ISBN: 978-0-9886890-1-5

Petroleum Production from Polystyrene Waste Plastic and Standard Polystyrene

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Science and Technology Publishing
www.scitecpub.com

Author's Biography

Moinuddin Sarker, PhD, MCIC, FICER, has been working as the Vice President (VP) of Research and Development and Head of Science Team (VP and CTO); at the Natural State Research (NSR), Inc at Stamford, CT and the inventor of NSR's award winning technology to convert municipal waste plastics into liquid hydrocarbon fuel. He has a M. Sc (1992) and Ph. D. degree in Chemistry from University of Manchester Institute of Science and Technology (UMIST), Manchester, UK (1996). He has more than 22 years of professional research experience in different universities and research organizations all over the world including the US, Canada, the Netherlands, Germany, Taiwan, Bangladesh and the UK. During his research work, he carried out research in four different synchrotron radiation sources around the world: CRCL lab. Daresbury, Warrington, Cheshire, UK (1991-1996), Synchrotron Radiation Research Center (SRRC), Hsinchu, Taiwan, R.O.C (1996-1999), Berlin Electron Storage Ring Company for Synchrotron Radiation (BESSY II) (2000) and Advance Photon Sources (APS), Chicago, USA (2001-2004). He has three patent pending and 75 research publications to his credit in pier reviewed journals and conferences. Dr. Sarker is a distinguished member of 35 professional organizations such as American Association of Naval Engineer (ASNE), Association of Consumer Growth (ACG), Society of Automobile International (SAE), American Chemical Society (ACS), American Physical Society (APS), American Institute of Chemical Engineering (AIChE), International Union of Pure and Applied Chemistry (IUPAC), Canadian Society for Chemistry (CSC), Chemical Institute of Canada (CIC), Canada and many more. Dr. Sarker has been invited speaker various conferences in around the USA and World. Dr. Sarker is the inventor of the technology and product entitles: "Method for converting waste plastics to lower – molecular weight hydrocarbons, particularly hydrocarbon fuel materials and the hydrocarbon material produced thereby" (US and International Patent Pending). In 2010, Dr. Sarker has received, the International Renewable Energy Innovator of the year Awards 2010 at Washington DC and presented by Association of Energy Engineers (AEE), USA. E-mail address: msarker@naturalstateresearch.com

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Science and Technology Publishing Inc
Science and Technology
Available online www.scitecpub.com

ISBN: 978-0-9886890-1-5, PP: 01- 40, Dated: 02/10/2013

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Table of Contents **Page #**

1. Introduction

The pyrolysis and combustion behavior of polystyrene (PS) is of technological interest since it is one of the omnipresent commercial plastics in insulation, pipes, foams, containers, appliances, rubber products, automotive instruments, and panels. Thus, the products of its combustion are of interest to both fire technology and waste-to-energy incineration. PS is the third most prominent polymer (plastic); its annual production rate currently exceeds 1 100 000 t in the United States alone. As most applications of PS are in disposable goods (packaging, cups, plastic cutlery, etc.) a large fraction of the polymer produced ends in the municipal waste stream (MSW). With landfill space dwindling, burning this non-biodegradable material in waste-to-energy plants is an attractive option. Thermal destruction of MSW offers several advantages as it provides maximum volume reduction, permanent disposal, and detoxification. However, to avoid exposure of populations to health-hazardous emissions from such facilities, combustion conditions must be carefully selected. Correlations between emissions and operating parameters, such as furnace temperature, residence time, fuel loading, excess air, and combustion staging, must be investigated. Emissions of special concern are CO, NOx, particulates, and polycyclic aromatic hydrocarbons (PAH), which are often mutagenic. Thermal degradation (pyrolysis) of PS ([-CH2CH- (C_6H_5)-] n) occurs first by chain scission and then by random scission [1]. Heating PS above 350 °C releases the styrene monomer but also releases the dimer and trimer. Such de-polymerization may produce up to 80 wt % monomer, depending on the heating rate and temperature [2, 3]. Plastic waste such as polystyrene (PS) disposal has been recognized as a worldwide environmental problem. Though various kinds of techniques have been proposed for the conversion of waste PS plastic, it is generally accepted that recycling material is not a long-term solution to the present problem (4). Due to their chemical stability and non-biodegradability, waste PS plastic is being mainly disposed by incineration, which will release a lot of toxic byproducts.

Thermal or catalytically degradation of waste PS plastic into fuel oils has been investigated in recent years (4-7). Unfortunately, this technique needs high temperature and appropriate catalysts to produce hydrocarbons with narrow distribution, which cause high costs (7). Consequently, new technologies have to be developed for the degradation of plastic waste [8]. Petrochemical based plastics, produced annually on the 100 million ton scale, pervade modern society as a result of their versatile and highly desirable properties. However, once disposed of, many of these plastics pose major waste management problems due to their recalcitrance. In the U.S. alone, over 3 million tons of polystyrene are produced annually, 2.3 million tons of which end up in a landfill [9]. Furthermore only 1% of post-consumer polystyrene waste was recycled in the U.S. in 2000. The poor rate of polystyrene recycling is due to direct competition with virgin plastic on a cost and quality basis [10]. Consequently, there is little or no market for recycled polystyrene [11]. As an alternative to polymer recycling, polystyrene can be burned to generate heat and energy [12] or converted back to its monomer components for use as a liquid fuel [12-14]. A number of techniques for converting plastic back to its monomer components have been developed, one of which, pyrolysis, involves thermal decomposition in the absence of air to produce pyrolysis oils or gases [12]. The physical and mechanical properties of these polymers, such as stiffness, brittleness, and melting point are dramatically affected by the monomer composition of the polymer [15]. While many studies have focused on the conversion of sugars and fatty

acids to PHA, a limited number of studies have investigated the conversion of waste materials to PHA [16-18]. However, to the best of our knowledge, this is the first study to investigate the conversion of a petrochemical plastic to a biodegradable plastic. Polystyrene was identified as a potentially attractive starting material for PHA production due to its widespread use and the waste management issues associated with it [19].

Keywords: waste plastic, PS, fuel, hydrocarbon, polystyrene, thermal, standard polystyrene, renewable, GC/MS

Abbreviation: ICP (Induced Couple Plasma), GC/MS (Gas Chromatography and Mass Spectrometer), TGA (Thermogravimetric Analyzer), EA-2400 (Elemental Analyzer 2400), ASTM (American Standard Testing Method), CHN mode (Carbon, Hydrogen and Nitrogen mode), ppm (parts per million), ppb (parts per billion), Btu (British thermal unit), API (American petroleum institution), FT-IR (Furrier Transform Infra-red Spectrometer).

2. Material and Method

2.1. Materials

Polystyrene waste plastics were collected from local restaurant and coffee shop and color was transparent. Collected polystyrene waste plastic comes with food particle and coffee. Food particle, coffee was stick with food container and coffee mug. Polystyrene waste plastic was clean by liquid soap and water into laboratory sink system. During washing period generated waste water kept into separate container for waste water treatment. Wash out polystyrene waste plastic dry into laboratory room air fan and polystyrene waste plastic cut into 4-5 inch slice and transfer into grinder machine for grinding purpose and size was 2-3 mm. On the other hand polystyrene standard plastic was collected from Sigma-Aldrich Company, catalog number 331651-500g, lot number MKBF9393V, average Mw 35,000 and polystyrene standard plastic was transparent small pellet size. Polystyrene standard plastic was fully analytical grade and purity was 99.99%.

2.2. Pre- analysis

Before start experiments for polystyrene waste plastic and polystyrene plastics to fuel production raw materials was per analyzed by ICP, TGA, EA-2400 (CHN), FT-IR and GC/MS. ICP analysis was perform by 3rd party laboratory Taxes oil tech laboratory, Huston, Taxes, USA. ICP per-analysis test performed ASTM test method followed ASTM D1976 and determine raw waste and standard plastic trace metal content which are using as an additives. TGA analysis was performed for raw polystyrene waste and polystyrene standard plastic onset temperature, inflection point temperature and how much percentage conversion and how much percentage leftover. By EA-2400 (CHN mode) analysis was perform for raw materials polystyrene waste and polystyrene standard plastic Carbon, Hydrogen and Nitrogen percentage determination. FT-IR (Spectrum-100) was use for raw materials compounds functional group and bend energy determination. By GC/MS per-analysis with pyroprobe for raw samples compounds structures, compounds formula, molecular weight and compound probability percentage determination. Above all per-analysis results describe in pre-analysis discussion section.

2.3. Process Description

Thermal degradation process was apply with polystyrene waste plastic and polystyrene standard plastic and temperature range 100- 400 ºC for both experiment. 1st experiment was polystyrene waste plastic to fuel and 2nd experiment was polystyrene standard plastic to fuel production. Grounded polystyrene waste plastic transfer into reactor chamber by manually then reactor chamber placed into reactor inside. 1st experimental purpose initial grounded polystyrene waste plastic was 1000 g or 1kg. Without any kind of catalyst and without vacuumed system experiment was placed into under laboratory fume hood. Rector cover and reactor body part was tightening properly percent gas loss. For visual understanding figure 1 showed reactor setup and reset of all devices setup accordingly. **Figure 1** showed number wise such as 1= Reactor Chamber, 2= Coil and Insulator, 3= Condenser unit, 4=Temperature controller & display, 5 = Electrical outlet, 6= 2'' ht. & 1'' dia. for gas pressure monitor, 7 = 2'' ht. & 1'' dia. for Glass monitor, 8= 2'' ht. & 1'' dia. for inside temperature monitor, 9 = 2'' ht. & 1'' dia. for Thermocouple, 10=2'' ht. & 1'' dia. for Glass monitor, 11=Condenser Inner dia. 2'', 12=Collection Tank, 13= Light Gas Collection Neck, 14= Fuel Product, 15= RCI Purification System, 16 =Gas Cleaning Device, 17= Light Gas Collection Teflon Bag, 18=Final Fuel Collection tank. Reactor run by electricity and reactor temperature rang 25-500 ºC. Polystyrene waste plastic to fuel production temperature range was 100 - 400 ºC. In this case TGA per-analysis data was showed less temperature from 400ºC experimental setup temperature. After finish setup all device with reactor sample was start too heated up from 100 ºC to up to 400 ºC until finished the experiment. Polystyrene waste plastic has benzene derivatives and this plastic melting temperature (240 ºC) high from other plastics for that reason its need little higher temperature to breakdown and its need take time to finish the experiment. Polystyrene waste plastic breakdown long chain compounds to short chain compounds step by step when temperature are increased gradually. Polystyrene waste plastic to fuel production process was notice that initial time huge amount of smoke are generating and it's was not condense. When temperature was increased from 100 ºC to 280 ºC then smoke generation was stop. Melted polystyrene waste plastic turned into liquid slurry and turned into vapor when temperature crossed the melting stage and temperature range was up to 300 ºC. Vapor passed through condensation unit and produced liquid fuel, production was continued and temperature profile was increased slowly up to 400 ºC until finish the experiment. Sometimes temperature need to increased or decreased for better quality fuel collection. Polystyrene waste plastic to fuel production period some light gas also generated and light gas was collected from fuel collection tank. Light gas was cleaned by alkali wash such as sodium hydroxide, sodium bicarbonate solution to removed impurity then light gas transfer into Teflon bag by using small pump. Collected liquid fuel was clean by RCI fuel purification technology provided RCI fuel purifier with centrifugal force and micron filter. Filtered liquid fuel was collected into separate container or tank. During liquid fuel filtration period some fuel sediment and watery substance collected those substance can be reuse with initial raw materials. Polystyrene waste plastic to fuel production mass balance calculation showed **Table 1**, 1000 gm polystyrene waste plastic to fuel is 802.9 g, sample as a light is gas 41.2 g and solid black residue 155.9 g. In the experiment fuel production yield percentage is 80.29%, light gas yield percentage is 4.12 and left over residue percentage is 15.59%. On the other experiment polystyrene standard plastic to fuel production was same as polystyrene waste plastic to fuel process. Temperature

profile and experimental setup and experimental running condition were same as PS waste to fuel production. In comparative study every parameter should be same for both experiments. Polystyrene standard plastic to fuel production initial sample was 1000 gm or 1kg by weight. 1000 gm polystyrene standard plastic to fuel production is 793.4 g, sample as light gas is 39.4 g and leftover solid black residue is 167.2 g. Polystyrene standard plastic to fuel production yield percentage is 79.34%, light gas percentage is 3.94% and leftover solid black residue percentage is 16.72%. Polystyrene waste plastic to fuel production input electricity was 6.66 kWh for 802.9 g fuel (985 ml), and polystyrene standard plastic to fuel production input electricity was 6.65 kWh for 793.4 g fuel (980 ml). Both experiments running time was same and experiment monitor was same way.

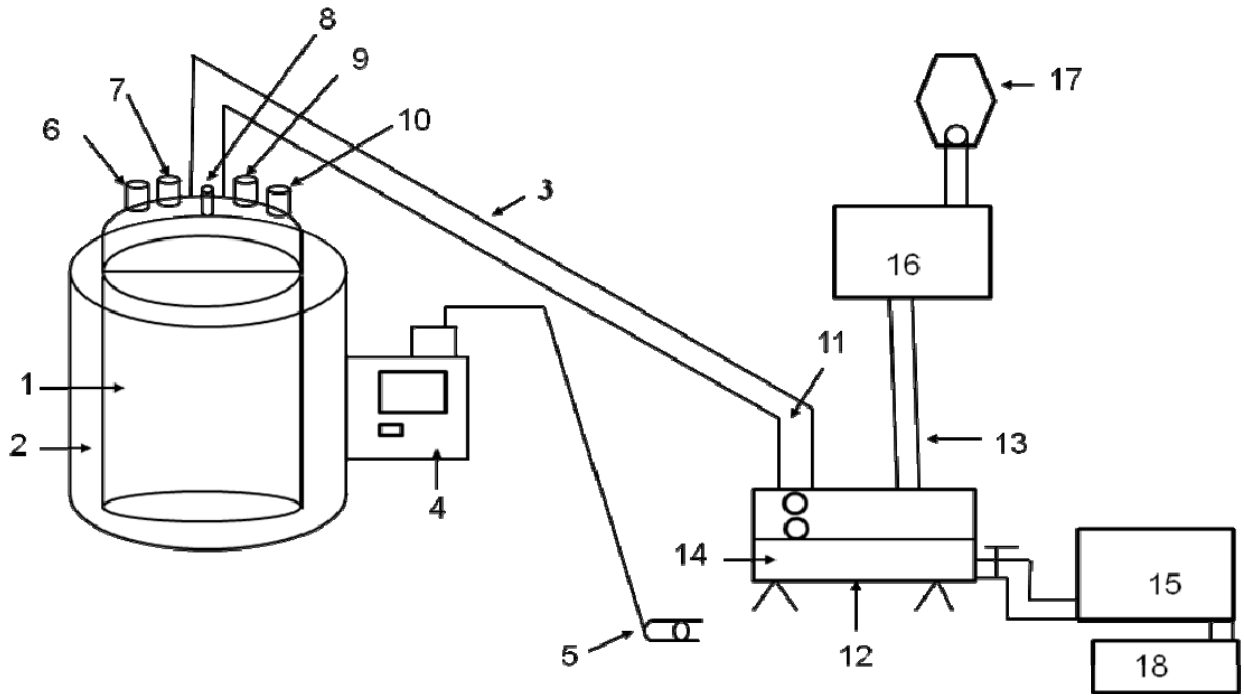

Figure 1: Polystyrene waste plastic and standard polystyrene plastic to fuel production process

Table 1: Polystyrene waste plastic and standard polystyrene plastic to liquid fuel production yield percentage

Name of Plastic	Sample Weight (g)	Liquid Fuel (g)	Liquid Fuel (ml)	Sample as Light Gas (g)	Residue Weight (g)	Total kWh for Experiment	Liquid Fuel Yield %	Light Gas Yield %	Solid Residue Yield %
Standard PS	1000 gm	793.4	980	39.4	167.2	6.65	79.34	3.94	16.72
PS waste Plastic	1000 gm	802.9	985	41.2	155.9	6.66	80.29	4.12	15.59

3. Result and Discussion

3.1. Analysis Procedure

ICP test was perform by 3rd party laboratory Taxes Oil Tech Laboratory as followed by ASTM test method, and ASTM test method name is ASTM D1976 for raw polystyrene waste plastic and polystyrene standard plastic trace metal determination. Same ASTM D1976 test was performing with polystyrene waste plastic to left over residue and polystyrene standard plastic to residue. TGA analysis was only for raw materials analysis and TGA temperature was 50 ºC to 800 ºC and temperature ramping rate was 20 ºC/ min, carrier gas was Helium. FT-IR was use for raw materials and liquid fuel analysis purpose. Raw sample analysis purpose ATR diamond plate was use and liquid sample analysis purpose Sodium Chloride cell was use. FT-IR (spectrum 100) analysis program was 4000-400 cm^{-1}, resolution 4 and scene number 32. EA-2400 (CHN) was for raw materials and liquid fuels analysis purpose and ASTM test followed ASTM D5291.a for raw materials and ASTM D5291 was use for liquid fuels analysis purpose. EA-2400 (CHN mode) carrier gas was Helium, Oxygen and Nitrogen and combustion temperature was 950 ºC. Gas Chromatography and Mass Spectrometer (GC/MS) was use for raw materials and liquid fuels analysis purpose. Carrier gas was use Helium. GC/MS with pyroprobe was use for raw materials analysis and GC/MS and auto sampler was use for liquid sample analysis. GC/MS analysis was performed on a Perkin-Elmer clarus 500 with autosampler system. Elite-5 capillary 30 meter length GC column was use and carrier gas was use Helium. Auto sampler method used for GC, syringe capacity 5.0 µL, injection volume 0.5 µL and sample injection speed normal. Sample split flow 101.0 mL/min and initial set point 1.00ML/MIN and sample injector port temperature 280 ºC. GC program setup for sample analysis initial temperature 40 ºC and initial temperature hold at 1 minute and equilibration time 0.5 min, temperature ramping 10 ºC/ minute to 325 ºC and also hold 15 minute for 325 ºC. For mass detection MS program setup type ms scan ion mode El+, data format centroid, start mass scan 35.00 to end mass scan 528.00 and mass scan time 0.25 sec, inter scan time 0.15 second.

3.2. Pre-analysis Discussion

Table 2: Polystyrene raw waste plastic and standard polystyrene plastic metal content analysis by ICP

Test Method Name	Trace Metal Name	Raw PS Waste Plastic (ppm)	Raw PS Standard Plastic (ppb)
ASTM D1976	Silver	<1.0	<1.0
	Aluminum	59.8	<1.0
	Boron	2.8	<1.0
	Barium	2.7	64.7
	Calcium	33420	<50.0
	Chromium	<1.0	30.9
	Copper	<1.0	28.8
	Iron	47.2	<1.0
	Potassium	28.4	<50.0
	Lithium	16.8	<1.0
	Magnesium	842.7	<1.0
	Molybdenum	<1.0	39.3
	Sodium	118.8	9652.0
	Nickel	<1.0	40.3
	Phosphorus	<1.0	<1.0

Lead	<1.0	32.6
Antimony	<1.0	3.2
Silicon	17.2	<1.0
Tin	<1.0	<1.0
Strontium		14.0
Titanium	60.8	<1.0
Thallium		<1.0
Vanadium	<1.0	<1.0
Zinc	89.9	193.8

Trace metals was detection from raw polystyrene waste plastic **(Table2)** by using ICP and ASTM test method followed ASTM D1976. General trace metals was detected from ICP such as Silver: <1.0 ppm, Aluminum: 59.8 ppm, Boron: 2.8 ppm, Barium: 2.7 ppm, Calcium: 33420 ppm, Chromium: <1.0 ppm, Copper: <1.0 ppm, Iron: 47.2 ppm, Potassium: 28.4 ppm, Lithium: 16.8 ppm, Magnesium: 842.7 ppm, Molybdenum: <1.0 ppm, Sodium: 118.8 ppm, Nickel: <1.0 ppm, Phosphorus: <1.0 ppm, Lead: <1.0 ppm, Antimony: <1.0 ppm, Silicon: 17.2 ppm, Tin: <1.0 ppm, Titanium : 60.8 ppm, Vanadium: <1.0 ppm, Zinc: 89.9 ppm. On the other hand Trace metal was detection from raw polystyrene standard plastic by using ICP and ASTM test method followed ASTM D1976. General trace metals was detected from ICP such as Silver: <1.0 ppb, Aluminum: <1.0 ppb, Boron: <1.0 ppb, Barium: 64.7 ppb, Calcium: <50.0 ppb, Chromium: 30.9 ppb, Copper: 28.8 ppb, Iron: <1.0 ppb, Potassium : <50.0 ppb, Lithium: <1.0 ppb, Magnesium: <1.0 ppb, Molybdenum: 39.3 ppb, Sodium: 9652.0 ppb, Nickel: 40.3 ppb, Phosphorus: <1.0 ppb, Lead: 32.6 ppb, Antimony: 3.2 ppb, Silicon: <1.0 ppb, Tin: <1.0 ppb, Strontium: 14.0 ppb, Titanium: <1.0 ppb, Thallium: <1.0 ppb, Vanadium: <1.0 ppb, Zinc: 193.8 ppb. Polystyrene waste plastic has higher percentage of trace metal then polystyrene standard plastic. Polystyrene standard plastic was 99.99% pure and it was analytical grade. Polystyrene waste plastic was made from pure polystyrene pellet and mixing with different types of additives or dye. All above metals content determine from raw materials as ppm and ppb level because for commercial use plastic need to be add more additives for plastic hardness, softness and different kind of shape. But standard plastic is made for analysis for that reason standard polystyrene plastic has less amount of metal content. Plastic production period different types of chemical, dye and additives are using based on their requirement. Above all trace metal are acting as a catalyst because catalyst are made by metal. In the present technology polystyrene waste plastic to fuel production doesn't need any kind of catalyst because catalyst already present in the initial raw materials which was detected by ICP. Extra catalyst adding also cost involve from polystyrene waste plastic to fuel production. This technology is patent pending technology and it can convert all polystyrene waste plastic into fuel as well polystyrene standard plastic into fuel.

Plastics are manufactured by polymerization, polycondensation, or polyaddition reactions where monomeric molecules are joined sequentially under controlled conditions to produce high-molecular-weight polymers whose basic properties are defined by their composition, molecular weight distribution, and their degree of branching or cross-linking. To control the polymerization process, a broad range of structurally specific proprietary chemical compounds is used for polymerization initiation, breaking, and cross-linking reactions (peroxides, Ziegler-Natta, and

metallocene catalysts). The polymerized materials are admixed with proprietary antioxidants (sterically hindered phenols, organophosphites),UV and light stability improvers (hindered amines and piperidyl esters), antistatic agents (ethoxylated amines), impact modifiers (methacrylatebutadiene-styrene compounds), heat stabilizers (methyl tin mercaptides), lubricants (esters), biostabilizers (arsine, thiazoline, and phenol compounds), and plasticizers used to modify the plasticity, softness, and pliability of plastics (phthalates and esters). World production of plastic additives is on the order of 18 billion pounds per year with plasticizers representing a 60% of the total amount [20, 21].

Table 3: TGA analysis result of polystyrene raw waste plastic and polystyrene standard plastic

Name of Sample	Sample Weight (g)	Onset Temperature (ºC)	Inflection Temperature (ºC)	Leftover Residue (g)	Conversion Rate %	Leftover Residue %
Waste Polystyrene	2.575	326.62	364.88	0.515	80%	20%
Standard Polystyrene	3.029	413.45	394.82	0.546	82%	18%

A raw material was analysis by TGA and analysis results showed in **Table 3**. Polystyrene waste plastic onset temperature was 326.62 ºC, inflection temperature was 364.88 ºC and sample was use for TGA 2.575 g. polystyrene waste plastic conversion rate indicate that 80% and left over residue was 20% by TGA onset temperature determination. On the other hand polystyrene standard plastic TGA onset temperature 413.45 ºC, inflection temperature 394.82 ºC and sample was use for TGA analysis 3.029 g. Polystyrene standard plastic conversion rate was 82% and leftover residue was 18%. Based on TGA analysis results experimental temperature profile was determine.

Table 4: Polystyrene raw waste and standard polystyrene plastic C, H and N Percentage by EA-2400 (CHN mode)

Name of Test Method	Name of Plastics	Carbon %	Hydrogen %	Nitrogen %
ASTM D5291.a	Waste Raw PS Plastics	78.60	7.21	<0.30
	Standard Raw PS Plastics	91.25	8.45	<0.30

Polystyrene waste plastic and standard plastic was pre-analyzed by EA-2400 (CHN mode) for carbon, hydrogen and nitrogen percentage determination in raw materials for liquefaction process. ASTM test method ASTM D5291.a was followed and result showed into **Table 4**. Polystyrene waste plastic EA data showed carbon percentage is 78.60%, hydrogen percentage is 7.21% and nitrogen percentage is <0.30%. In polystyrene waste plastic carbon and hydrogen total percentage showed 85.81%, rest of 13.89% did not detect by EA-2400 analysis result because in EA-2400 was only CHN mode. In polystyrene waste plastic 13.89% was different kind of dye or additives which was use for during plastic manufacturing period. Polystyrene standard plastic also analyzed by EA-2400 and same method was followed. In analysis table showed for polystyrene standard plastic carbon percentage 91.25%, hydrogen percentage is 8.45% and nitrogen percentage is <0.30%. Standard plastic carbon and hydrogen total percentage is 99.7%, nitrogen percentage is <0.30%. Polystyrene standard plastic is analytical grade and its use for only analysis purpose.

Polystyrene plastic made for consumer daily use and it's made with different color additive or dye for different shape for that reason polystyrene waste plastic has high percentage of additives and low percentage carbon.

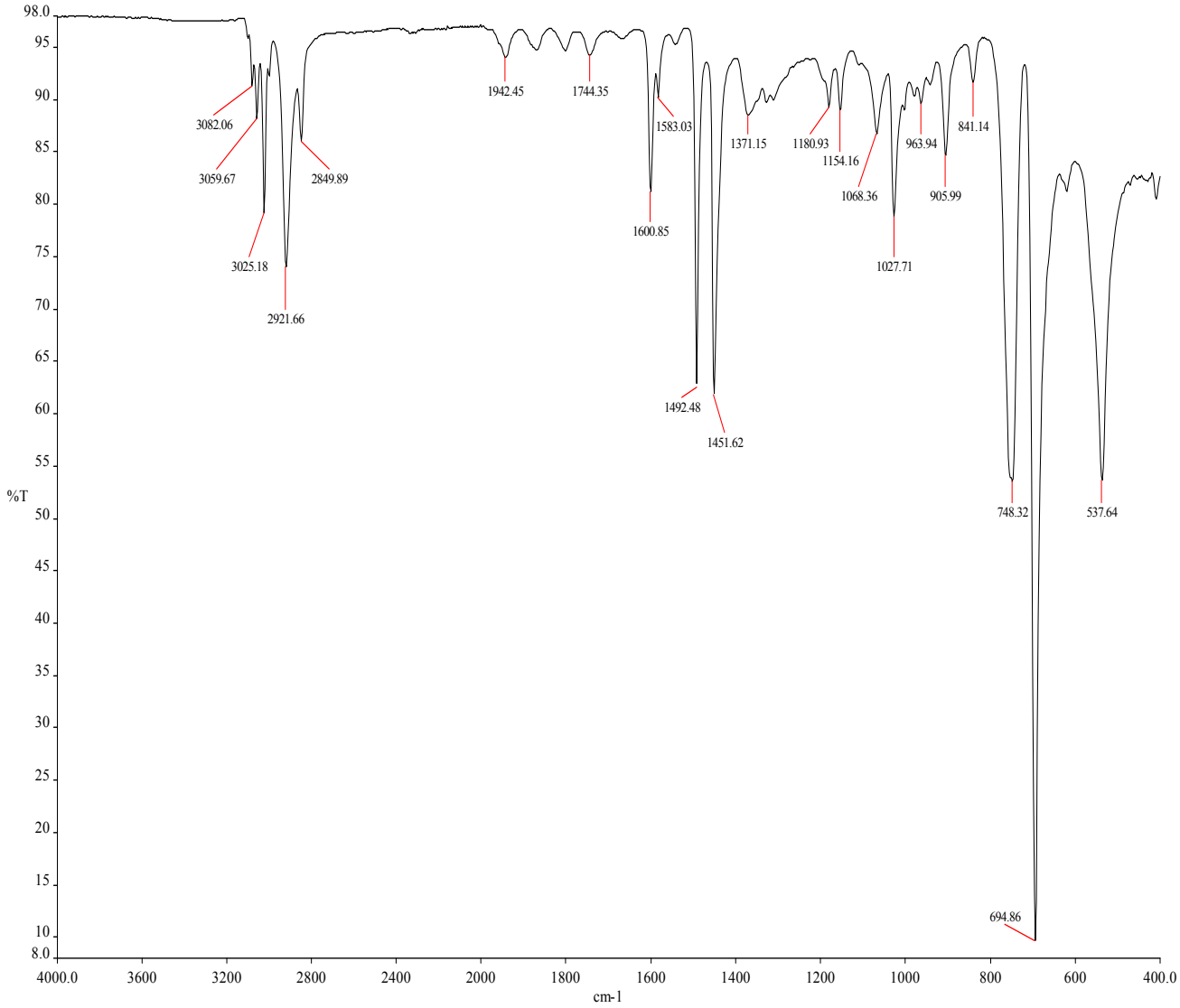

Figure 2: FT-IR spectrum of Polystyrene raw waste plastic

Table 5: Polystyrene raw waste plastic functional group name from FT-IR

Number of Peak	Wave Bend Number (cm^{-1})	Functional Group Name	Number of Peak	Wave Band Number (cm^{-1})	Functional Group Name
1	3082.06	H Bonded NH	12	1371.15	CH_3
2	3059.67	=C-H	13	1180.93	
3	3025.18	Chelate Compounds	14	1154.16	
4	2921.66	C-CH_3	15	1068.36	
5	2849.89	CH_2	16	1027.71	Acetates
6	1942.45		17	963.94	-CH=CH-(trans)

7	1744.35	Non-Conjugated	18	905.99	-CH=CH_2
8	1600.85	Conjugated	19	841.14	
9	1583.03		20	748.32	-CH=CH-(cis)
10	1492.48		21	694.86	-CH=CH-(cis)
11	1451.62	CH_3	22	537.64	

Perkin Elmer FT-IR (Spectrum 100) analyses of polystyrene (PS) raw waste plastic (**Figure 2 and Table 5**) in accordance with the different wave number different types of functional groups are appeared. In according to wave number on the spectrum such as wave number 3082.06 cm^{-1}, functional group is H Bonded NH, wave number 3059.67 cm^{-1} , functional group is Free =C-H, wave number 3025.18 cm^{-1},functional group is Chelate Compounds, wave number 2921.66 cm^{-1}, functional group is C-CH_3, wave number 2849.89 cm^{-1} functional group is CH_2, wave number 1744.35 cm^{-1}, functional group is Non-Conjugated, wave number 1600.85 cm^{-1} functional group is Conjugated, wave number 1451.62 cm^{-1} and 1371.15 cm^{-1} functional group is CH_2 / CH_3 , wave number 1027.71 cm^{-1}, functional group is Acetates, wave number 963.94 cm^{-1}, functional group is -CH=CH-(trans), wave number 905.99 cm^{-1} , functional group is -CH=CH_2 etc. In the end of the spectrum phase wave number 748.32 cm^{-1} and , 694.86 cm^{-1}, functional group is -CH=CH-(cis) as well. Some of functional groups energy values are calculated, using formula is E=hυ, Where h=Planks Constant, h =$6.626x10^{-34}$ J, υ= Frequency in Hertz (sec^{-1}), Where υ=c/λ, c=Speed of light, where, c=$3x10^{10}$ m/s, W=1/λ, where λ is wave length and W is wave number in cm^{-1}. Therefore the equation E=hυ, can substitute by the following equation, E=hcW. According to their wave number such as for 2921.66 (cm^{-1}) calculated energy, E=$5.81x10^{-20}$ J. Similarly, wave number 1744.35 (cm^{-1}) energy, E =$3.47x10^{-20}$ J, wave number 1371.15 (cm^{-1}) energy, E = $2.73x10^{-20}$ J and eventually wave number 905.99 (cm^{-1}) functional group is $1.97x10^{-20}$ J respectively.

Table 6: Polystyrene raw standard plastic functional group name from FT-IR

Number of Peak	Wave Bend Number (cm^{-1})	Functional Group Name	Number of Peak	Wave Band Number (cm^{-1})	Functional Group Name
1	3024.94	=C-H	6	1027.37	Acetates
2	2919.42	C-CH_3	7	906.16	-CH=CH_2
3	1600.54	Conjugated	8	750.59	-CH=CH-(cis)
4	1492.21		9	695.24	-CH=CH-(cis)
5	1451.06	CH_3	10	537.19	

From FT-IR analyses of polystyrene (PS) raw standard plastic (**Figure 3 and Table 6**) in accordance with the different wave number different types of functional groups are appeared. In according to wave number on the spectrum such as wave number 3024.94 cm^{-1}, functional group is H Bonded NH, wave number 2919.42 cm^{-1} , functional group is Free =C-H, wave number 1600.54 cm^{-1} functional group is Conjugated, wave number 1451.06 cm^{-1} functional group is CH_2 / CH_3 , wave number 1027.37 cm^{-1}, functional group is Acetates, wave number 906.16 cm^{-1}, functional group is -CH=CH_2, etc. In the end of the spectrum phase wave number 750.59 cm^{-1} and , 695.24 cm^{-1}, functional group is -CH=CH-(cis) as well. Some of functional groups energy values are calculated, using formula is E=hυ, Where h=Planks Constant, h =$6.626x10^{-34}$ J, υ= Frequency in Hertz (sec^{-1}), Where υ=c/λ, c=Speed of light,

where, c=3x10^{10} m/s, W=1/λ, where λ is wave length and W is wave number in cm^{-1}. Therefore the equation E=hυ, can substitute by the following equation, E=hcW. According to their wave number such as for 2919.42 (cm^{-1}) calculated energy, E=5.81x10^{-20} J. Similarly, wave number 1600.54 (cm^{-1}) energy, E =3.17x10^{-20} J, wave number 1451.06 (cm^{-1}) energy, E = 2.88x10^{-20} J and eventually wave number 906.16 (cm^{-1}) functional group is 1.80x10^{-20} J respectively.

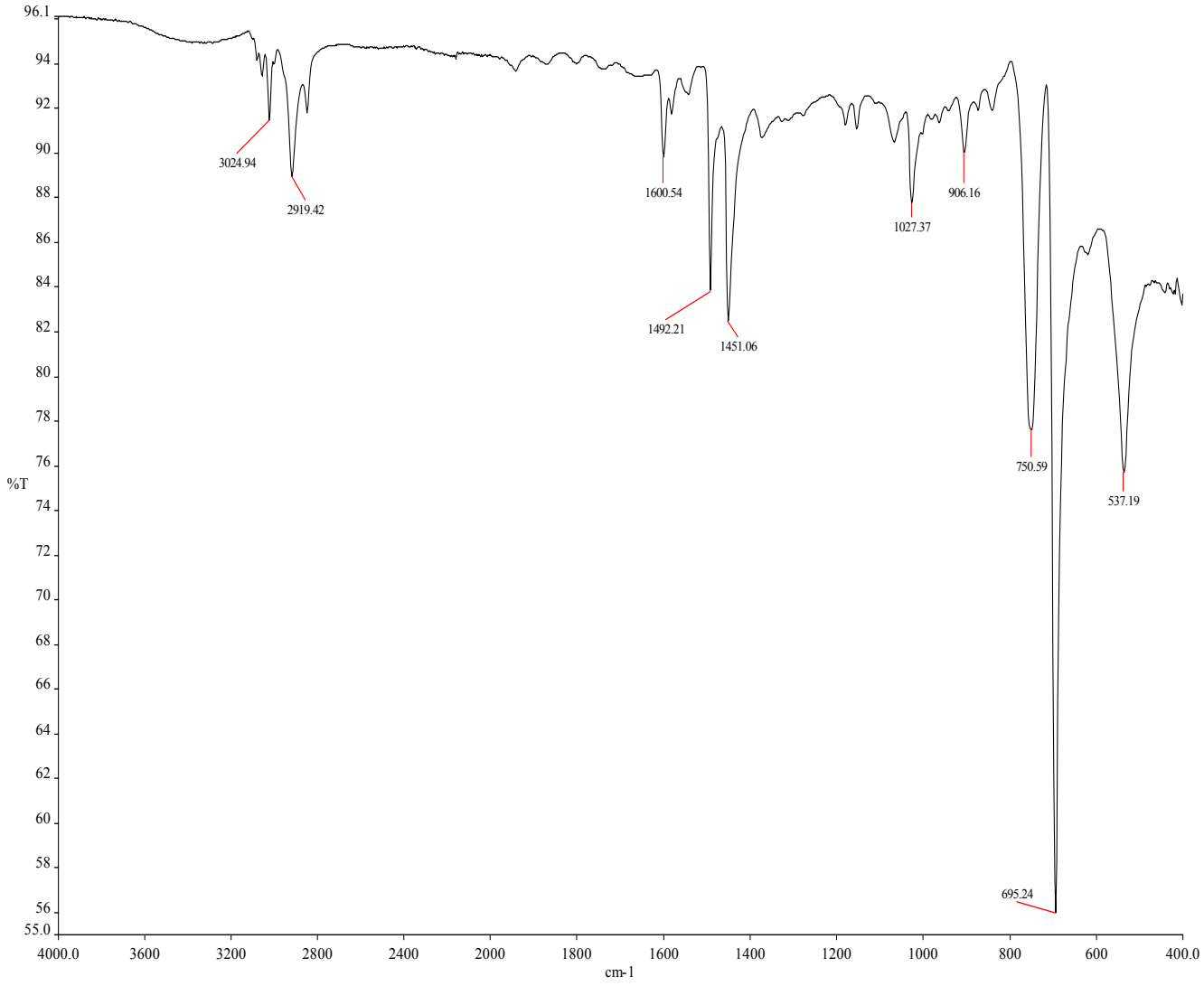

Figure 3: FT-IR spectrum of polystyrene raw standard plastic

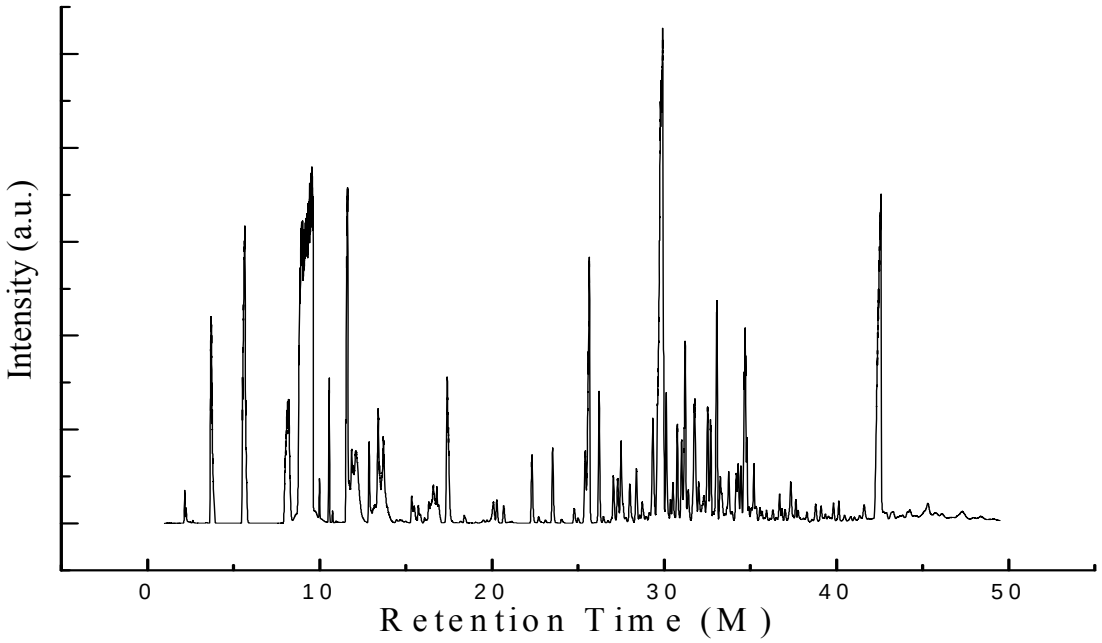

Figure 4: GC/MS chromatogram of polystyrene raw waste plastic

Table 7: Polystyrene raw waste plastic GC/MS chromatogram compound list

Peak Number	Retention Time (min)	Trace Mass (m/z)	Compound Name	Compound Formula	Molecular Weight	Probability %	NIST Library Number
1	2.17	41	Cyclopropane	C_3H_6	42	77.7	18854
2	2.25	39	Methylenecyclopropane	C_4H_6	54	47.5	161511
3	2.64	66	1,3-Cyclopentadiene	C_5H_6	66	48.0	196
4	3.65	78	Benzene	C_6H_6	78	61.2	291514
5	3.70	51	1,5-Hexadiyne	C_6H_6	78	66.4	113116
6	5.52	92	Toluene	C_7H_8	92	64.8	291301
7	5.65	89	1,5-Heptadien-3-yne	C_7H_8	92	63.0	142710
8	7.99	91	Ethylbenzene	C_8H_{10}	106	58.4	158804
9	8.89	52	Pyridine, 3-ethenyl-	C_7H_7N	105	13.1	1339
10	9.01	76	Phenylethyne	C_8H_6	102	33.0	118527
11	9.31	49	3,5-Octadiyne	C_8H_{10}	106	7.83	231838
12	9.40	49	Phenylethyne	C_8H_6	102	24.8	118527
13	9.62	49	Benzene, 1-azido-2-methyl-	$C_7H_7N_3$	133	8.92	39080
14	9.99	105	Benzene, 1,2,4-trimethyl-	C_9H_{12}	120	23.8	114280
15	10.55	117	Benzene, 2-propenyl-	C_9H_{10}	118	16.0	114744
16	10.75	91	Benzene, propyl-	C_9H_{12}	120	67.3	113930
17	11.57	117	α-Methylstyrene	C_9H_{10}	118	21.7	30236
18	11.61	117	Benzene, cyclopropyl	C_9H_{10}	118	16.4	113961
19	12.87	117	Benzene, 2-propenyl-	C_9H_{10}	118	15.6	114744
20	13.35	116	Indene	C_9H_8	116	31.9	228349

21	13.40	116	1-Propyne, 3-phenyl-	C_9H_8	116	26.3	164327
22	13.47	115	Benzene, 1-propynyl-	C_9H_8	116	41.7	113196
23	13.69	116	1H-Indene, 1-chloro-2,3-dihydro-	C_9H_9Cl	152	22.6	4882
24			1-Propyne, 3-phenyl-	C_9H_8	116	8.86	164327
25	15.35	130	Benzene, 1,3-diethenyl-	$C_{10}H_{10}$	130	19.3	291351
26	15.49	130	Benzene, 1,3-diethenyl-	$C_{10}H_{10}$	130	24.3	291351
27	15.74	130	Naphthalene, 1,2-dihydro-	$C_{10}H_{10}$	130	13.7	114028
28	15.83	130	Benzene, 1,3-diethenyl-	$C_{10}H_{10}$	130	17.6	2811
29	16.34	130	1H-Indene, 3-methyl-	$C_{10}H_{10}$	130	13.6	214914
30	16.60	128	Naphthalene	$C_{10}H_8$	128	33.3	291095
31	16.80	130	Naphthalene, 1,2-dihydro-	$C_{10}H_{10}$	130	28.7	114028
32	17.40	127	Naphthalene	$C_{10}H_8$	128	47.4	114935
33	18.20	128	1H-Indene, 1,1-dimethyl-	$C_{11}H_{12}$	144	9.85	4008
34	18.39	115	1-Phenylbicyclo[2.1.1]hexane	$C_{12}H_{14}$	158	22.6	210402
35	19.07	129	1H-Cyclopropa[b]naphthalene, 1a,2,7,7a-tetrahydro-	$C_{11}H_{12}$	144	13.3	26743
36	20.09	142	1,4-Methanonaphthalene, 1,4-dihydro-	$C_{11}H_{10}$	142	22.7	191172
37	20.28	142	Benzocycloheptatriene	$C_{11}H_{10}$	142	50.4	151559
38	20.69	142	Naphthalene, 1-methyl-	$C_{11}H_{10}$	142	23.2	21183
39	22.30	154	Biphenyl	$C_{12}H_{10}$	154	76.3	114218
40	22.71	168	Naphthalene, 1-(2-propenyl)-	$C_{13}H_{12}$	168	25.7	114214
41	23.52	167	Diphenylmethane	$C_{13}H_{12}$	168	31.5	114004
42	24.05	152	Acenaphthylene	$C_{12}H_8$	152	52.9	121335
43	24.78	167	1,1'-Biphenyl, 3-methyl-	$C_{13}H_{12}$	168	34.1	118476
44	25.01	168	1,1'-Biphenyl, 4-methyl-	$C_{13}H_{12}$	168	37.6	113287
45	25.43	180	(E)-Stilbene	$C_{14}H_{12}$	180	17.4	221117
46	26.60	91	Benzene, 1,1'-(1,2-ethanediyl)bis-	$C_{14}H_{14}$	182	88.2	113286
47	25.64	182	1,2-Diphenylethylene	$C_{14}H_{12}$	180	9.72	7372
48	26.23	105	Benzene, 1,1'-(1-methyl-1,2-ethanediyl)bis-	$C_{15}H_{16}$	196	16.1	34633
49	26.48	179	α-Methylstilbene	$C_{15}H_{14}$	194	23.1	243255
50	27.05	166	Fluorene	$C_{13}H_{10}$	166	73.4	34972
51	27.30	103	1,2-Diphenylcyclopropane	$C_{15}H_{14}$	194	27.7	135351
52	27.50	180	1,1'-Biphenyl, 4-ethenyl-	$C_{14}H_{12}$	180	22.8	313329
53	28.00	180	1,1'-Biphenyl, 4-ethenyl-	$C_{14}H_{12}$	180	40.5	313329
54	28.39	92	Benzene, 1,1'-(1,3-propanediyl)bis-	$C_{15}H_{16}$	196	88.2	34894
55	28.74	194	Benzene, 1,1'-cyclopropylidenebis-	$C_{15}H_{14}$	194	27.8	194336
56	29.34	180	Anthracene, 9,10-dihydro-	$C_{14}H_{12}$	180	31.5	113290
57	29.78	178	Naphthalene, 1,2,3,4-tetrahydro-1-phenyl-	$C_{16}H_{16}$	208	51.1	9509
58	29.90	104	Benzene, 1,1'-(1-butenylidene)bis-	$C_{16}H_{16}$	208	30.2	156823
59	30.12	194	1,2-Diphenylcyclopropane	$C_{15}H_{14}$	194	24.1	135351
60	30.38	117	Benzene, 1,1'-(1-butene-1,4-diyl)bis-, (Z)-	$C_{16}H_{16}$	208	64.0	63166
61	30.51	206	Benzene, 1,1'-(1,3-butadienylidene)bis-	$C_{16}H_{14}$	206	18.3	150533
62	30.77	192	Phenanthrene, 1-methyl-	$C_{15}H_{12}$	192	19.1	113354

63	31.02	219	2,3-Diazabicyclo[2.2.1]hept-2-ene, 1,4-diphenyl-, N-oxide	$C_{17}H_{16}N_2O$	264	45.0	142357
64	31.21	178	Anthracene	$C_{14}H_{10}$	178	20.4	113337
65	31.40	178	1,4-Dihydro-1,4-ethanoanthracene	$C_{16}H_{14}$	206	35.9	194121
66	31.74	117	Benzene, 1,1'-(1,3-butadienylidene)bis-	$C_{16}H_{14}$	206	18.3	150533
67	31.77	117	1,4-Diphenyl-1,3-butadiene	$C_{16}H_{14}$	206	19.5	118796
68	32.01	91	Benzene, 1,1'-(1,3-butadienylidene)bis-	$C_{16}H_{14}$	206	16.2	150533
69	32.51	203	Naphthalene, 1-phenyl-	$C_{16}H_{12}$	204	16.5	67947
70	32.69	191	Phenanthrene, 1-methyl-	$C_{15}H_{12}$	192	16.0	113354
71	33.06	130	Bicyclo[2.1.1]hexane, 1,4-diphenyl-	$C_{18}H_{18}$	234	39.5	142342
72	33.26	206	Naphthalene, 1,2-dihydro-4-phenyl-	$C_{16}H_{14}$	206	17.7	118829
73	33.75	192	Phenanthrene, 1-methyl-	$C_{15}H_{12}$	192	11.4	113354
74	34.19	206	[14]Annulene, 1,6:8,13-bis(methano)-, syn	$C_{16}H_{14}$	206	13.0	151490
75	34.29	206	Naphthalene, 1,2-dihydro-4-phenyl-	$C_{16}H_{14}$	206	17.5	157501
76	34.46	219	2,3-Diazabicyclo[2.2.1]hept-2-ene, 1,4-diphenyl-	$C_{17}H_{16}N_2$	248	75.7	142912
77	34.69	204	2-Phenylnaphthalene	$C_{16}H_{12}$	204	20.2	113420
78	35.21	117	1,5-Diphenyl-1,5-hexadiene	$C_{18}H_{18}$	234	52.9	211272
79	36.31	202	Fluoranthene	$C_{16}H_{10}$	202	58.2	291148
80	36.84	218	9-Phenyl-5H-benzocycloheptene	$C_{17}H_{14}$	218	20.8	200996
81	37.03	202	5-(2-Propenylidene)-10,11-dihydro-5H-dibenzo[a,d]cycloheptene	$C_{18}H_{16}$	232	17.8	280818
82	37.35	218	Naphthalene, 1-(phenylmethyl)-	$C_{17}H_{14}$	218	18.5	113426
83	37.64	230	p-Terphenyl	$C_{18}H_{14}$	230	47.6	118487
84	38.79	216	Fluoranthene, 2-methyl-	$C_{17}H_{12}$	216	21.3	214119
85	39.11	216	11H-Benzo[b]fluorene	$C_{17}H_{12}$	216	17.6	227514
86	39.83	91	Benzene, 1,1'-[1-(ethylthio)propylidene]bis-	$C_{17}H_{20}S$	256	18.2	149972
87	40.14	180	Benzene, 1,1',1",1'"-(1,2,3,4-butanetetrayl)tetrakis-	$C_{28}H_{26}$	362	44.5	150211
88	41.05	268	7-Benzhydrylidene-5-methylenebicyclo[2.2.1]hept-2-ene	$C_{21}H_{18}$	270	18.5	210690
89	41.34	268	9-Benzylphenanthrene	$C_{21}H_{16}$	268	28.1	233270
90	41.62	193	Benzene, 1,1'-(1-butenylidene)bis-	$C_{16}H_{16}$	208	20.8	156823
91	42.59	117	Benzene, 1,1'-(3-methyl-1-propene-1,3-diyl)bis-	$C_{16}H_{16}$	208	19.9	9505
92	44.26	193	α-N-Normethadol	$C_{20}H_{27}NO$	297	46.3	248097
93	45.30		4-Oxatricyclo[6.3.0.0(2,6)]undecan-5-one-1-carboxylic acid, 10-methylene-9-phenyl-, methyl ester	$C_{19}H_{20}O_4$	312	31.8	159408
94	47.32	91	2,5-Furandione, dihydro-3-octadecyl-	$C_{22}H_{40}O_3$	352	10.7	231636

Polystyrene raw waste plastic (**Figure 5 and Table 8**) was analyzed by GC/MS with CDS pyroprobe equipment. Pyroprobe temperature 1200 ºC was use for solid sample to volatile sample transform because GC/MS cannot

perform with direct solid sample. In GC/MS analysis result compounds was detected by based on retention time and trace mass. In analysis table indicate that polystyrene waste plastic has benzene derivatives because it was made by polymer and benzene group combination. Hydrocarbon compound was combination with benzene group compounds and some are alkane and alkene group compounds. Some different types of compound appeared from GC/MS analysis such as halogenated, oxygenated, alcoholic and nitrogenated compounds and all of these compounds appeared from polystyrene additives mixture was present in raw materials. GC/MS analysis showed initial compound was Cyclopropane (C_3H_6) (t=2.17, m/z=41) compound molecular weight is 42 and compound probability percentage is 77.7% and rest of some compound are described below such as Benzene (C_6H_6) (t=3.65, m/z=78) compound molecular weight is 78 and compound probability percentage is 61.2%, 3-ethenyl- Pyridine (C_7H_7N) (t=8.89, m/z=52) compound molecular weight is 105 and compound probability percentage is 13.1%, 2-propenyl- Benzene (C_9H_{10}) (t=10.55, m/z=117) compound molecular weight is 118 and compound probability percentage is 16.0%, 3-phenyl-1-Propyne (C_9H_8) (t=13.40, m/z=116) compound molecular weight is 116 and compound probability percentage is 26.3%, 1,3-diethenyl- Benzene ($C_{10}H_{10}$) (t=15.49, m/z=130) compound molecular weight is 130 and compound probability percentage is 24.3%, Naphthalene ($C_{10}H_8$) (t=16.60, m/z=128) compound molecular weight is 128 and compound probability percentage is 33.3%, 1,4-dihydro-1,4-Methanonaphthalene ($C_{11}H_{10}$) (t=20.09, m/z=142) compound molecular weight is 142 and compound probability percentage is 22.7%, Biphenyl ($C_{12}H_{10}$) (t=22.30, m/z=154) compound molecular weight is 154 and compound probability percentage is 76.3%, 4-methyl-1,1'-Biphenyl ($C_{13}H_{12}$) (t=25.01, m/z=168) compound molecular weight is 168 and compound probability percentage is 37.6%, α-Methylstilbene ($C_{15}H_{14}$) (t=26.48, m/z=179) compound molecular weight is 194 and compound probability percentage is 23.1%, bis-1,1'-(1,3-propanediyl) Benzene ($C_{15}H_{16}$) (t=28.39, m/z=92) compound molecular weight is 196 and compound probability percentage is 88.2%, Z-bis-1,1'-(1-butene-1,4-diyl)Benzene ($C_{16}H_{16}$) (t=30.38, m/z=117) compound molecular weight is 208 and compound probability percentage is 64.0%, 2,3-Diazabicyclo[2.2.1]hept-2-ene, 1,4-diphenyl-, N-oxide ($C_{17}H_{16}N_2O$) (t=31.02, m/z=219) compound molecular weight is 264 and compound probability percentage is 45.0%, bis-1,1'-(1,3-butadienylidene) Benzene ($C_{16}H_{14}$) (t=32.01, m/z=91) compound molecular weight is 206 and compound probability percentage is 16.2%, 1-methyl-Phenanthrene ($C_{15}H_{12}$) (t=33.75, m/z=192) compound molecular weight is 192 and compound probability percentage is 11.4%, 1,4-diphenyl-2,3-Diazabicyclo[2.2.1]hept-2-ene ($C_{17}H_{16}N_2$) (t=34.46, m/z=219) compound molecular weight is 248 and compound probability percentage is 75.7%, 9-Phenyl-5H-benzocycloheptene ($C_{17}H_{14}$) (t=36.84, m/z=218) compound molecular weight is 218 and compound probability percentage is 20.8 %, p-Terphenyl ($C_{18}H_{14}$) (t=37.64, m/z=230) compound molecular weight is 230 and compound probability percentage is 47.6%, 1,1',1'',1'''-(1,2,3,4-butanetetrayl)tetrakis-Benzene ($C_{28}H_{26}$) (t=40.14, m/z=180), compound molecular weight is 362 and compound probability percentage is 45.5%, bis-1,1'-(3-methyl-1-propene-1,3-diyl)Benzene ($C_{16}H_{16}$) (t=42.59, m/z=117) compound molecular weight is 208 and compound probability percentage is 19.9%, dihydro-3-octadecyl-2,5-Furandione ($C_{22}H_{40}O_3$) (t=47.32,

m/z=91) compound molecular weight is 352 and compound probability percentage is 10.7% as well. Compound structures are showed from analysis result initial short chain hydrocarbon carbon C_3 and long chain hydrocarbon carbon C_{28}.

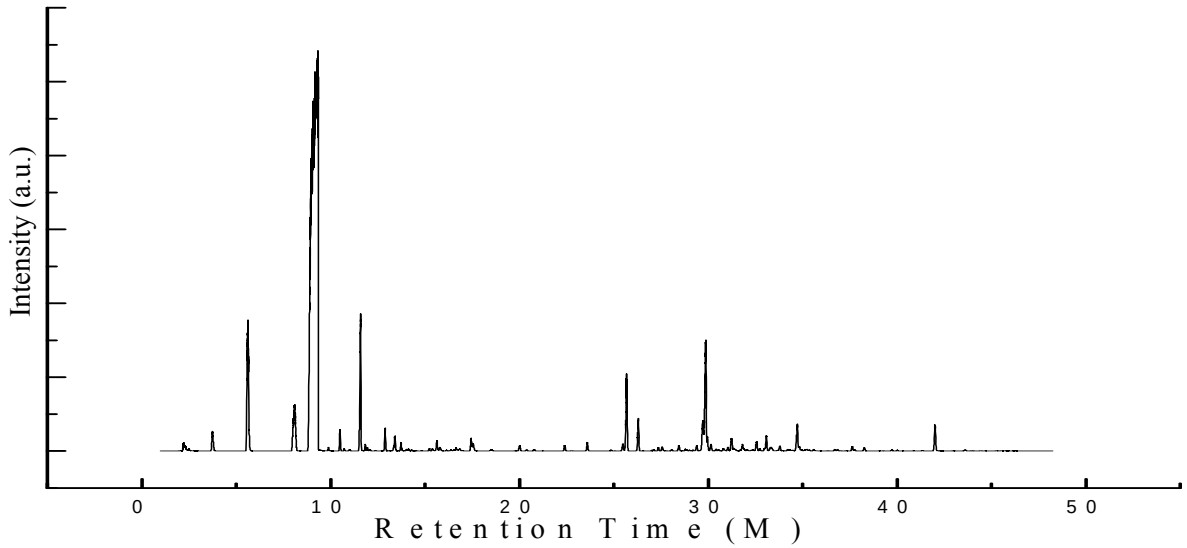

Figure 5: GC/MS chromatogram of polystyrene raw standard plastic

Table 8: Polystyrene raw standard plastic GC/MS chromatogram compound list

Number of Peak	Retention Time (min.)	Trace Mass (m/z)	Compound Name	Compound Formula	Molecular Weight	Probability %	NIST Library Number
1	2.20	44	2-Pentanamine	$C_5H_{13}N$	87	42.8	118246
2	2.22	44	2-Propanamine	C_3H_9N	59	42.8	154506
3	2.30	44	Cyclopropyl carbinol	C_4H_8O	72	57.2	114824
4	2.50	44	Cyclopropane, 1,2-dimethyl-, cis-	C_5H_{10}	70	19.7	19070
5	3.74	78	Benzene	C_6H_6	78	78.0	114388
6	5.58	91	Toluene	C_7H_8	92	65.2	291301
7	8.03	91	Ethylbenzene	C_8H_{10}	106	59.0	158804
8	8.98	103	Styrene	C_8H_8	104	34.4	291542
9	9.06	103	1,3,5,7-Cyclooctatetraene	C_8H_8	104	34.9	154586
10	9.88	105	Benzene, (1-methylethyl)-	C_9H_{12}	120	30.6	114201
11	10.49	117	Benzene, 2-propenyl-	C_9H_{10}	118	15.3	114744
12	10.72	91	Benzene, propyl-	C_9H_{12}	120	74.9	113930
13	10.99	105	Benzaldehyde	C_7H_6O	106	63.9	291541
14	11.59	118	α-Methylstyrene	C_9H_{10}	118	32.4	2021
15	11.84	117	Benzene, cyclopropyl-	C_9H_{10}	118	18.4	113961
16	11.94	117	Benzene, cyclopropyl-	C_9H_{10}	118	18.9	113961
17	12.09	117	Benzene, 2-propenyl-	C_9H_{10}	118	13.4	114744
18	12.38	105	Benzene, 1-methyl-2-(2-propenyl)-	$C_{10}H_{12}$	132	26.9	114137

19	12.89	117	cis-β-Methylstyrene	C_9H_{10}	118	14.4	113518
20	13.41	115	Benzene, 1-propynyl-	C_9H_8	116	39.9	113196
21	13.73	117	Benzene, (1-methylenepropyl)-	$C_{10}H_{12}$	132	35.1	118149
22	14.03	103	Bicyclo[4.2.0]octa-1,3,5-triene, 7-chloro-	C_8H_7Cl	138	48.6	288888
23	14.14	138	2-Chlorostyrene	C_8H_7Cl	138	20.3	107358
24	14.30	103	Benzene, 1-chloro-4-ethenyl-	C_8H_7Cl	138	22.2	107670
25	14.84	105	Benzene, (1-methyl-3-butenyl)-	$C_{11}H_{14}$	146	26.6	61229
26	15.23	103	Benzene, (2-chloroethenyl)-	C_8H_7Cl	138	20.3	135286
27	15.39	130	Benzene, 1,3-diethenyl-	$C_{10}H_{10}$	130	26.1	2811
28	15.63	103	Benzene, (2-chloroethenyl)-	C_8H_7Cl	138	32.1	135286
29	17.44	128	Naphthalene	$C_{10}H_8$	128	61.7	114935
30	17.56	128	Naphthalene	$C_{10}H_8$	128	37.7	114935
31	18.47	115	1-Phenylbicyclo[2.1.1]hexane	$C_{12}H_{14}$	158	33.1	210402
32	18.50	92	Pentacyclo[6.4.0.0(2,10).0(3,6).0(9,11)] dodec-6(7)-ene	$C_{12}H_{14}$	158	20.5	223175
33	18.52	91	[4.4.2]Propella-3,8,11-triene	$C_{12}H_{14}$	158	21.3	37023
34	18.57	92	Bicyclo[4.2.1]nona-2,4,7-triene, 7-isopropenyl-	$C_{12}H_{14}$	158	16.9	164411
35	20.00	118	Benzene, (3-methyl-1-methylenepentyl)-	$C_{13}H_{18}$	174	23.2	64031
36	20.00	118	Benzene, (1-methylenepentyl)-	$C_{12}H_{16}$	160	23.0	149206
37	20.02	118	Benzene, (3-methyl-1-methylenepentyl)-	$C_{13}H_{18}$	174	33.2	64031
38	20.38	142	Benzocycloheptatriene	$C_{11}H_{10}$	142	38.5	151559
39	20.49	141	1H-Indene, 1-ethylidene-	$C_{11}H_{10}$	142	47.5	55614
40	22.39	154	Biphenyl	$C_{12}H_{10}$	154	72.6	114218
41	23.60	167	Diphenylmethane	$C_{13}H_{12}$	168	54.8	114004
42	24.85	167	Benzene, 1,1'-ethylidenebis-	$C_{14}H_{14}$	182	15.9	22224
43	25.48	180	cis-Stilbene	$C_{14}H_{12}$	180	18.1	291438
44	25.67	91	Benzene, 1,1'-(1,2-ethanediyl)bis-	$C_{14}H_{14}$	182	94.2	113286
45	25.70	91	Benzene, 1,1'-(1,2-ethanediyl)bis-	$C_{14}H_{14}$	182	83.6	113286
46	26.26	105	Benzene, 1,1'-(1-methyl-1,2-ethanediyl)bis-	$C_{15}H_{16}$	196	62.6	34633
47	26.30	105	Benzene, 1,1'-(1-methyl-1,2-ethanediyl)bis-	$C_{15}H_{16}$	196	71.1	34633
48	27.01	105	Benzene, 1,1'-(1,2-dimethyl-1,2-ethanediyl)bis-	$C_{16}H_{18}$	210	32.6	157030
49	27.11	165	1H-Phenalene	$C_{13}H_{10}$	166	46.6	33161
50	27.36	103	1,2-Diphenylcyclopropane	$C_{15}H_{14}$	194	54.6	135351
51	27.56	180	1,2-Diphenylethylene	$C_{14}H_{12}$	180	13.1	7372
52	27.68	117	Benzene, 1,1'-(1-butene-1,4-diyl)bis-, (Z)-	$C_{16}H_{16}$	208	27.9	63166
53	27.82	115	Benzene, 1,1'-(3-methyl-1-propene-1,3-diyl)bis-	$C_{16}H_{16}$	208	25.2	9505
54	28.46	92	Benzene, 1,1'-(1,3-propanediyl)bis-	$C_{15}H_{16}$	196	91.3	133399
55	28.79	115	1,2-Diphenylcyclopropane	$C_{15}H_{14}$	194	53.1	135351
56	28.89	115	Benzene, 1,1'-(3-methyl-1-propene-1,3-diyl)bis-	$C_{16}H_{16}$	208	33.4	9505

57	29.09	105	Benzene, 1,1'-(1-methyl-1,3-propanediyl)bis-	$C_{16}H_{18}$	210	77.9	149665
58	29.19	131	Benzene, 1,1'-[1-(2-propenyl)-1,2-ethanediyl]bis-	$C_{17}H_{18}$	222	70.3	150318
59	29.40	180	Anthracene, 9,10-dihydro-	$C_{14}H_{12}$	180	31.5	113290
60	29.88	91	Naphthalene, 1,2,3,4-tetrahydro-2-phenyl-	$C_{16}H_{16}$	208	43.1	9510
61	29.97	105	Benzene, (1-methyl-3-butenyl)-	$C_{11}H_{14}$	146	16.5	61229
62	30.15	115	1,2-Diphenylcyclopropane	$C_{15}H_{14}$	194	49.5	135351
63	30.81	192	1H-Indene, 2-phenyl-	$C_{15}H_{12}$	192	13.6	305225
64	31.06	219	2,3-Diazabicyclo[2.2.1]hept-2-ene, 1,4-diphenyl-, N-oxide	$C_{17}H_{16}N_2O$	264	53.3	142357
65	31.21	178	Anthracene	$C_{14}H_{10}$	178	24.9	113337
66	31.24	178	Anthracene	$C_{14}H_{10}$	178	29.8	113337
67	31.36	115	Benzene, 1,1'-(3-methyl-1-propene-1,3-diyl)bis-	$C_{16}H_{16}$	208	27.4	9505
68	31.82	117	Benzene, 1,1'-(1-butene-1,4-diyl)bis-, (Z)-	$C_{16}H_{16}$	208	35.8	63166
69	32.57	203	Naphthalene, 1-phenyl-	$C_{16}H_{12}$	204	19.5	156081
70	32.73	192	Anthracene, 2-methyl-	$C_{15}H_{12}$	192	12.2	8305
71	33.08	130	2,3-Diazabicyclo[2.2.2]oct-2-ene, 1,4-diphenyl-	$C_{18}H_{18}N_2$	262	41.5	142344
72	33.32	202	Naphthalene, 1,8-di-1-propynyl-	$C_{16}H_{12}$	204	12.8	37071
73	33.80	192	Benzene, 1,1'-(1,2-propadienylidene)bis-	$C_{15}H_{12}$	192	14.4	160625
74	34.72	204	2-Phenylnaphthalene	$C_{16}H_{12}$	204	42.4	113420
75	34.84	220	2,3-Diazabicyclo[2.2.1]hept-2-ene, 1,4-diphenyl-	$C_{17}H_{16}N_2$	248	26.9	142912
76	36.71	167	Benzene, 1,1',1"-(1-ethanyl-2-ylidene)tris-	$C_{20}H_{18}$	258	22.2	157972
77	36.85	218	Naphthalene, 1-(phenylmethyl)-	$C_{17}H_{14}$	218	17.4	113426
78	37.64	230	p-Terphenyl	$C_{18}H_{14}$	230	64.4	221130
79	37.77	181	1-Methylsulfonyl-1,2-diphenylethane	$C_{15}H_{16}O_2S$	260	58.2	241677
80	38.27	230	p-Terphenyl	$C_{18}H_{14}$	230	71.8	221130
81	39.73	91	Benzenemethanamine, N-hydroxy-N-(phenylmethyl)-	$C_{14}H_{15}NO$	213	29.7	75379
82	40.03	180	Benzene, 1,1',1",1'"-(1,2,3,4-butanetetrayl)tetrakis-	$C_{28}H_{26}$	362	45.7	150211
83	42.01	91	(2,3-Diphenylcyclopropyl)methyl phenyl sulfoxide, trans-	$C_{22}H_{20}OS$	332	35.6	142947

Polystyrene standard raw plastic (**Figure 5 and Table 8**) was analyzed by Gas Chromatography and Mass Spectrometer (GC/MS) with pyroprobe for hydrocarbon compound structure determination. GC/MS analysis result indicate that polystyrene standard plastic has different types of compound with hydrocarbon compounds such as halogenated, oxygenated, alcoholic and nitrogen containing compounds. All compounds was detected form GC/MS based on retention time and trace mass and compound molecular weight, compounds probability. Polystyrene standard plastic and polystyrene waste plastics detected compounds are not all similar because polystyrene standard plastic is fully pure and analytical grade plastic. Based on different retention time and trace mass in standard

polystyrene raw plastic small compound detected 2-Pentanamine ($C_5H_{13}N$) and largest compounds detected 1,1',1",1'"-(1,2,3,4-butanetetrayl)tetrakis-Benzene ($C_{28}H_{26}$). Some analysis compounds describe below base on their retention time, trace mass, molecular weight and compounds probability percentage such as 2-Pentanamine ($C_5H_{13}N$) (t=2.20, m/z=44) compound molecular weight is 87 and compound probability percentage is 42.8%, Benzene (C_6H_6) (t=3.74, m/z=78) compound molecular weight is 78 and compound probability percentage is 78.0%, Styrene (C_8H_8) (t=8.98, m/z=103) compound molecular weight is 104 and compound probability percentage is 34.4%, Benzaldehyde (C_7H_6O) (t=10.99, m/z=105) compound molecular weight is 106 and compound probability percentage is 63.9%, 1-methyl-2-(2-propenyl)- Benzene ($C_{10}H_{12}$) (t=12.38, m/z=105) compound molecular weight is 132 and compound probability percentage is 26.9%, 2-Chlorostyrene (C_8H_7Cl) (t=14.14, m/z=138) compound molecular weight is 138 and compound probability percentage is 20.3%, Naphthalene ($C_{10}H_8$) (t=17.44, m/z=128) compound molecular weight is 128 and compound probability percentage is 61.7%, 3-methyl-1-methylenepentyl- Benzene ($C_{13}H_{18}$) (t=20.00, m/z=118) compound molecular weight is 174 and compound probability percentage is 23.2%, Biphenyl ($C_{12}H_{10}$) (t= 22.39, m/z=154) compound molecular weight is 154 and compound probability percentage is 72.6%, bis-1,1'-(1,2-ethanediyl) Benzene ($C_{14}H_{14}$) (t=25.67, m/z=91) compound molecular weight is 182 and compound probability percentage is 94.2%, bis-1,1'-(1,2-dimethyl-1,2-ethanediyl) Benzene ($C_{16}H_{18}$) (t=27.01, m/z=105) compound molecular weight is 210 and compound probability percentage is 32.6%, bis-1,1'-(3-methyl-1-propene-1,3-diyl) Benzene ($C_{16}H_{16}$) (t=27.82, m/z=115) compound molecular weight is 208 and compound probability percentage is 25.2%, bis-1,1'-(1-methyl-1,3-propanediyl) Benzene ($C_{16}H_{18}$) (t=29.09, m/z=105) compound molecular weight is 210 and compound probability percentage is 77.9%, 1,2-Diphenylcyclopropane ($C_{15}H_{14}$) (t=30.15, m/z=115) compound molecular weight is 194 and compound probability percentage is 49.5%, 2,3-Diazabicyclo[2.2.1]hept-2-ene, 1,4-diphenyl-, N-oxide ($C_{17}H_{16}N_2O$) (t=31.06, m/z=219) compound molecular weight is 264 and compound probability percentage is 53.3%, bis-1,1'-(3-methyl-1-propene-1,3-diyl)Benzene ($C_{16}H_{16}$) (t=31.36, m/z=115) compound molecular weight is 208 and compound probability percentage is 27.4%, 2,3-Diazabicyclo[2.2.2]oct-2-ene, 1,4-diphenyl- ($C_{18}H_{18}N_2$) (t=33.08, m/z=130) compound molecular weight is 262 and compound probability percentage is 41.5%, tris-1,1',1"-(1-ethanyl-2-ylidene)Benzene ($C_{20}H_{18}$) (t=36.71, m/z=167) compound molecular weight is 258 and compound probability percentage is 22.2%, 1,1',1",1'"-(1,2,3,4-butanetetrayl)tetrakis-Benzene ($C_{28}H_{26}$) (t=40.03, m/z=180) compound molecular weight is 362 and compound probability percentage is 45.7% as well.

3.3. Liquid Fuel Analysis

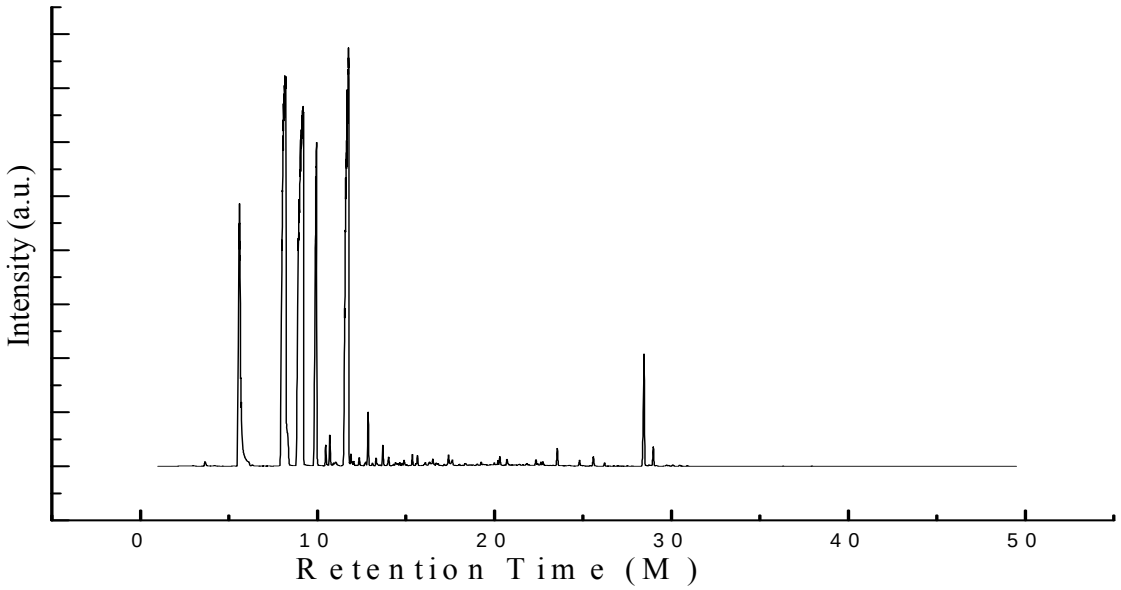

Figure 6: GC/MS chromatogram of polystyrene waste plastic to liquid fuel

Table 9: Polystyrene waste plastic to liquid fuel GC/MS chromatogram compound list

Number of Peak	Retention Time (min.)	Trace Mass (m/z)	Compound Name	Compound Formula	Molecular Weight	Probability %	NIST Library Number
1	3.65	78	Benzene	C_6H_6	78	76.2	114388
2	4.05	56	Cyclopentane, 1,2-dimethyl-, cis-	C_7H_{14}	98	11.5	114027
3	5.59	92	Toluene	C_7H_8	92	55.2	291301
4	5.60	65	Toluene	C_7H_8	92	44.7	291301
5	6.51	91	Cyclopropane, (2,2-dimethylpropylidene)-	C_8H_{14}	110	5.92	60981
6	6.68	91	2-Octyn-1-ol	$C_8H_{14}O$	126	15.2	196867
7	6.81	81	Bicyclo[2.2.1]hept-2-en-7-ol	$C_7H_{10}O$	110	36.1	20149
8	6.99	67	1-Methyl-2-methylenecyclohexane	C_8H_{14}	110	9.26	113437
9	7.26	81	Bicyclo[2.2.1]hept-2-en-7-ol	$C_7H_{10}O$	110	6.21	20149
10	8.06	106	p-Xylene	C_8H_{10}	106	24.7	113952
11	8.09	92	Ethylbenzene	C_8H_{10}	106	24.5	158804
12	8.12	92	Ethylbenzene	C_8H_{10}	106	14.5	158804
13	8.17	92	Benzene, 1-azido-3-methyl-	$C_7H_7N_3$	133	27.7	3117
14	8.21	92	Benzene, 1-azido-3-methyl-	$C_7H_7N_3$	133	25.4	3117
15	8.93	104	Styrene	C_8H_8	104	50.8	291542
16	8.96	103	Styrene	C_8H_8	104	49.2	291542
17	8.96	103	Styrene	C_8H_8	104	49.2	291542
18	9.05	50	1,3,5,7-Cyclooctatetraene	C_8H_8	104	44.5	1259

19	9.13	105	Benzene, 1-(bromomethyl)-2-methyl-	C_8H_9Br	184	12.3	113276
20	9.16	52	1,3,5,7-Cyclooctatetraene	C_8H_8	104	14.1	1259
21	9.19	102	Benzene, 1-azido-4-methyl-	$C_7H_7N_3$	133	5.58	39082
22	9.95	103	1-Hexen-4-yne, 3-ethylidene-2-methyl-	C_9H_{12}	120	24.2	150222
23	10.47	117	Benzene, 2-propenyl-	C_9H_{10}	118	13.8	114744
24	10.71	91	Benzene, propyl-	C_9H_{12}	120	85.6	113930
25	10.92	105	Benzene, 1-ethyl-3-methyl-	C_9H_{12}	120	29.2	228743
26	11.04	105	Benzene, (1-methylethyl)-	C_9H_{12}	120	16.3	228742
27	11.60	117	α-Methylstyrene	C_9H_{10}	118	34.6	2021
28	11.69	118	α-Methylstyrene	C_9H_{10}	118	37.2	30236
29	11.96	105	Benzene, 1,2,4-trimethyl-	C_9H_{12}	120	19.8	114280
30	12.06	57	Decane	$C_{10}H_{22}$	142	30.2	114147
31	12.20	55	Bicyclo[2.2.2]octan-1-ol, 4-methyl-	$C_9H_{16}O$	140	5.57	3696
32	12.74	117	Benzene, 1-methyl-4-(2-propenyl)-	$C_{10}H_{12}$	132	16.4	113549
33	12.88	117	Benzene, 2-propenyl-	C_9H_{10}	118	18.1	114744
34	13.11	117	Benzene, 2-propenyl-	C_9H_{10}	118	13.7	114744
35	13.32	91	Benzene, 3-butenyl-	$C_{10}H_{12}$	132	81.6	113933
36	13.53	105	Benzene, 1-methyl-2-propyl-	$C_{10}H_{14}$	134	15.2	229624
37	13.70	91	1,2,3,4,5,8-Hexahydronaphthalene	$C_{10}H_{14}$	134	21.1	113559
38	14.03	117	Benzene, 1-methyl-4-(2-propenyl)-	$C_{10}H_{12}$	132	19.7	113549
39	14.32	117	2,3-Epoxycarane, (E)-	$C_{10}H_{16}O$	152	10.9	156146
40	14.42	117	Benzene, 2-butenyl-	$C_{10}H_{12}$	132	14.5	114033
41	14.57	117	Benzene, 1-ethenyl-4-ethyl-	$C_{10}H_{12}$	132	10.3	291350
42	14.66	55	2-Undecene, (Z)-	$C_{11}H_{22}$	154	6.13	60564
43	14.80	105	Benzene, (1-methyl-3-butenyl)-	$C_{11}H_{14}$	146	41.9	61229
44	14.90	57	Undecane	$C_{11}H_{24}$	156	20.6	114185
45	15.05	105	10,12-Octadecadiynoic acid	$C_{18}H_{28}O_2$	276	11.7	136706
46	15.37	117	Benzene, 1-methyl-4-(2-propenyl)-	$C_{10}H_{12}$	132	9.45	113549
47	15.57	91	7-Ethylidenebicyclo[4.2.1]nona-2,4-diene	$C_{11}H_{14}$	146	13.7	99215
48	16.66	117	Benzene, 1-butenyl-, (E)-	$C_{10}H_{12}$	132	14.6	113927
49	16.10	118	Benzene, (1-ethyl-2-propenyl)-	$C_{11}H_{14}$	146	33.6	113986
50	16.34	115	1H-Indene, 3-methyl-	$C_{10}H_{10}$	130	11.4	190595
51	16.53	91	Benzene, pentyl-	$C_{11}H_{16}$	148	59.0	113915
52	16.72	104	Naphthalene, 1,2,3,4-tetrahydro-	$C_{10}H_{12}$	132	33.3	113929
53	16.83	131	Benzene, 2-ethenyl-1,3,5-trimethyl-	$C_{11}H_{14}$	146	16.4	113001
54	17.17	129	Benzene, (3-methyl-2-butenyl)-	$C_{11}H_{14}$	146	12.8	4232
55	17.41	128	Naphthalene	$C_{10}H_8$	128	30.7	114935
56	17.63	57	Dodecane	$C_{12}H_{26}$	170	12.4	291499
57	18.02	103	1-Phenyl-3-hydroxy-2-fluoropropene-1	C_9H_9FO	152	15.5	222263

58	18.21	91	7-Azabicyclo[4.2.2]deca-2,4,9-trien-8-one	C_9H_9NO	147	12.6	36855
59	18.38	117	Benzene, cyclopentyl-	$C_{11}H_{14}$	146	31.8	187011
60	18.59	117	Bicyclo[4.2.1]nona-2,4,7-triene, 7-ethyl-	$C_{11}H_{14}$	146	13.5	164426
61	18.67	118	1,6-Heptadiene, 2-methyl-6-phenyl-	$C_{14}H_{18}$	186	18.8	217260
62	18.78	91	Falcarinol	$C_{17}H_{24}O$	244	20.4	112661
63	19.03	91	Bicyclo[3.1.1]hept-3-ene-spiro-2,4'-(1',3'-dioxane), 7,7-dimethyl-	$C_{12}H_{18}O_2$	194	12.6	149762
64	19.25	91	Benzene, hexyl-	$C_{12}H_{18}$	162	65.0	113954
65	19.78	104	5,6,7,8,9,10-Hexahydrobenzocyclooctene	$C_{12}H_{16}$	160	10.4	99222
66	20.00	55	7-Tetradecene	$C_{14}H_{28}$	196	6.47	70643
67	20.21	57	Tridecane	$C_{13}H_{28}$	184	22.1	114282
68	20.32	142	Benzocycloheptatriene	$C_{11}H_{10}$	142	24.4	151559
69	20.58	91	Tricyclo[6.4.0.0(3,7)]dodeca-1,9,11-triene	$C_{12}H_{14}$	158	27.4	298964
70	20.72	142	Naphthalene, 1-methyl-	$C_{11}H_{10}$	142	31.6	291511
71	21.43	143	Oct-3-ene-1,5-diyne, 3-t-butyl-7,7-dimethyl-	$C_{14}H_{20}$	188	14.8	211230
72	21.62	91	Falcarinol	$C_{17}H_{24}O$	244	18.0	112661
73	21.84	91	Benzene, heptyl-	$C_{13}H_{20}$	176	47.9	118464
74	22.36	154	Biphenyl	$C_{12}H_{10}$	154	60.7	114218
75	22.45	55	7-Tetradecene	$C_{14}H_{28}$	196	4.26	70643
76	22.64	57	Tetradecane	$C_{14}H_{30}$	198	27.5	113925
77	22.74	167	Naphthalene, 1-(2-propenyl)-	$C_{13}H_{12}$	168	25.7	6407
78	23.33	156	Benzene, 2,5-cyclohexadien-1-yl-	$C_{12}H_{12}$	156	9.87	163786
79	23.56	167	Diphenylmethane	$C_{13}H_{12}$	168	49.3	114004
80	24.82	167	Benzene, 1,1'-ethylidenebis-	$C_{14}H_{14}$	182	33.5	60991
81	24.93	57	Nonadecane	$C_{19}H_{40}$	268	4.95	114098
82	25.03	168	1,1'-Biphenyl, 4-methyl-	$C_{13}H_{12}$	168	25.2	113287
83	25.42	180	1,2-Diphenylethylene	$C_{14}H_{12}$	180	16.8	7372
84	25.60	91	Benzene, 1,1'-(1,2-ethanediyl)bis-	$C_{14}H_{14}$	182	92.1	113286
85	26.23	105	Benzene, 1,1'-(1-methyl-1,2-ethanediyl)bis-	$C_{15}H_{16}$	196	72.6	151418
86	26.50	179	Phenanthrene, 9,10-dihydro-1-methyl-	$C_{15}H_{14}$	194	26.0	80195
87	27.53	105	Benzene, 1,1'-(1-methyl-1,2-ethanediyl)bis-	$C_{15}H_{16}$	196	42.8	34633
88	27.65	117	Benzene, 1,1'-(1-butene-1,4-diyl)bis-, (Z)-	$C_{16}H_{16}$	208	12.1	63166
89	28.46	92	Benzene, 1,1'-(1,3-propanediyl)bis-	$C_{15}H_{16}$	196	93.9	133399
90	28.98	105	Benzene, 1,1'-(1-methyl-1,3-propanediyl)bis-	$C_{16}H_{18}$	210	90.3	149665

91	29.74	91	Naphthalene, 1,2,3,4-tetrahydro-2-phenyl-	$C_{16}H_{16}$	208	21.7	9510
92	30.10	194	1,2-Diphenylcyclopropane	$C_{15}H_{14}$	194	48.3	135351
93	30.91	105	Pentane, 1,4-diphenyl-	$C_{17}H_{20}$	224	76.9	149966
94	31.09	91	Benzeneacetic acid, 3-pentadecyl ester	$C_{23}H_{38}O_2$	346	17.1	282027

Polystyrene waste plastic turned into liquid petroleum product by using thermal degradation without catalyst and without vacuumed system. Laboratory batch process was performed with 1 kg of polystyrene waste plastic and temperature used up 400 ºC and produce liquid hydrocarbon fuel. Polystyrene waste plastic was breakdown by heat and turned into short compounds to large compounds. Produce fuel **(Figure 6 and Table 9)** was analysis by Perkin Elmer Gas Chromatography and Mass Spectrometer (GC/MS) with auto sampler system. Analysis results indicate that polystyrene waste plastic to fuel has aromatic group compounds and aliphatic group compounds, also some different types of compounds was detected from GC/MS analysis such as oxygen containing compounds, halogen content compounds, nitrogen content compounds and alcoholic compounds. All compounds were detected based on retention time, trace mass, molecular weight and compound probability percentage. In this analysis result showed staring carbon number is C_6 and finishing compounds carbon number showed C_{23}. Initial compound was detected from GC/MS analysis Benzene (C_6H_6) and a largest compound was detected Benzeneacetic acid, 3-pentadecyl ester ($C_{23}H_{38}O_2$). Some compounds are describe below according to their retention time and based on their trace mass such as Benzene (C_6H_6) (t=3.65, m/z=78) compound molecular weight is 78 and compound probability percentage is 76.2%, Toluene (C_7H_8) (t=5.60, m/z=65) compound molecular weight is 92 and compound probability percentage is 44.7%, Bicyclo[2.2.1]hept-2-en-7-ol ($C_7H_{10}O$) (t= 6.81, m/z=81) compound molecular weight is 110 and compound probability percentage is 36.1%, Ethylbenzene (C_8H_{10}) (t=8.09, m/z=92) compound molecular weight is 106 and compound probability percentage is 24.5%, 1-azido-3-methyl-Benzene ($C_7H_7N_3$) (t=8.21, m/z=92) compound molecular weight is 133 and compound probability percentage is 25.4%, Styrene (C_8H_8) (t=8.96, m/z=103) compound molecular weight is 104 and compound probability percentage is 49.2%, 1-(bromomethyl)-2-methyl- Benzene (C_8H_9Br) (t=9.13, m/z=105) compound molecular weight is 184 and compound probability percentage is 12.3%, propyl- Benzene (C_9H_{12}) (t=10.71, m/z=91) compound molecular weight is 120 and compound probability percentage is 85.6%, α-Methylstyrene (C_9H_{10}) (t=11.69, m/z=118) compound molecular weight is 118 and compound probability percentage is 37.2%, Decane ($C_{10}H_{22}$) (t=12.06, m/z=57) compound molecular weight is 142 and compound probability percentage is 30.2%, 3-butenyl-Benzene ($C_{10}H_{12}$) (t=13.32, m/z=91) compound molecular weight is 132 and compound probability percentage is 81.6%, 1-methyl-3-butenyl-Benzene ($C_{11}H_{14}$) (t=14.80, m/z=105) compound molecular weight is 146 and compound probability percentage is 41.9%, 1-ethyl-2-propenyl-Benzene ($C_{11}H_{14}$) (t=16.10, m/z=118) compound molecular weight is 146 and compound probability percentage is 33.6%, Dodecane ($C_{12}H_{26}$) (t=17.63, m/z=57) compound molecular weight is 170 and compound probability percentage is 12.4%, 2-methyl-6-phenyl-1,6-Heptadiene ($C_{14}H_{18}$) (t=18.67,

m/z=118) compound molecular weight is 186 and compound probability percentage is 18.8%, Tridecane ($C_{13}H_{28}$) (t= 20.21, m/z=57) compound molecular weight is 184 and compound probability percentage is 22.1%, 1-methyl-Naphthalene ($C_{11}H_{10}$) (t=20.72, m/z=142) compound molecular weight is 142 and compound probability percentage is 31.6%, Biphenyl ($C_{12}H_{10}$) (t=22.36, m/z=154) compound molecular weight is 154 and compound probability percentage is 60.7%, Diphenylmethane ($C_{13}H_{12}$) (t=23.56, m/z=167) compound molecular weight is 168 and compound probability percentage is 49.3%, bis-1,1'-(1,2-ethanediyl)Benzene ($C_{14}H_{14}$) (t=25.60, m/z=91) compound molecular weight is 182 and compound probability percentage is 92.1%, Z-bis- 1,1'-(1-butene-1,4-diyl) Benzene ($C_{16}H_{16}$) (t=27.65, m/z=117) compound molecular weight is 208 and compound probability percentage is 12.1%, 1,4-diphenyl-Pentane ($C_{17}H_{20}$) (t=30.91, m/z=105) compound molecular weight is 224 and compound probability percentage is 76.9%, 3-pentadecyl ester Benzeneacetic acid ($C_{23}H_{38}O_2$) (t=31.09, m/z=91) compound molecular weight is 346 and compound probability percentage is 17.1% respectively.

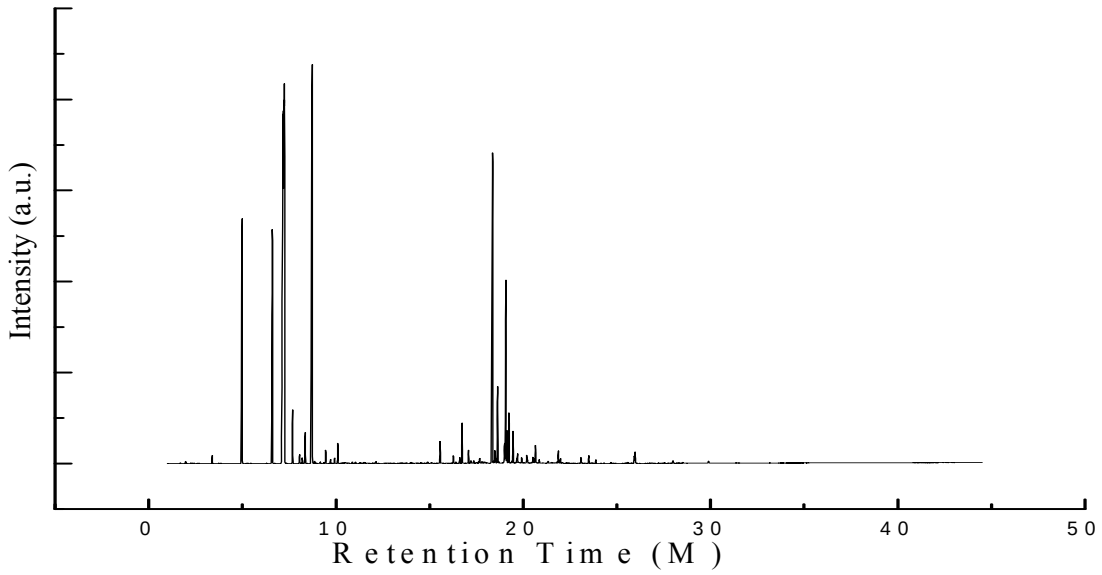

Figure 7: GC/MS chromatogram of polystyrene standard plastic to liquid fuel

Table 10: Polystyrene standard plastic to liquid fuel GC/MS chromatogram compound list

Number of Peak	Retention Time (min)	Trace Mass (m/z)	Compound Name	Compound Formula	Molecular Weight	Probability %	NIST Library Number
1	1.69	41	1-Propene, 2-methyl-	C_4H_8	56	22.5	61293
2	1.90	41	3-Buten-1-ol	C_4H_8O	72	14.1	114446
3	1.96	43	Acetone	C_3H_6O	58	70.6	114413
4	2.00	43	Pentane	C_5H_{12}	72	36.6	114462
5	2.11	55	Cyclopropane, 1,2-dimethyl-, trans-	C_5H_{10}	70	11.5	19071
6	2.34	41	1-Pentene, 4-methyl-	C_6H_{12}	84	5.65	487

7	2.60	41	Cyclopropane, 1-ethyl-2-methyl-, cis-	C_6H_{12}	84	19.2	113658
8	3.38	78	Benzene	C_6H_6	78	64.9	114388
9	3.74	41	1-Heptene	C_7H_{14}	98	8.02	19704
10	3.86	41	Heptane	C_7H_{16}	100	23.4	1048
11	4.98	90	1,5-Heptadien-3-yne	C_7H_8	92	47.4	142710
12	5.21	56	1-Heptene, 2-methyl-	C_8H_{16}	112	4.93	113675
13	5.29	41	2-Octene	C_8H_{16}	112	5.91	1603
14	5.44	43	Hexane, 3-ethyl-	C_8H_{18}	114	14.6	113940
15	6.60	106	3,5-Octadiyne	C_8H_{10}	106	18.3	231838
16	7.18	105	Benzene, 1-(bromomethyl)-2-methyl-	C_8H_9Br	184	13.0	113276
17	7.19	105	Benzene, 1-azido-4-methyl-	$C_7H_7N_3$	133	10.7	39082
18	7.24	63	Benzene, 1-(chloromethyl)-2-nitro-	$C_7H_6ClNO_2$	171	15.3	115682
19	7.68	105	Benzene, (1-methylethyl)-	C_9H_{12}	120	18.6	2135
20	8.05	117	Benzene, cyclopropyl-	C_9H_{10}	118	16.9	113961
21	8.19	91	Benzene, propyl-	C_9H_{12}	120	75.5	113930
22	8.36	77	Benzaldehyde	C_7H_6O	106	70.2	291541
23	8.73	51	(3H)Indazole, 3,3-dimethyl-	$C_9H_{10}N_2$	146	21.7	217141
24	9.45	117	Benzene, 2-propenyl-	C_9H_{10}	118	18.3	114744
25	9.71	91	Benzene, 3-butenyl-	$C_{10}H_{12}$	132	67.6	113933
26	9.93	91	Benzene, (1-methylenepropyl)-	$C_{10}H_{12}$	132	10.5	118149
27	10.10	77	Acetophenone	C_8H_8O	120	76.3	34989
28	10.46	105	Oxirane, 2-methyl-2-phenyl-	$C_9H_{10}O$	134	23.5	63955
29	10.56	105	Benzene, (1-methyl-3-butenyl)-	$C_{11}H_{14}$	146	13.8	61229
30	10.68	105	Oxirane, 2-methyl-2-phenyl-	$C_9H_{10}O$	134	12.2	231978
31	10.87	117	Benzene, 2-butenyl-	$C_{10}H_{12}$	132	12.5	114033
32	11.04	117	Benzene, 1-butenyl-, (E)-	$C_{10}H_{12}$	132	19.8	113927
33	11.25	91	Benzene, 3-pentenyl-, (E)-	$C_{11}H_{14}$	146	25.1	39298
34	11.30	118	Benzene, (1-ethyl-2-propenyl)-	$C_{11}H_{14}$	146	46.0	113986
35	11.41	104	Benzene, 4-pentenyl-	$C_{11}H_{14}$	146	39.3	61228
36	11.50	129	Benzene, (cyclopropylidenemethyl)-	$C_{10}H_{10}$	130	15.5	54284
37	11.53	91	Benzene, pentyl-	$C_{11}H_{16}$	148	38.0	113915
38	12.13	128	Naphthalene	$C_{10}H_8$	128	41.3	114935
39	13.53	43	Tridecane	$C_{13}H_{28}$	184	6.26	114282
40	13.77	142	Bicyclo[4.4.1]undeca-1,3,5,7,9-pentaene	$C_{11}H_{10}$	142	50.0	190616
41	14.01	141	Benzocycloheptatriene	$C_{11}H_{10}$	142	30.5	151559
42	14.90	154	Biphenyl	$C_{12}H_{10}$	154	56.7	114218
43	15.10	167	1,1'-Biphenyl, 2-methyl-	$C_{13}H_{12}$	168	23.4	6409
44	15.56	167	Diphenylmethane	$C_{13}H_{12}$	168	62.2	114004
45	16.27	167	Benzene, 1,1'-ethylidenebis-	$C_{14}H_{14}$	182	50.2	22224
46	16.39	168	1,1'-Biphenyl, 4-methyl-	$C_{13}H_{12}$	168	30.4	113287
47	16.61	165	cis-Stilbene	$C_{14}H_{12}$	180	19.1	291438
48	16.73	91	Benzene, 1,1'-(1,2-ethanediyl)bis-	$C_{14}H_{14}$	182	90.9	113286

49	17.05	105	Benzene, 1,1'-(1-methyl-1,2-ethanediyl)bis-	$C_{15}H_{16}$	196	69.1	34633
50	17.20	179	Phenanthrene, 9,10-dihydro-1-methyl-	$C_{15}H_{14}$	194	22.3	80195
51	17.35	167	1,1'-Biphenyl, 2-ethyl-	$C_{14}H_{14}$	182	36.9	7577
52	17.67	103	1,2-Diphenylcyclopropane	$C_{15}H_{14}$	194	43.1	135351
53	17.79	105	Bicyclo[4.2.0]octa-1,4-diene, 7-methyl-7-phenyl-, (6α,7α)-	$C_{15}H_{16}$	196	19.3	221386
54	18.36	104	Benzene, 1,1'-(1,3-propanediyl)bis-	$C_{15}H_{16}$	196	60.4	133399
55	18.48	115	1,2-Diphenylcyclopropane	$C_{15}H_{14}$	194	66.0	135351
56	18.63	105	Benzene, 1,1'-(1-methyl-1,3-propanediyl)bis-	$C_{16}H_{18}$	210	76.8	149665
57	19.00	179	(E)-Stilbene	$C_{14}H_{12}$	180	25.1	290791
58	19.07	115	Naphthalene, 1,2,3,4-tetrahydro-2-phenyl-	$C_{16}H_{16}$	208	50.5	9510
59	19.13	105	Benzene, (1-methyl-3-butenyl)-	$C_{11}H_{14}$	146	18.9	61229
60	19.24	115	1,2-Diphenylcyclopropane	$C_{15}H_{14}$	194	61.6	135351
61	19.46	91	Benzene, 1,1'-(1,4-butanediyl)bis-	$C_{16}H_{18}$	210	91.7	118778
62	19.65	115	Benzene, 1,1'-(1-butenylidene)bis-	$C_{16}H_{16}$	208	54.8	156823
63	19.70	105	Pentane, 1,4-diphenyl-	$C_{17}H_{20}$	224	82.3	149966
64	20.18	117	Benzene, 1,1'-(1-butene-1,4-diyl)bis-, (Z)-	$C_{16}H_{16}$	208	36.4	63166
65	20.51	105	β-Phenylpropiophenone	$C_{15}H_{14}O$	210	69.0	243440
66	20.61	91	Benzene, 1,1'-(1-ethyl-1,3-propanediyl)bis-	$C_{17}H_{20}$	224	50.2	149667
67	20.65	203	Naphthalene, 1-phenyl-	$C_{16}H_{12}$	204	22.0	156081
68	20.85	105	Benz[a]anthracene, 7,12-dihydro-	$C_{18}H_{14}$	230	29.4	134385
69	21.33	104	1-Pentene, 1,5-diphenyl-	$C_{17}H_{18}$	222	18.1	63202
70	21.50	91	Tricyclo[6.6.0.0(3,6)]tetradeca-1(8),4,11-triene	$C_{14}H_{18}$	186	9.25	151409
71	21.57	105	1,4-Diphenyl-1-pentanone	$C_{17}H_{18}O$	238	13.4	101469
72	21.80	219	1-Phenyl-4-(3,5-dimethylphenyl)buta-1,3-diene	$C_{18}H_{18}$	234	39.2	202150
73	21.87	204	2-Phenylnaphthalene	$C_{16}H_{12}$	204	42.3	113420
74	21.9	218	1,2,3,4-Tetrahydro-1-phenyl-1,2,3-methanonaphthalene	$C_{17}H_{14}$	218	21.9	200979
75	22.08	91	1-Phenyl-4-(3,5-dimethylphenyl)buta-1,3-diene	$C_{18}H_{18}$	234	30.9	202150
76	23.08	218	9-Phenyl-5H-benzocycloheptene	$C_{17}H_{14}$	218	23.6	200996
77	23.50	230	p-Terphenyl	$C_{18}H_{14}$	230	63.6	118487
78	23.66	232	5-(2-Propenylidene)-10,11-dihydro-5H-dibenzo[a,d]cycloheptene	$C_{18}H_{16}$	232	60.0	280818
79	25.59	91	Benzene, 1,1'-[1-(2,2-dimethyl-3-butenyl)-1,3-propanediyl]bis-	$C_{21}H_{26}$	278	13.8	61097
80	25.93	91	Benzene, 1,1'-(1,3-propanediyl)bis-	$C_{15}H_{16}$	196	21.0	150655

81	25.97	91	(2,3-Diphenylcyclopropyl)methyl phenyl sulfoxide, trans-	$C_{22}H_{20}OS$	332	40.2	142947
82	27.99	306	1,1':2',1'':2'',1'''-Quaterphenyl	$C_{24}H_{18}$	306	29.9	14543
83	28.53	91	(3-Methyl-1,4-diphenylbicyclo[2.2.0]hex-2-yl)methanol	$C_{20}H_{22}O$	278	22.1	210039

Polystyrene standard plastic to fuel production purposed analytical grade polystyrene plastic was use and thermal degradation temperature was up 400 ºC. Polystyrene waste plastic to fuel compound structure and polystyrene standard plastic to fuel compounds structure fully different showed GC/MS analysis results. Analytical grade polystyrene standard plastic to fuel (**Figure 7 and Table 10**) was analyzed by GC/MS with auto sampler system. Polystyrene standard plastic to fuel initial compound is 2-methyl-1-Propene (C_4H_8) and same fuel show large compounds is 1, 1':2', 1'':2'', 1'''-Quaterphenyl ($C_{24}H_{18}$). All compounds were detected based on their retention time; trace mass, molecular weight, compound probability percentage. In analysis table showed some different type of compound present into produce fuel such as halogen content compounds, nitrogen content compounds, oxygen content compounds, alcoholic group compounds and aromatic, aliphatic compounds. Most of the compound are appeared aromatic derivatives and some compounds are describe below based on retention time, trace mass, molecular weight and compounds probability percentage such as 2-methyl-1-Propene (C_4H_8) (t=1.69, m/z=41) compound molecular weight is 56 and compound probability percentage is 22.5%, 3-Buten-1-ol (C_4H_8O) (t= 1.90, m/z=41) compound molecular weight is 72 and compound probability percentage is 14.1%, Pentane (C_5H_{12}) (t=2.00, m/z=43) compound molecular weight is 72 and compound probability percentage is 36.6%, Benzene (C_6H_6) (t=3.38, m/z=78) compound molecular weight is 78 and compound probability percentage is 64.9%, 1,5-Heptadien-3-yne (C_7H_8) (t=4.98, m/z=90) compound molecular weight is 92 and compound probability percentage is 47.4%, 3,5-Octadiyne (C_8H_{10}) (t=6.60, m/z=106) compound molecular weight is 106 and compound probability percentage is 18.3%, 1-methylethyl-Benzene (C_9H_{12}) (t=7.68, m/z=105) compound molecular weight is 120 and compound probability percentage is 18.6%, 3,3-dimethyl- (3H)Indazole ($C_9H_{10}N_2$) (t=8.73, m/z=51) compound molecular weight is 146 and compound probability percentage is 21.7%, Acetophenone (C_8H_8O) (t=10.10, m/z=77) compound molecular weight is 120 and compound probability percentage is 76.3%, E-1-butenyl- Benzene ($C_{10}H_{12}$) (t= 11.04, m/z=117) compound molecular weight is 132 and compound probability percentage is 19.8%, 4-pentenyl- Benzene ($C_{11}H_{14}$) (t=11.41, m/z=104) compound molecular weight is 146 and compound probability percentage is 39.3%, Tridecane ($C_{13}H_{28}$) (t=13.53, m/z=43) compound molecular weight is 184 and compound probability percentage is 6.26%, Biphenyl ($C_{12}H_{10}$) (t=14.90, m/z=154) compound molecular weight is 154 and compound probability percentage is 56.7%, Diphenylmethane ($C_{13}H_{12}$) (t=15.56, m/z=167) compound molecular weight is 168 and compound probability percentage is 62.2%, bis-1,1'-(1,2-ethanediyl)Benzene ($C_{14}H_{14}$) (t=16.73, m/z=91) compound molecular weight is 182 and compound probability percentage is 90.9%, 2-ethyl-

1,1'-Biphenyl ($C_{14}H_{14}$) (t=17.35, m/z=167) compound molecular weight is 182 and compound probability percentage is 36.9%, bis-1,1'-(1,3-propanediyl)Benzene ($C_{15}H_{16}$) (t=18.36, m/z=104) compound molecular weight is 196 and compound probability percentage is 60.4%, bis- 1,1'-(1,4-butanediyl) Benzene ($C_{16}H_{18}$) (t=19.46, m/z=91) compound molecular weight is 210 and compound probability percentage is 91.7%, 1,4-diphenyl- Pentane ($C_{17}H_{20}$) (t=19.70, m/z=105) compound molecular weight is 224 and compound probability percentage is 82.3%, β-Phenylpropiophenone ($C_{15}H_{14}O$) (t=20.51, m/z=105) compound molecular weight is 210 and compound probability percentage is 69.0%, 1-Phenyl-4-(3,5-dimethylphenyl)buta-1,3-diene ($C_{18}H_{18}$) (t=21.80, m/z=219) compound molecular weight is 234 and compound probability percentage is 39.2%, p-Terphenyl ($C_{18}H_{14}$) (t=23.50, m/z=230) compound molecular weight is 230 and compound probability percentage is 63.6%, Benzene, 1,1'-[1-(2,2-dimethyl-3-butenyl)-1,3-propanediyl]bis- ($C_{21}H_{26}$) (t=25.59, m/z=91) compound molecular weight is 278 and compound probability percentage is 13.8%, (2,3-Diphenylcyclopropyl)methyl phenyl sulfoxide, trans- ($C_{22}H_{20}OS$) (t=25.97, m/z=91) compound molecular weight is 332 and compound probability percentage is 40.2%, 1,1':2',1":2",1"'-Quaterphenyl ($C_{24}H_{18}$) (t=27.99, m/z=306) compound molecular weight is 306 and compound probability percentage is 29.9% respectively.

Table 11: FT-IR spectrum of polystyrene waste plastic to liquid fuel functional group

Number of Peak	Wave Bend Number (cm^{-1})	Functional Group Name	Number of Peak	Wave Band Number (cm^{-1})	Functional Group Name
1	3830.15		25	1603.23	Conjugated
2	3723.02		26	1575.55	
3	3648.75		27	1537.88	
4	3620.69	Free OH (Sharp)	28	1495.71	
5	3442.08	Free NH	29	1452.04	CH_2
6	3024.54	=C-H	30	1413.04	
7	2970.70	C-CH_3	31	1376.39	CH_3
8	2872.93	C-CH_3	32	1333.60	
9	2732.74	C-CH_3	33	1315.02	
10	2629.27		34	1301.85	
11	2598.94		35	1290.05	
12	2511.61		36	1202.15	
13	2410.37		37	1179.17	
14	2337.09		38	1156.18	
15	2313.19		39	1106.92	
16	2264.16		40	1082.18	
17	2185.39	C-C=-C-C=-CH	41	1029.17	Acetates
18	1943.46		42	991.16	Secondary Cyclic Alcohol
19	1873.64	Non-Conjugated	43	907.16	-CH=CH_2
20	1802.25	Non-Conjugated	44	840.32	
21	1745.37	Non-Conjugated	45	775.49	
22	1705.76	Non-Conjugated	46	730.01	-CH=CH-(cis)
23	1688.13	Conjugated	47	699.14	-CH=CH-(cis)
24	1630.00	Conjugated	48	621.16	

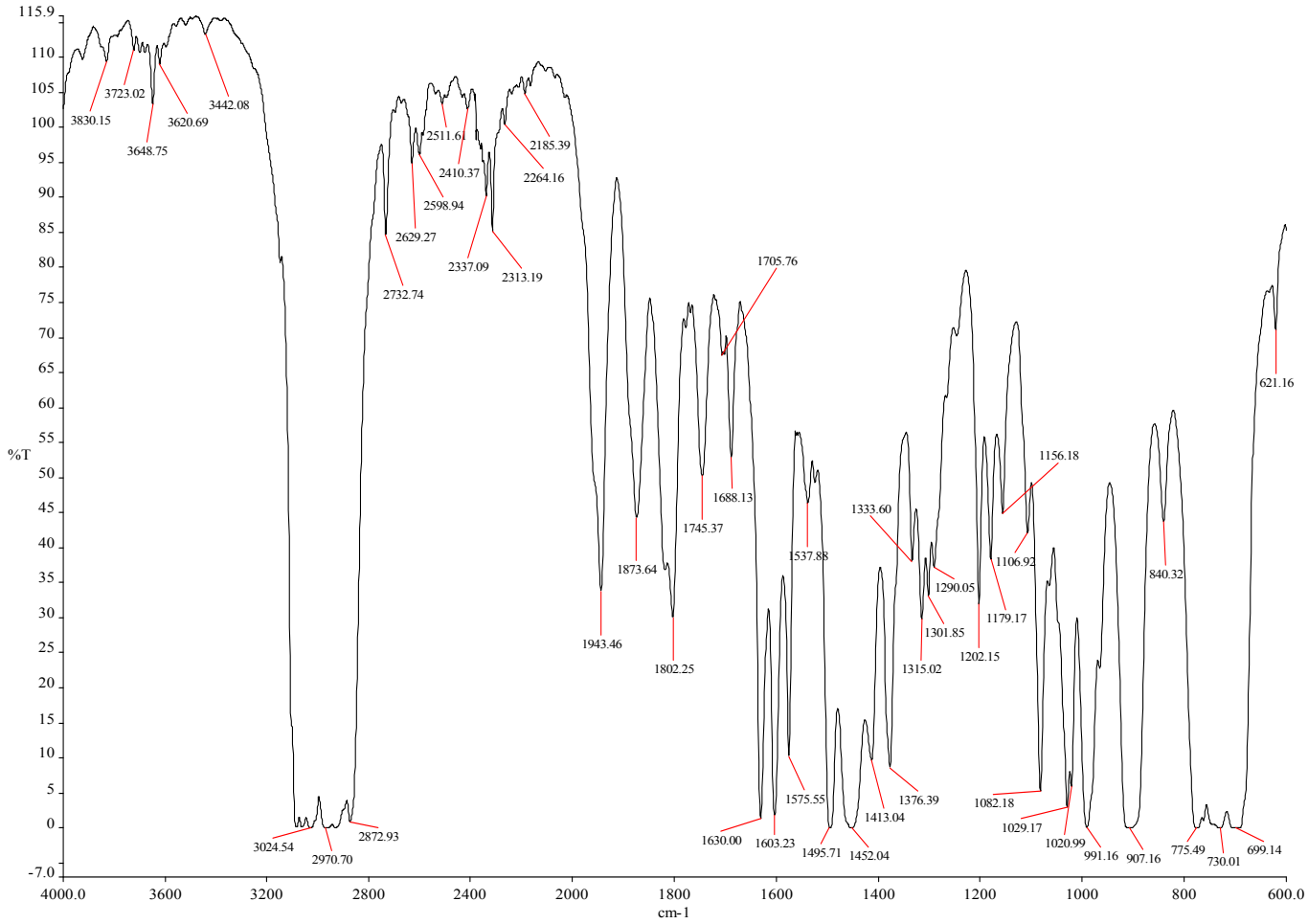

Figure 8: FT-IR spectrum of polystyrene waste plastic to liquid fuel

FT-IR (Spectrum 100) analyses of polystyrene (PS) waste plastic to fuel (**Figure 8 and Table 11**) in accordance with the different wave number different types of functional groups are appeared. In according to wave number on the spectrum such as wave number 3620.69 cm^{-1}, functional group is Free OH (Sharp), wave number 3442.08 cm^{-1} , functional group is Free NH, wave number 3024.54 cm^{-1},functional group is =C-H, wave number 2970.70 cm^{-1}, functional group is CH_3, wave number 2872.93 cm^{-1} functional group is C-CH_3, wave number 2732.74 cm^{-1},functional group is C-CH_3, wave number 2185.39 cm^{-1}, functional group is C-C=-C-C=-CH , wave number 1873.64 cm^{-1}, 1802.25 cm^{-1} and 1745.37 cm^{-1} functional group is Non-Conjugated, wave number 1688.13 cm^{-1} and 1630.00 cm^{-1},functional group is Conjugated, wave number 1452.04 cm^{-1} and 1376.39 cm^{-1} functional group is CH_2 / CH_3 , wave number 1029.17 cm^{-1}, functional group is Acetates, wave number 991.16 cm^{-1}, functional group is Secondary Cyclic Alcohol, wave number 907.16 cm^{-1} functional group is -CH=CH_2 etc. In the end of the spectrum phase wave number 730.01 cm^{-1} and , 699.14 cm^{-1}, functional group is -CH=CH-(cis) as well. Some of functional groups energy values are calculated, using formula is E=hυ, Where h=Planks Constant, h =6.626x10^{-34} J, υ= Frequency in Hertz (sec^{-1}), Where υ=c/λ, c=Speed of light, where, c=3x10^{10} m/s, W=1/λ, where λ is wave length and W is wave number in cm^{-1}. Therefore the equation E=hυ, can substitute by the following equation, E=hcW.

According to their wave number such as for 2970.70 (cm^{-1}) calculated energy, $E=5.80x10^{-20}$ J. Similarly, wave number 1745.37 (cm^{-1}) energy, $E = 3.46x10^{-20}$ J, wave number 1376.39 (cm^{-1}) energy, $E = 2.73x10^{-20}$ J and eventually wave number 991.16 (cm^{-1}) functional group energy is $1.97x10^{-20}$ J respectively.

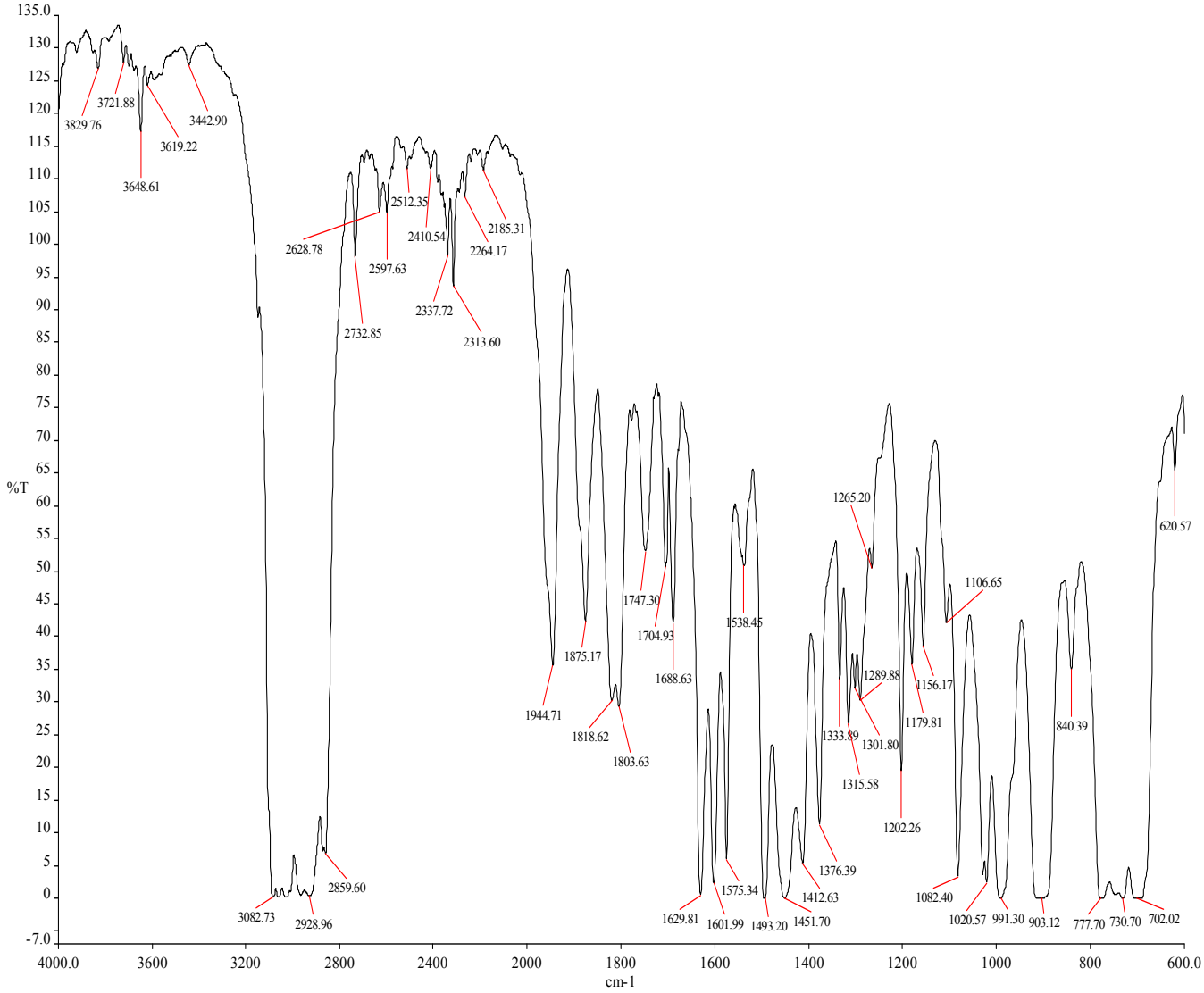

Figure 9: FT-IR spectrum of polystyrene standard plastic to liquid fuel

Table 12: FT-IR spectrum of polystyrene standard plastic to liquid fuel functional group

Number of Peak	Wave Bend Number (cm^{-1})	Functional Group Name	Number of Peak	Wave Bend Number (cm^{-1})	Functional Group Name
1	3829.76		26	1601.99	Conjugated
2	3721.88		27	1575.34	
3	3648.61		28	1538.45	
4	3619.22	Free OH	29	1493.20	
5	3442.90	Intermolecular H bonds	30	1451.70	CH_2

6	3082.73	H Bonded NH	31	1412.63	
7	2928.96	C-CH_3	32	1376.39	CH_3
8	2859.60	C-CH_3	33	1333.89	
9	2732.85	C-CH_3	34	1315.58	
10	2628.78		35	1301.80	
11	2597.63	Chelate Compounds	36	1289.88	
12	2512.35	Chelate Compounds	37	1265.20	
13	2410.54		38	1202.26	
14	2337.72		39	1179.81	
15	2313.60		40	1156.17	
16	2264.17		41	1106.65	
17	2185.31	C-C=-C-C=-CH	42	1082.40	
18	1944.71		43	1020.57	Acetates
19	1875.17	Non-Conjugated	44	991.30	-CH=CH_2
20	1818.62	Non-Conjugated	45	903.12	
21	1803.63	Non-Conjugated	46	840.39	
22	1747.30	Non-Conjugated	47	777.70	
23	1704.93	Non-Conjugated	48	730.70	-CH=CH-(cis)
24	1688.63	Conjugated	49	702.02	-CH=CH-(cis)
25	1629.81	Conjugated	50	620.57	

Perkin Elmer FT-IR (Spectrum-100) analyses of polystyrene (PS) standard plastic to fuel (**Figure 9 and Table 12**) in accordance with the different wave number different types of functional groups are appeared. In according to wave number on the spectrum such as wave number 3619.22 cm^{-1}, functional group is Free OH (Sharp), wave number 3442.90 cm^{-1} , functional group is Free NH, wave number 3082.73 cm^{-1},functional group is H bonded NH, wave number 2928.96 cm^{-1}, functional group is CH_3, wave number 2859.60 cm^{-1} functional group is C-CH_3, wave number 2732.85 cm^{-1},functional group is C-CH_3, wave number 2597.63 cm^{-1} and 2512.35 cm^{-1}, functional group is Chelate group, wave number 2185.31 cm^{-1}, functional group is C-C=-C-C=-CH , wave number 1875.17 cm^{-1}, 1818.62 cm^{-1} and 1747.30 cm^{-1} functional group is Non-Conjugated, wave number 1688.63 cm^{-1} and 1629.81cm^{-1},functional group is Conjugated, wave number 1451.70 cm^{-1} and 1376.39 cm^{-1} functional group is CH_2 / CH_3 , wave number 1020.57 cm^{-1}, functional group is Acetates, wave number 991.30 cm^{-1}, functional group is Secondary Cyclic Alcohol and -CH=CH_2 etc. In the end of the spectrum phase wave number 730.02 cm^{-1} and , 702.02 cm^{-1}, functional group is -CH=CH-(cis) as well. Some of functional groups energy values are calculated, using formula is $E=h\upsilon$, Where h=Planks Constant, $h = 6.626 \times 10^{-34}$ J, υ= Frequency in Hertz (sec^{-1}), Where $\upsilon = c/\lambda$, c=Speed of light, where, $c = 3 \times 10^{10}$ m/s, $W = 1/\lambda$, where λ is wave length and W is wave number in cm^{-1}. Therefore the equation $E=h\upsilon$, can substitute by the following equation, E=hcW. According to their wave number such as for 2928.96 (cm^{-1}) calculated energy, $E = 5.81 \times 10^{-20}$ J. Similarly, wave number 1747.30 (cm^{-1}) energy, $E = 3.47 \times 10^{-20}$ J, wave number 1376.39 (cm^{-1}) energy, $E = 2.73 \times 10^{-20}$ J and eventually wave number 991.30 (cm^{-1}) functional group is 1.97×10^{-20} J respectively.

Table 13: Polystyrene waste plastic to liquid fuel ASTM test results

Name of Test Method	Name of Test	PS Waste Plastic to Fuel Results	Units
ASTM D240	Gross Heat of Combustion	16716	BTU/lb
ASTM D240	Gross Heat of Combustion (Calculated)	126590	BTU/gal
ASTM D4052	API Gravity @ 60°F	24.1	°API
ASTM D86-07b	IBP Recovery	124.4	°C
ASTM D86-07b	5% Recovery	130.0	°C
ASTM D86-07b	10% Recovery	134.4	°C
ASTM D86-07b	20% Recovery	137.8	°C
ASTM D86-07b	30% Recovery	140.0	°C
ASTM D86-07b	40% Recovery	142.2	°C
ASTM D86-07b	50% Recovery	144.4	°C
ASTM D86-07b	60% Recovery	147.8	°C
ASTM D86-07b	70% Recovery	152.2	°C
ASTM D86-07b	80% Recovery	168.9	°C
ASTM D86-07b	90% Recovery	292.2	°C
ASTM D86-07b	95% Recovery	322.2	°C
ASTM D86-07b	FBP Recovery	326.7	°C
ASTM D86-07b	Recovery	95.0	Vol%
ASTM D86-07b	Residue	4.2	Vol%
ASTM D2500	Cloud point	-11.2	°C
ASTM D2500	Cloud Point	11.8	°F
ASTM D97	Pour point	-45.0	°C
ASTM D97	Pour point	-49.0	°F
ASTM D2386	Freezing Point	-14.0	°C
ASTM D2386	Freezing Point	6.8	°F
ASTM D2624	Temperature	24.0	°C
ASTM D2624	Electrical Conductivity	1159	pS/M
ASTM D5453	Sulfur	1.3	Mg/kg
AST M D1500	ASTM Color	<6.0	
ASTM D4176	Appearance: Clean and Bright	Fail	
ASTM D4176	Free Water Content/Particles	No water	Mg/kg
ASTM D4176	Haze Rating	6.0	
ASTM D4176	Special Observation	Darker than usual	
ASTM D4737	Cetane Index by D4737 (Procedure A)	25.1	
ASTM D5708_MOD	Vanadium	<1.0	ppm
ASTM D5708_MOD	Nickel	<1.0	ppm
ASTM D5708_MOD	Iron	<1.0	ppm, or, mg/Kg
ASTM D482	Ash	<0.001	Wt%
ASTM D93	Procedure Used	A	
ASTM D93	Corrected Flash Point	32.0	°C
ASTM D4530	Average Micro Method Carbon Residue 10% distillation	0.4	Wt%
ASTM D664	Procedure Used	A	
ASTM D664	Acid Number	<0.10	mgKOH/gm
ASTM D130	Copper Corrosion @ 50°C (122°F)/3 hrs.	1a	
ASTM D2709	Sediment and Water	<0.005	Vol%
ASTM D5291	Carbon Content	98.85	Wt%
ASTM D5291	Hydrogen Content	8.68	Wt%
ASTM D5291	Nitrogen Content	<0.75	Wt%

Polystyrene waste plastic to liquid fuel (**Table 13**) was analysis from 3rd party Intertek laboratory, New Jersey, USA. All tests was performed according to American Standard Testing Method (ASTM) and test results are described below such as ASTM D240 Gross Heat of Combustion: 16716 BTU/lb, ASTM D240 Gross Heat of Combustion (Calculated): 126590 BTU/gal, ASTM D4052 API Gravity @ 60°F: 24.1 °API, ASTM D86-07b IBP Recovery: 124.4 °C, ASTM D86-07b 5% Recovery: 130.0 °C, ASTM D86-07b 10% Recovery: 134.4 °C, ASTM D86-07b 20% Recovery: 137.8 °C, ASTM D86-07b 30% Recovery: 140.0 °C, ASTM D86-07b 40% Recovery: 142.2 °C, ASTM D86-07b 50% Recovery: 144.4 °C, ASTM D86-07b 60% Recovery: 147.8 °C, ASTM D86-07b 70% Recovery: 152.2 °C, ASTM D86-07b 80% Recovery: 168.9 °C, ASTM D86-07b 90% Recovery: 292.2 °C, ASTM D86-07b 95% Recovery: 322.2 °C, ASTM D86-07b FBP Recovery: 326.7 °C, ASTM D86-07b Recovery: 95.0 Vol%, ASTM D86-07b Residue: 4.2 Vol%, ASTM D2500 Cloud point: -11.2 °C, ASTM D2500 Cloud Point:11.8 °F, ASTM D97 Pour point: -45.0 °C, ASTM D97 Pour point: -49.0 °F, ASTM D2386 Freezing Point: -14.0 °C, ASTM D2386 Freezing Point: 6.8 °F, ASTM D2624 Temperature: 24.0 °C, ASTM D2624 Electrical Conductivity: 1159 pS/M, ASTM D5453 Sulfur: 1.3 Mg/kg, AST M D1500 ASTM Color: <6.0, ASTM D4176 Appearance: Clean and Bright: Fail, ASTM D4176 Free Water Content/Particles : No water Mg/kg, ASTM D4176Haze Rating: 6.0 , ASTM D4176 Special Observation: Darker than usual, ASTM D4737 Cetane Index by D4737 (Procedure A): 25.1, ASTM D5708_MOD Vanadium: <1.0 ppm, ASTM D5708_MOD Nickel: <1.0 ppm, ASTM D5708_MOD Iron: <1.0 ppm, or, mg/Kg, ASTM D482 Ash: <0.001 Wt%, ASTM D93 Procedure UsedA and ASTM D93 Corrected Flash Point: 32.0 °C, ASTM D4530 Average Micro Method Carbon Residue 10% distillation: 0.4 Wt%, ASTM D664 Procedure Used A and ASTM D664 Acid Number : <0.10 mgKOH/gm, ASTM D130 Copper Corrosion @ 50°C (122°F)/3 hrs.: 1a, ASTM D2709 Sediment and Water: <0.005 Vol%, ASTM D5291 Carbon Content: 98.85 Wt%, ASTM D5291 Hydrogen Content: 8.68 Wt%, ASTM D5291 Nitrogen Content: <0.75 Wt%. In analysis sulfur result indicate that produce fuel sulfur content less than outside commercial fuel and also less then USA environmental protection agency (EPA) level. Produce fuel metal content showed negligible because produce fuel metal come from waste plastic used metal as additives. All metals melting point more than high from experimental temperature profile for that reason experimental temperature did not melt properly any metal from waste plastic. Whatever metal present into fuel it will not affect combustion engines.

Table 14: Polystyrene standard plastic to liquid fuel ASTM test results

Name of Test Method	Name of Test	PS Standard Plastic to Fuel Results	Units
ASTM D240	Gross Heat of Combustion	17359	BTU/lb
ASTM D240	Gross Heat of Combustion (Calculated)	132224	BTU/gal
ASTM D4052	API Gravity @ 60°F	23.2	°API
ASTM D86-07b	IBP Recovery	126.7	°C
ASTM D86-07b	5% Recovery	133.3	°C
ASTM D86-07b	10% Recovery	136.7	°C
ASTM D86-07b	20% Recovery	140.0	°C
ASTM D86-07b	30% Recovery	142.2	°C
ASTM D86-07b	40% Recovery	144.4	°C
ASTM D86-07b	50% Recovery	147.8	°C
ASTM D86-07b	60% Recovery	152.2	°C

ASTM D86-07b	70% Recovery	166.7	°C
ASTM D86-07b	80% Recovery	293.3	°C
ASTM D86-07b	90% Recovery	302.2	°C
ASTM D86-07b	95% Recovery	-	°C
ASTM D86-07b	FBP Recovery	304.4	°C
ASTM D86-07b	Recovery	92.0	Vol%
ASTM D86-07b	Residue	8.0	Vol%
ASTM D2500	Cloud point	-11.5	°C
ASTM D2500	Cloud Point	11.3	°F
ASTM D97	Pour point	<-57	°C
ASTM D97	Pour point	<-70.6	°F
ASTM D2386	Freezing Point	-21.3	°C
ASTM D2386	Freezing Point	-6.3	°F
ASTM D2624	Temperature	24.0	°C
ASTM D2624	Electrical Conductivity	582	pS/M
ASTM D5453	Sulfur	1.2	Mg/kg
ASTM D1500	ASTM Color	<4.5	
ASTM D4176	Appearance: Clean and Bright	Fail	
ASTM D4176	Free Water Content/Particles	No water particles	Mg/kg
ASTM D4176	Haze Rating	6.0	
ASTM D4176	Special Observation	Darker than usual	
ASTM D4737	Cetane Index by D4737 (Procedure A)	26.7	
ASTM D5708_MOD	Vanadium	<1.0	ppm
ASTM D5708_MOD	Nickel	<1.0	ppm
ASTM D5708_MOD	Iron	<1.0	ppm OR, mg/Kg
ASTM D482	Ash	<0.001	Wt%
ASTM D93	Procedure Used	A	
ASTM D93	Corrected Flash Point	33.0	°C
ASTM D4530	Average Micro Method Carbon Residue 10% distillation	0.2	Wt%
ASTM D664	Procedure Used	A	
ASTM D664	Acid Number	<0.10	mgKOH/gm
ASTM D130	Copper Corrosion @ 50°C (122°F)/3 hrs.	1a	
ASTM D2709	Sediment and Water	<0.005	Vol%
ASTM D5291	Carbon Content	91.66	Wt%
ASTM D5291	Hydrogen Content	8.27	Wt%
ASTM D5291	Nitrogen Content	<0.75	Wt%

Polystyrene standard plastic to liquid fuel (**Table 14**) was analysis by 3rd party Intertek laboratory, New Jersey, USA. Produce fuel was analysis by using American Standard Testing Method (ASTM) followed and results discuss such as ASTM D240 Gross Heat of Combustion: 17359 BTU/lb, ASTM D240 Gross Heat of Combustion (Calculated): 132224 BTU/gal, ASTM D4052 API Gravity @ 60°F: 23.2 °API, ASTM D86-07b IBP Recovery: 126.7 °C, ASTM D86-07b 5% Recovery: 133.3 °C, ASTM D86-07b 10% Recovery: 136.7 °C, ASTM D86-07b 20% Recovery: 140.0 °C, ASTM D86-07b 30% Recovery: 142.2 °C, ASTM D86-07b 40% Recovery: 144.4 °C, ASTM D86-07b 50% Recovery: 147.8 °C, ASTM D86-07b 60% Recovery: 152.2 °C, ASTM D86-07b 70% Recovery : 166.7 °C, ASTM D86-07b 80% Recovery: 293.3 °C, ASTM D86-07b 90% Recovery: 302.2 °C, ASTM D86-07b 95% Recovery: - °C, ASTM D86-07b FBP Recovery: 304.4 °C, ASTM D86-07b Recovery: 92.0 Vol%, ASTM D86-07b Residue:8.0 Vol%, ASTM D2500 Cloud point: -11.5 °C, ASTM D2500 Cloud Point: 11.3 °F, ASTM D97 Pour point: <-57 °C, ASTM D97 Pour point: <-70.6 °F, ASTM D2386 Freezing Point: -21.3 °C, ASTM

D2386 Freezing Point: -6.3 °F, ASTM D2624 Temperature: 24.0 °C, ASTM D2624 Electrical Conductivity: 582 pS/M, ASTM D5453 Sulfur: 1.2 Mg/kg, ASTM D1500 ASTM Color: <4.5, ASTM D4176 Appearance Clean and Bright: Fail, ASTM D4176 Free Water Content/Particles: No water particles Mg/kg, ASTM D4176 Haze Rating: 6.0, ASTM D4176 Special Observation: Darker than usual, ASTM D4737 Cetane Index by D4737 (Procedure A): 26.7, ASTM D5708_MOD Vanadium: <1.0 ppm, ASTM D5708_MOD Nickel: <1.0 ppm, ASTM D5708_MOD Iron: <1.0ppm OR, mg/Kg, ASTM D482 Ash: <0.001 Wt%, ASTM D93 Procedure Used A and ASTM D93 Corrected Flash Point: 33.0 °C, ASTM D4530 Average Micro Method Carbon Residue 10% distillation: 0.2 Wt%, ASTM D664 Procedure Used A and ASTM D664 Acid Number: <0.10 mgKOH/gm, ASTM D130 Copper Corrosion @ 50°C (122°F)/3 hrs.: 1a, ASTM D2709 Sediment and Water: <0.005 Vol%, ASTM D5291 Carbon Content: 91.66 Wt%, ASTM D5291 Hydrogen Content: 8.27 Wt%, ASTM D5291 Nitrogen Content: <0.75 Wt%.

3.4 Residue Analysis

Table 15: Polystyrene waste plastic and polystyrene standard plastic to solid black residue analysis results by ICP

Name of Test Method	Name of Trace Metal	PS Standard Plastic to Residue (ppm)	PS Waste Plastic to Residue (ppm)
ASTM D1976	Silver	<1.0	<1.0
	Aluminum	<1.0	<1.0
	Arsenic	<1.0	<1.0
	Boron	<1.0	3.9
	Barium	<1.0	<1.0
	Beryllium	<1.0	<1.0
	Calcium	<1.0	<1.0
	Cadmium	<1.0	<1.0
	Chromium	<1.0	<1.0
	Copper	<1.0	3.5
	Iron	17.2	219.9
	Potassium	<1.0	70.5
	Lithium	<1.0	<1.0
	Magnesium	<1.0	<1.0
	Manganese	<1.0	8.2
	Sodium	<1.0	303.6
	Nickel	<1.0	4.9
	Lead	<1.0	<1.0
	Antimony	<1.0	<1.0
	Selenium	<1.0	<1.0
	Silicon	<1.0	35.4
	Tin	<1.0	<1.0
	Titanium	<1.0	<1.0
	Vanadium	<1.0	<1.0
	Zinc	<1.0	86.0

Polystyrene standard plastic to fuel production period some percentage of solid black residue was leftover and leftover residue was (**Table 15**) analyzed by ICP and ASTM test method was followed by ASTM D1976. Residue analysis result showed residue has different types of trace metal some metal was detected with ppm level such as Silver : <1.0 ppm, Aluminum: <1.0 ppm, Arsenic: <1.0 ppm, Boron: <1.0 ppm, Barium: <1.0 ppm, Beryllium: <1.0

ppm, Calcium: <1.0 ppm, Cadmium: <1.0 ppm, Chromium: <1.0 ppm, Copper: <1.0 ppm, Iron: 17.2 ppm, Potassium: <1.0 ppm, Lithium: <1.0 ppm, Magnesium: <1.0 ppm, Manganese: <1.0 ppm, Sodium: <1.0 ppm, Nickel: <1.0 ppm, Lead: <1.0 ppm, Antimony: <1.0 ppm, Selenium: <1.0 ppm, Silicon: <1.0 ppm, Tin: <1.0 ppm, Titanium: <1.0 ppm, Vanadium: <1.0 ppm, Zinc: <1.0 ppm. On the other hand Polystyrene waste plastic to fuel production period also generated some percentage residue and residue was analyzed by ICP and ASTM test method followed ASTM D1976. General trace metal detected from left over residue and showed ppm level such as Silver: <1.0 ppm, Aluminum: <1.0 ppm, Arsenic: <1.0 ppm, Boron: 3.9 ppm, Barium: <1.0 ppm, Beryllium: <1.0 ppm, Calcium: <1.0 ppm, Cadmium: <1.0 ppm, Chromium: <1.0 ppm, Copper: 3.5 ppm, Iron: 219.9 ppm, Potassium: 70.5 ppm, Lithium: <1.0 ppm, Magnesium: <1.0 ppm, Manganese: 8.2 ppm, Sodium: 303.6 ppm, Nickel: 4.9 ppm, Lead: <1.0 ppm, Antimony: <1.0 ppm, Selenium: <1.0 ppm, Silicon: 35.4 ppm, Tin: <1.0 ppm, Titanium: <1.0 ppm, Vanadium<1.0 ppm, Zinc: 86.0 ppm. In this analysis results indicate that standard plastic residue has less amount of trace metal then polystyrene waste plastic to residue. Above all trace metal was detected from left over residue and residue can be use for roof carpeting or road carpeting. Solid black residue could be use in nano tube technology but need to be separate metal part from residue. Residue has good Btu value and it's could be use for power plant.

Table 16: Polystyrene waste plastic and polystyrene standard plastic to solid black residue C, H and N % by EA-2400 (CHN mode)

Name of Test Method	Name of Plastics Residue	Carbon %	Hydrogen %	Nitrogen %
ASTM D5291.a	PS Waste Plastic to Residue	52.62	1.04	<0.30
	PS Standard Plastic to Residue	75.10	4.01	<0.30

Polystyrene waste plastic and polystyrene standard plastic to residue were analyzed by EA-2400 (CHN mode) and test method was followed ASTM D5291.a. ASTM test result showed **Table 16** polystyrene waste plastic to residue carbon percentage is 52.62%, hydrogen percentage is 1.04% and nitrogen percentage is <0.30%. Polystyrene standard plastic to residue carbon percentage is 75.10%, hydrogen percentage is 4.01% and nitrogen percentage is <0.30%. Polystyrene waste plastic to residue carbon percentage was less then polystyrene standard plastic to residue carbon percentage. In this analysis results indicate that both experimental left over residue carbon percentage more than 50%. This type of residue could be reuse as catalyst for waste plastic to fuel production purpose because in analysis results showed carbon percentage is high. Residue has also metal content that metal content can be performed as a catalyst during waste plastic to fuel production.

4. Environmental Impact

Today waste plastics are a major source of hazardous environmental problems all over the World. Waste plastics severely affect our natural environment in a diversified way. Experimentally it has been found that compositions of waste plastics are harmful and hazardous. Utilizing NSR technology these diversified problems can be solved

forever. Waste plastics are disposed into the water body whereby aquatic organism including birds and mammal are severely affected. Eventually some of the species are in en-danger situations. NSR technology can convert these waste plastic into valuable hydrocarbon liquid fuels for combustion engines. Solid Waste management is another major environmental problem Worldwide. The United State of America alone produces about 48 million tons / year of solid waste plastics. Waste plastics are non biodegradable solid waste, it affects hydrology and vegetation also enhances the contamination process of underground water. By converting these solid waste plastics the USA alone can produce around 2.4 billion barrel of liquid hydrocarbon fuel. Job scarcity is another major problem all over the World including the USA. The NSR process of converting waste plastics into fuel is a new arena to solve environmental problems as well as create new jobs in each major city and town of the USA. The energy crisis is a major global issue as well as source energy is limited. Each development activity of modern civilization is dependent on energy. Governments and individual entrepreneurs can implement the NSR developed process. It will mitigate some environmental problems and enhance additional alternative energy sources. Plastic doesn't need to ban because it can create job sector all over the World. Every plastic manufacturing company need man power for consumer plastic production. City and municipality doesn't need to spent huge amount of money for waste plastic dumping by using Natural State Research technology can convert all plastic into liquid hydrocarbon fuel. This technology can save city municipality waste plastic dumping cost and reduce some foreign oil dependency. All over the world are generating 280 million ton waste plastics each year and 9% occupy polystyrene waste plastic. All waste plastics can be converting into liquid hydrocarbon fuel for internal combustion engines and produce electricity.

5. Economical Benefit

Polystyrene waste plastic to fuel production input electricity was 6.66 kWh and polystyrene standard plastic to fuel production input electricity was 6.65 kWh. Both experiments input electricity almost same. Polystyrene waste plastic to fuel production input electricity 6.66 kWh for 802.9 gm fuel or 985 ml fuel. Polystyrene waste plastic to one gallon production fuel input electricity need 25.69 kWh and 1gallon fuel output electricity from BTU analysis result 37.09 kWh. Polystyrene waste plastic to fuel production was laboratory batch scale and it was not commercial stage and still output electricity higher then input electricity. Same as polystyrene standard plastic to one gallon fuel production input electricity 25.78 kWh and one gallon fuel output electricity from BTU value 38.75 kWh. Both experiments were conducted in laboratory scale and both processes were batch process. When it will go to commercial facility that time one gallon fuel production input electricity will be less and production cost will be less. Raw materials are abundant everywhere and its can be get free of cost from city or municipality and based on raw material viability production cost will be less. In this technology one time need electricity from grid to start process then rest of time doesn't need grid electricity because during fuel production period light gas generation also those light gas can be use as heat source. One time used electricity to fuel production then produce fuel to electricity generation that generated electricity can be use whole fuel production plant. Based on this technology to fuel production cost will be less for every plant because it was tested and proved from Natural State Research facilities.

6. Conclusion

Polystyrene waste plastic and polystyrene standard plastic into fuel production temperature were use 100-400 ºC. Laboratory batch process experiments were conducted and raw sample was 1000 gm for each experiments. Without catalyst and without vacuumed system experiments were performed successfully. Polystyrene waste plastic to fuel density is 0.81 g/ml, polystyrene standard plastic to fuel density is 0.81 g/ml. in GC/MS analysis results indicate that polystyrene waste plastic to fuel carbon range C_6 to C_{23} and polystyrene standard plastic to fuel carbon range C_4 to C_{24}. Both fuels has aromatic derivative and aliphatic group because initial raw materials was same one was polystyrene waste plastic and another was polystyrene standard plastic. Polystyrene waste plastics come from consumer use and standard plastic come from Sigma Aldrich Company. Polystyrene standard plastic was fully analytical grade and polystyrene waste plastic was collected from local city. Two types of plastic was investigated with different types of equipment such as GC/MS, FT-IR, ICP, EA-2400, TGA, etc.. Above all result indicate that consumer use plastic like polystyrene waste plastic and analytical grade standard plastic fully different. By using this technology polystyrene waste plastic can convert into liquid hydrocarbon fuel for next generation and as well as save the environmental problems. If this technology use all over the World then doesn't need to plastic company ban because this technology can convert all waste plastic into liquid hydrocarbon fuel at lower cost. Its can boost up renewable or alternative energy sector and reduce some percentage foreign oil depended. This produce fuel can use internal combustion engine, feed for feed stock refinery, electricity generation or feed for power plant.

Acknowledgement

The authors acknowledge the support of Dr. Karin Kaufman, the founder and sole owner of Natural State Research, Inc. The authors also acknowledge the valuable contributions NSR laboratory team members during the preparation of this manuscript.

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