separation procedures are implemented to remove impurities from post-use plastics. See WO2012/117250A1, WO2017/003802A1, and WO2008/058303A1. In many instances, the harsh conditions PP is subjected to during mechanical recycling results in downgraded PP compared to virgin PP.

[0009] Chemical recycling technologies are also currently in use to convert post-use PP into fuel or energy. See, WO2014/040634A1 and WO2016/091993A1. Such technologies are typically high energy and they result in low carbon efficiency.

[0010] Thus, there is a need in the art for methods and systems that provide for the decomposition of PP waste that overcome the limitations of known methods.

SUMMARY ~~OF THE INVENTION~~

[0011] The following examples~~embodiments and aspects~~ thereof are described and illustrated in conjunction with compositions and methods which are meant to be exemplary and illustrative, not limiting in scope.

[0011a] In a first aspect, the present disclosure refers to a method for decomposing polypropylene (PP) waste, comprising:

a. adding PP waste to a reaction vessel;

b. adding at least one oxidizing agent to the reaction vessel to give a mixture; and

c. subjecting the mixture obtained in b. to conditions effective to decompose the PP waste to produce decomposition products, wherein the decomposition products comprise at least one dicarboxylic acid optionally substituted by a nitro group; or the salts or esters or anhydrides thereof.

[0011b] In another aspect, the present disclosure refers to a composition, comprising 2-methylsuccinic acid, 3-methylglutaric acid, 2,4-dimethylglutaric acid, 2,4-dimethyladipic acid, 3,5-dimethylpimelic acid, 2,4,6-trimethylpimelic acid, 2,4,6-trimethylsebacic acid, and 2,4,6,8-tetramethyl-azelaic acid, or the salts, or esters or anhydrides thereof.

[0012] Provided is a method for decomposing polypropylene (PP) waste, comprising:

a. adding PP waste to a reaction vessel;

b. adding at least one oxidizing agent to the reaction vessel to give a mixture; and

c. subjecting the mixture obtained in b. to conditions effective to decompose the PP waste to produce decomposition products, wherein the decomposition products

comprise at least one dicarboxylic acid optionally substituted by a nitro group; or the salts or esters or anhydrides thereof.

[0013] In one example~~embodiment~~, the decomposition products further comprise at least one carboxylic acid, optionally substituted by a nitro group.

[0014] In one ~~embodiment~~example, the PP waste further comprises at least one plastic material; and at least one non-plastic material. In another ~~embodiment~~example, wherein the plastic material comprises at least one selected from the group consisting of plastic film, plastic foam, plastic packaging, plastic bags, plastic wrap, and combinations thereof. In another ~~embodiment~~example, the non-plastic material comprises at least one selected from the group consisting of non-plastic organic material, inorganic material, fluid, and combinations thereof.

[0015] In some ~~embodiment~~examples, the at least one oxidizing agent is oxygen (O_2), nitric oxide (NO), nitrous oxide (N_2O), nitrogen dioxide (NO_2), nitric acid (HNO_3), aqueous nitric

acid (HNO_3), or combinations thereof. In one ~~embodiment~~example, the at least one oxidizing agent is aqueous nitric acid (HNO_3). In another ~~embodiment~~example, the nitric acid has a concentration of 10-100 wt%. In one ~~embodiment~~example, the nitric acid has a concentration of about 67 to about 70 wt%.

[0016] In some ~~embodiment~~examples, the weight ratio of nitric acid to PP is at least 3:1. In one ~~embodiment~~example, the weight ratio of nitric acid to PP is at least 10:1. In another ~~embodiment~~example, the weight ratio of nitric acid to PP is 10-100:1.

[0017] In one ~~embodiment~~example, the conditions comprise a temperature range from 60 ^oC to 200 ^oC. In another ~~embodiment~~example, the conditions comprise an initial pressure range of 0 psi to 1000 psi. In another ~~embodiment~~example, the conditions comprise the presence of a gas that is at least one selected comprising air, nitrogen (N_2), oxygen (O_2), or combinations thereof. In another ~~embodiment~~example, the conditions comprise a residence time in the reaction vessel of 30 minutes to 30 hours.

[0018] In one ~~embodiment~~example, the dicarboyxlic acid or dicarboxylic acid substituted with at least one nitro group is substituted with one or more methyl groups.

[0019] In one ~~embodiment~~example, the decomposition products comprise at least one C_4-C_{15} dicarboxylic acid. In another ~~embodiment~~example, the decomposition products comprise at least one C_4-C_9 dicarboxylic acid. In another ~~embodiment~~example, wherein when the dicarboxylic acid comprises a carbon chain of an even number n between the two carboxy groups, it is substituted by (n/2)-1 methyl groups. In another ~~embodiment~~example, wherein when the dicarboxylic acid comprises a carbon chain of an odd number n between the two carboxy groups, it is substituted by (n/2)-1 or (n/2)-2 methyl groups.

[0020] In one ~~embodiment~~example, the decomposition products obtained from the method comprise at least one of 2-methylsuccinic acid, 3-methylglutaric acid, 2,4-dimethylglutaric acid, 2,4-dimethyladipic acid, 3,5-dimethylpimelic acid, 2,4,6-trimethylpimelic acid, 2,4,6-trimethylsebacic acid, and 2,4,6,8-tetramethyl-azelaic acid. In another ~~embodiment~~example, the decomposition products further comprise at least one of Butanedioic acid, methyl-, dimethyl ester; Butanedioic acid, methyl-, dimethyl ester; Butanedioic acid, methyl-, dimethyl ester; Pentanedioic acid, 2,4-dimethyl-, dimethyl ester; 1,4-Benzenedicarbonitrile, 2-formyl-1H-; Pentanedioic acid, 2,4-dimethyl-, dimethyl ester; 5-Acetoxy-3-methyl-hexanoic acid, methyl ester; 9-Decenoic acid, 2,4-dimethyl-, methyl ester, (R,R)-(-)-; Heptanedioic acid, 2-methyl-, dimethyl ester;

Heptanedioic acid, 3,5-dimethyl-, dimethyl ester; Quinoline, 2-butyl; Cyclohexanecarboxylic acid, ethyl ester; 3-Cyclobut-1-enyl-hydroxy-2-methyl-propionic acid, methyl ester; Adipic acid, methyl propyl ester; Methyl 2-methyl-3-cyclopropylpropanoate; 2-Propanone, 1-cyclopentyl-3-ethoxy-; Cyclohexane, 1,2-diethyl-, cis-; Cyclohexane, 1,2-diethyl-3-methyl-; Octanedioic acid, 2,2,7,7-tetramethyl-; 9-Decenoic acid, 2,4-dimethyl-, methyl ester, (2S, 4R)-(+)-; O-Fluoroacetophenone oxime; Dibenzo[b,f]oxepin-3-ylamine; Carbamic acid, (4-ethoxyphenyl)-, ethyl ester; Quinoline, 2-(1-methyl-1H-imidazol-4-yl); 2,8-Bis(1,5,5-trimethylpyrrolidin-2,4-dion-3-ylidene)-3,7-diazanonan; 2-Amino-3,5,7,8-tetrahydro-4,6-pteridinedione; or 1,2-Dimethoxy-4-(1,2-dimethoxyethyl)benzene.

[0021] In one ~~embodiment~~example, the carboxylic acid or dicarboxylic acid obtained from the method is substituted with at least one nitro group. In another ~~embodiment~~example, the carboxylic acid or dicarboxylic acid is substituted in the 2-position with the nitro group. In another ~~embodiment~~example, the carboxylic acid or dicarboxylic acid is substituted in the 3-position with the nitro group. In another ~~embodiment~~example, the carboxylic acid or dicarboxylic acid is substituted at an internal position with the nitro group.

[0022] In one ~~embodiment~~example, the method further comprises adding at least one solid state catalyst to the reaction vessel. In another ~~embodiment~~example, the at least one solid state catalyst is selected from the group consisting of zeolite, alumina, silico-alumino-phosphate, sulfated zirconia, zinc oxide, titanium oxide, zirconium oxide, niobium oxide, iron carbonate, calcium carbide, and combinations thereof.

[0023] In one ~~embodiment~~example, the method further comprises separating the decomposition products into a solid phase and a liquid phase. In another ~~embodiment~~example, the solid phase comprises at least one selected from the group consisting of oligomer, polymer, and combinations thereof. In another ~~embodiment~~example, the solid phase further comprises at least one solid state catalyst.

[0024] In one ~~embodiment~~example, the liquid phase comprises a carboxylic acid, dicarboxylic acid, carboxylic acid substituted with a nitro group, or dicarboxylic acid substituted with a nitro group, or the salt, or ester or anhydride thereof.

[0025] In one ~~embodiment~~example, the method further comprises converting the carboxylic acid optionally substituted with a nitro group and/or the dicarboxylic acid optionally substituted with a nitro group into an ester.

[0026] In one ~~embodiment~~example, the method further comprises separating the carboxylic acid optionally substituted with a nitro group and/or the dicarboxylic acid optionally substituted with a nitro group, or the salts, or esters or anhydrides thereof. In another ~~embodiment~~example, the method further comprises separating the at least one corresponding ester. In one ~~embodiment~~example, the ester is at least one of 2-methylsuccinic acid, dimethyl ester; 3-methylglutaric acid, dimethyl ester; 2,4-dimethylglutaric acid, dimethyl ester; 2,4-dimethyladipic acid, dimethyl ester; 3,5-diethylpimelic acid, dimethyl ester; 2,4,6-trimethylpimelic acid, dimethyl ester; 4,6-trimethylsebacic acid, dimethyl ester; 2,4,6,8-tetramethyl-azelaic acid; or a combination thereof.

[0027] In one ~~embodiment~~example, the method further comprises feeding the oligomer, the polymer, and combinations thereof back into the reaction vessel.

[0028] In one ~~embodiment~~example, the liquid phase further comprises the at least one oxidizing agent. In another ~~embodiment~~example, method further comprises collecting and regenerating the at least one oxidizing agent.

[0029] Also provided is a composition, comprising 2-methylsuccinic acid, 3-methylglutaric acid, 2,4-dimethylglutaric acid, 2,4-dimethyladipic acid, 3,5-dimethylpimelic acid, 2,4,6-trimethylpimelic acid, 2,4,6-trimethylsebacic acid, and 2,4,6,8-tetramethyl-azelaic acid, or the salts, or esters or anhydrides thereof. In one ~~embodiment~~example, the composition further comprises at least one of Butanedioic acid, methyl-, dimethyl ester; Butanedioic acid, methyl-, dimethyl ester; Butanedioic acid, methyl-, dimethyl ester; Pentanedioic acid, 2,4-dimethyl-, dimethyl ester; 1,4-Benzenedicarbonitrile, 2-formyl-1H-; Pentanedioic acid, 2,4-dimethyl-, dimethyl ester; 5-Acetoxy-3-methyl-hexanoic acid, methyl ester; 9-Decenoic acid, 2,4-dimethyl-, methyl ester, (R,R)-(-)-; Heptanedioic acid, 2-methyl-, dimethyl ester; Heptanedioic acid, 3,5-dimethyl-, dimethyl ester; Quinoline, 2-butyl; Cyclohexanecarboxylic acid, ethyl ester; 3-Cyclobut-1-enyl-hydroxy-2-methyl-propionic acid, methyl ester; Adipic acid, methyl propyl ester; Methyl 2-methyl-3-cyclopropylpropanoate; 2-Propanone, 1-cyclopentyl-3-ethoxy-; Cyclohexane, 1,2-diethyl-, cis-; Cyclohexane, 1,2-diethyl-3-methyl-; Octanedioic acid, 2,2,7,7-tetramethyl-; 9-Decenoic acid, 2,4-dimethyl-, methyl ester, (2S, 4R)-(+)-; O-Fluoroacetophenone oxime; Cyclohexanone, 2-(1-mercapto-1-methylethyl)-5-methyl-, trans-; Dibenzo[b,f]oxepin-3-ylamine; Carbamic acid, (4-ethoxyphenyl)-, ethyl ester; Quinoline, 2-(1-methyl-1H-imidazol-4-yl)-; 2,8-Bis(1,5,5-trimethylpyrrolidin-2,4-