Gasification of bagasse to syngas and advanced liquid fuel production, including biofuels for aviation

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Outline

1. SUPERGEN Bioenergy Hub
2. Aviation biofuel chains
3. Biomass resource
4. Conversion technologies
5. System techno-economics
6. Environmental performance
7. Wider system issues
8. Policy framework
1. SUPERGEN Bioenergy Hub
SUPERGEN Bioenergy Hub non-academic partners

Committee on Climate Change
CF
Centre for Process Intensification
C-Tech innovation
Department of Energy & Climate Change
EOn
E4Tech
Ecometrica
Future Blends
Greenacres Energy
North Energy Associates
Progressive Energy
Renewable Energy RES Ltd
Sembcorp
Sustainable Energy Ltd
Veolia
Energy Technologies Institute
Croda
ReBio Tech
Nova Tech
Alstom
ZuvaSyntha
Sutton Grange AD
BioGas Hochreiter UK
Biomass Energy Centre
Danish Teknologik Inst.
Drax
LCA Works
Wyse Group
Wyse Group
Unicorn Power Ltd
<table>
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<th>Category</th>
<th>Institutions</th>
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<tr>
<td>Biomass</td>
<td>Aberystwyth, Rothamsted, Southampton</td>
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<tr>
<td>Gasification</td>
<td>Aston, Glasgow, Lancaster, Leeds, Newcastle</td>
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<tr>
<td>Pyrolysis</td>
<td>Aston, Leeds</td>
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<tr>
<td>Combustion</td>
<td>Leeds, Newcastle</td>
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<td>Photocatalysis</td>
<td>Heriot Watt, QUB, Robert Gordon, Swansea</td>
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<td>Biofuels</td>
<td>Aston, Heriot Watt, Liverpool, Newcastle, UCL</td>
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<td>Modelling</td>
<td>Aberystwyth, Aston, Glasgow, Imperial, Leeds, Liverpool, Manchester, Surrey, UCL</td>
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<td>Techno-economics</td>
<td>Aston, Imperial, Manchester, Rothamsted</td>
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<td>Environment</td>
<td>Aberystwyth, Bath, Imperial, Lancaster, Leeds, Manchester, Open, Rothamsted, Southampton</td>
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<td>Social + Policy</td>
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Hub activities

- Biomass
- Gasification
- Pyrolysis
- Combustion
- Biofuels
- Photocatalysis
- Modelling
- Techno-economics
- Environment
- Social + Policy

Aberystwyth
Aston
Bath
Glasgow
Heriot Watt
Imperial
Lancaster
Leeds
Liverpool
Manchester
Newcastle
Open
QU Belfast
Robert Gordon
Rothamsted
Southampton
Surrey
Swansea
UCL
Aviation biofuel chains

Primary conversion
- Fast pyrolysis to bio-oil
- Hydrothermal processing (HTU) to bio-crude
- Gasification of solid or liquefied biomass to syngas

Secondary conversion
- Fermentation of syngas to ethanol or butanol
- Synthesis of alcohols (MeOH, EtOH etc) from syngas
- Catalytic cracking of bio-oil for hydrocarbons
- Hydrodeoxygenation of bio-oil or HTU product
- Synthesis of hydrocarbons e.g. Fischer Tropsch et al.

Tertiary conversion
- Alcohol dehydration and oligomerisation to hydrocarbons

Refining
- Refining to specified fuel standards
3. Biomass resource
Biomass Resource Analysis

University of Manchester’s Biomass Resource Model:

- Biomass Resource Availability
- Bioenergy Generation Potential
- Biomass Supply Chain Analyses
- Biomass Supply vs. Demands
- Import Demand / Export Potential

Brazil Biomass Availability Analysis

Extensive Availability of Crops Produced Specifically for Bioenergy Pathways

Graph showing biomass resource availability from 2015 to 2030.
Brazil Bioenergy Scenarios

Forecast Primary Energy Demand

Potential Bioenergy Energy from Brazilian Resources

Contribution from Bioenergy within the Developed Bioenergy Scenarios
4. Conversion technologies
Aviation and biofuel options

**Gasification routes**
- Biomass
  - Fast pyrolysis
    - Syngas
    - Gasification
      - Ferment
      - -OH dehydration
    - Synthesise

**Pyrolysis routes**
- Biomass
  - Fast pyrolysis
    - Bio-oil
    - Zeolite cracking
    - Hydro-treating
  - Bio-oil

**HTP routes**
- Biomass
  - Hydro-thermal processing
  - Hydro-treating

**Refining**
- Hydrocarbons
Newcastle University Gasification Workshop

23rd October 2013 (Newcastle University)

Identified Key challenges

1. Tar Clean-up
2. Operation and control
3. Few good exemplars of biomass gasification at larger scales in the UK
4. Variable feedstock (require “omnivorous” gasifiers)
A Use for Carbon Dioxide

Non-thermal plasma converts CO2 to CO + O(radical). Both are more reactive and more useful as chemical feedstock/reactants.

The oxygen radical can be used for a variety of oxidation reactions, including, tar breakdown and/or polymerisation.

Here, toluene is used as a tar analogue

Conversion of toluene in the presence of CO₂ in a Dielectric barrier discharge (DBD) reactor. Ambient temperature to 120 °C.
Tar clean-up (Leeds)

**Biomass Gasification:**
European Climate Foundation Roadmap 2050; "gasification as a major potential route for decarbonising power production."

**BUT-Problem:**
- Tar in the syngas.
- Blockages, plugging & corrosion of fuel lines, filters, nozzles etc.

**Plasma Catalysis**
- Non-thermal plasmas: A low energy, low temperature process
- Highly energetic electrons in the plasma are highly energetic: Break down tar compounds.
- Plasma + solid catalysts = Synergistic effect enhancing tar conversion

Low temperature non-thermal plasma-catalysis 50-200°C for Tar removal
Operation and control (Glasgow)

Challenges
- Expansive control system
- Online tar detection and control system
- Product gas quality
- Variable biomass resource utilization

Tar detection techniques

1. Fluorescence
   - Blank Slide (No fluorescence)
   - Slide with sample (Liquid phase)

2. Flame analysis

Lab view
Syngas Upgrading Challenges

- **Tar Kills.** Biomass gasification invariably leads to tar formation. This must be dealt with in order to exploit syngas.

- **Catalysts are Zero Tolerant.** Syngas must have ppb levels of contaminants, which is only achievable where tars are effectively addressed.
FULL CHAIN £23M DEMONSTRATION PROJECT UNDERWAY

SECURED, PROCESSED WASTE FEEDSTOCK

CONVERSION TO HIGH QUALITY SYNGAS (WITH PLASMA)

CONVERSION TO GRID & TRANSPORT QUALITY SNG

DELIVERY TO GAS NETWORK AND EXISTING HGV FLEET

WILL PRODUCE 1.5 MILLION KG OF SUBSTITUTE NATURAL GAS IN 2018

EXPLOITING INNOVATIVE TECHNOLOGY, THIS WILL BE THE WORLD’S FIRST GRID CONNECTED, FULL CHAIN, WASTE TO SNG FACILITY OPERATING AT COMMERCIALLY REPRESENTATIVE SCALE UNDER COMMERCIAL CONDITIONS.

Undertaken by Supergen partner Progressive Energy and a Wider Consortium
5. System techno-economics
BTL mass and energy %

Process

Energy conversion
Mass conversion

0.0% 20.0% 40.0% 60.0% 80.0%
Capital costs, 2012

\[ y = 0.536x^{0.574} \]
Techno-economic model

- A model that examines each thermally based process to aviation and transport fuels is under development in SUPERGEN Bioenergy.
- It is based on decomposition of each process summarised below into modules and synthesis of modules into plausible processes.
- This will particularly explore process performance, capital cost, product cost and technological uncertainty.
6. Environmental performance
Environmental performance

Impact assessment for 1 MJ miscanthus, options 4-6c, with 1 MJ natural gas comparison. Global warming potential (GWP) is measured in kg CO\textsubscript{2} eq using the left hand axis, and eutrophication in kg PO\textsubscript{4} eq and acidification in kg SO\textsubscript{2} eq using the right hand axis.
Maximizing the greenhouse gas reductions from biomass: The role of life cycle assessment

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ABSTRACT

Biomass can deliver significant greenhouse gas reductions in electricity, heat and transport fuel supply. However, our biomass resource is limited and should be used to deliver the most strategic and significant impacts. The relative greenhouse gas reduction merits of different bioenergy systems (for electricity, heat, chemical and biochar production) were examined on a common, scientific basis using consistent life cycle assessment methodology, scope of system and assumptions. The results show that bioenergy delivers substantial and cost-effective greenhouse gas reductions. Large scale electricity systems deliver the largest absolute reductions in greenhouse gases per unit of energy generated, while medium scale wood chip district heating boilers result in the highest level of greenhouse gas reductions per unit of harvested biomass. However, ammonia and biochar systems deliver the most cost effective carbon reductions, while biochar systems poten-
Greenhouse gas metrics

- Pellet boiler pathway results in largest GHG burden; chip boiler pathway has substantially lower emissions
- Both of the electricity systems give very much higher GHG savings than the heating ones
- The district heating system gives the highest percentage reduction of greenhouse gases compared to the reference system
7. Wider system issues
System evaluation criteria

The key criteria for evaluation are:

• Development costs including demonstration
• Biomass availability, cost, logistics, characteristics
• Product selection
• Scale of operation
• Process route complexity and maturity
• Efficiency of process of biomass to biofuels
• Capital cost
• Production cost of biofuel
• Integration into established infrastructure
• Scaleability down scaling and upscaling
• Risks and uncertainties of technology
• Current status
Sugarcane biomass potential additional to bagasse:

- Requires change in harvesting practice to green cane
- Tops and leaves 40% of total stalk biomass
- 15-20 t/ha (dry matter)
- 50% removable (especially green leaves remain in field as nutrient return, soil protection, weed control, less irrigation)

Socio-economic performance

Case study sugarcane in South Africa
Case study sugarcane in South Africa

- Different bioenergy pathways will have different trade-offs and outcomes
- Choices depend on the actual perspective and the goal
- Large-scale and centralised pathway (e.g., field to sugar mill)
  - Economic often most feasible option
  - Fits into existing infrastructure and logistically most feasible
  - Contribute to national energy security (but might not reach poor and people in need)
- Small-/medium-scale decentralised pathways (e.g., field to community facility)
  - Cost might be higher and infrastructure requires development
  - Serves a local energy demand and improves local energy security
  - Empowers local community and gives them ownership in decision making
- Policy frameworks often support large-scale/centralised pathway, while development and empowerment of local energy systems is neglected
8. Policy framework
• Resource available in significant quantities but need to ensure sustainability
• Current market structure doesn’t incentivize aviation biofuels
• Efficiency: Approximately 1.2 t of vegetable oil is required for 1 t of HEFA fuel (via hydro-processing) corresponding to 83% conversion efficiency from vegetable oil to fuel. Is this the best use of biomass?
• Taxes and incentive will affect the time scales for significant penetration of aviation biofuel
Summary

1. Gasification promising route to drop-in fuels
2. Brazilian resource potential
3. Significant technical challenges
4. Economics requires targeted support
5. Significant GHG reductions possible but performance needs to be confirmed for specific chains and
6. Engine testing with high blending needed (several commercial flights up to 50% blend (HEFA) with convectional petrochemical fuel but fuel quality standards and specification are key
7. Policy regime needed that makes sustainable systems economically viable
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