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Research Article

New Alternative Vehicle Hydrocarbon Liquid Fuels from Municipal Solid Waste Plastics

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Abstract Millions of vehicles on the road today are releasing a large amount of carbon dioxides (CO_2) causing the climates to change drastically. Studies indicate that the CO_2 released from vehicles is the main contributor of global warming. Alternative fuels developed from waste plastics have the potential to have a positive impact on the environment in two ways. First of all, the presence of waste plastics in the landfill causes fertile soils to decay and these waste plastics can be used for the production of high quality alternate fuels. Removing these harmful waste plastics from landfill and converting them into liquid hydrocarbon fuels can create a more stable environment than the one we are living in. This technology is environmentally friendly and projected to be produced at a very low cost compared to the current commercial fuels. Preliminary results showed that the NSR fuel has many similar characteristics as the current gasoline.

Keywords fuel; hydrocarbon; thermal; waste plastic; condensation; catalyst; DSC; fraction; FT-IR; GC/MS

1 Introduction

Plastic is a macromolecule polymer, formed by polymerization of hydrocarbon materials and it has the ability to be shaped by the application of reasonable amount of heat and pressure. Plastics contain compounds such as carbon monoxide, sulfur and nitrogen. Plastics are being used all over the world, and afterwards, these plastics turn into waste plastics. The types of plastics include high-density polyethylene (HDPE, code 2), low-density polyethylene (LDPE, code 4), polypropylene (PP, code 5), and polystyrene (PS, code 6). According to a recent study, in the U.S., 30 million tons of total plastic are produced each year, with only about 4% now being recycled [5]. The rest of the waste plastics either end up in landfill or incineration. The waste plastic that ends up in the landfill when littered does not degrade for thousands of years causing lands to become infertile and environmentally unsafe for its habitants around them. Due to excessive amount of waste plastics discarded everyday, a large amount of them end up in incineration facilities. When incinerated, waste plastics release toxic gases such as carbon monoxide (CO), which causes health hazards, sulfur dioxides (SO_2) when incinerated, which contributes to acid rain, nitrogen oxides (NOx) which contribute to ozone depilation and acid rain, and carbon dioxide (CO_2), greenhouse gases that contribute to global warming.

Plastics like polyethylene bags are very lightweight. They do not stay steady in the landfill. If the plastic bags are not recycled, eventually they will find their way into water stream and end up in the Ocean region. Not only plastic bags but any plastic materials that are not recycled end up in the Ocean as well. This is proven in a study conducted by Charles J. Moore (Long Beach, California) about the Great Pacific Garbage Patch, which shows the horror and impacts that waste plastic can have on oceanic and marine life. According to his study, the Garbage Patch is estimated to be twice the size of Texas and contains $\sim$ 3.5 million tons of waste material and 80% of it is waste plastic litter [9]. According to C. J. Moore's 1999 study, there were 6 times more waste plastic in this part of the ocean than the zooplankton that feeds ocean life [9]. Also another study performed in 2002 showed that even off the coast of California, waste plastic outweigh zooplankton by a factor of 5 to 2 [10].

Many researches have been conducted to convert waste plastics into renewable energy sources. This is possible because plastics are originally made from crude oil. Crude oil is a very limited natural resource that is used to make transportation fuel, plastics and other products. Crude oil is a non-renewable energy source and since it is a natural resource it will deplete in the near future.

Successful methods have been carried out to convert waste plastics into liquid based fuels [1,8,12]. These methods include various procedures to convert the waste plastics such as Pyrolysis, in which the contents of waste plastics are thermally degraded to produce liquid-based fuels and other products without the presence of oxygen [3,

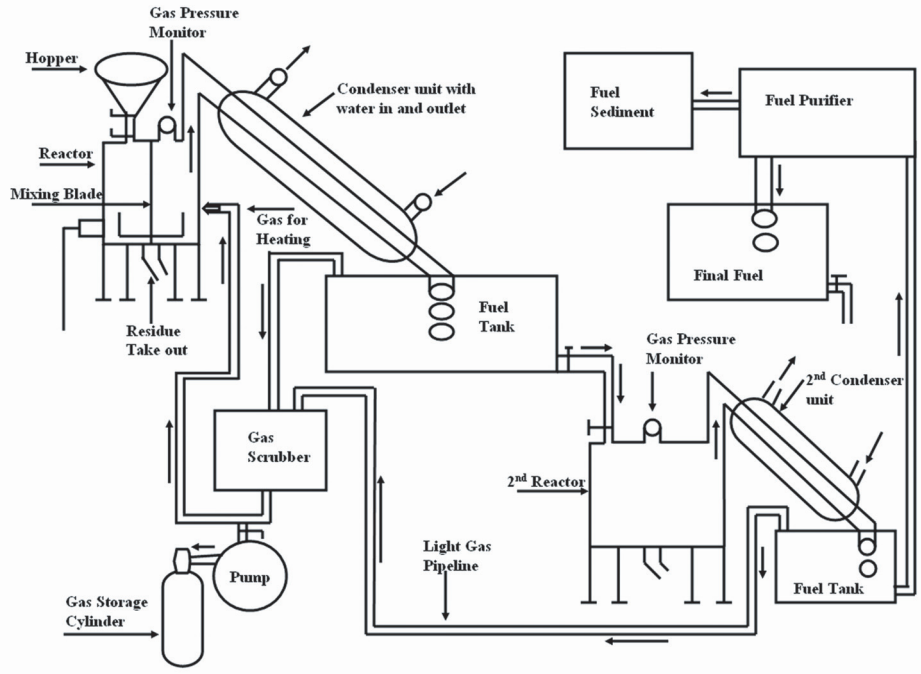

Figure 1: Waste plastic to fuel production process.

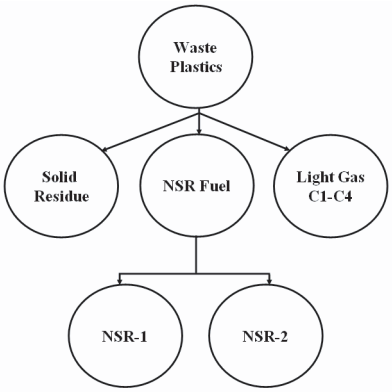

Figure 2: Waste plastic to fuel production diagram.

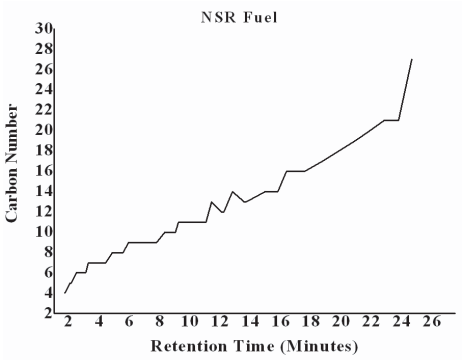

Figure 3: NSR fuel GC/MS chromatogram of carbon content with retention time.

4,6,7,14]. The process described in this particular paper to convert solid waste plastics into renewable energy sources is accomplished utilizing a basic form of thermal degradation. The basic form of thermal degradation has been tested and proven to produce fuel that can be used as an energy source [2,11,13,15].

The final product produced obtained from utilizing the thermal degradation process is in the form of liquid and it contains hydrocarbon materials. The experiment conducted to produce the liquid fuel is carried out in a stainless steel reactor system (Figure 1).

Figure 2 shows the process in which the waste plastics is processed using thermal degradation and distillation process.

Figures 3, 4, and 5 demonstrate the carbon content of NSR, NSR-1, and NSR-2 fuel in against their retention time analyzed using a GC/MS.

2 Experimental process description

The process uses thermal cracking to heat the waste plastic to form a liquid slurry, at a temperature ranging from 370 °C–420 °C, then the liquid slurry turns into vapor; that vapor is then condensed/distilled (see Figure 1) to produce the liquid hydrocarbon fuels. It should be noted that no chemicals are used to carry out this process and the end product is filtered using a commercial fuel purifier that operates using coalescence and centrifugal force.

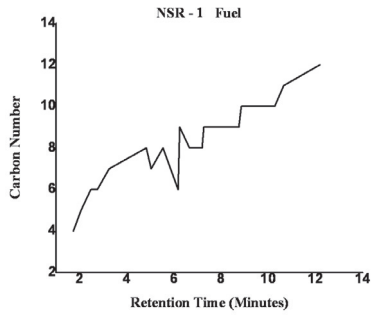

Figure 4: NSR-1 fuel GC/MS chromatogram of carbon content with retention time.

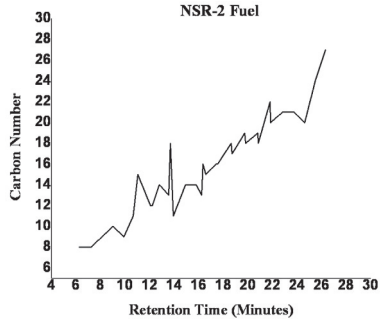

Figure 5: NSR-2 fuel GC/MS chromatogram of carbon content with retention time.

Experiments conducted in a mini-scale have been performed with the majority of waste plastic types: high-density polyethylene (HDPE, code 2), low-density polyethylene (LDPE, code 4), polypropylene (PP, code 5), and polystyrene (PS, code 6). These plastic types were investigated singly and in combination with each other. In a laboratory scale, the weight of a single batch of input plastic for the fuel production process ranges from 350 gm to 5 kg. The waste plastics are collected, optionally sorted, cleaned of contamination or without cleaning and grinded into small pieces prior to the thermal liquefaction process. In the double condensation process, two different types of fuel are collected at two types of different temperature range. The double condensed fuels are classified as NSR-1, NSR-2. NSR-1 (gasoline) will be collected at 200–240 °C and NSR-2 (diesel) in the range of 240–360 °C. Also during the fuel production process, some very light gas is produced (C_1–C_4). The gases include methane, ethane, propane and butane. These gases can be utilized as a heat source to carry out the fuel production process. A very minimum amount of solid carbon residue is leftover from the production step. The residues contents are similar to contents which are used for road and roof carpeting.

The initial and double condensed fuels were tested by the GC/MS to identify their compositions. A hydrocarbon chain length of (C3-C27) (see Table 1) is present in the NSR fuel with a retention time ranging from 2 min to 27 min. After fractionating the NSR fuel, hydrocarbon chains are broken down into shorter ones because different temperature is used for each of the fuels. NSR-1 hydrocarbon chain was in the range (C_4–C_{12}) (see Table 2) and NSR-2 in the range (C_9–C_{27}) (see Table 3). These data indicate that the NSR fuels have a wide range of hydrocarbon groups resulting in a higher thermal content. The thermal content allows the fuel to burn for a longer period of time resulting in efficiency when used in compatible engines.

3 Fuel analysis and discussion

The initial and double condensed fuels were tested by the GC/MS to identify their compositions. A hydrocarbon chain length of (C_3–C_{27}) is present in the NSR fuel with a retention time ranging from 2 min to 27 min. After fractionating the NSR fuel, hydrocarbon chains are broken down into shorter ones because different temperature is used for each of the fuels. NSR-1 hydrocarbon chain was in the range (C_4–C_{12}) and NSR-2 in the range (C_9–C_{27}). These data indicate that the NSR fuels have a wide range of hydrocarbon groups resulting in a higher thermal content. The thermal content allows the fuel to burn for a longer period of time resulting in efficiency when used in compatible engines.

Experiments conducted showed that 2 mL of initial fuel could burn for about 5 min; also, emission released from burning of the fuel contains very low concentration of benzene, toluene, styrene, xylene, and naphthalene and contains low traces of sulfur.

Results obtained from Elemental Analyzer (EA) – 2400 series II CHNS mode indicate that the initial fuel contains 86.44% carbon and 13.96% hydrogen. The average of the fractionated fuels contains 86.00% carbon and 13.00% hydrogen. Empirical formula indicates that all the fuel's carbon and hydrogen ratio is 1:2.

FTIR spectrum shows (Figure 6) NSR fuel has H bonded NH, CH2, C–CH3, non conjugated, non conjugated, conjugated, conjugated, CH2, CH3, secondary cyclic alcohol, –CH=CH2, –CH=CH– (trans), –CH=CH2, C=CH2, –CH=CH– (cis), –CH=CH– (cis), –CH=CH– (cis), –CH=CH– (cis). NSR-1 fuel (Figure 7) has H bonded NH, C–CH3, C–CH3, C–CH3, amides (–NH), CH3/CH2, CH3, acetates (CH3COO–), secondary cyclic alcohols, –CH=CH– (trans), –CH=CH2, C=CH2, –CH=CH– (cis), –CH=CH– (cis), –CH=CH– (cis). NSR-2 fuel (Figure 8) has H bonded NH, C–CH3, C–CH3, C–CH3, C–CH3, CH3, CH3, acetates (CH3COO–), secondary cyclic alcohols, –CH=CH– (trans), –CH=CH2, C=CH2, –CH=CH– (cis), –CH=CH– (cis), –CH=CH– (cis). NSR initial fuel, NSR-1 and NSR-2 contain secondary cyclic alcohols, C=CH2, Cis and Trans alkenes as well as CH3, CH2 group. These fuels have many compound group similarities, such as H bonded NH, C–CH3, –CH=CH2, –CH=CH– (trans) and

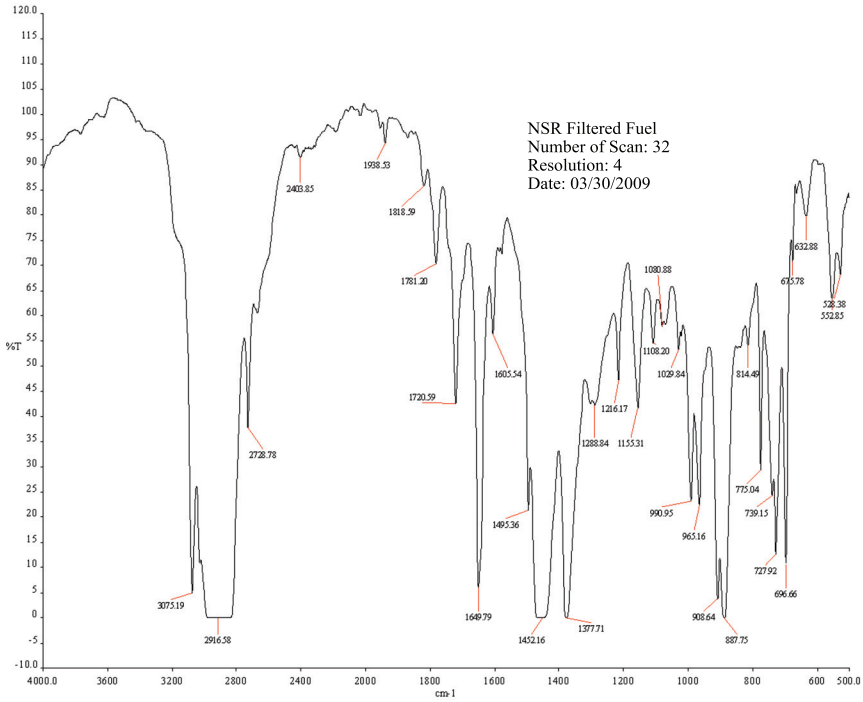

Figure 6: FT-IR spectrum of NSR fuel.

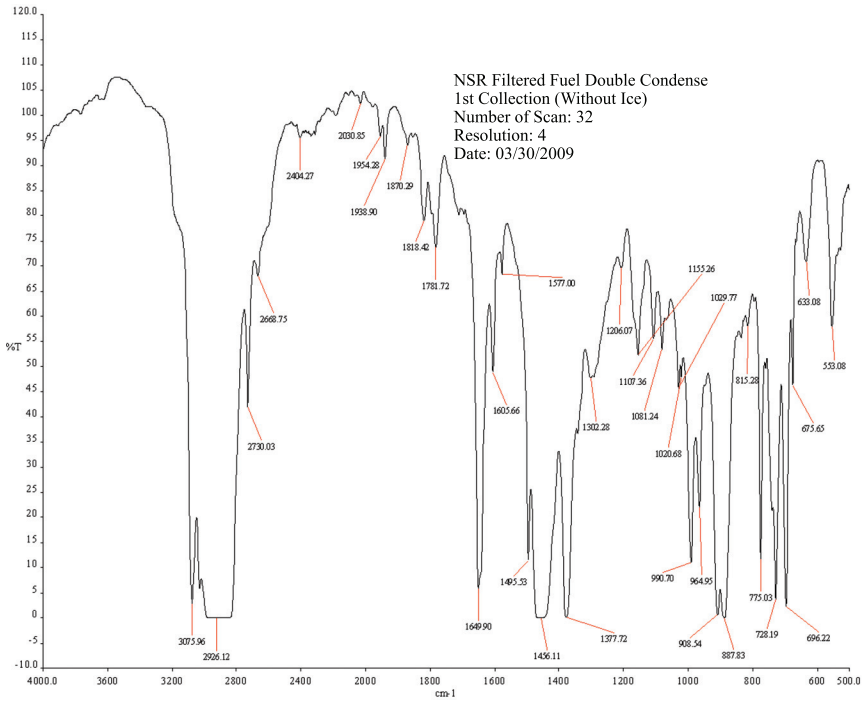

Figure 7: FT-IR spectrum of NSR-1 fuel.

–CH=CH– (cis). These similar groups resemble the fuels containing an identical fingerprint, which suggests that the fuels are of a good quality. From the above comparative discussion, we can say that our NSR initial fuel, NSR-1 fuel and NSR-2 fuel have very long carbon chain hydrocarbon functional groups. Also most of the groups in the fuel are short chain hydrocarbon and contains light compounds resulting in higher burning time.

Compound name	Formula
Cyclopropane	C_3H_6
2-Butene, (E)-	C_4H_8
Pentane	C_5H_{12}
Pentane, 2-Methyl-	C_6H_{14}
1-Pentene, 2-methyl-	C_6H_{12}
Hexane	C_6H_{14}
1-Pentene, 2,4-dimethyl-	C_7H_{14}
1-Heptene	C_7H_{14}
Heptane	C_7H_{16}
Heptane, 4-methyl-	C_8H_{18}
Toluene	C_7H_8
1-Octene	C_8H_{16}
Octane	C_8H_{18}
Heptane, 2,4-dimethyl-	C_9H_{20}
2,4-dimethyl-1-Heptene	C_9H_{18}
Ethylbenzene	C_8H_{10}
Styrene	C_8H_8
Benzene, (1-methyethyl)-	C_9H_{12}
-Methylstyrene	C_9H_{10}
Decane	$C_{10}H_{22}$
Nonane, 2,6-dimethyl-	$C_{11}H_{24}$
Benzene, 1-Propenyl-	C_9H_{10}
Cyclooctane, 1,4-dimethyl-, trans-	$C_{10}H_{20}$
Cyclopropane, 1-heptyl-2-methyl-	$C_{11}H_{22}$
Undecane	$C_{11}H_{24}$
1-Dodecanol, 3,7,11-trimethyl-	$C_{15}H_{32}O$
1-Dodecene	$C_{12}H_{24}$
Dodecane	$C_{12}H_{26}$
Decane, 2,3,5,8-tetramethyl-	$C_{14}H_{30}$
1-Tridecene	$C_{13}H_{26}$
Tridecane	$C_{13}H_{28}$
Isotridecanol-	$C_{13}H_{28}O$
Benzene, heptyl-	$C_{13}H_{20}$
5-Tetradecene, (E)-	$C_{14}H_{28}$
Tetradecane	$C_{14}H_{30}$
Benzene, (3-Octylundecyl)-	$C_{25}H_{44}$
1-Pentadecene	$C_{15}H_{30}$
Pentadecane	$C_{15}H_{32}$
Benzene, 1,1'-(3-methylbutylidene) bis-	$C_{17}H_{20}$
1-Hexadecene	$C_{16}H_{32}$
Hexadecane	$C_{16}H_{34}$
Benzene, 1,1'-(1,3-Propanediyl) bis-	$C_{15}H16$
Heptadecane	$C_{17}H_{36}$
Benzene, 1,1'-(2-Butene-1,4-Diyl) bis-	$C_{16}H_{16}$
3-Eicosene, (E)-	$C_{20}H_{40}$
Nonadecane	$C_{19}H_{40}$
9-Nonadecene	$C_{19}H_{38}$
Eicosane	$C_{20}H_{42}$
2-Phenylnaphthalene	$C_{16}H_{12}$
Heneicosane	$C_{21}H_{44}$
Nonadecane	$C_{19}H_{40}$
Benzene, hexadecyl-	$C_{22}H_{38}$
Heptacosane	$C_{27}H_{56}$

Table 1: GC/MS chromatogram of NSR fuel carbon compound and formula list.

Compound name	Formula
2-Methyl-1-Propene	(C_4H_8)
Pentane	(C_5H_{12})
3. 2-Methyl-Pentane	(C_6H_{14})
2-Methyl-1-Pentene	(C_7H_{14})
Hexane	(C_6H_{14})
2,4-Dimethyl-1-Pentene	(C_7H_{14})
3,5-Dimethyl-2-Hexene	(C_8H_{16})
Toluene	(C_7H_8)
Octane	(C_8H_{18})
2,4-Dimethyl-1-Heptene	(C_9H_{18})
Ethyl-Benzene	(C_8H_{10})
Styrene	(C_8H_8)
1-Methyl-Benzene	(C_9H_{12})
1-Decene	$(C_{10}H_{20})$
3,3-Dimethyl-Octane	$(C_{10}H_{22})$
3,7-Dimethyl-1-Octene	$(C_{10}H_{20})$
Undecane	$(C_{11}H_{24})$
Dodecane	$(C_{12}H_{26})$

Table 2: GC/MS chromatogram of NSR-1 fuel carbon compound and formula list.

Compound name	Formula
2,4-Dimethyl-1- Heptene	C_9H_{18}
Styrene	C_8H_8
Decane	$C_{10}H_{22}$
2,4-Dimethyl-1-Heptanol	$C_9H_{20}O$
1,4-Dimethyl-Cyclooctane	$C_{10}H_{20}$
Undecane	$C_{11}H_{24}$
3,7,11-Trimethyl-1-decanol	$C_{15}H_{32}O$
3-Dodecene	$C_{12}H_{24}$
Dodecane	$C_{12}H_{26}$
2,3,5,8-Tetramethyl-Decane	$C_{14}H_{30}$
2-Tridecene	$C_{13}H_{26}$
3-Octadecene	$C_{18}H_{36}$
2-Isopropyl-5-Methyl-1-Heptanol	$C_{11}H_{24}O$
1-Tetradecene	$C_{14}H_{30}$
Tetradecane	$C_{14}H_{30}$
2,3,5,8-Tetramethyl-Decane	$C_{14}H_{30}$
1-Tridecene	$C_{13}H_{26}$
Hexadecane	$C_{16}H_{34}$
3,7,11-Trimethyl-1-Dodecanol	$C_{15}H_{32}O$
Hexadecane	$C_{16}H_{34}$
1-Nonadecene	$C_{19}H_{38}$
Heptadecane	$C_{17}H_{36}$
Octadecane	$C_{18}H_{38}$
Nonadecane	$C_{19}H_{40}$
Eicosane	$C_{20}H_{42}$
Heniecosane	$C_{21}H_{44}$
Heptacosane	$C_{27}H_{56}$

Table 3: GC/MS chromatogram of NSR-2 fuel carbon compound and formula list.

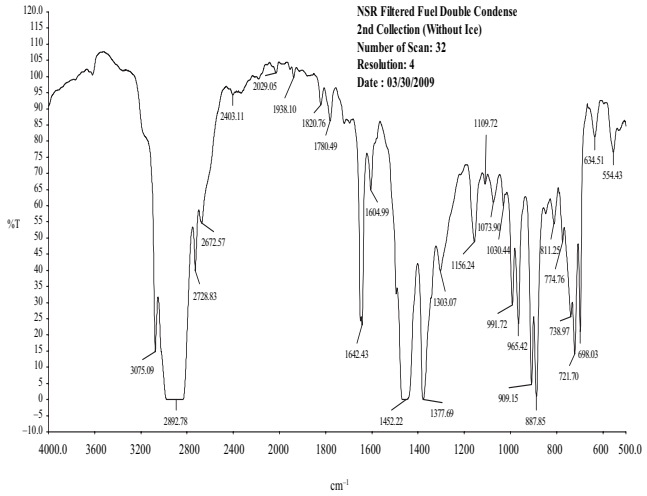

Figure 8: FT-IR spectrum of NSR-2 fuel.

Band serial	Band number (cm^{-1})	Group name
1st	3075.19	H bonded NH
2nd	2916.58	CH2
3srd	2728.78	C–CH3
6th	1818.59	Non conjugated
7th	1781.21	Non conjugated
8th	1720.59	Non conjugated
9th	1649.79	Conjugated
10th	1605.54	Conjugated
11th	1495.36	
12th	1452.16	CH2
13th	1377.71	CH3
19th	1029.84	Secondary cyclic alcohol
20th	990.95	–CH=CH2
21st	965.16	–CH=CH– (trans)
22nd	908.64	–CH=CH2
23rd	887.75	C=CH2
26th	739.15	–CH=CH– (cis)
27th	727.92	–CH=CH– (cis)
28th	696.66	–CH=CH– (cis)
29th	675.78	–CH=CH– (cis)

Table 4: FT-IR spectrum functional compound group name of NSR fuel.

According to EPA standards, the NSR-1 fuel contains no additional additives of octane booster as shown in Table 10. Also the concentration of benzene is very negligible.

4 Diesel car test emission result

The NSR-2 fuel was tested in a diesel engine to measure the emission released from burning the fuel. The results are listed in Table 11.

Band serial	Band number (cm^{-1})	Group name
1st	3075.72	H bonded NH/=C–H
2nd	2892.97	C–CH3
3rd	2729.93	C–CH3
4th	2668.80	C–CH3
8th	1819.42	Non conjugated
9th	1781.64	Non conjugated
10th	1721.38	Non conjugated
11th	1649.97	$\sim$ amides
12th	1605.44	Conjugated
14th	1452.17	CH3/CH2
15th	1377.75	CH3
20th	1030.01	CH3COO–
21st	991.51	Secondary cyclic alcohol
22nd	964.73	–CH=CH– (trans)
23rd	908.97	–CH=CH2
24th	887.74	C=CH2
26th	728.10	–CH=CH– (cis)
27th	695.52	–CH=CH– (cis)
28th	676.14	–CH=CH– (cis)

Table 5: FT-IR spectrum compound group name of NSR-1 fuel.

Band serial	Band number (cm^{-1})	Group name
1st	3075.09	H bonded NH / =C–H
2nd	2892.78	C–CH3
3rd	2728.83	C–CH3
4th	2672.57	C–CH3
8th	1820.76	Non conjugated
9th	1780.49	Non conjugated
10th	1642..43	Conjugated
11th	1604.99	Conjugated
12th	1452.22	CH3/CH2
13th	1377.69	CH3
18th	1030.44	CH3COO–
19th	991.72	Secondary cyclic alcohol
20th	965.42	–CH=CH– (trans)
21st	909.15	–CH=CH2
22nd	887.85	C=CH2
25th	738.97	–CH=CH– (cis)
26th	721.70	–CH=CH– (cis)
27th	698.03	–CH=CH– (cis)

Table 6: FT-IR spectrum compound group name of NSR-2 fuel.

5 ASTM test results

The fuels produced have been also tested according to the American Standard for Testing Materials (ASTM) methods. Tests performed by a third party certified laboratory (INTERTEK, NJ) demonstrate the parameters of the NSR fuels. The results show that a very considerate amount of harmful compounds are present in the NSR fuels. The results are listed in Tables 7, 8, and 9.

Method	Test	Result	Units
ASTM D240	Gross BTU-LB	19599	BTU/lb
ASTM D240	Gross BTU-Gal(calculated)	127413	BTU/gal
ASTM D4052	API gravity @ 60 °F	49.7	°API
ASTM D86	Barometric pressure	760	mm Hg
ASTM D86	IBP recovery	109.5	°F
ASTM D86	10% recovery	246.2	°F
ASTM D86	50% recovery	487.5	°F
ASTM D86	FBP recovery	633.5	°F
ASTM D86	Residue	28.2	Vol%
ASTM D86	Corrected loss	1.2	Vol%
ASTM D86	Corrected recovery	70.6	Vol%
ASTM D97	Pour point	9	°C
ASTM D97	Pour point	48.2	°F
ASTM D97	Upper pour point	9	°C
ASTM D2500	Cloud point	12	°C
ASTM D2500	Cloud point	53.6	°F
ASTM D 2624	Temperature	72	°F
ASTM D 2624	Electrical conductivity	2	pS/M
ASTM D5453	Sulfur	2.8	mg/kg
ASTM D1500	ASTM color	1.5	
ASTM E203	Water content	37	mg/kg
ASTM D5708	Vanadium content	< 1.00	mg/kg
ASTM D5708	Nickel content	< 1.00	mg/kg
ASTM D5708	Iron content	2.70	mg/kg
ASTM D5708_MOD	Calcium	< 1	ppm
ASTM D5708_MOD	Copper	< 1	ppm
ASTM D5708_MOD	Sodium	< 1	ppm
ASTM D482	Ash @ 775 °C	0.001	Wt%
ASTM D93 (procedure used A)	Corrected flash point	$<$ room temperature	°F
ASTM D4530	Carbon residue	< 0.10	Wt%
ASTM D664 (procedure used A)	Acid number	0.10	mg KOH/g
ASTM D2386	Freezing point	12.0	°C
ASTM D2386	Freezing point	54	°F

Table 7: ASTM test result of waste plastic to produce NSR fuel.

Method	Test	Result	Units
ASTM D4052	API gravity @ 60 °F	59.0	°API
ASTM D5191 (EPA)	Dry vapor pressure equivalent	5.18	Psi
ASTM D2699 (Procedure C)	Research octane number	79.2	
ASTM D2700 (Procedure C)	Motor octane number	72.6	
ASTM D4814 (Avg. Octane)	Octane average	75.9	
ASTM D4176 (Procedure 1)	Appearance	Pass-Clear and Bright	
ASTM D4176 (Procedure 1)	Presence of water or particles	None	
Color	Color	Undyed	
ASTM D5769	Total aromatics	< 10	Vol%
ASTM D86	Initial boiling point	106.7	°F
ASTM D86	10% evaporated	166.4	°F
ASTM D86	50% evaporated	262.0	°F
ASTM D86	90% evaporated	338.4	°F
ASTM D86	Final boiling point	431.7	°F
ASTM D86	E150	5.3	%
ASTM D86	E200	22.6	%
ASTM D86	E300	79.1	%
ASTM D525	Oxidation stability induction period @ 100 °C	> 240	min
ICP	Calcium	< 1	ppm

Table 8: Continued.

Method	Test	Result	Units
ICP	Magnesium	< 1	ppm
ICP	Copper	< 1	ppm
ICP	Phosphorus	< 0.004	g/gal
IP 309	Cold filter plugging point	< –51	°C
IP 309	Cold filter plugging point	< –59.8	°F
ASTM D6304	Water	126	ppm
ASTM D2624	Temperature	76.0	°F
ASTM D2624	Electric conductivity	3	pS/m
ASTM D2500	Cloud point	< –24	°C
ASTM D2500	Cloud point	< –11.2	°F
ASTM D4737	Calculated cetane index	42.3	
ASTM D5972	Freezing point	< –50.0	°C
ASTM D5972	Freezing point	< –58.0	°F
ASTM D5453	Sulfur	6.2	ppm
ASTM D240	Gross heat of combustion-LB	18427	BTU/ lb
ASTM D240	Gross heat of combustion-Gal	113934	BTU/Gal
ASTM D1319	Oxygenate corrected olefins	> 55	Vol%

Table 8: ASTM test result of waste plastic to produce fuel NSR-1.

Method	Test	Result	Units
ASTM D4052	API gravity @ 60 °F	44.8	°API
ASTM D5191 (EPA)	Dry vapor pressure equivalent	0.36	Psi
ASTM D4176 (Procedure 1)	Appearance	Pass-clear & bright	
ASTM D4176 (Procedure 1)	Presence of water or particles	None	
Color	Color	Undyed	
ASTM D5453	Sulfur	3.0	ppm
ASTM D86	Initial boiling point	341.2	°F
ASTM D86	10% recovery	394.8	°F
ASTM D86	50% recovery	476.9	°F
ASTM D86	90% recovery	576.4	°F
ASTM D86	Final boiling point	625.9	°F
ASTM D86	% recovered	98.1	Vol%
ASTM D86	% residue	1.0	Vol%
ASTM D86	% loss	0.9	Vol%
ICP	Calcium	< 1	ppm
ICP	Magnesium	< 1	ppm
ICP	Copper	< 1	ppm
ICP	Phosphorus	< 1	ppm
IP309	Cold filter plugging point	–12	°C
IP309	Cold filter plugging point	10	°F
ASTM D6304	Water	93	ppm
ASTM D2624	Temperature	65.0	°F
ASTM D2624	Electrical conductivity	< 1	pS/m
ASTM D2500	Cloud point	–12	°C
ASTM D2500	Cloud point	10.4	°F
ASTM D4737 (Procedure B)	Calculated cetane index	58.3	
ASTM D240	Gross heat of combustion-LB	19959	BTU/lb
ASTM D240	Gross heat of combustion-Gal	133366	BTU/gal
ASTM D93 (Method A)	Corrected flash point	80	°F
ASTM D482	Ash @ 775 °C	< 0.001	Wt%
ASTM D445	Kinematic viscosity @ 100 °F	2.187	cSt
ASTM D2161	Saybolt universal viscosity @ 100 °F	33.2	SUS
ASTM D130	Copper corrosion @ 122 °F for 3 Hours	1a	
ASTM D5972	Freezing point	–7.1	°C
ASTM D5972	Freezing point	19.2	°F

Table 9: ASTM fuel test result of waste plastic to produce NSR-2 fuel.

Flow Int. (kg)	Flow Exh. (kg)	CO_2(kg)	CO (kg)	HC (g)	NOx (g)	FC (kg)	PM (g)
135.92	132.59	11.65	4.44	3.49	74.54	3.68	0.03098

Table 11: NSR-2 fuel diesel car emission test result.

Method	Test	Result	Unit
ASTM D5599 (EPA)	Methanol	0.00	Vol%
ASTM D5599 (EPA)	Ethanol	0.00	Vol%
ASTM D5599 (EPA)	t-butanol	0.00	Vol%
ASTM D5599 (EPA)	MTBE	0.00	Vol%
ASTM D5599 (EPA)	DIPE	0.00	Vol%
ASTM D5599 (EPA)	ETBE	0.00	Vol%
ASTM D5599 (EPA)	TAME	0.00	Vol%
ASTM D5599 (EPA)	Oxygen	0.00	Vol%
ASTM D3606	Benzene	0.15	Vol%

Table 10: ASTM fuel additives test result of waste plastic to produce NSR-1 fuel.

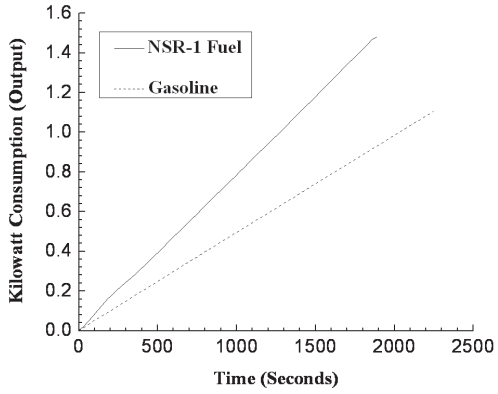

Figure 9: Comparison graph of NSR-1 and gasoline-87 kilowatt output consumption using gasoline generator.

6 Electricity production

Since the claim is that NSR-1 has similar properties as gasoline, the NSR-1 fuel was used in a gasoline-based generator to test its capabilities (Figure 9). Both NSR-1 and gasoline were injected into the gasoline generator one after the other to compare the kilowatt output of the two. The results showed a significantly higher kilowatt output from NSR-1 than gasoline.

7 Conclusion

As mentioned above, the fraction fuels are obtained at a certain temperature; NSR still has the option to produce the fuels under different temperatures and see if better results are obtainable from the previous temperature profile. Through the use of GC/MS and FTIR, we can assure the identification, accuracy of the fuel to meet the standard requirements for commercialization of the NSR fuel.

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