 80%, from 75% to 680%, from 45% to 75%, or from 50% to 70%).

In some examples, the headspace volume in each reactor comprises 20% or more of the volume of the reactor (e.g., 21% or more, 22% or more, 23% or more, 24% or more, 25% or more, 26% or more, 27% or more, 28% or more, 29% or more, 30% or more, 31% or more, 32% or more, 33% or more, 34% or more, 35% or more, 36% or more, 37% or more, 38% or more, 39% or more, 40% or more, 41% or more, 42% or more, 43% or more, 44% or more, 45% or more, 46% or more, 47% or more, 48% or more, 49% or more, 50% or more, 51% or more, 52% or more, 53% or more, 54% or more, 55% or more, 56% or more, 57% or more, or 58% or more). In some examples, the headspace volume in each reactor comprises 60% or less of the volume of the reactor (e.g., 59% or less, 58% or less, 57% or less, 56% or less, 55% or less, 54% or less, 53% or less, 52% or less, 51% or less, 50% or less, 49% or less, 48% or less, 47% or less, 46% or less, 45% or less, 44% or less, 43% or less, 42% or less, 41% or less, 40% or less, 39% or less, 38% or less, 37% or less, 36% or less, 35% or less, 34% or less, 33% or less, 32% or less, 31% or less, 30% or less, 29% or less, 28% or less, 27% or less, 26% or less, 25% or less, 24% or less, 23% or less, or 22% or less). The headspace volume in the reactor can range from any of the minimum values described above to any of the maximum values described above. For example, the headspace volume in the reactor can comprise from 20% to 60% of the reactor volume (e.g., from 20% to 40%, from 40% to 60%, from 20% to 30%, from 30% to 40%, from 40% to 50%, from 50% to 60%, from 20% to 55%, from 20% to 50%, from 20% to 45%, from 20% to 35%, from 20% to 25%, from 25% to 60%, from 30% to 60%, from 35% to 60%, from 45% to 60%, from 55% to 60%, from 25% to 55%, or from 30% to 50%).

Hydrocarbon vapor generated inside each reactor exits the reactor through a piping or ducting manifold connected to a product recovery system which is described below. In some examples, the reactor vapor pressure is monitored. The type and quality of product output can be controlled to some degree by altering the pressure inside the reactor. Each reactor is connected to a manifold, and vapor flow from each reactor is controlled by a valve designed to operate at the high vapor exit temperature or a down-stream blower/vacuum system, allowing the individual reactors to be maintained as needed between a slight positive pressure and a slight vacuum pressure, depending on reactor performance and the types of hydrocarbon products condensing in the downstream product recovery which operates under a slight vacuum as described below.

The piping manifold system also allows inert gases to be introduced when necessary to purge the reactor interior, or displace the liquid bath or vapor headspace in each reactor to another reactor without the use of pumps.

The pressure inside each reactor can, for example, be −7.25 psig or more (e.g., −7 psig or more, −6.5 psig or more, −6 psig or more, −5.5 psig or more, −5 psig or more, −4.5 psig or more, −4 psig or more, −3.5 psig or more, −3 psig or more, −2.5 psig or more, −2 psig or more, −1.5 psig or more, −1 psig or more, −0.5 psig or more, 0 psig or more, 0.5 psig or more, 1 psig or more, 1.5 psig or more, 2 psig or more, 2.5 psig or more, 3 psig or more, 3.5 psig or more, 4 psig or more, 4.5 psig or more, 5 psig or more, 5.5 psig or more, 6 psig or more, 6.5 psig or more, 7 psig or more, 7.5 psig or more, 8 psig or more, 8.5 psig or more, 9 psig or more, 9.5 psig or more, 10 psig or more, 10.5 psig or more, 11 psig or more, 11.5 psig or more, 12 psig or more, 12.5 psig or more, 13 psig or more, 13.5 psig or more, or 14 psig or more). In some examples, the pressure inside the reactor can be 14.5 psig or less (e.g., 14 psig or less, 13.5 psig or less, 13 psig or less, 12.5 psig or less, 12 psig or less, 11.5 psig or less, 11 psig or less, 10.5 psig or less, 10 psig or less, 9.5 psig or less, 9 psig or less, 8.5 psig or less, 8 psig or less, 7.5 psig or less, 7 psig or less, 6.5 psig or less, 6 psig or less, 5.5 psig or less, 5 psig or less, 4.5 psig or less, 4 psig or less, 3.5 psig or less, 3 psig or less, 2.5 psig or less, 2 psig or less, 1.5 psig or less, 1 psig or less, 0.5 psig or less, 0 psig or less, −0.5 psig or less, −1 psig or less, −1.5 psig or less, −2 psig or less, −2.5 psig or less, −3 psig or less, −3.5 psig or less, −4 psig or less, −4.5 psig or less, −5 psig or less, −5.5 psig or less, −6 psig or less, −6.5 psig or less, or −7 psig or less). The pressure within the reactor can range from any of the minimum values described above to any of the maximum values described above. For example, the pressure inside the reactor can be from −7.25 to 14.5 psig (e.g., from −7.25 to 3.5 psig, from 3.5 to 14.5 psig, from −7.25 to 0 psig, from 0 to 7.25 psig, from 7.25 to 14.5 psig, from −7.25 to 10 psig, from −7.25 to 5 psig, from −5 to 14.5 psig, from 5 to 14.5 psig, from −5 to 10 psig, from −5 to 5 psig, or from −2.5 to 2.5 psig).

The residence time of the feedstock within the reactor (e.g., the time that it takes to pyrolyze) can vary based on a variety of factors. For example, the residence time of the feedstock within the reactor can vary based on the type of reactor, the composition of the feedstock, the temperature within the reactor, the pressure within the reactor, the agitation rate, the amount of char, or a combination thereof.

For example, the residence time of a given polymer comprising the feedstock within the reactor can be 1 second or more (e.g., 2 seconds or more, 3 seconds or more, 4 seconds or more, 5 seconds or more, 10 seconds or more, 15 seconds or more, 20 seconds or more, 25 seconds or more, 30 seconds or more, 35 seconds or more, 40 seconds or more, 45 seconds or more, 50 seconds or more, 55 seconds or more, 1 minute or more, 2 minutes or more, 3 minutes or more, 4 minutes or more, 5 minutes or more, 10 minutes or more, 15 minutes or more, 20 minutes or more, 25 minutes or more, 30 minutes or more, 35 minutes or more, 40 minutes or more, 45 minutes or more, 50 minutes or more, 55 minutes or more, 1 hour or more, 1.5 hours or more, 2 hours or more, 2.5 hours or more, 3 hours or more, 3.5 hours or more, 4 hours or more, 4.5 hours or more, 5 hours or more, 5.5 hours or more, 6 hours or more, 7 hours or more, 8 hours or more, 9 hours or more, 10 hours or more, 12 hours or more, 14 hours or more, 16 hours or more, 18 hours or more, 20 hours or more, or 22 hours or more). In some examples, the residence time of a given polymer comprising the feedstock within the reactor can be 24 hours or less (e.g., 22 hours or more, 20 hours or more, 18 hours or more, 16 hours or more, 14 hours or more, 12 hours or more, 10 hours or more, 9 hours or more, 8 hours or more, 7 hours or more, 6 hours or more, 5.5 hours or more, 5 hours or more, 4.5 hours or more, 4 hours or more, 3.5 hours or more, 3 hours or more, 2.5 hours or more, 2 hours or more, 1.5 hours or more, 1 hour or less, 55 minutes or less, 50 minutes or less, 45 minutes or less, 40 minutes or less, 35 minutes or less, 30 minutes or less, 25 minutes or less, 20 minutes or less, 15 minutes or less, 10 minutes or less, 5 minutes or less, 4 minutes or less, 3 minutes or less, 2 minutes or less, 1 minute or less, 55 seconds or less, 50 seconds or less, 45 seconds or less, 40 seconds or less, 35 seconds or less, 30 seconds or less, 25 seconds or less, 20 seconds or less, 15 seconds or less, 10 seconds or less, or 5 seconds or less). The residence time of a given polymer comprising the feedstock within the reactor can range from any of the minimum values described above to any of the maximum values described above. For example, the residence time of a given polymer comprising the feedstock within the reactor can be from 1 second to 24 hours (e.g., from 1 second to 12 hours, from 12 hours to 24 hours, from 1 second to 1 minute, from 1 minute to 1 hour, from 1 hour to 24 hours, from 1 second to 1 hour, from 1 hour to 6 hours, from 6 hours to 12 hours, from 12 hours to 18 hours, to 24 hours, from 1 minute to 20 hours, from 1 second to 18 hours, from 1 second to 16 hours, from 1 second to 14 hours, from 1 second to 10 hours, from 1 second to 8 hours, from 1 second to 4 hours, from 1 second to 2 hours, from 1 second to 30 minutes, from 1 second to 15 minutes, from 1 second to 10 minutes, from 1 second to 5 minutes, from 1 minute to 24 hours, from 5 minutes to 24 hours, from 10 minutes to 24 hours, from 15 minutes to 24 hours, from 30 minutes to 24 hours, from 1 hour to 24 hours, from 2 hours to 24 hours, from 4 hours to 24 hours, from 6 hours to 24 hours, from 8 hours to 24 hours, from 10 hours to 24 hours, from 12 hours to 24 hours, from 14 hours to 24 hours, from 16 hours to 24 hours, from 20 ours to 24 hours, from 30 seconds to 22 hours, or from 1 minute to 20 hours).

Inert material that enters the reactors, such as bits of metal and grit, as well as loose char that can be created through the heating process, can optionally be removed by any suitable processing component or step, such as sedimentation, decantation, filtration, sieving, etc.

In some examples, the reactor can further include an additive, such as a catalyst, a diluent, an adsorbent, etc.

Vaporized Product Recovery

Vapor leaving the reactors contains a complex hydrocarbon mixture ranging from light molecules (short carbon chains) to heavy molecules (long carbon chains). The process uses one or more stages of cooling and condensation to condense the vapor product into one or more liquid products. In some examples, the vapor can be subjected to an additional processing step (e.g., further heated, distilled, filtered, etc.) before and/or after condensation.

For example, vapor from the reactors enters a condenser where hydrocarbons that have a boiling point at or above the temperature of the condenser are condensed. The condenser can comprise any suitable condenser. Condensed liquid from the condenser can then be transferred, for example, to a storage tank. In some examples, condensed liquid from the condenser can then be distilled, for example to separate the product into one or more fractions and/or purify the product.

In some examples, the process uses a plurality of stages of cooling and condensation to selectively separate reactor vapor product into a wax product (e.g., comprising long-chain hydrocarbons that are a solid or semi-solid wax at ambient temperatures) and an oil product (e.g., comprising lighter, shorter-chain hydrocarbons that are a liquid at ambient temperatures). In some examples, there is also uncondensed gas.

In some examples, wax condensation takes place inside a first condenser (e.g., a wax condenser). The first condenser can comprise any suitable condenser. For example, vapor from the reactors enters the first condenser where hydrocarbons that have a boiling point at or above the temperature of the first condenser are condensed. Condensed liquid (e.g., liquid wax) from the first condenser can then be transferred, for example, to a storage tank (e.g., a wax storage tank).

In some examples, vapor phase material that passes through the wax condenser can flow to a second condensing system (e.g., a second condenser). The second condenser can comprise any suitable condenser. For example, vapor from the wax condenser enters the second condenser where hydrocarbons that have a boiling point at or above the temperature of the second condenser are condensed. Condensed liquid (e.g., liquid oil) from the second condenser can then be transferred, for example, to a storage tank (e.g., an oil storage tank).

In some examples, vapor phase material that passes through the second condenser, such as uncondensed hydrocarbons (e.g., pentanes and some heavier, longer chain alkanes) and non-condensables (e.g., butane and lighter hydrocarbons and any non-hydrocarbon gases), can flow to a gas-liquid separator and/or to a third condenser. The gas-liquid separator, when present, can comprise any suitable separator.

In some examples, vapor phase material that passes through the second condenser can flow to a third condenser. The third condenser can comprise any suitable condenser. For example, vapor from the second condenser enters to the third condenser where hydrocarbons that have a boiling point at or above the temperature of the third condenser are condensed, such as C_5-C_7 hydrocarbons. Condensed liquid from the third condenser can then be transferred, for example, to a storage tank.

In some examples, the temperature cut-off of each of the one or more condensers can be selected in view of a variety of factors. In some examples, the temperature cut-off of the one or more condensers can be selected such that a portion of the oil product is not condensed. For example, a certain portion of the oil product can, in some examples, comprise a high concentration of contaminants, and the condensers can be configured to selectively allow this portion of the oil product to pass through each of the one or more condensers without condensing.

In some examples, the systems and/or methods described herein can produce the pyrolysis products (e.g., wax and/or oil) at a yield of 50% or more (e.g., 51% or more, 52% or more, 53% or more, 54% or more, 55% or more, 56% or more, 57% or more, 58% or more, 59% or more, 60% or more, 61% or more, 62% or more, 63% or more, 64% or more, 65% or more, 66% or more, 67% or more, 68% or more, 69% or more, 70% or more, 71% or more, 72% or more, 73% or more, 74% or more, 75% or more, 76% or more, 77% or more, 78% or more, 79% or more, 80% or more, 81% or more, 82% or more, 83% or more, 84% or more, 85% or more, 86% or more, 87% or more, 88% or more, 89% or more, 90% or more, 91% or more, 92% or more, 93% or more, 94% or more, 95% or more, 96% or more, 97% or more, 98% or more, or 99% or more). In some examples, the systems and/or methods described herein can produce the pyrolysis products (e.g., wax and/or oil) at a yield of 100% or less (e.g., 99% or less, 98% or less, 97% or less, 96% or less, 95% or less, 94% or less, 93% or less, 92% or less, 91% or less, 90% or less, 89% or less, 88% or less, 87% or less, 86% or less, 85% or less, 84% or less, 83% or less, 82% or less, 81% or less, 80% or less, 79% or less, 78% or less, 77% or less, 76% or less, 75% or less, 74% or less, 73% or less, 72% or less, 71% or less, 70% or less, 69% or less, 68% or less, 67% or less, 66% or less, 65% or less, 64% or less, 63% or less, 62% or less, 61% or less, 60% or less, 59% or less, 58% or less, 57% or less, 56% or less, 55% or less, 54% or less, 53% or less, or 52% or less). The yield of the systems and/or methods described herein can range from any of the minimum values described above to any of the maximum values described above. For example, the systems and/or methods described herein can produce the pyrolysis products (e.g., wax and/or oil) at a yield of from 50% to 100% (e.g., from 50% to 75%, from 75% to 100%, from 50% to 60%, from 60% to 70%, from 70% to 80%, from 80% to 90%, from 90% to 100%, from 50% to 95%, from 50% to 90%, from 50% to 85%, from 50% to 80%, from 50% to 70%, from 50% to 65%, from 50% to 55%, from 55% to 100%, from 60% to 100%, from 65% to 100%, from 70% to 100%, from 80% to 100%, from 85% to 100%, from 90% to 100%, from 55% to 95%, or from 80% to 95%).

Post-Treatment

In some examples, the methods and systems herein produce a raw pyrolysis product with a reduced level of contaminants, for example such that no further post-treatment of the product is needed (e.g., the methods substantially exclude any hydrotreatment or further refining steps after the pyrolysis).

In some examples, the methods and systems herein can further comprise post-treating the pyrolysis products. For example, the wax and/or oil can be further processed by refining, filtering, cracking, hydrotreating, distilling, etc., or a combination thereof. In some examples, the post-treatment can reduce the level of one or more contaminants in the pyrolysis product (e.g., oil and/or wax).

Product Storage

After hydrocarbon product has been condensed as wax (molten) and/or oil (and optionally post-treated), it is transferred to storage tanks. Liquid product can be transferred using any suitable means to the storage tanks.

The storage tanks can be constructed of any suitable material. In some examples, the storage tanks can further include a feedback system. For example, liquid levels in the tanks can be monitored using an electronic sensor. In some examples, the feedback system can include a temperature control system (e.g., to control the temperature of the liquid within the storage tank, for example by heating and/or cooling). The feedback system can, for example, activate the heating and/or cooling systems as needed, for example based on particular temperature set-points. In some examples, at least a portion of the storage tank(s) can be insulated.

Heat Tracing

In some examples, the system can further include heat trace components. For example, mineral insulated heat trace cable can be used on some or all process lines conveying either molten plastic or liquid products. This cable can ensure that products within the process lines remain flowable under all conditions. Such cables can be protected through cladded insulation. Thermocouples on each independent section of heat trace can be installed to monitor heat levels within these sections and feedback mechanisms can provide an alert if piping sections may not be receiving proper heating. For example, some or all of the piping running from the extruder into the reactors can be insulated and/or include heat tracing. Such insulating and heat tracing to process lines can be particularly important during colder ambient conditions. It is imperative that all process lines always remain fully open and operable, regardless of the ambient temperature.

System Availability

System availability is typically expressed as a percentage and refers to the amount of time a system is operating, divided by the total amount of time in the period. Availability is a combination of scheduled maintenance (non-operating hours) and reliability (defined as 1 minus forced outages divided by operating hours). Availability is dependent on several factors, including the quality of equipment, engineering and construction employed, the degree of backup or redundant equipment, the expertise and effort of personnel, the level of preventative, predictive and corrective maintenance, the replenishment of spare parts, the operating demand placed on a facility, and first year versus mature operation.

In some examples, the systems and methods described herein can have an availability factor of 50% or more (e.g., 55% or more, 60% or more, 65% or more, 70% or more, 75% or more, 80% or more, 85% or more, 90% or more, or 95% or more). In some examples, the systems and methods described herein can have an availability factor of 100% or less (e.g., 95% or less, 90% or less, 85% or less, 80% or less, 75% or less, 70% or less, 65% or less, or 60% or less). The availability factor can range from any of the minimum values described above to any of the maximum values described above. For example, the systems and methods described herein can have an availability factor of from 50% to 100% (e.g., from 50% to 75%, from 75% to 100%, from 50% to 60%, from 60% to 70%, from 70% to 80%, from 80% to 90%, from 90% to 100%, from 50% to 80%, from 50% to 80%, from 50% to 70%, from 60% to 100%, from 70% to 100%, from 80% to 100%, from 90% to 100%, from 95% to 100%, from 55% to 95%, or from 60% to 90%).

Compositions, Articles of Manufacture, Methods of Use

Also disclosed herein are compositions comprising any of the waxes disclosed herein, any of the oils disclosed herein, any of the blends disclosed herein, or any of the products of the methods or systems disclosed herein.

Also disclosed herein are compositions derived from any of the waxes disclosed herein, any of the oils disclosed herein, any of the blends disclosed herein, or any of the products of the methods or systems disclosed herein.

Also disclosed herein are methods of using any of the compositions described herein (e.g., any of the waxes disclosed herein, any of the oils disclosed herein, any of the blends disclosed herein, or any of the products of the methods or systems disclosed herein).

Also disclosed herein are articles of manufacture comprising any of the compositions described herein (e.g., any of the waxes disclosed herein, any of the oils disclosed herein, any of the blends disclosed herein, or any of the products of the methods or systems disclosed herein).

Also disclosed herein are methods of making any of the compositions or articles of manufacture, for example, wherein the method comprises additional processing of the composition, such as refining, filtering, cracking, hydrotreating, etc.

In some examples, the composition or article comprises a lubricating oil, a mineral oil, a group III base oil, a fully refined paraffin wax, or a combination thereof.

In some examples, the composition or article comprises a binder, a processing aid, or a combination thereof.

In some examples, the composition or article comprises kerosene including cosmetic kerosene, white oils, high value paraffin and purified liquid fuels, or a combination thereof.

In some examples, the composition or article comprises naphtha.

In some examples, the composition or article comprises fuel.

In some examples, the composition or article comprises liquefied petroleum gas (LPG), naphtha, kerosene, diesel and gas oil, or a combination thereof.

In some examples, the composition or article comprises lube oil, gasoline, jet fuel, diesel fuel, or a combination thereof.

In some examples, the composition or article comprises packaging, film, and/or fibers for carpets and clothing, molded articles, and extruded pipes, or a combination thereof.

In some examples, the composition or article comprises a medical device.

In some examples, the composition or the article comprises lubricant, candles, adhesives, packaging, rubber, cosmetics, fire logs, bituminous mixtures, superficial wear coatings, asphalt, sealing coatings, or a combination thereof.

In some examples, the composition or article comprises asphalt, automotive fuel, aviation fuels, base oil, bitumen, cadalene, cutting fluid, diesel fuel, fuel oil, gasoline, heating oil, heavy fuel oil, hydrocarbon solvents, jet fuel, kerosene, ligroin, lubricant, mazut, microcrystalline wax, mineral oil, motor fuel, motor oil, naphtha, naphthenic acid, paraffin wax, petroleum benzine, petroleum ether, petroleum jelly, petroleum naphtha, petroleum resin, retene, or a combination thereof.

In some examples, the composition or article comprises gasoline, jet fuel, diesel and other fuels, asphalt, heavy fuel oil, lubricants, paraffin wax, tar, asphalt, fertilizer, flooring, perfume, insecticide, petroleum jelly, soap, vitamin, amino acid, or a combination thereof.

In some examples, the composition or article comprises wood-based composites such as oriented-strand board (OSB), particleboard, hardboard, medium density fiberboard, gypsum board, or a combination thereof.

In some examples, the composition or article comprises fully refined paraffin which is used to produce candles, cosmetics, crayons, food packaging, paper and carton coatings, or a combination thereof.

In some examples, the composition or article comprises a hydrocarbon feedstock for a petroleum refinery, a catalytic cracking system, a thermal cracking system, a polymerization system, or a combination thereof. For example, also disclosed herein are methods of using any of the compositions disclosed herein as a hydrocarbon feedstock for a petroleum refinery, a catalytic cracking system, a thermal cracking system, a polymerization system, or a combination thereof.

A number of embodiments of the invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. Accordingly, other embodiments are within the scope of the following claims.

The examples below are intended to further illustrate certain aspects of the systems and methods described herein, and are not intended to limit the scope of the claims.

EXAMPLES

The following examples are set forth below to illustrate the methods and results according to the disclosed subject matter. These examples are not intended to be inclusive of all aspects of the subject matter disclosed herein, but rather to illustrate representative methods and results. These examples are not intended to exclude equivalents and variations of the present invention which are apparent to one skilled in the art.

Efforts have been made to ensure accuracy with respect to numbers (e.g., amounts, temperature, etc.) but some errors and deviations should be accounted for. Unless indicated otherwise, parts are parts by weight, temperature is in ° C. or is at ambient temperature, and pressure is at or near atmospheric. There are numerous variations and combinations of measurement conditions, e.g., component concentrations, temperatures, pressures and other measurement ranges and conditions that can be used to optimize the described process.

Example 1

A wax derived from pyrolysis of a feedstock comprising post-consumer and/or post-industrial plastics was produced and analyzed. At ambient temperature and pressure, the wax was a solid with an amber to beige color.

The following techniques were applied to the wax: UV-Vis, FTIR, carbon number distribution by GC, hydrocarbon types by clay-gel absorption chromatography, ^{1}H-NMR, and ^{13}C-NMR.

A summary of the substance identity profile is provided in Table 1.

TABLE 1

Summary of wax product.

Hydrocarbon type	Concentration (% w/w)
Saturated content	97.9
Unsaturated content	1.0
Aromatic content	1.1
Asphaltene content	<0.1
Hydrocarbon number	**Concentration (% w/w)**
C9	0.59
C10	0.40
C11	0.75
C12	0.87
C13	1.27
C14	1.78
C15	1.94
C16	2.39
C17	3.07
C18	3.78

TABLE 1-continued

C19	4.15
C20	5.06
C20-C24	22.80
C24-C28	22.10
C28-C32	14.91
C32-C36	7.75
C36-C40	3.63
C40-C44	1.49
C44-C46	0.39
C46+	0.88

UV-Vis spectrophotometry was performed using a Shimadzu UV1800 spectrophotometer using a single cell (10 mm) over a wavelength range of from 200 to 800 nm. The sample was dispersed in hexane (dilution factor 100 and 100×). The UV-Vis results (FIG. **6** and FIG. **7**) show that the sample had maximum absorptions at wavelengths of 380 nm, 325 nm, 255 nm, and 200 nm.

FTIR-ATR spectroscopy was performed using a Perkin Elmer Instruments Spectrum Three FT-IR Spectrometer, equipped with an ATR Golden Gate bridge (crystal diamond) over a spectral range of 4000 to 600 cm^{-1} with baseline correction. The FTIR spectrum is shown in FIG. **7**. The FTIR main peaks are summarized in Table 2.

TABLE 2

FTIR main peaks of wax product.

Main FTIR-ATR Peaks (cm^{-1})	Interpretation
2955	Anti-symmetric stretching of methyl
2916	Anti-symmetric stretching of methylene
2871	Symmetric stretching of methyl
2848	Symmetric stretching of methylene
1472/1463	Anti-symmetric bending vibrations of methyl and methylene
1378	Umbrella bending vibrations of methyl
965	C-C skeleton vibrations, methyl bending
729/719	Methylene bending rocking vibrations (crystallinity)

Carbon number distribution in the wax product was assessed by simulated distillation (GC) using ASTM D5442M and ASTM D2887. The GC chromatogram of the wax product is shown in FIG. **9**. The results are summarized in Table 3-Table 5.

TABLE 3

Carbon number distribution parameters.

TEST	RESULT	UNITS
Initial Boiling Point	148.2	° C.
Final Boiling Point (@ 99.5%)	571.0	° C.
% OFF	**BOILING POINT**	**UNITS**
0.5	148.2	° C.
5.0	251.3	° C.
10.0	287.0	° C.
15.0	307.5	° C.
20.0	325.2	° C.
25.0	340.0	° C.
30.0	352.2	° C.
35.0	363.1	° C.
40.0	373.1	° C.
45.0	383.3	° C.
50.0	393.1	° C.
55.0	401.9	° C.
60.0	410.4	° C.
65.0	419.3	° C.

TABLE 3-continued

70.0	428.7	° C.
75.0	438.8	° C.
80.0	450.5	° C.
85.0	462.6	° C.
90.0	479.0	° C.
95.0	503.2	° C.
99.5	571.0	° C.

TABLE 4

ASTM D86 correlation results.

% OFF	BOILING POINT	UNITS
IBP	239.9	° C.
5.0	291.9	° C.
10.0	310.5	° C.
20.0	334.7	° C.
30.0	355.9	° C.
40.0	—	° C.
50.0	383.5	° C.
60.0		° C.
70.0	414.3	° C.
80.0	428.1	° C.
90.0	451.3	° C.
95.0	471.3	° C.
FBP	484.3	° C.

% vol at 350° C.

TABLE 5

Cut points.

CARBON NUMBER	BP (° C.)	% OFF
C9	151	0.5907
C10	174	0.9886
C11	196	1.7416
C12	216	2.6140
C13	235	3.8843
C14	254	5.6676
C15	271	7.6124
C16	287	10.0047
C17	302	13.0783
C18	316	16.8539
C19	330	21.0007
C20	344	26.0614
C24	391	48.8578
C28	431	70.9595
C32	466	85.8719
C36	496	93.6182
C40	522	97.2452
C44	545	98.7369
C46	556	99.1241

Hydrocarbon types in the wax sample were further assessed using clay-gel absorption chromatography according to ASTM D2007. The results are summarized in Table 6.

TABLE 6

ASTM D2007 results.

Hydrocarbon	Result	Units
Saturate content	86.1	Wt %
Aromatic content	12.8	Wt %
Polar content	1.1	Wt %
Asphaltenes	<0.1	Wt %

The wax sample was further subjected to ^{1}H-NMR spectroscopy. The ^{1}H spectra were obtained in $CDCl_3$ solvent (Goss Scientific D, 99.8%) at ambient laboratory temperature and auto referenced against the solvent peak using the JEOL ECS 400 NMR spectrometer.

The ^{1}H-NMR spectra are shown in FIG. **11** and FIG. **12**. The annotations in FIG. **12** is a guide highlighting certain peaks of interest. The ^{1}H-NMR spectra generated for the wax sample are dominated by resonances that are consistent with saturated, unsaturated and aromatic hydrocarbons.

The normalized NMR integration values indicate there is 97.9% aliphatic protons (region 0.5-3.2 ppm), 1.0% unsaturated protons (region 4.5-6.0 ppm) and 1.1% aromatic protons (region 6.5-8.5 ppm). This refers to the percentage of proton atoms in the aliphatic saturated, unsaturated and aromatic rings only relative to the total proton content. There were no signals observable outside the range shown in the ^{1}H-NMR spectra.

The wax sample was further subjected to ^{13}C-NMR spectroscopy. The ^{13}C-NMR spectra were obtained in $CDCl_3$ solvent (Goss Scientific D, 99.8%) at ambient laboratory temperature and auto referenced against the solvent peak.

The ^{13}C-NMR spectra are shown in FIG. **13** and FIG. **14**. The annotations in FIG. **14** is a guide highlighting certain peaks of interest. The ^{13}C-NMR spectra generated for the wax sample are dominated by resonances that are consistent with saturated, unsaturated and aromatic hydrocarbons. There were no signals observable outside the range shown in the ^{13}C-NMR spectra.

Example 2

An oil derived from pyrolysis of a feedstock comprising post-consumer and/or post-industrial plastics was produced and analyzed. At ambient temperature and pressure, the oil was a dark brown, clear liquid.

The following techniques were applied to the wax: UV-Vis, FTIR, GC-FID, GC-MS, kinematic viscosity, flash point, distillation characteristics, ^{1}H-NMR, and ^{13}C-NMR.

A summary of the substance identity profile is provided in Table 7.

TABLE 7

Summary of oil product.

Hydrocarbon types	Concentration (% w/w)
Aliphatic content	94.8
Unsaturated content	3.8
Aromatic content	1.4
Hydrocarbon number	**Concentration (% w/w)**
C2	0.03
C3	0.61
C4	1.64
C5	6.62
C6	9.03
C7	5.47
C8	8.68
C9	14.1
C10	6.34
C11	7.69
C12	5.30
C13	5.14
C14	6.19
C15	4.32
C16	3.51
C17	3.09
C18	2.82
C19	2.21
C20	1.63
C21	1.22

TABLE 7-continued

C22	0.86
C23	0.64
C24	0.85
C25	0.70
C26	0.58
C27	0.42
C28	0.24
C29	0.13

UV-Vis spectrophotometry was performed using a Shimadzu UV1800 spectrophotometer using a single cell (10 mm) over a wavelength range of from 200 to 800 nm. The sample was dispersed in hexane (dilution factor 100 and 100×). The UV-Vis results (FIG. **15** and FIG. **16**) show that the sample had maximum absorptions at wavelengths of 335 nm, 245 nm, and 200 nm.

FTIR-ATR spectroscopy was performed using a Perkin Elmer Instruments Spectrum Three FT-IR Spectrometer, equipped with an ATR Golden Gate bridge (crystal diamond) over a spectral range of 4000 to 600 cm^{-1} with baseline correction. The FTIR spectrum is shown in FIG. **17**. The FTIR main peaks are summarized in Table 8.

TABLE 8

FTIR main peaks of oil product.

Main FTIR-ATR Peaks (cm^{-1})	Interpretation
2956	Anti-symmetric stretching of methyl
2922	Anti-symmetric stretching of methylene
2853	Symmetric stretching of methylene
1457	Anti-symmetric bending vibrations of methylene
1378	Umbrella bending vibrations of methyl
992	Methyl bending
965	C-C skeleton vibrations, methyl bending
721	Methylene bending rocking vibrations

Gas chromatography was performed on the oil product using an Agilent 6890 Gas Chromatograph with Atlas software and a flame ionization detector (GC-FID) (GC temperature program: Initial 20° C. 10 minutes; Ramp 1.5° C./min to 250° C.; Final 250° C. 10 minutes). The GC spectra are shown in FIG. **18** and FIG. **19**. The results are summarized in Table 9 and Table 10.

TABLE 9

Extended PIONA results.

Identified carbon chain length	Area %	Identified carbon chain length	Area %
C1	<0.01	C15	4.32
C2	0.03	C16	3.51
C3	0.61	C17	3.09
C4	1.64	C18	2.82
C5	6.62	C19	2.21
C6	9.03	C20	1.63
C7	5.47	C21	1.22
C8	8.68	C22	0.86
C9	14.1	C24	0.85
C10	6.34	C25	0.70
C11	7.69	C26	0.58
C12	5.30	C27	0.42
C13	5.14	C28	0.24
C14	6.19	C29	0.13
		Total	100

TABLE 10

Extended PIONA substance list.					
Substance	Area %	Substance	Area %	Substance	Area %
Pentane	3.95	Decane	2.82	Hexadecane	2.77
Hexane	2.14	Undecane	2.98	Heptadecane	2.44
Heptane	2.48	Dodecane	3.14	Octadecane	2.19
Octane	2.59	Tridecane	3.14	Nonadecane	1.79
3-ethylheptane	2.96	Tetradecane	3.12	Eicosane	1.45
Nonane	2.68	Pentadecane	2.91	Heneicosane	1.09

Gas chromatography-Mass spectrometry (GC-MS) was performed using a Thermo Scientific Trace 1300 GC with a Thermo Scientific ISQ QD (injection volume 0.5 microliters; split ratio 1:5; injection temperature 250° C.: oven program—70° C., hold 1 min, 10° C./min to 300° C., hold 24 min). The GC-MS results are summarized in Table 11.

TABLE 11

GC-MS results.			
Retention time (min)	Component	Retention time (min)	Component
1.57	Propane	10.21	(m/z 131, 146, 162)
1.61	Isobutane	10.27	(m/z 162, 166, 91)
1.63	1-butene	10.38	(m/z 162, 105, 145)
1.65	2-butene	10.43	(m/z 131, 146, 145)
1.73	Butane, 2-methyl-	10.47	(m/z 146, 131, 144)
1.77	Pentane	10.53	(m/z 144, 129, 145)
1.80	C5 alkene (m/z 55, 42, 41)	10.62	1-tridecene
1.91	1-Pentene, 4-methyl-	10.82	Tridecane
1.94	Butane, 2,3-dimethyl-	10.84	(m/z 182, 197, 111)
2.01	Pentane, 2-methyl-	10.89	(m/z 111, 43, 125)
2.05	n-Hexane	10.98	(m/z 111, 141, 142)
2.08	C6 alkene (m/z 84, 41, 69)	11.09	(m/z 111, 154, 125)
2.12	C6 alkene (m/z 41, 55, 84)	11.23	Methylnaphthalene (m/z 142, 141, 115)
2.15	C6 alkene (m/z 41, 67, 39)	11.44	C13 alkene (m/z 182, 125, 111)
2.18	Hexane, 2-methyl-	11.51	(m/z 180, 154, 176)
2.20	Cyclopentane, methyl-	11.59	(m/z 155, 145, 154)
2.28	1-Pentene, 2.4-dimethyl-	11.60	(m/z 145, 160, 176)
2.30	C7 alkene (m/z 83, 98, 41)	11.69	(m/z 176, 169, 168)
2.33	Cyclopentene, 1-methyl-	11.75	(m/z 111, 125, 168)
2.38	Hexane, 2-methyl-	11.88	(m/z 159, 145, 176)
2.40	Benzene	12.00	1-Tetradecene
2.44	Hexane, 3-methyl-	12.17	Tetradecane
2.54	C7 alkene (m/z 41. 98. 55)	12.30	(m/z 196, 156, 141)
2.61	Heptane	12.69	Dimethylnaphthalene (m/z 156, 141, 174)
2.65	(m/z 98, 81, 96)	12.75	(m/z 156, 155, 154)
2.71	C7 alkene (m/z 98, 41, 39)	12.81	(m/z 196, 168, 83)
2.84	Cyclohexane. methyl-	12.90	(m/z 190, 169, 168)
2.92	Cyclopentane, ethyl-	13.00	(m/z 156, 183, 182)
2.98	C7H12 (m/z 81. 96. 79)	13.07	(m/z 190, 194, 159)
3.08	C7H12 (m/z 81. 96. 95)	13.14	(m/z 190, 105, 155)
3.19	Heptane, 4-methyl-	13.18	(m/z 156, 157, 172)
3.24	Toluene	13.28	1-Pentadecene
3.28	C7H12 (m/z 96, 81, 91)	13.46	Pentadecane
3.39	C8 alkene (m/z 41, 112, 55)	13.51	(m/z 167, 141, 182)
3.43	C8 alkene (m/z 41. 55. 43)	13.58	2,4-Di-tert-butylphenol
3.55	Octane	13.71	(m/z 111, 208, 153)
3.59	(m/z 112, 41, 55)	13.82	(m/z 155, 170, 153)
3.61	Dimethylcyclohexane	13.89	1-Isopropenylnaphthalene
3.79	C9H20 alkane (m/z 85, 43, 41)	13.92	(m/z 153, 97, 204)
3.91	(m/z 83, 126, 41)	14.01	(m/z 168, 169, 155)
4.07	C9 alkene (m/z 43, 126, 55)	14.04	(m/z 170, 155, 153)
4.15	(m/z 110. 95. 109)	14.14	C15 alkene (m/z 183, 210, 182)
4.30	Cyclohexane, 1,3,5-trimethyl-	14.16	(m/z 157, 204, 208)
4.37	xylene (m/z 91, 106, 105)	14.23	(m/z 197, 196, 155)

TABLE 11-continued

GC-MS results.			
Retention time (min)	Component	Retention time (min)	Component
4.47	xylene + (m/z 106, 91, 109)	14.35	(m/z 204. 208. 170)
4.57	C9H16 (m/z 109. 124. 83)	14.42	(m/z 204. 105. 224)
4.70	C9 alkene (m/z 41, 43, 97)	14.51	Cetene
4.76	C10H20 (m/z 43. 83. 104)	14.67	Hexadecane
4.82	xylene + (m/z 106, 43, 91)	14.80	(m/z 224, 111, 195)
4.84	Nonane	15.10	(m/z 155, 168, 154)
5.23	Benzene. (1-methylethyl)-	15.18	(m/z 182. 183. 169)
5.32	(m/z 97, 83, 126)	15.25	(m/z 167, 196, 182)
5.64	Benzene. propyl-	15.32	(m/z 197. 196. 155)
5.71	(m/z 124. 41. 95)	15.36	(m/z 167. 224. 165)
5.76	aromate C9H12 (m/z 105. 120, 103)	15.39	(m/z 218, 211, 210)
5.79	aromate C9H12 (m/z 105, 120, 106)	15.48	(m/z 196, 197, 105)
5.86	aromate C9H12 (m/z 105, 120, 119)	15.57	(m/z 167. 218. 165)
6.05	aromate C9H12 (m/z 105. 120, 103)	14.80	(m/z 224. 111. 195)
6.14	C10H20 alkene (m/z 41 97. 55)	15.66	1-Heptadecene
6.29	Decane	15.83	Heptadecane
6.35	C10H20 alkene (m/z 140. 97. 41)	15.95	C17 alkene (m/z 238. 111. 169)
6.43	(m/z 113, 43, 41)	16.06	C17 alkene (m/z 97, 198, 238)
6.50	C11H24 alkane (m/z 43, 113, 41)	16.25	(m/z 168. 180. 182)
6.79	(m/z 154. 41. 111)	16.30	(m/z 179. 196. 194)
6.97	Indane	16.38	(m/z 165. 182. 167)
7.13	aromate C10H14 (m/z 105. 134, 85)	16.43	(m/z 211, 181, 210)
7.24	(m/z 119, 43, 85)	16.48	(m/z 179, 194, 178)
7.32	(m/z 119, 105, 41)	16.53	(m/z 225, 224, 111)
7.48	(m/z 111. 112, 41)	16.54	(m/z 179. 232. 194)
7.55	(m/z 119, 111, 112)	16.62	(m/z 165, 181, 210)
7.68	(m/z 119, 41, 97)	15.95	C17 alkene (m/z 238. 111. 169)
7.76	aromate C10H12 (m/z 117, 115, 132)	16.76	1-Octadecene
7.86	Undecane	16.91	Octadecane
7.89	C11H22 alkene (m/z 154. 97. 41)	17.19	(m/z 178, 250, 97)
8.01	C11H22 alkene (m/z 154. 41. 152)	17.49	(m/z 225, 179, 178)
8.22	(m/z 152. 125, 41)	17.57	(m/z 239. 179. 194)
8.44	(m/z 154, 119, 152)	17.63	(m/z 246, 179, 194)
8.57	aromate (m/z 117. 152, 115)	17.72	(m/z 266. 193. 181)
8.61	(m/z 131, 119, 146)	17.81	1-Nonadecene
8.67	aromate (m/z 148, 105, 106)	17.94	Nonadecane
8.75	aromate (m/z 117. 115. 132)	18.51	(m/z 179. 239. 208)
8.83	aromate (m/z 148, 119, 115)	18.60	(m/z 253, 252, 193)
8.92	aromate (m/z 148, 105, 106)	18.69	(m/z 260, 192, 191)
9.17	C12 alkene (m/z 97, 168. 41)	18.80	1-Eicosene
9.29	(m/z 131, 170, 43)	18.93	Eicosane
9.32	Naphthalene	19.47	(m/z 253. 274. 252)
9.37	Dodecane	19.76	1-Heneicosene
9.39	C12 alkene (m/z 168. 97. 131)	19.87	Heneicosane
9.46	aromate C11H14 (m/z 131, 146, 115)	20.77	Docosane
9.50	(m/z 168. 131, 146)	21.64	Tricosane
9.82	(m/z 145, 155, 160)	22.47	Tetracosane
9.92	(m/z 162. 166, 155)	23.27	Pentacosane
9.97	(m/z 168. 117. 183)	24.04	Hexacosane
10.02	(m/z 162, 117, 119)	24.84	Heptacosane
10.07	(m/z 145. 166, 160)	25.74	Octacosane
10.12	(m/z 145, 162, 160)	26.79	Nonacosane

The kinematic viscosity of the oil was assessed using ASTM D445 and ASTM D7042 using an Anton Paar SVM3000 Stabinger Viscometer G2. The oil sample had a kinematic viscosity of 28.2 mm^2/s, cSt.

The flash point of the oil was measured using ASTM D93A using a Pensky Martens Herzog, Electronic MP329 instrument. The oil had a flashpoint of 11.3° C.

The oil was subjected to distillation according to EN ISO 405. The results are summarized in Table 12.

TABLE 12

Distillation results of oil sample.

	Analysis No. 1	Analysis No. 2	Units
Receiver temperature	16	16	° C.
Starting Sample Temperature	22.0	22.0	° C.
Initial Boiling Point	37	37	° C.
25% Recovery	137.7	135.8	° C.
35% Recovery	163.1	161.8	° C.
45% Recovery	189.6	188.5	° C.
55% Recovery	216.1	217.6	° C.
65% Recovery	244.9	244.4	° C.
75% Recovery	271.6	270.8	° C.
80% Recovery	288.9	286	° C.
85% Recovery		305	° C.

The oil sample was further subjected to ^{1}H-NMR spectroscopy. The ^{1}H spectra were obtained in $CDCl_3$ solvent (Goss Scientific D, 99.8%) at ambient laboratory temperature and auto referenced against the solvent peak using the JEOL ECS 400 NMR spectrometer.

The ^{1}H-NMR spectra are shown in FIG. **20** and FIG. **21**. The annotations in FIG. **21** is a guide highlighting certain peaks of interest. The ^{1}H-NMR spectra generated for the oil sample confirm the presence of saturated, unsaturated and aromatic hydrocarbons. ^{1}H-NMR indicates the presence of vinyl, internal and vinylidene olefinic functionalities.

The normalized NMR integration values indicate there is 94.8% aliphatic protons (region 0.2-4 ppm), 3.8% olefinic protons (region 4.5-6.0 ppm) and 1.4% aromatic protons (region 6.7-8.3 ppm). This refers to the percentage of proton atoms in the aliphatic saturated, olefinic and aromatic rings only relative to the total proton content. There were no signals observable outside the range shown in the ^{1}H-NMR spectra.

The oil sample was further subjected to ^{13}C-NMR spectroscopy. The ^{13}C-NMR spectra were obtained in $CDCl_3$ solvent (Goss Scientific D, 99.8%) at ambient laboratory temperature and auto referenced against the solvent peak.

The ^{13}C-NMR spectra are shown in FIG. **22** and FIG. **23**. The annotations in FIG. **23** is a guide highlighting certain peaks of interest. The ^{13}C-NMR spectra generated for the oil sample are dominated by resonances that are consistent with saturated, unsaturated and aromatic hydrocarbons. ^{13}C-NMR indicates the presence of vinyl, internal and vinylidene olefinic functionalities. There were no signals observable outside the range shown in the ^{13}C-NMR spectra.

Other advantages which are obvious and which are inherent to the invention will be evident to one skilled in the art. It will be understood that certain features and sub-combinations are of utility and may be employed without reference to other features and sub-combinations. This is contemplated by and is within the scope of the claims. Since many possible embodiments may be made of the invention without departing from the scope thereof, it is to be understood that all matter herein set forth or shown in the accompanying drawings is to be interpreted as illustrative and not in a limiting sense.

The methods of the appended claims are not limited in scope by the specific methods described herein, which are intended as illustrations of a few aspects of the claims and any methods that are functionally equivalent are intended to fall within the scope of the claims. Various modifications of the methods in addition to those shown and described herein are intended to fall within the scope of the appended claims. Further, while only certain representative method steps disclosed herein are specifically described, other combinations of the method steps also are intended to fall within the scope of the appended claims, even if not specifically recited. Thus, a combination of steps, elements, components, or constituents may be explicitly mentioned herein or less, however, other combinations of steps, elements, components, and constituents are included, even though not explicitly stated.

What is claimed is:

1. An oil derived from pyrolysis of a feedstock comprising post-consumer and/or post-industrial plastics, wherein:

the oil is produced at an industrial scale;

the oil has a number average molecular weight and/or a weight average molecular weight of from 50 to 300 Daltons;

the oil comprises a mixture of different hydrocarbons, any of which can optionally be substituted, and the oil comprises 90% to 100% (w/w) of C_4-C_{20} hydrocarbons, and wherein the oil is substantially free of hydrocarbons comprising 30 or more carbons;

the oil has a Reid vapor pressure of 12.5 psig or less; and

the oil has:

a final boiling point of 750° F. to 1000° F.;

a pour point of 0° F. to 20° F.;

a total chloride content of 500 ppm or less;

a nitrogen content of 600 ppm or less;

a silicon content of 2000 ppm or less;

a sodium content of 100 ppm or less;

an iron content of 10 ppm or less;

a phosphorus content of 25 ppm or less;

a sulfur content of 250 ppm or less;

a calcium content of 50 ppm or less;

or a combination thereof.

2. The oil of claim **1**, wherein the mixture comprises:

25-35% C_4-C_8 hydrocarbons,

55-65% C_9-C_{20} hydrocarbons, and

1-10% C_{21}-C_{29} hydrocarbons.

3. The oil of claim **1**, wherein the mixture comprises:

90-100 wt. % unsaturated hydrocarbons;

0-5 wt. % unsaturated non-aromatic hydrocarbons; and

0-2.5 wt. % aromatic hydrocarbons.

4. The oil of claim **1**, wherein the oil has a final boiling point of from 750° F. to 1000° F.

5. The oil of claim **1**, wherein the oil has a pour point of from 0° F. to 20° F.

6. The oil of claim **1**, wherein the oil has a total chloride content of 500 ppm or less.

7. The oil of claim **1**, wherein the oil has a nitrogen content of 600 ppm or less.

8. The oil of claim **1**, wherein the oil has a silicon content of 2000 ppm or less.

9. The oil of claim **1**, wherein the oil has a sodium content of 100 ppm or less.

10. The oil of claim **1**, wherein the oil has an iron content of 10 ppm or less.

11. The oil of claim **1**, wherein the oil has a phosphorus content of 25 ppm or less.

12. The oil of claim **1**, wherein the oil has a sulfur content of 250 ppm or less.

13. The oil of claim **1**, wherein the oil has a calcium content of 50 ppm or less.

14. The oil of claim **1**, wherein the oil has a copper content of 10 ppm or less, a nickel content of 250 ppm or less, a vanadium content of 25 ppm or less, or a combination thereof.

15. The oil of claim **1**, wherein the oil has:

a total chloride content of 100 ppm or less;

a nitrogen content of 575 ppm or less;

a silicon content of 250 ppm or less;

a sodium content of 25 ppm or less;

an iron content of 10 ppm or less;

a phosphorus content of 9 ppm or less;

a sulfur content of 10 ppm or less;

a calcium content of 5 ppm or less;

or a combination thereof.

16. The oil of claim **1**, wherein the oil has a water by distillation amount of 0.5 vol. % or less, a total sediment content of 0.5 vol. % or less, an n-heptane insoluble content of 0.1 wt. % or less, a total acid number of 1 mg KOH/g or less, or a combination thereof.

17. The oil of claim **1**, wherein the oil has:

a final boiling point of 750° F. to 1000° F.; and

a pour point of 0° F. to 20° F.

18. The oil of claim **1**, wherein the oil is produced via pyrolysis in a volume of from 10,000 to 1,000,000 gallons per 5 to 90 days.

19. A method of making the oil of claim **1**, wherein the method comprises pyrolysis of a feedstock comprising post-consumer and/or post-industrial plastics.

20. A composition, wherein the composition comprises or is derived from the oil of claim **1**.

21. The composition of claim **20**, wherein the composition comprises a lubricating oil, a mineral oil, a group III base oil, a paraffin wax, a binder, a processing aid, kerosene, white oils, liquefied petroleum gas (LPG), naphtha, diesel and gas oil, gasoline, diesel fuel, asphalt, automotive fuel, aviation fuels, base oil, bitumen, cadalene, cutting fluid, fuel oil, heating oil, heavy fuel oil, hydrocarbon solvents, ligroin, mazut, microcrystalline wax, mineral oil, motor fuel, motor oil, naphthenic acid, petroleum benzine, petroleum ether, petroleum jelly, petroleum naphtha, petroleum resin, retene, or a combination thereof.

22. An article of manufacture, wherein the article of manufacture comprises or is derived from the oil of claim **1**.

23. The article of claim **22**, wherein the article comprises packaging, film, fibers, carpets, clothing, molded articles, extruded pipes, a medical device, lubricant, candles, adhesives, packaging, rubber, cosmetics, fire logs, bituminous mixtures, superficial wear coatings, asphalt, sealing coatings, automotive fuel, aviation fuels, base oil, bitumen, cadalene, cutting fluid, diesel fuel, fuel oil, gasoline, heating oil, heavy fuel oil, hydrocarbon solvents, kerosene, ligroin, mazut, microcrystalline wax, mineral oil, motor fuel, motor oil, naphtha, naphthenic acid, paraffin wax, petroleum benzine, petroleum ether, petroleum jelly, petroleum naphtha, petroleum resin, retene, tar, fertilizer, flooring, perfume, insecticide, soap, vitamin, amino acid, wood-based composites, oriented-strand board (OSB), particleboard, hardboard, medium density fiberboard, gypsum board, crayons, paper and carton coatings, or a combination thereof.

24. A method of use of the composition of claim **20**, wherein the method comprises using the composition as a hydrocarbon feedstock for a petroleum refinery, a catalytic cracking system, a thermal cracking system, a polymerization system, or a combination thereof.

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