Fuels, chemicals and materials from waste

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UK Waste: 288.5 Million Tonnes/Year

- Household: 31.5 Mt/y
- Commercial & Industrial: 67.3 Mt/y
- Mining & Quarrying: 86 Mt/y
- Construction & Demolition: 101 Mt/y
- Other

Defra (2008)
EU-27 Waste Generation

- Mining: 728 Mt
- Manufacturing: 343 Mt
- Energy Sector: 92 Mt
- Waste & Water Management: 191 Mt
- Construction: 862 Mt
- Households: 223 Mt
- Agriculture: 45 Mt
- Others: 139 Mt

2.62 Billion Tonnes/year

European Commission Eurostat (2008)

MSW Treatment – EU-27 (2009)

Waste management

- Landfilled
- Recycled/composted/other
- Incinerated

EU-27
UK Household Waste: Treatment

Currently:
- Landfill - 49%
- Incineration with energy recovery - 11%
- Recycling/Composting - 39%

The Hierarchy of Waste Management
Thermal conversion technologies

- **Incineration** (e.g. 1100 °C)
  - Flue gas + ash
- **Gasification** (e.g. 800 °C)
  - Syngas + ash
- **Pyrolysis** (e.g. 500 °C)
  - Oil + char + gas

Contents

- **Pyrolysis**
  - Pyrolysis technologies
  - Commercial pyrolysis plants
- **Gasification**
  - Gasification technologies
  - Commercial gasification plants
- **Valorization of waste**
  - Higher value products from wastes

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Pyrolysis

Pyrolysis - The thermal degradation of organic waste in the absence of oxygen to produce a carbonaceous char, oil and combustible gases

![Pyrolysis diagram]

- Gas
- Liquid
- Char
- Fuel
- Chemical feedstock
- Liquid fuel
- Refinery feedstock
- Chemicals
- Solid fuel
- Activated carbon
- Soil improver
### Pyrolysis: Technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Residence time</th>
<th>Heating rate</th>
<th>Temp (°C)</th>
<th>Major products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow pyrolysis</td>
<td>Hours - days</td>
<td>Very low</td>
<td>300 - 500</td>
<td>Charcoal</td>
</tr>
<tr>
<td>Conventional pyrolysis</td>
<td>5 – 30 min</td>
<td>Medium</td>
<td>400 - 600</td>
<td>Char, liquids, syngas</td>
</tr>
<tr>
<td>Conventional pyrolysis</td>
<td>5 – 30 min</td>
<td>Medium</td>
<td>700 - 900</td>
<td>Char, syngas</td>
</tr>
<tr>
<td>Fast pyrolysis</td>
<td>0.1 – 2 sec</td>
<td>High</td>
<td>400 - 650</td>
<td>Liquids</td>
</tr>
<tr>
<td>Fast pyrolysis</td>
<td>&lt; 1 sec</td>
<td>High</td>
<td>650 - 900</td>
<td>Liquids, syngas</td>
</tr>
<tr>
<td>Fast pyrolysis</td>
<td>&lt; 1 sec</td>
<td>Very high</td>
<td>1000 - 3000</td>
<td>Syngas</td>
</tr>
</tbody>
</table>

The terms “slow pyrolysis”, “fast pyrolysis” or “flash pyrolysis” are somewhat arbitrary and have no precise definition of the times or heating rates for each process. "Fast pyrolysis" and "flash pyrolysis" sometimes are all characterized as "fast pyrolysis".

### Pyrolysis reactors

<table>
<thead>
<tr>
<th>Reactor Type</th>
<th>Heating Method</th>
<th>Heating Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluidised Bed</td>
<td>Heated recycle gas</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Firetubes</td>
<td>Moderate</td>
</tr>
<tr>
<td>Entrained Flow</td>
<td>Recycled hot sand</td>
<td>High</td>
</tr>
<tr>
<td>Fixed Bed</td>
<td>Heated recycle gas</td>
<td>Low</td>
</tr>
<tr>
<td>Rotary Kiln</td>
<td>Wall heating</td>
<td>Low</td>
</tr>
</tbody>
</table>
Biomass Fast pyrolysis: Bio-oil

- Very high heating rates and heat transfer rate to waste materials
- Carefully controlled pyrolysis temperature (e.g. 500 °C) to maximise the liquid yield
- Short hot vapour residence times - Rapid removal of the pyrolysis vapours from the hot zone
- Rapid cooling of the pyrolysis vapours to generate bio-oil
- Bio-oil production up to 70wt%

Some Processes;
Dynamotive, Fluidised bed process

[Diagram showing Biomass Fast pyrolysis process]
Ensyn entrained flow reactor

Bio-oil from fast pyrolysis

- Potential substitute for fuel oil and as a feedstock for production of synthetic gasoline or diesel fuel

*However the bio-oil properties;*

- High acidity
- Corrosive
- Poor stability
- High content oxygenated organic compounds
- Low heating value
Bio-oil Fuel Specifications

<table>
<thead>
<tr>
<th>Bio-oil fuel specifications</th>
<th>No2 Fuel</th>
<th>Ensyn bio-oil</th>
<th>Union Fenosa bio-oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feedstock</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture %</td>
<td>0</td>
<td>19</td>
<td>23</td>
</tr>
<tr>
<td>HHV MJ/kg</td>
<td>45</td>
<td>25</td>
<td>21</td>
</tr>
<tr>
<td>Viscosity cSt</td>
<td>2.7 (40 C)</td>
<td>1154 (25 C)</td>
<td>579 (25 C)</td>
</tr>
<tr>
<td>Solids %</td>
<td>0.05</td>
<td>0.65</td>
<td>0.94</td>
</tr>
<tr>
<td>Carbon</td>
<td>86.94</td>
<td>59.46</td>
<td>58.08</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>12.48</td>
<td>6.22</td>
<td>5.97</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.02</td>
<td>0.06</td>
<td>-</td>
</tr>
<tr>
<td>Sulphur</td>
<td>0.3</td>
<td>0.016</td>
<td>0.1</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0.17</td>
<td>34.26</td>
<td>35.68</td>
</tr>
</tbody>
</table>

Composition

- Organic acids: 5-10 wt%
- Aldehydes and hydroxyldehydes: 5 - 20 wt%
- Ketones and hydroxyketones: 0 – 10 wt%
- Phenolics: 20 – 30 wt%
- Water: 15 – 30 wt%

Example of compounds of bio-oil from screw kiln pyrolysis of pine wood
Bio-oil upgrading

Catalytic cracking: Catalyst, 300-500 °C

Hydrodeoxygenation: Catalyst + H₂, 70-150 °C, Pressure e.g. 40 Bar

Some Processes;

Plastics Pyrolysis

MCC Ltd., Yukaki, Japan
Mogami-Kiko Co., Ltd, Yamagata, Japan
Environment System Co., Ltd., Gunma, Japan
Small scale, batch pyrolysis for plastics pyrolysis

e.g. Mogami-Kiko Co., Ltd., Yamagata, Japan

Toshiba Mixed plastics pyrolysis, Sapporo, Japan

- Rotary kiln technology
- Mixed plastics from MSW
- 14,000 tpa (40 tpd – 2 lines)
- Pyrolysis oil & gas output
- HCl recovery from PVC
Splainex, Ltd, Netherlands

Pyrolysis of various wastes

- Rotary kiln technology
- Tyre, plastics, sewage sludge, MSW
- 7,000-150,000 tpa
- Pyrolysis oil & char output
- Electricity generation

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  - Commercial gasification plants
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Fuels, chemicals and materials from waste
Gasification Reactions

Gasification – The partial oxidation of waste in which organic compounds are converted to a syngas comprising CO, H₂, CH₄, tar and ash

**Solid-Gas Reactions**

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Description</th>
<th>Endothermic/Exothermic</th>
</tr>
</thead>
<tbody>
<tr>
<td>C + ½O₂ → CO</td>
<td>partial combustion</td>
<td>exothermic</td>
</tr>
<tr>
<td>C + O₂ → CO₂</td>
<td>combustion</td>
<td>exothermic</td>
</tr>
<tr>
<td>C + 2H₂ → CH₄</td>
<td>hydrogasification</td>
<td>exothermic</td>
</tr>
<tr>
<td>C + H₂O → CO + H₂</td>
<td>water-gas</td>
<td>endothermic</td>
</tr>
<tr>
<td>C + CO₂ → 2CO</td>
<td>Boudouard</td>
<td>endothermic</td>
</tr>
</tbody>
</table>

**Gas-Gas Reactions**

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Description</th>
<th>Endothermic/Exothermic</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO + H₂O → CO₂ + H₂</td>
<td>shift</td>
<td>exothermic</td>
</tr>
<tr>
<td>CO + 3H₂ → CH₄ + H₂O</td>
<td></td>
<td>exothermic</td>
</tr>
</tbody>
</table>

Gasification Reactor Designs

<table>
<thead>
<tr>
<th>Reactor Type</th>
<th>Mode of contact</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fixed Bed</strong></td>
<td>Solids move ↓, Gas moves ↓, ie: co-current</td>
</tr>
<tr>
<td>Downdraft</td>
<td></td>
</tr>
<tr>
<td>Updraft</td>
<td>Solids move ↓, Gas moves ↑, ie: counter-current</td>
</tr>
<tr>
<td>Cross-draft</td>
<td>Solids move ↓, Gas moves at right angles ie: ← or →</td>
</tr>
<tr>
<td><strong>Fluidised Bed</strong></td>
<td>Relatively low gas velocity, inert solid stays in reactor</td>
</tr>
<tr>
<td>Bubbling</td>
<td>Much higher gas velocities, inert solid is elutriated, separated and re-circulated</td>
</tr>
<tr>
<td>Circulating</td>
<td></td>
</tr>
<tr>
<td><strong>Moving Bed</strong></td>
<td>Mechanical transport of solid, usually horizontal. Typically used for lower temperature processes, ie: pyrolysis</td>
</tr>
<tr>
<td>Variants</td>
<td>Multiple hearth, Horizontal moving bed, sloping hearth, screw/augur kiln</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>Usually there is an inert solid, has highest gas velocity of lean phase systems</td>
</tr>
<tr>
<td>Entrained bed</td>
<td>Good gas-solid contact</td>
</tr>
<tr>
<td>Rotary kiln</td>
<td>High particle velocities and turbulence to effect high reaction rates</td>
</tr>
<tr>
<td>Cyclonic reactor</td>
<td></td>
</tr>
</tbody>
</table>
Syngas

Syngas can be used to produce Fuel, Power and Heat

However: tar content & fine particulates, pollutants such as SOx etc. are challenges for the subsequent process after the gasification of waste

Combustion of the ‘dirty’ syngas in a conventional boiler or thermal oxidizer → produce steam → power (Lower Net Efficiency 10-20%)

Cleaning of the syngas to produce a ‘clean’ fuel gas → power via gas engines or turbines (Higher Net Efficiency 13-28%)

Tar

A dark, oily, viscous material, consisting mainly of high molecular weight hydrocarbons: Causes blockages, plugging and corrosion in downstream fuel lines, filters, engine nozzles etc

**Methods to reduce/remove tar:**

*Primary:*
  - High-temperature gasification
  - Add bed materials such as dolomite

*Secondary:*
  - Hot gas filters
  - Wet scrubbers
  - Catalytic cracking
Gasification plants processing MSW

Operating plants by supplier (country of origin)

111 Plants in 8 Countries

(Source Whiting–WSP, 2010)

Syngas end-use

Gas engine (13-28% Net Efficiency)
Chemicals
Over-the-fence
Steam cycle (10-20% Net Efficiency)

111 Plants in 8 Countries

(Source Whiting–WSP, 2010)
Some processes;

**Ebara TwinRec Gasifier**
- Combined gasification and melting process
- Fluidised bed and ash melting process
- 12 commercial plants in Japan
  - 3 mixed wastes and 9 for MSW
  - Capacities range from 19,000 to 165,000 tpa

Ebara TIFG, Kawaguchi, Japan, 2002, 125,000 Tpa

**Nippon Steel**
- Vertical shaft fixed bed updraft, slagging gasifier
- Municipal solid waste
- Produces ‘dirty’ syngas - combusted for steam for power generation
  - slag for recycling as construction aggregate
- 30 plants operating

Nippon Steel, Ibaraki, Japan, 1980, 135,000 Tpa

**Mitsui R21 Process**
- Gasification with high temperature combustion and slagging
- Municipal solid waste
- Mitsui and Takuma (Japanese licensees)
- 7 plants in total (largest 135 kTpa)

Mitsui R21, Toyohashi, Japan, 2002, 120,000 Tpa
Combined Pyrolysis-Gasification

**Thermoselect**
- Two stage pyrolysis-gasification
- Municipal solid waste, industrial waste
- Syngas - combusted for steam for power generation
- 6 plants operating
  Thermoselect, Chiba, Japan, 100,000 tpa

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Fuels, chemicals and materials from waste
“VALORIZATION OF WASTE”

“Transformation of waste to energy, fuels, and other useful materials”

Valorization of Waste

Examples;

1. Tyres
2. Plastics
3. Composite waste
1. Waste Tyres

World
13.5 Million Tonnes/year
(1000 Million Tyres/year)

Europe
2.7 Million Tonnes/year
(200 Million Tyres/year)

Pyrolysis of Tyres

Fuel Test | Tyre Oil | Gas Oil | Light Fuel Oil
---|---|---|---
CV MJ/kg | 42.1 | 46.0 | 44.8
Viscosity 60 °C | 2.38 | 1.3 | 4.3
40 °C | 6.30 | 3.3 | 21.0
Initial B.Pt. | 100 | 180 | 200
10% B.Pt | 140 | - | -
50% B.Pt. | 264 | 300 | 347
90% B.Pt. | 355 | - | -
Hydrogen % | 9.4 | 12.6 | 12.4
Carbon % | 88.0 | 87.1 | 85.5
Sulphur % | 1.45 | 0.2 | 1.4
Nitrogen % | 0.45 | 0.05 | 0.15
Carbon residue | 2.2 | 0.35 | -
Flash point °C | 20 | 75 | 79

Typical char properties

Char Test | Tyre Char
---|---
CV MJ/kg | 30.5
Moisture content % | 0.4
Volatiles % | 2.8
Ash content % | 11.9
Carbon % | 94.6
Hydrogen % | 1.1
Nitrogen % | 0.7
Sulphur % | 2.4
Surface area m²/g | 67

Gas composition (wt%)

| Hydrogen | 0.25 |
| Carbon monoxide | 0.22 |
| Carbon dioxide | 0.60 |
| Methane | 0.96 |
| Ethane | 0.51 |
| Ethene | 0.40 |
| Propane | 0.43 |
| Propene | 0.60 |
| Butadiene | 2.13 |
| Other C4 hydrocarbons | 0.37 |
| Total | 4.27 |
**Tyre oil composition**

<table>
<thead>
<tr>
<th>Peak</th>
<th>Compound</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Cyclopentanone</td>
</tr>
<tr>
<td>2.</td>
<td>Dimethylcyclopentanone</td>
</tr>
<tr>
<td>3.</td>
<td>Ethylbenzene</td>
</tr>
<tr>
<td>4.</td>
<td>Xylene</td>
</tr>
<tr>
<td>5.</td>
<td>Styrene</td>
</tr>
<tr>
<td>6.</td>
<td>Ethylmethylbenzene</td>
</tr>
<tr>
<td>7.</td>
<td>Methylstyrene</td>
</tr>
<tr>
<td>8.</td>
<td>Benzonitrile</td>
</tr>
<tr>
<td>9.</td>
<td>Limonene</td>
</tr>
<tr>
<td>10.</td>
<td>Terpinolene</td>
</tr>
<tr>
<td>11.</td>
<td>Methylbenzonitrile</td>
</tr>
<tr>
<td>12.</td>
<td>Benzoic acid</td>
</tr>
<tr>
<td>13.</td>
<td>Benzothiazole</td>
</tr>
<tr>
<td>14.</td>
<td>Caprolactama</td>
</tr>
<tr>
<td>15.</td>
<td>Methylnaphthalene</td>
</tr>
<tr>
<td>16.</td>
<td>Dimethylnaphthalene</td>
</tr>
<tr>
<td>17.</td>
<td>Pentadecene</td>
</tr>
<tr>
<td>18.</td>
<td>Trimethylnaphthalene</td>
</tr>
<tr>
<td>19.</td>
<td>Heptadecene</td>
</tr>
<tr>
<td>20.</td>
<td>N-hexylbenzamide</td>
</tr>
<tr>
<td>21.</td>
<td>Hexadecanitrile</td>
</tr>
<tr>
<td>22.</td>
<td>Heptadecanitrile</td>
</tr>
</tbody>
</table>

**Catalytic pyrolysis of Tyres: Fuels & Chemicals**

- **Fluidised bed catalytic pyrolysis**
  - Reactor – Fluidised bed
  - Waste - Tyres
  - Catalysts – Zeolite ZSM-5, Y Zeolite
  - Temperature – 500 °C
  - Bed catalyst loading 2.5 – 10 wt%
Production of premium grade fuels or chemicals;
Catalytic pyrolysis of tyres

Oil Composition Zeolite ZSM-5
Fluidised bed

Oil Composition Y Zeolite
Fixed bed

Char: Production of activated carbons from tyres

Surface area in relation to carbon ‘burn-off’

Porosity of activated carbon in relation to carbon ‘burn-off’
# 2. Waste plastics

## World Plastics Production
- **245 Million Tonnes/year**

## Europe Plastics Production
- **60 Million Tonnes/year**

---

### Plastics pyrolysis: Product Yield & Gas Composition

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Reactor Type</th>
<th>Temperature (°C)</th>
<th>Gas* (wt%)</th>
<th>Oil/Wax (wt%)</th>
<th>Char (wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic Mixture</td>
<td>Vacuum</td>
<td>520</td>
<td>6.1</td>
<td>90.8</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>Fixed bed</td>
<td>700†</td>
<td>9.6</td>
<td>75.1</td>
<td>2.9</td>
</tr>
<tr>
<td>Plastic mixture</td>
<td>Fixed bed</td>
<td>600</td>
<td>44.7</td>
<td>45.2</td>
<td>7.6</td>
</tr>
<tr>
<td>Plastic mixture</td>
<td>Fixed bed</td>
<td>580</td>
<td>88.2</td>
<td>12.5</td>
<td>3.0</td>
</tr>
<tr>
<td>MSW Plastic</td>
<td>Fluidized bed</td>
<td>787</td>
<td>43.6</td>
<td>26.4</td>
<td>25.4</td>
</tr>
<tr>
<td>MSW Plastic</td>
<td>Fixed bed</td>
<td>430</td>
<td>25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Gas Composition

- **Product yield**

---

## Reactor Type
- **H₂ (wt%)**
- **CH₄ (wt%)**
- **C₂H₆ (wt%)**
- **C₂H₄ (wt%)**
- **C₃H₈ (wt%)**
- **C₃H₆ (wt%)**
- **C₄H₁₀ (wt%)**
- **C₄H₈ (wt%)**
- **CO₂ (wt%)**
- **CO (wt%)**
- **HCl (wt%)**
- **H₂O (wt%)**
- **N₂ (wt%)**
- **O₂ (wt%)**
- **CH₃OH (wt%)**
Oil Analysis: Pyrolysis of plastics

Oil Composition

Fuel properties

<table>
<thead>
<tr>
<th>Property</th>
<th>PE</th>
<th>PP</th>
<th>PS</th>
<th>Nylon</th>
<th>PP 50%</th>
<th>PE 43%</th>
<th>Nylon 7%</th>
<th>Polyester</th>
<th>Styrene copolymer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flash point (°C)</td>
<td>33.6</td>
<td>27.8</td>
<td>26.1</td>
<td>34.8</td>
<td>26.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pour point (°C)</td>
<td>2.7</td>
<td>-39</td>
<td>-67</td>
<td>-28</td>
<td>-5.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water content (ppm)</td>
<td>0.18</td>
<td>0.13</td>
<td>0.67</td>
<td>2500</td>
<td>310</td>
<td>0.53</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash (w%)</td>
<td>0.013</td>
<td>0.010</td>
<td>0.006</td>
<td>0.018</td>
<td>0.001</td>
<td>0.013</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Viscosity (cst 50 ºC)</td>
<td>2.19</td>
<td>1.9</td>
<td>1.4</td>
<td>1.8</td>
<td>1.485</td>
<td>3.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>0.858</td>
<td>0.792</td>
<td>0.960</td>
<td>0.926</td>
<td>0.799</td>
<td>0.83</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cetane rating</td>
<td>-</td>
<td>56.8</td>
<td>-</td>
<td>12.6</td>
<td>-</td>
<td>54.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon (w%)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>86.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen (w%)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>7.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulphur (w%)</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.013</td>
<td>0.0</td>
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<tr>
<td>Initial B.Pt (°C)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>75</td>
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<tr>
<td>10% B.Pt (°C)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>93</td>
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<tr>
<td>50% B.Pt (°C)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>189</td>
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<tr>
<td>90% B.Pt. (°C)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>35.4</td>
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<tr>
<td>CV (MJ/Kg)</td>
<td>52.3</td>
<td>53.4</td>
<td>50.4</td>
<td>44.4</td>
<td>46.3</td>
<td>33.6</td>
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Production of hydrogen: Two-Stage Pyrolysis-Catalytic gasification

- Reactor – Screw kiln
- Plastic – Polypropylene
- Pyrolysis temperature – 500 ºC
- Gasification temperature – 800 ºC
- Catalysts – Ni based – with steam
Coke deposition on the surface of catalyst

TGA-TPO and DTG-TPO of the reacted catalysts

Layered type carbon deposits

Filamentaeous carbon deposits

3. Composite plastic waste

Layered type carbon deposits

Catalyst

Carbons

Composite plastic waste
Recycling process for glass fibre reinforced composite plastic waste

![Diagram of recycling process]

Recovered Glass Fibre

- Virgin Glass Fibre
- Recovered Glass Fibre

![Graph showing fibre tests comparison]

Recovered Glass Fibre: Strength Tests
Recovery and re-use of glass fibre

(a) Carbon fibre/resin waste
(b) Solid pyrolysis residue
(c) Recovered carbon fibres

Virgin Carbon Fibre
Recovered Carbon Fibre

Scanning electron microscopy

Carbon Fibre/Plastic Composite Waste

Virgin fibre
Recovered fibre

Breaking force
Elongation
Tensile strength
Young’s modulus

Recovered Carbon Fibre: Strength Tests
Activated Carbon Fibre

Steam activation of recovered carbon fibre

Conclusions

- Enormous research and interest in pyrolysis & gasification of biomass & waste
- Commercialization of some processes
- Upgrading is needed for biomass pyrolysis oils
- Tar reduction is a key problem for gasification
- Increasing interest in higher value products from waste
Fuels, chemicals and materials from waste

Professor Paul T. Williams

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