From Biomass/Waste to Valuable Chemicals and Fuels via Gasification and Pyrolysis

Prof. Maria Olea
School of Science & Engineering
Teesside University
e-mail: M.Olea@tees.ac.uk
Biomass Program

- Reduce dependence upon Fossil Fuels
- Realization of the Industrial Biorefinery

1 year

- Plant growth through photosynthesis
- Renewable biomass
- CHOREN-Carbo-Y® Process + Shell SMDS

24 hours

- Energy source
  - The sun

400 million years

- Plant growth through photosynthesis
- Fossil energy fuels are created
- Exploitation of exhaustible resources
- Current fuels: Gasoline / diesel

http://www.choren.com
Develop

Sustainable chemical technologies

Through

Sustainable design (environmental design)

Comply

Sustainability
Sustainable chemical technologies

“...use less energy, fewer limited resources, do not deplete natural resources, do not directly or indirectly pollute the environment, and can be reused or recycled at the end of their useful life”.

http://www.chemistryinnovation.co.uk/roadmap/sustainable/roadmap.asp, accessed on the 2nd of March 2010
Latin *sustinere* (*tenere*, to hold; *sus*, up).

“Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs…and requires the reconciliation of environmental, social and economic demands

(“three pillars" of sustainability )”


Anything that can be made from fossil fuels and petroleum products - can also be made from biomass.

BIOMASS = CH_{1.4}O_{0.6}

Building blocks/renewable sources of energy from biomass:
- biogas (anaerobic digestion)
- bio syngas (gasification, pyrolysis, catalytic conversion of biogas)
- bio oil (rapeseed oil)
- glycerol (biodiesel byproduct)
- pyrolysis oil (bio oil)
Woody biomass

Agricultural residue biomass

Municipal solid waste
Environmental impacts

- 0.48 MJ – to produce 1 HDPE plastic bag*

8.7 bags ≡ 1 Km

- UK - if 50% of 40 million shoppers/year, use other types of bags rather than plastic (13 billion/year), 151,000 tones of CO$_2$ emissions would be saved per year ≡ one person driving around the world 18,000 times.**

* Australian Bureau of Statistics, 2004

Biorefinery Opportunity

Advanced Biomass R&D

Sugar Platform
Sugar Feedstocks
Residues
Combined Heat & Power
Clean Gas
Thermochemical Platform
Conditioned Gas
Fuels, Chemicals, & Materials
Integrated Industrial Biorefineries

Biomass

Systems Integration

NREL 2004
Technical Barrier Areas

- Feed Processing and Handling
- Gasification / Conversion
- Gas Cleanup and Catalytic Conditioning
- Syngas Utilization
- Process Integration
- Process Control, Sensors, and Optimization
## Biomass Thermochemical Conversion
### Primary Technical Barriers

<table>
<thead>
<tr>
<th>Gasification</th>
<th>Pyrolysis</th>
<th>Black Liquor Gasification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Pretreatment</td>
<td>Oil Handling</td>
<td>Containment</td>
</tr>
<tr>
<td>- Feeder reliability</td>
<td>- Toxicity</td>
<td>- Metals</td>
</tr>
<tr>
<td>- Feed modification</td>
<td>- Stability</td>
<td>- Refractories</td>
</tr>
<tr>
<td>Gasification</td>
<td>- Storage</td>
<td>- Vessel design</td>
</tr>
<tr>
<td>- Tar &amp; Heteroatom chemistry</td>
<td>- Transportation</td>
<td>- Bed behavior/agglomeration</td>
</tr>
<tr>
<td>- Gasifier Design</td>
<td>Oil Properties</td>
<td>Mill Integration</td>
</tr>
<tr>
<td>Gas Cleanup &amp; Conditioning</td>
<td>- Ash</td>
<td>- Steam</td>
</tr>
<tr>
<td>- Catalytic Conversion</td>
<td>- Acidity</td>
<td>- Power</td>
</tr>
<tr>
<td>- Condensing Cleanup</td>
<td>Oil Commercial Properties</td>
<td>- Causticizing</td>
</tr>
<tr>
<td>- Non-condensing Cleanup</td>
<td>- Commercial Specifications</td>
<td></td>
</tr>
<tr>
<td>Syngas Utilization</td>
<td>- Use in Petroleum Refineries</td>
<td></td>
</tr>
<tr>
<td>- Cleanliness requirements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Gas composition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process Integration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensors and Controls</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NREL 2004
Representative Gasification Pathways

- Biomass
  - Feed Preparation & Handling
  - Low Pressure Gasification
    - Oxygen
      - High Pressure Gasification
        - Hot Gas Cleanup
          - Reforming
            - Compression
              - Acid Gas Removal
                - Synthesis
  - LP Indirect Gasification
    - Catalytic Conditioning & Reforming
      - Compression
## Pyrolysis severity

<table>
<thead>
<tr>
<th>Mode</th>
<th>Conditions</th>
<th>Gas (wt %)</th>
<th>Liquid (wt %)</th>
<th>Solid (wt %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast</td>
<td>fast heating rate (1000 °C/s) short vapour residence time (&lt;2 s) small</td>
<td>13</td>
<td>75</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>particle sizes (&lt;2 mm) moderate temperature (450 °C - 500 °C)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Intermediate</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>moderate temperature (500 °C) moderate vapour residence time (10 - 20 s)</td>
<td>30</td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Slow</td>
<td>35</td>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>slow heating rate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>long solids residence time (hrs) large particle sizes low temperature (400</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>°C)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
PYROlysis based process to convert small WWTP sewage sludge into useful bioCHAR

Gas Clean-up technologies

Professor Maria Olea
Saeed Hajimirzaee
Emmanuel Iro
Novel catalyst synthesis - from lab to industrial-scale

- Primary screening
- Catalyst synthesis
- Characterisation
- Catalyst screening
- Mechanism & kinetics
- Stability tests
- Time, money, reality

- Idea
- Synthesis
- Characterisation
- Screening
- Secondary screening
- Optimisation
- Scale up
- Plant testing
- Reactor design
- Pilot testing
- Scale up

Research at Teesside University
Advanced catalysis for the conversion of biomass-derived syngas to fuels and chemicals

\[ \text{Biogas} \xrightarrow{\text{Catalyst}} \text{Syngas} \]

\[ \text{CH}_4 + \text{CO}_2 \xrightarrow{\text{Ni/Mesoporous Silica}} 2\text{CO} + 2\text{H}_2 \]

\[ \text{Syngas} \xrightarrow{\text{Fischer–Tropsch catalysis}} \text{Fuels} + \text{Chemicals} \]

Syngas \equiv \text{a renewable fuel with conventional quality}
Integrated Biorefining Technologies towards zero waste, zero emissions through:

Interdisciplinary approach; bridging the 1st and 2nd generation fermentation routes to thermochemical ones, to make a range of platform chemicals as well as fuel; choose the most viable and sustainable alternative.
• **Optimisation of feedstock composition**: controlling the uptake of undesirable elements (K, Na, metals, Cl, etc) from brownfield or contaminated land by adding soil amendments;

• **Improve the biodiesel production process by**:
- using enzymatic and heterogeneous catalysis as an alternative to the homogeneous catalysis to increase the yield of transesterification and the purity of glycerol, the byproduct;
- find environmentally friendly purification ways for glycerol;
- transform glycerol into value-added products such as biosurfactants.
• **Biofuel from waste:**

- Biobutanol through 2\textsuperscript{nd} generation fermentation – enzymatic hydrolysis of lignocelluloses;

- Gas-to-Liquid conversion through anaerobic digestion, followed by catalytic transformation of biogas to syngas and then by catalytic conversion of syngas to butanol; possibly look to the $\text{H}_2$ separation and purification from syngas, to use in fuel cells;

- Algae butanol;

- Economic analysis and risk assessment of the three technologies to decide on the best one.
Thank you for your attention!