

Bioenergy directed research: opportunities for the Carbon Trust and bioenergy community

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Workshop Report

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This document is a report by the organiser of a technical meeting set up as part of UKERC's research programme. It is believed to be an objective record of the meeting but has not been separately reviewed by the participants

THE UK ENERGY RESEARCH CENTRE

Operating at the cusp of research and policy-making, the UK Energy Research Centre's mission is to be the UK's pre-eminent centre of research, and source of authoritative information and leadership, on sustainable energy systems.

The Centre takes a whole systems approach to energy research, incorporating economics, engineering and the physical, environmental and social sciences while developing and maintaining the means to enable cohesive research in energy.

To achieve this we have developed the Energy Research Atlas, a comprehensive database of energy research, development and demonstration competences in the UK. We also act as the portal for the UK energy research community to and from both UK stakeholders and the international energy research community.

THE CARBON TRUST

The Carbon Trust is an independent company funded by Government. Its role is to help move to a low carbon economy by assisting business and the public sector reduce carbon emissions and capture the commercial opportunities of low carbon technologies.

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DAY 1, 12 November

Introduction

The Carbon Trust has been supporting low-carbon research and development in the UK since 2002, with the Carbon Vision and Applied Research grant-funding programmes. In this time, the Trust has supported over 120 projects, with nearly a quarter leading to patent applications. The Trust is now hoping to build on the success of these activities by launching a further, complementary initiative: "Directed Research". Its primary distinctions from the existing activities will be the targeting of funding to specified topics and the form of support from the Carbon Trust, to be structured as an investment, rather than a grant. The directed research initiative has been described in the following terms:

"a catalyst to stimulate development of products from early stage concepts, by integrating emerging technologies and directing research towards overcoming identified innovation gaps and delivering key performance requirements for specific target applications."

The Carbon Trust intends to operate public competitions for partners to work with the Trust to carry out research directed at these "innovation gaps". These projects could involve a combination of the private sector – including both small and medium sized enterprises ("SMEs") and larger businesses – and universities and other research establishments. The process is currently being piloted for research topics in the area of advanced photovoltaic devices. Going forward, the Trust will seek to identify other research topics where a targeted intervention from the Carbon Trust would result in significant acceleration of a promising new low-carbon technology.

Having carried out some initial opportunity analysis, the Carbon Trust has identified bioenergy as the most likely field for the next large directed research programme. The Trust intends to consult widely with the research community before selecting a particular topic for support; this workshop, co-hosted and co-sponsored with UKERC, forms part of that process and will have the following objectives:

- to inform the bioenergy research community of the Carbon Trust's new 'directed research' approach;
- to generate interest among researchers for responding to a potential Carbon Trust directed research call in bioenergy;

- to enable the Carbon Trust to consult with the bioenergy research community before deciding on specific directed research topic(s); and
- to strengthen Carbon Trust and UK bioenergy research community networks

The two-day residential workshop brought together experts from the bioenergy community to explore bioenergy research opportunities which could benefit from financial support from the Carbon Trust using its new directed research approach.

All presentations given at the workshop are available on the UKERC website¹

Session 1: Overview of Carbon Trust and Workshop Aims and Objectives

presented by Gary Staunton, Carbon Trust

a) Overview of the Carbon Trust

- The Carbon Trust is an independent company funded by Government.
- Our mission is to accelerate the move to a low carbon economy by developing commercial low carbon technologies and helping organisations reduce their carbon emissions. Our aim is to get existing and potential ideas into the marketplace.
- The Carbon Trust has invested heavily in innovation. We're moving much more to a directed approach.
- Bioenergy emerged strongly as an area for support
- Key thing we're looking to do is find out what kind of response we'd get with any call we might make. Looking for significant investment opportunities

b) Workshop Objectives

- To inform the bioenergy research community of the Carbon Trust's 'directed research' approach

¹ <http://www.ukerc.ac.uk/TheMeetingPlace/Activities/Activities2007/0711Bioenergy.aspx>

- To generate interest for responding to a potential Carbon Trust directed research call in bioenergy
- To consult before deciding on specific directed research topics
- To strengthen Carbon Trust and UK bioenergy research community networks

c) Workshop Aims:

1. We are looking for opportunities to invest in actions that have a material impact on the commercialisation of low carbon technologies
Your expert views are sought in this context
2. This workshop is designed to identify potential opportunities for targeted interventions
Exploring 'capacity and desire to respond'

d) Desired Outcomes:

- Everyone leaves feeling that they have contributed fully and are excited by what they have heard.
- We all have an improved picture of UK capacity in the biofuel area and how this can be harnessed
- Carbon Trust and UKERC have improved insight into where research could have a material impact on the emergence of novel biofuel technologies.
- Carbon Trust will have an improved basis on which we can make calls for proposals

Session 2: Carbon Trust 'directed research' approach: Photovoltaics as a case study

presented by Robert Trezona, Carbon Trust

Directed Research is the Carbon Trust's most recent initiative. It seeks investment in the capacity to develop IP in specific areas which will address technology barriers to prospective low-carbon products. Support for directed research is based on:

- Impact – targeted, efficient interventions that deliver the greatest progress with limited resources;

- Distinctiveness – requires thorough understanding of low carbon technology innovation and extensive knowledge of the relevant research landscape;
- Insight – value of the initiative depends on choosing the right topics AND being recognised for doing so.

Directed Research is designed to work with our existing Technology Acceleration programme and each directed research project will be supported using a commercial approach that will encourage enterprise and value creation

The case of Advanced Photovoltaics (APV) was presented, emphasising that the Carbon Trust's intervention was based on the following three criteria:

Additional

- The Carbon Trust's Directed Research initiatives will capture the value from Research Council-funded work by world-class research groups in UK universities.

Material

- Research and development of organic photovoltaics is concentrated in universities and research organisations in UK, Europe, US and Japan and a handful of venture-capital backed spin-outs. A multi-million pound integrated initiative from the Carbon Trust coordinating university and advanced materials processing industry efforts could have a major impact.

Distinctive

- The Carbon Trust will set challenge and build team to provide focus on integrated technology development plan, leading towards specific applications.
- New materials with potential to radically reduce costs of PV are emerging from work in the UK and elsewhere. It is timely to address the challenges to large-scale, low-cost fabrication of advanced PV devices.

Process for Selection: APV Example

- Following call for Expressions of Interest, received fifteen describing programmes of research worth over £70m, from consortia including over 60 different organisations;
- Shortlisted five of these opportunities and evaluated them in detail, including detailed work programmes, technical and market assessments;

- Shortlisted proposals covered three distinct technology areas: roll-to-roll processing of organic polymer-based PV; deposition of inorganic thin-films on flexible substrates; and PV coatings for rolled steel cladding and roof products.
- Finally announced that a consortium led by Cambridge University, with The Technology Partnership (TTP) had been selected as preferred bidders.

Carbon Trust Investment and Timescale: APV

- Intend to invest **£5m over 3 years**, with the expectation of sharing risk and reward with private investors and realising an attractive return on our investment.
- Expect to commence work early in 2008, with deliverables including demonstrator modules and manufacturing processes by 2011.

Discussion

There was discussion on whether the Carbon Trust will only support one area of bioenergy research. The Carbon Trust will likely only support one area, but would promote suitable proposals to other funders.

Robert emphasised that the Directed Approach should be seen as a partnership, with the Carbon Trust as a commercial partner. The Carbon Trust is more than a mere donor – any directed research proposal would need to show that access to Carbon Trust personnel is helpful as well.

Regarding risk, the Carbon Trust is interested in supporting riskier ideas, with the caveat of being as well-informed as possible regarding the risks.

The Carbon Trust's success is about disseminating knowledge, particularly on technology acceleration. As such, expect that knowledge generated under this research approach will be shared along the way.

Session 3: The UKERC bioenergy landscape and roadmap,

presented by Gail Taylor, University of Southampton/UKERC

As a UKERC initiative, the National Energy Research Atlas provides:

- a. Research Landscape: Characterising energy research activities and capabilities in the UK
- b. Research Register: An on-line searchable database of energy-related awards and projects
- c. Research Roadmaps: Identifying the sequence of research (and other) problems to be overcome before new technologies can be commercially viable

Research Landscape

- A Bioenergy Landscape document has been produced and is updated semi-annually. This document can be found at the following URL:
www.ukerc.rl.ac.uk/ERL001.html
- The landscape document has the following headings:
 - Overview
 - Capabilities assessment
 - Basic Strategic Research
 - Research Funding
 - UK Providers
 - Applied Research
 - Research Funding
 - Key applied Providers
 - Development and deployment
 - Funding for major projects inc commercial
 - UK Research Facilities and resources
 - Networks (UK and EU)
 - UK Participation in EU Framework Programmes
 - International Activity
- The landscape document shows that current activity on biomass energy research is extensive, uncoordinated and fragmented
- From looking at the Bioenergy Landscape, it has been ascertained that basic and strategic research in 2007 was approximately £60 million, with 19 groups identified.
- It is much more difficult to identify applied research in this area. To date, eight groups have been identified. £87 million available, and DTI technologies dominate.

The Bioenergy Research Roadmap:

Aims and Objectives for Roadmap

- To prioritise research activity and overcome the gaps in knowledge in bioenergy
- To influence research funding strategies in energy research.
- To encourage closer collaboration between academic research groups and technology developers
- To seek funding for collaborative research from Research Councils, DTI, DEFRA, Carbon Trust EU, etc.
- To establish partnerships with the outside the existing bioenergy research community

Roadmap Timeline

- Oct 2005 – Biomass Task Force Report
- April 2006 – Government response to BTF – 40 recommendations
- March 2006 – BBSRC publishes report 'Bioenergy Research'
- April 2006 – Biomass Action Plan – EU
- May 2006 – 2030 Roadmap for biofuels – EU
- June 2006 – DOE Roadmap for Bioenergy following Dec 2005 meeting
- June 2006 – BP announces £250 M Bioenergy Centre
- July 2006 – Office of Science and Innovation – Foresight Horizon Scanning
 - Biomass for Heat and Power
 - Biomass for biofuels and the biorefinery concept
- September 2006 – Research Atlas for Bioenergy – UK
- 2006 – UK COMMITMENT TO LIQUID BIOFUELS DIRECTIVE
- June 2007 – Biomass Strategy –UK
- June 2007 – Bioenergy Funders Forum Research Priorities

General research areas identified:

1. Feedstock improvement
2. Basic microbial science, cells walls, bioscience
3. Sustainability, land use (UK), Global, public perception, Whole system analysis, use of waste, biomass resource

It has been noted that the bioenergy research community is lacking in conversion activities, fuel characterisation and chemical engineering.

We wanted a flexible, underpinning science approach to enable identification of different priorities and areas of importance. We didn't want to pick winners, per se.

Next Steps

- Draft report for circulation Nov 07
- Additional consultation
- Report December 2007
- Peer Review –early 2008

Discussion

Public education and public perception need to be addressed, particularly regarding terminology (eg. Bioenergy and biofuels used interchangeably). May need another workshop to discuss fuel conversion and fuel characterisation. Decentralisation missing from the list – this was identified at the roadmap workshop and is becoming more and more important.

In terms of UK distinctiveness, strength was identified in basic science. There is a need, however, to harness this so we don't lose out in terms of intellectual property and commercialisation.

Given the performance of the USA, it was suggested that the UK should be taking a joint European lead. It was acknowledged that the UK is heavily involved with Europe through the Framework Programmes and the European Research Council.

It was noted that UK intellectual property is likely to be generated by things not necessarily located here given our small land area. UK drivers are different from those of the United States. We have a window of opportunity now.

The Carbon Trust invests in research that is meant to be in the market within 5-10 years. While the Carbon Trust will support work leading to 2010 targets, this will probably be more reactive/applied research.

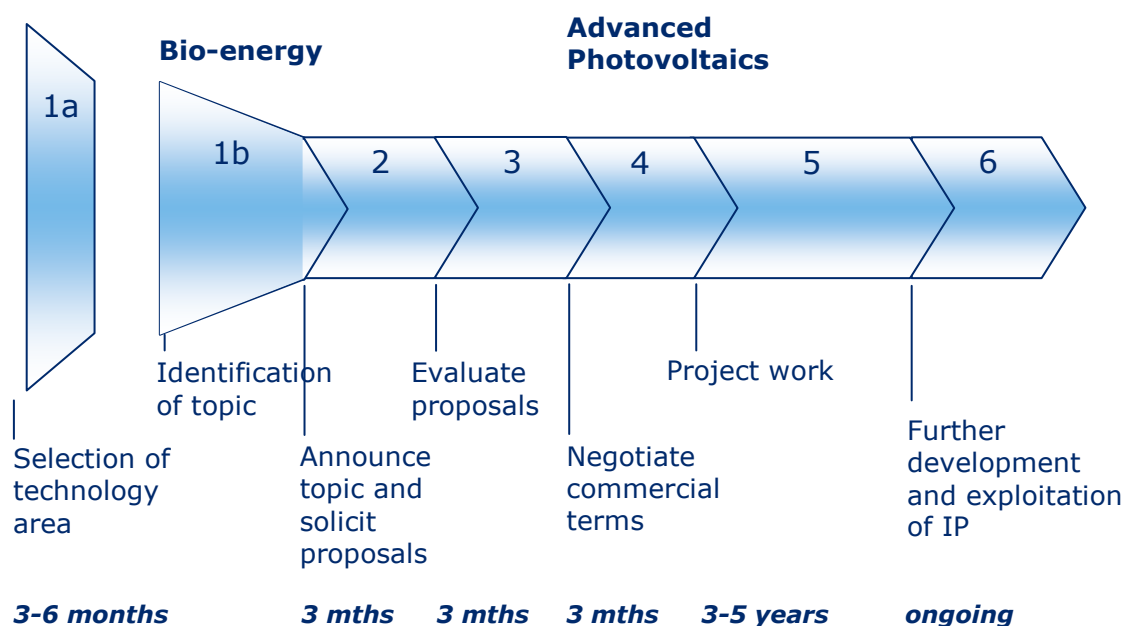
Session 4: Carbon Trust framework for selecting topics for directed research and current state-of-play

presented by Robert Trezona, Carbon Trust

Directed Research Topic Criteria

1. Degree of innovation
 - “Breakthroughs”
 - Breadth of application of the results
 - Timing of scientific success
 - Degree of risk
 - Defensibility of resulting Intellectual Property
2. Carbon saving potential
 - Basis for the technology supported by the research to save carbon
 - Breadth of application to multiple technologies
 - World-wide and UK opportunity
 - Whole life cycle and sustainability considerations
3. Evidence of insufficient current investment
 - Support from the Carbon Trust must be demonstrably additional
 - Demonstration that there is underinvestment at the moment
 - Complementary with other work in the area (supported by, for example, the Research Councils)
 - Impact of non-technical barriers
4. Strength of UK research capability
 - How the UK research base (that could be used to progress each topic) rates on an international scale
 - Capability may be latent
 - Include the UK industrial sector - both within SMEs and large corporates – as well as academia
 - Extent of coordination and cooperation in the research community
5. Potential to contribute economic value in the UK
 - Potential for the research to contribute to UK economic value (building on the assessment of the defensibility of the resulting Intellectual Property)
 - Consideration of non-technical barriers to entry for resulting technologies
 - Possible timescale of wider market deployment

Dedicated process for Directed Research projects

*Discussion*

This is a large landscape. The Carbon Trust will probably only select one area, and expect that the winning bidder will be a leading UK university with industrial players.

Noted that the timetable is rather compressed. The Carbon Trust (CT) is flexible. For example, with the APV process they asked for a short proposal from a consortia. The CT had a month to adjudicate, then short-listed to five. CT provided funding for these bidders to develop a commercial idea.

A criteria that isn't explicit is technology relevance. Need sensible locking in to the front and the back of the process.

An additional problem – for example novel fuels – relates to the fact that combustion technology is changing, so biodiesels might not be important. We need to be clear on the end point. It's not the fuels, but the movement of people and goods. We might be adjusting a problem that may be a different question in 10 years from now.

The technology needs to have wide breadth of application.

To act, we need to be relatively focussed on something.

The timing for applications will depend on the topic we select. The timescale may change, but we are under pressure to deliver something quickly.

Applicants should feel free to bring in overseas partners as long as they can demonstrate how this will benefit the UK economy.

Session 5: Plenary brainstorm and syndicates for new ideas on bioenergy directed research

Based on the question, 'What research ideas would lend themselves to the Carbon Trust's directed approach and would UK researchers be best qualified to address?', participants wrote ideas on large post-it notes for seven topic areas:

1. Bioenergy feedstock development
2. Thermal and chemical conversion
3. Biologically-enabled conversion
4. Concepts for biorefineries
5. Options for novel biofuels and other valuable biomass products
6. Challenges in utilisation of waste biomass
7. System perspectives (including end use) and sustainability

Facilitators clustered these ideas to form themes. The ideas for each topic heading were given to the relevant syndicate working on the topic area. Groups were asked to consider the ideas put forward on the topic/theme and to take one idea or set of related ideas they thought were important, worth pursuing and feasible. The group then had to work on this idea in more detail, providing:

- Brief description of research idea
- Degree of innovation required
- Carbon saving potential
- Evidence of insufficient current funding or investment (additionality)
- Potential for results to contribute economic value in the UK
- Strength of UK research capability relative to rest of world

These ideas were summarised on a poster template and displayed for other syndicates to review. The seven ideas developed by the syndicates were:

1. Advanced Selective Process Control
2. Identifying the "Show Stopper"? (Systems and Sustainability)
3. Tools for Accelerated Design of low carbon sustainable bioenergy crops
4. Combustion Technology and Biofuel Product Development
5. Smaller-Scale Conversion Processes
6. Biorefineries: Novel Chem-Bio process to fuels/chemicals
7. High Tolerance Microbial Fermentation for Mixed Biowastes

All seven posters can be found in the Appendix.

Discussion

On Day 2, the teams were required to develop their research proposals in more detail, taking into account feedback from the Carbon Trust and peers, and to give an oral presentation in plenary. At the end of Day 1, the Carbon Trust offered feedback on the first drafts of the proposals:

1. Systems & Sustainability group: looking for the 'show stopper'.

Predicted this as a possible outcome for this topic area, but wanted to give the participants the opportunity to discuss this. This isn't a directed research approach, but it could definitely be developed for other areas, and thus happy with the outcome. These ought to be criteria for anything that we do – very useful.

2. Feedstocks:

Exciting area within this topic – a very challenging and engaging area. This is an obvious thing to focus on.

3. Biorefinery & Novel Biofuels:

This is a tough and difficult topic to define – what are the assumptions on the inputs and outputs and what should the refinery produce? What modules should be concentrated on first? Would like to see the group adding in constraints now – wants the group to be opinionated. The group were asked by a participant of the scale that was being considered – the group responded that this had deliberately been left ambiguous.

4. Waste biomass:

Interesting and poses a problem with specific outcomes which is very helpful for directed research. This is a lateral approach to the problem – how do we change the

process to be more flexible? Why ethanol? Are people willing to take on different products?

5. Thermochemical conversion:

6. Advanced selective process control:

May be some activity in this area already and suggest optimisation – but what is the big question? What are we producing and what goes into the ground?

7. Combustion technology & biofuel product development:

This is something that the Carbon Trust has looked at already. This is definitely something needed within the automotive industry (better engines). However, at present there is little evidence that the automotive industry and the biofuel industry are communicating; so what would be the role for the CT in that case?

Making small scale fuel may cause problems and engines are known to be 'fussy'. Therefore, it makes it a current topic, but the issue is how to utilise it.

8. Optimising the value of the UK's limited biomass:

Initial reactions are that this is innovative and something necessary. However, what is the Carbon Trust's role and UK capability? Missing how the resource interacts with the market(s). Where does the revenue come from?

9. Small scale conversion processes:

This is very interesting as an area, but smacks of the 'chicken and egg' problem concerning the biomass and problems getting investment. We need to get a sense of scale of innovation. Yes, this is very exciting and could transform bioenergy value chains but what are the risks?

There is a wider question in that biomass has a low energy density and thus needs increasing – however, this is a very interesting approach.

Day 2, 13 November

Session 6: Parallel Syndicate Groups

Each syndicate group prepared a presentation of their research proposal for plenary addressing the following:

- a. Why should we do this?
- b. What would it look like?
- c. Who would be involved?
- d. What will we get at the end that we don't have now (what am I buying?)?
- e. Who (else) might pay for this?

Six presentations were developed covering the following proposals:

- A High Throughput Tools
- B Optimisation of biofuel/engine
- C Novel Processes for biorefineries
- D Small scale conversion processes
- E Mixed biowaste
- F System Perspectives

These presentations are available on the UKERC website².

Group A: High throughput tools for accelerated design of low carbon sustainable bioenergy crops

Why should we do this?

- To optimise energy yield of biomass per hectare with maximum GHG mitigation
- We can't select fast enough for useful phenotypes and genotypes for bioenergy feedstocks
- Techniques exist but they are not specific enough for energy crops

What would it look like?

- R&D project with potential spin outs
- Phase I: Develop tools in collaboration with biologists and end users [2.5 yrs, £3-4m]
 - Design techniques for high through put

² <http://www.ukerc.ac.uk/TheMeetingPlace/Activities/Activities2007/0711Bioenergy.aspx>

- Develop new phenotyping techniques
- Invest in computing tools
- Phase II: Validation [1yr, £1-2m]
 - Identifying optimal germ plasm for breeding or GM
- Phase III: Beyond the project
 - Using the technique to develop varieties from 1 year onwards. Enables a pipeline. Tool will enable “better” energy crops in the long term.

Who would be involved?

- Virtual platform:
- Market expertise (Fuel co., biomass co.) – drivers for characterisation, definition of tools required. Expect accelerated provision of selected and improved feedstock.
- Chemical engineers & biochemists – tool development. Expect involvement in any spin-outs.
- Bioscientists & breeders – genotyping validation and implementation. Expect breeders’ rights.
- Highly interdisciplinary collaboration, involving CT commercialisation expertise, UK & international market expertise

What will we get at the end that we don’t have now?

- What are we buying?
 - Expertise to develop tool
 - Potential to mitigate ghg emissions
- What will be the tangible outputs?
 - Validated tools and screened germ plasm
 - Breeder’s toolkit – association of phenotype with genotype. Value in using it or selling it.
- Intangible:
 - Potential to get IP in next round of breeding
- Promoting cooperation across research communities to create a new internationally competitive community
- It will overcome a bottleneck in design of bioenergy crops

Who (else) might pay for this?

- BBSRC and EPSRC could pay for parts of it but the mechanisms are not currently available.
- ETI?
- Small parts of it are being funded but not in a coherent way. Falls across the boundaries of existing funding agencies.
- This is a larger scale project than the research councils could afford

Additional thoughts

- Spin off? - May be able to patent the tool- for use in the field?

Discussion

During the plenary discussion session, the Carbon Trust put questions to each of the groups, before discussion was opened up to plenary.

What are the most likely enhancement areas of feedstocks?

A better understanding of lignin and cellulose chemistry is required. Much wet chemistry is likely to be involved. The bottle neck is getting the material and screening in a high throughput way. We need to determine what is more amenable to breakdown for use in biofuels. This addresses an important issue such as land take. We know marginal lands will become more important. Climate change will have an impact. There are a number of areas where the tool may be useful. A lot of the genotyping technology is available and being deployed for food and human health. We can gain from the knowledge that this has produced. We need to optimise yield with lignin-cellulose crops.

Is the UK market big enough? There is already an issue about land availability.

Globally, less than 1% of the biomass is used for feedstock. We will need to import feedstock in the future. Develop this for growth outside the UK.

Can the third world afford this technology?

In India, they are paying for higher GM products as they get better yield, on more marginal land. What we are proposing is very distinct from the large research projects on common foodstocks such as wheat.

The Carbon Trust is outcome driven. Your output is tools?

Within the constraints laid out by the Carbon Trust, this is what we felt was doable.

Group B: Optimisation of biofuel-engine interaction: Protecting the market for 1st and 2nd generation biofuels*Why should we do this?*

- Chicken and egg scenario- is it a fuel problem or an engine problem? BOTH!
- Fuels and engines not optimised- increased pollution emissions and waste of resources
- New fuels do not match modern- lack of understanding

What would it look like?

- Total funding of £10 million over 3-5 years
- Consortia with minimum of five main areas covering fuel specification, manufacture, engine expertise, fuel additives and sensors
- Predominantly R&D project based at a research centre (such as Imperial and Bath)

Who would be involved?

- Universities, fuel supplier, engine OEMs and additive suppliers and auto catalyst suppliers
- Multi-disciplinary - biochemistry, fuel chemistry, process expertise sensor technology and mechanical engineering
- Generate IP, and seek solutions to current problems
- Extensive UK expertise

What will we get at the end that we don't have now?

- The widespread uptake of biofuels without having the need for new vehicle design
- Possible decentralisation of fuel supply
- Reduced carbon dioxide with minimal impact on pollutant emissions

Who (else) might pay for this?

- Potential to be supported by biofuel companies
- BERR or the EC may support to minimise CO₂ emissions
 - Looking for generic and transferable solutions
- A valuable area but fragmented. Heavy reliance on standardised and 'centralised' fuel supply

Final thoughts:

- Without the work-risk destroying the biofuel market due to adverse customer/user experience
- Current issues with bio-diesel use in modern diesel engines that have not reached the public domain YET!

Discussion*Do you start with the existing engine and adapt the fuel?*

We don't know where to start. We have a completely new fuel, we don't know how it will affect the engines and what modifications will be required.

Are there sensors to say what the fuel is or what the fuel does to the engine?

We might need new sensors depending on what we find out. For example, are there sensors for fatty acids. Additives unlikely to work with biodiesels, don't know which to use. Additives that might help with problem of fuel getting into the oil, etc., we don't know.

In terms of first generation fuels, what percentage impact can you have?

Currently, 5% is giving problem with engines. Ultimately there are proposals going to B10 and B20. At the end of day we need to be able to use it successfully.

Ultimately, don't want to put it out there and damage customers engines. At the moment, lots of resistance going beyond 5% because of risks. Problem is the volatility of the fuels and there is no recovery with biodiesel. There's a fundamental chemistry problem now, which may, for example, may be fixed by additives. This is currently not known.

Group C: Novel Processes for Biorefineries

Overall idea:

Novel process for bolt on to existing and next generation biorefineries, covering either: a new product molecule; new or improved process e.g. higher efficiency; use of by-products, moving towards zero waste.

Why should we do this?

New or improved process e.g. higher efficiency; use of by-products, moving towards zero waste; help overall economics of the process; improved carbon emissions; much lower energy use; additionality - wide opportunity space. Focuses on getting a process that can be used, rather than academic projects. Has a commercial link; should generate industry-validated IP; UK has world class life science, chemistry, chemical engineering, but not focused on working together in multidisciplinary way; chemical industry strength and spare capacity, budding biofuel industry; EU partnership could help.

What would it look like?

- 5m, 3 years
- Would expect a lot of expressions of interest
- Type of activity
 - Up to 3 projects funded
 - Pilot scale demonstration – multi-litre

Who?

- Dream team: multidisciplinary academic team (chemistry or catalysis group, engineering group, biology group), with at least one industrial partner
 - Academic team with large partner → create company or incorporate in large partner
 - Academic team with SME to get technology out of the lab
- Should be linked to a specific biofuel process
- Academia must bring novel ideas, that can generate IP
- Specific groups / companies: BP, Green Biologics, CPI, CoEBio3 (bio), LGM (engineering)
- Interesting opportunity for an EU partner or partner worldwide

What am I buying?

- Enhanced economically viable and sustainable biorefinery
- Proof of concepts ready for scale up
- Coherent technologies
- IP associated with concepts
- Clearly commercially focused academic research
- Moves from single product focused biofuel production to a true multi-product biorefinery including biofuel production

Who would pay?

- Who else could potentially support the idea?
 - Industry e.g. BP
 - Industrial partners with existing processes
 - ETI, BERR, RDAs
 - Bioscience for Business KTN – IBTI project, which may not have right amount of money and mixed industrial focus – CT could join up with this
- Why would industry pay to support it?
 - Would help their process
 - Would need proper structuring: scope of call, strong multidisciplinary teams, single point of contact with academics, skills in economic and life cycle assessment
- If it's such a valuable area to work in, why doesn't it have sufficient funding already?
 - Genuinely breakthrough technologies – companies haven't thought about them
 - Difficult for companies to bring together expertise from different areas to get new technologies developed – access to multidisciplinary groups

Discussion

Quite generic. Can you illustrate? What specifically could we do to make it a multi-product process?

For example, with biodiesel there is a huge amount of waste at the front end. There's also the waste products such as glycerol which makes an excellent feedstock for fuels. There are a lot of people working on this, but many of the solutions now not particularly sophisticated and we need a more technical approach to get higher value niche chemicals. This is an expertise we have in the UK. Improving overall efficiency of the process has huge impact on energy and cost-saving in terms of both energy and carbon. There's a lot going on in this area, but so there should be. There are many opportunities, which is why we've kept it generic and open. Suggested that the CT make a targeted call that is not just academic but commercial to put discrete units into existing facilities.

You mentioned glycerol from biodiesel. Do you see this as a method of purifying, or transferring to something else?

We see this as a feedstock. There are several things you could do. One example is you could ferment glycerol to butanol, and have butanol alongside an ethanol process, and could mix and match.

Presumably a key output is the IP? What distinctive IP are you developing, or is it more proof of concept?

A bit of both, each will generate their own IP. Offers a step change and improvement in efficiency. IP surrounding the process.

In your dream team, did you identify who is currently designing this?

We didn't, in terms of retro fit or bolt-on. There may be need for additional expertise.

Group D: Smaller-scale "second generation" conversion processes for multi-fuels: Municipal solutions for combined heat and conservation (CHC)

Why should we do this?

- Biomass feedstock is distributed by its nature and it would be a real advantage to be able to develop distributed conversion technology (low energy density resource to high energy density product)
- Potential to optimise overall process efficiency (have to compete with getting oil out of the ground)

- Empowering local communities to produce some of their own energy
- Concept and learnings are potentially exportable to other countries (esp. developing countries)
- Much of the technology will be based on enablers, like catalysts, which are replicable and know-how which can be disseminated
- Opportunity to utilise 'waste' heat from conversion process – CHC: combined heat and conversion
- Potential to achieve RTFO targets using a significantly lower carbon value chain (using more indigenous feedstock and less imported)

What would it look like?

- Large research project (2-3 years, £2.5m, clear stage gates) with a consortium involving academics, SMEs and industry develops solutions to knowledge gaps in conversion
- Explicit objective of the project is to carry out the research required to found a company to implement the technology
- Researchers have opportunity to convert their contribution to the project to equity in the company
- CT input of £2m to help establish the enterprise
- That company must create a product (takes another 3 years for field trials)
- Key value-add of the company is to integrate processes, many of which exist already

Who would be involved?

- Skills: multi-disciplinary technical team for research project
 - chemical engineers,
 - process engineers,
 - mechanical engineers,
 - chemists,
 - social scientists,
 - techno-economists,
 - representative of end user
- Commercial project management (not managed by an academic)
- Oxford Catalysts, CPI, Johnson Matthey, Aston (pyrolysis and FT), Liverpool John Moores (hybrid microwave heating, plasma), an energy co., Birmingham Uni (gasification and optimisation of fuel), professional engineering company, Combilift (Ireland), end users – possibly a company like Scottish and Southern
- Value proposition for developers around equity stake in company that will exploit the knowledge, not just in the UK

- Customer getting overall commercial business case – can help deliver low carbon corporate objectives
- Government (and CT) get contribution towards GHG targets

What will we get at the end that we don't have now?

- Valuable bioenergy products produced in an efficient and low(er) carbon way
- Improved energy security
- Genuine export opportunity for the UK
- Difficult problem and large markets suggest defensible IP and significant value for "UK plc"
- "Community energy" concept – improved connection between communities and agriculture
- Enabling technology – provides a demand to encourage new feedstocks
- Cleaner fuels (sulphur-free etc.)

Who (else) might pay for this?

- Research councils? Industry (a large player might decided to take the whole thing on)
- BERR, TSB, EU money?
- Local government, RDAs

If it's such a valuable area to work in, why doesn't it have sufficient funding already?

- Challenging technology
- Difficult to find the right organisation to bring it all together
- Challenging need to mix academic and commercial
- Need to meet future needs

Discussion

Distributed is expensive. Could the economics ever stack up?

That's the challenge of the project. That's why we need heat, power and fuel to optimise efficiency. Could be economic when CO2 taxes imposed. Need new and improved catalysts, engineers to make this work.

Who will be able to afford this?

There are options that are not necessarily expensive (eg. pyrolysis). We are thinking of supplying a town, not the household level.

Where do you see the biggest value creation?

For a company that makes a product, here is an idea that takes a large-scale idea that works on a small-scale. Then raise venture capital to support this. As an

example, with syngas it doesn't matter what you start with, you get the same product which is carbon-hydrogen-oxygen rich.

Group E: High Tolerance Microbial Fermentation for Heterogeneous Bio-Wastes "HIGHTOL"

Why should we do this?

Selection criteria	Rationale
Degree of Innovation required	Breakthrough in the microbial science and engineering for fermentation is required to deal with highly heterogeneous wet bio-waste streams
Carbon saving potential	Significant substitution credit opportunities (avoided methane, fossil fuels) Main and co-products
Evidence of insufficient current investment	Current focus on composting and AD
Strength of UK research capability	Good in microbial science and food-engineering
Potential to contribute economic value in the UK	Significant – domestic markets for cost products and export licences, help to reduce UK problem/cost of waste

What would it look like?

- "Stage gate" approach:
 - Phase 0: Detailed feasibility (waste stream characterisation, logistics etc.) ~£250K 3-6 Months
 - Phase 1: Microbial science (is it possible, identify "Grozy" strain of microbes) ~£1.5M 2 Years
 - Phase 3: Integrating engineering challenges (scalability, costs, maintainability of conditions and additional heat inputs required) ~£1M 1year
 - Phase 4: Routes to market ~£300K 6 Months
 - Overhead: £750K
 - TOTALS: £3.8-4M 3-3.5 years
- Type of activity
 - Fundamental lab-based R&D amongst several academic centres (distributed) *then*;
 - Engineering analysis (single location) *then*;

- Commercial proof of concept/prototype development and logistics analysis

Who would be involved?

- Team composition:
 - Academic leads "core" (microbial science), distributed in centres of excellence throughout the UK;
 - Engineering partner (brewing/food industry);
 - Commercial partner (Biffa, Onyx), waste treatment

Value from different participants:

- Fundamental science research required to "break" problem – must be world class and draw from wide range of existing expertise in UK
- Engineering challenges (not enormous but) need a commercial focus from start
- Logistics and commercial waste-management realities need to be included in consortium from early stage

What will we get at the end that we don't have now?

- A completely new Microbial process;
- Detailed data on the operational parameters (feedstock tolerances, efficiencies) required to make the above work;
- CT buys in to a potentially new (IP predictable) microbial process and engineering system to maintain and handle the operating environment;
- IP on process and new strains of microbes, Engineering solution for distributed applications
- Materially different by handling widest possible variety of typical municipal "green" wastes (without need for separation). Also scale of application and co-products are higher value than typical AD products with existing markets

Who (else) might pay for this?

- Other government departments/institutes (due to waste cross-over)
- Commercial interest from large food manufacturers/brewing industry for onsite waste handling solutions?
- Interest from waste management contractors? (mainly customers of technology but may like to take an early stage stake?)
- If it's such a valuable area to work in, why doesn't it have sufficient funding already?
 - Existing waste management solutions exist that provide a reasonable solution
 - Green waste levels/landfill tax not yet severe enough to stimulate radical solution investment

Additional thoughts:

- A large number of carbon “upsides” (co-product displacement)
- Cross over in to waste management policy and potential sources of partnership/funding (not just GHG reductions)
- Project is stage-controlled
- Co-products have established home markets
- If technology can be scaled it could be highly exportable
- A distributed model may work in other parts of the world, while a hybrid model likely works best for UK.

Discussion*What is the major benefit?*

An advantage of this process over anaerobic digestion is the ethanol or butanol will be a more valuable, useful product. One of the problems with anaerobic digestion is methane-generation. This doesn't produce methane. On the microbial side, using thermophiles, we can overcome the existing organisms in the waste; likely about management of a microbial community.

How do you set about searching for the right bugs?

We do this through classic enrichment culture. You'd use a meta-genomic approach. By running at a thermophilic level, you have a reduced population, fewer organisms. I don't see the development of a suitable inoculant as a barrier.

You have bacteria that can deal with Ph.

Enrich the microbial culture so it can deal with it. You need some kind of blending station at the beginning. It's bringing in various sorts of wastes. You try to regularise the inputs as much as possible, as the waste will vary, even perhaps seasonally.

The issues are about process-control and at the end of the day, how do you break down the cellulose? This is still an issue, not the microbial process.

You're right, there is a large waste-food input side we should target first, and then we add in things such as grass cuttings at a later stage. Depends on how much surface heat available to you at the beginning. There are other technologies that are or will be available to deal with cellulose breakdown issue.

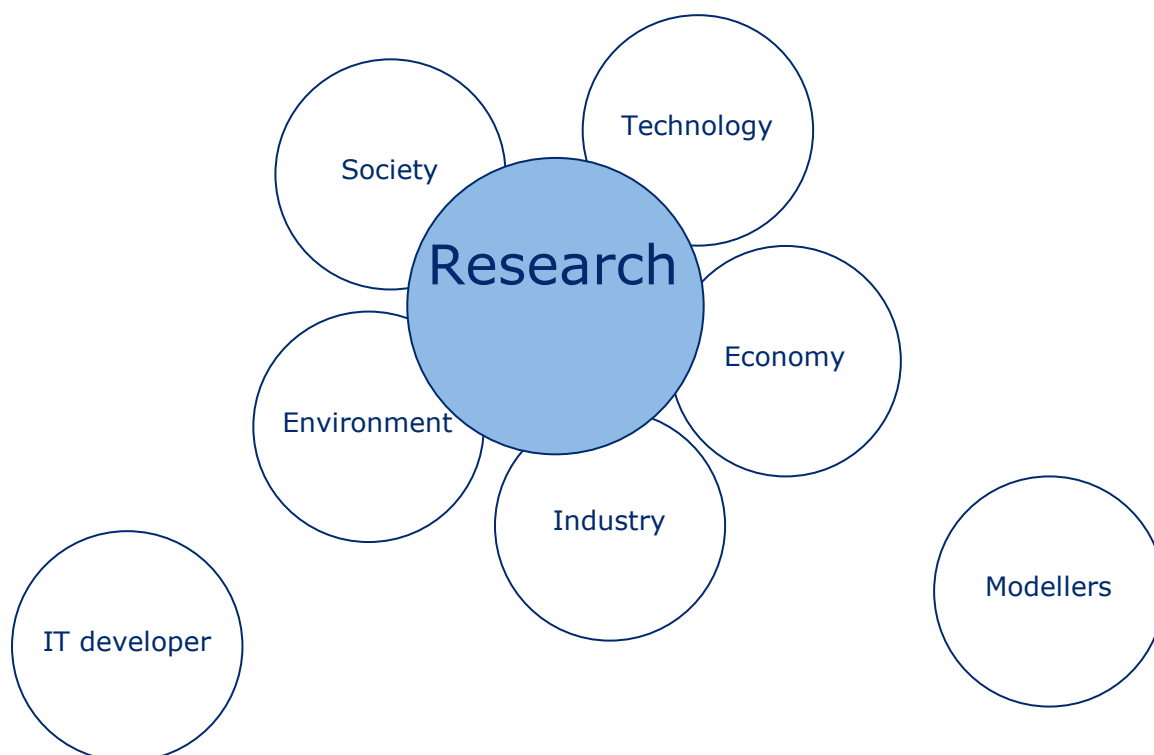
Group F: Systems perspectives (including end use) and Sustainability*Why should we do this?*

- Unforeseen consequences
- Contribute to sustainability objectives within an evolving UK energy sector
- Minimising risk/maximising opportunities to facilitate effective spending

What would it look like?

- Widely used generic assessment process
 - Decision support
 - Based on relevant strong IT and expert advice
 - Built around defined system boundaries
- Cost
 - Setup: £0.5M 1 year
 - Application: To review projects on a consultancy basis (ongoing, could be ad hoc); £20K per project
 - Aim to embody information in expert system

Who would be involved?



What will we get at the end that we don't have now?

- A process and a tool
- Smart expert system, framework for assessment
- What will be the tangible outputs?

- Mapped landscape
- Informed decision making
- A useable and understandable system
- Better value for money
- Ability to identify a step change
- How is this materially different from the current situation?
 - Whole systems approach
 - Fewer unforeseen consequences (including technology failures and project failures)
- How will this change the landscape?
 - Evidence based policy

Who (else) might pay for this?

- Carbon Trust vision
- Government and Research councils and EU
- Technology Strategy Board, Energy Technology Institute (£1billion)

Why would they pay to support it?

- Reduce risk (fewer project failures)
- improve direction
- Forecast not projections
- If it's such a valuable area to work in, why doesn't it have sufficient funding already?
- Can't capture IP, too broad, cross-disciplinary, no clear ownership

Additional thoughts:

- Not fundable by directed research
- Carbon Trust role

Discussion [jen – who is 'we' and 'you']

Who is the real customer here?

The customer is the one with the money. Advising them so we can look at the project, where there may be complementary projects that could be delivered at the same time. We're looking at the wider landscape. How does it fit in with the end use. We're asking you to look at how applications are done in new ways. We'd help you develop the framework for calls. There is a team that would look at the larger, wider community from a multidisciplinary perspective. Incredibly broad scope. How do you keep this up to date and relevant and choose the group?

You would need to be looking for people with the expertise for the initial money. You're looking for a team with informal links and networks, the UKERC NERN, for example.

What you have to do is make an assessment of not only the bid (you expect this), but if you deliver this, how does the landscape change once implemented. Without this, you progress in a linear and slow way. It might be a feedstock, a cultural change, an infrastructure change. Our proposal is formalising this approach.

Session 7: Voting Session

All participants were asked to vote on:

- a) which proposal is the most appropriate for the Carbon Trust to support; and
- b) which proposal would be most appropriate for other funders (public money) to support.

Each participant was given four notes of "money" each representing £250K of Carbon Trust "money", and 4 notes of "money" each representing £250K of other public money. Delegates could choose to place their money on posters according to how they would spend the money (not including their own poster). Delegates were allowed to place more than one note on any poster and were not obliged to spend all their money. Voting results were as follows:

	Public	CT	Total	£ CT	£ public
A	23	22	45	5.5	5.75
B	17	16	33	4	4.25
C	10	15	25	3.75	2.5
D	13	21	34	5.25	3.25
E	28	26	54	6.5	7
F	17	9	26	2.25	4.25
G	19	16	35	4	4.75
Total	127	125	252	31.25	31.75

Session 8: Closing Remarks

Part of the goal for this workshop was to develop an appetite for this work. The Carbon Trust is convinced this is the case, both within the UK and among workshop participants. The ideas developed by participants will help the Carbon Trust to focus its call for proposals. The Carbon Trust intends to issue an invitation for expressions of interest before Christmas. The Carbon Trust invited participants to reflect further, add to the developed ideas and to start thinking about how to respond to the call.

APPENDIX 1 - Syndicate posters completed at end of Day 1

Topic area [e.g., feedstock, systems, etc.]: Thermochemical Conversion
Facilitator:
Group members:
Title: Advanced Selective Process Control
Description of Directed Research challenge
Real time selectivity The use of new novel technology based on microwave and plasma technology
Degree of innovation required
The process may lead to same or higher yields in companies – with conventional technique
Carbon saving potential
Low cost based on the use of microwave oven (household)
Evidence of insufficient current funding or investment (“additionality”)
No project has been supported yet in this research area
Potential for results to contribute economic value in the UK
As a multipurpose generic system the UK renewable energy company will benefit hugely Doable (?) optimum market for UK Biomass resources
Strength of UK research capability relative to the rest of the world
This will open new dimensions to new challenging technology, would compete in cost, efficiency at any scale. Latent capability (but needs coordination) of microwave engineers, physicists, chemists, biologists, computer scientists, Control (?)

Topic area [e.g., feedstock, systems, etc.]:	Systems and Sustainability
Facilitator:	Jane Garnet
Group members:	Brian Cumming, David Ketchel, Ausilio Bauen, Charles Banks, Laura Pleasants, Philip Jones, David Howard, Matt Holgate
Title:	Identifying the "Show Stopper"?
Description of Directed Research challenge	<p>Show stoppers:</p> <ol style="list-style-type: none"> 1. Where is the technology? Step Change 2. Where is the carbon saving? 3. Where is the intellectual property? <p>Systems does not equate to the generation of intellectual property But should be applied to all other bioenergy-directed research projects</p>
Degree of innovation required	
Carbon saving potential	Not directly
Evidence of insufficient current funding or investment ("additionality")	Whole systems approach Does not fit Carbon Trust funding criteria
Potential for results to contribute economic value in the UK	Whole systems approach can be used for evaluating projects or contributing to roadmaps Can however generate tools or methods that can be commercialised (but already in the public domain) via: <ol style="list-style-type: none"> 1. accreditation system; 2. mapping services; 3. protocols; 4. measurements
Strength of UK research capability relative to the rest of the world	

Topic area [e.g., feedstock, systems, etc.]: Feedstocks
Facilitator: Claire and Jo
Group members:
Title: Tools for Accelerated Design of low carbon sustainable bioenergy crops
Description of Directed Research challenge
<p>Crops are not optimised for bioenergy conversion technologies Current tools are not fast enough to screen genetic diversity Time to market is too long This includes both conventional and GM technologies.</p> <ul style="list-style-type: none"> A. Develop Tool B. Apply and validate tool with companies
Degree of innovation required
<p>Collaboration between physical sciences, engineers, computing and bioscience to develop techniques for high throughput screening and set up activity (some already available)</p>
Carbon saving potential
<p>Enabling life cycle low carbon crops (reduced inputs, efficient conversion, etc.) With these tools: faster, broader range of traits. Doubling yield by when?</p>
Evidence of insufficient current funding or investment ("additionality")
<p>Current activity not clearly directed towards industry needs Work out/ask what industry will want in future and use this as a target Work with a limited number of companies to prove. Eg. Ethanol company, oil company Activity elsewhere won't lead to UK crops or necessarily crops for outside UK.</p>
Potential for results to contribute economic value in the UK
<p>Services in crop development (globally) unless US gets there first IP in germ plasm New patentable tool technologies.</p>
Strength of UK research capability relative to the rest of the world
<p>World class basic science Appetite to work with other countries Obvious thing to focus on Commercial value important</p>

Topic area [e.g., feedstock, systems, etc.]: Thermal Conversion
Facilitator:
Group members:
Title: Combustion Technology and Biofuel Product Development
Description of Directed Research challenge
Combustion (engines) for variable quality fuels from small scale plant
Degree of innovation required
Need to understand and control combustion process and engine events (injection, valves, aftertreatment)
Carbon saving potential
Huge savings on large % Blends of biofuels
Evidence of insufficient current funding or investment ("additionality")
Very little funding for use of biofuels in modern engines
Potential for results to contribute economic value in the UK
Large engine and machine industry and export (LR, OCB, ...)
Strength of UK research capability relative to the rest of the world
A number of world-class engine/combustion centres (Academic research and development Ricardo Lotus Cosworth/Mamle, etc.)

Topic area [e.g., feedstock, systems, etc.]: Thermal and chemical conversion
Facilitator:
Group members:
Title: Smaller-Scale Conversion Processes
Description of Directed Research challenge
Producing liquid fuels from biomass on small scales. Balance size of plant against maximum economic distance to collect biomass Distributed generation of fuel (+heat and power) Small/medium scale (farm ↔ small town)
Degree of innovation required
Technologies work on large scales, but not so far economical on small/medium scales. (miniaturisation? Process intensification?) Biomass/waste → Convert to syngas (Anaerobic digestion, gasification, reforming) → convert to liquid fuels (FT [synfuel], bioethanol) → Use fuel locally or transport products to refinery for final stage processing, use heat locally, use spare power locally (CHP) Can we get the technologies (which ones?) to work on small scales economically.
Carbon saving potential
Use biomass to replace oil imports Integrate CMP to improve efficiency and reduce waste Use renewable electricity (local wind turbine?) to help run process If works and rolled out nationally = large greenhouse gas savings
Evidence of insufficient current funding or investment ("additionalty")
Very little research (if any) on small scale BTL (Biomass-to-liquid = BTL; Gas-to-liquid = GTL) Large petrochemical companies focus on large scale GTL Some work on flare gas/associated gas GTL but still 'large scale'
Potential for results to contribute economic value in the UK
Opportunity to bring together existing UK expertise to gain first novel advantage in new markets. Technical and 'integration' problems mean barriers to entry for other players Can roll out in rural communities on global stage
Strength of UK research capability relative to the rest of the world
Strengths in catalysis, engineering (including oil industry), agriculture (biotech, etc.) But, these technologies need integration and involvement of industry including SMEs How can they find each other?

Topic area [e.g., feedstock, systems, etc.]: Biorefinery/Novel Fuels
Facilitator: Sarah Keay-Bright
Group members: Philip, Edward, John, Michael, Andrew, Richard, Justin
Title: Novel Chem-Bio process to fuels/chemicals
Description of Directed Research challenge
Process technologies for higher value and sustainable fuels and chemicals from bio-derived feedstocks Target is a package and play module for a future biorefinery
Degree of innovation required
High innovation required but broad opportunity set Multi-disciplinary – requires new approaches to work together (MD – essential component of any funding proposal)
Carbon saving potential
Very high, demonstrate better carbon saving than conventional biofuels (factors of 3) compared to current state of play. CCS adds additional carbon saving.
Evidence of insufficient current funding or investment (“additionality”)
Few SMEs Limited focus on this area until recently from funding agencies Emergent activity is not visible
Potential for results to contribute economic value in the UK
Invigorate UK chemicals sector Build innovative/dynamic SME biotech cluster EU-wide opportunity to lead
Strength of UK research capability relative to the rest of the world
Very good – strong in chemical engineering, chemistry, and world leading in life sciences and interdisciplinary effort is good/improving

Feedback:

What are modules?

What are assumptions input/output?

Different one – need more work

What module to concentrate on first? Topic area [e.g., feedstock, systems, etc.]: Changes in Utilisation of Waste Biomass
Facilitator: Keiran Allen
Group members: Saran Sohi, Richard Murphy, Simon Mc-Queen-Mason
Title: High Tolerance Microbial Fermentation for Mixed Biowastes
Description of Directed Research challenge
Develop a pre-treatment and fermentation process that can produce ethanol from a wide variety of waste streams and operate in a highly-toxic environment. Also require small-medium scale viability.
Degree of innovation required
High. Current fermentation focuses on high yields from relatively homogenous feedstocks (alcohol) Need to develop very hardy organisms to operate Some knowledge transfer from sewage digestion (anaerobic process needed)
Carbon saving potential
Significant. ~25 Mt biological mixed-wastes produced per annum. ~30% ethanol yield possible. Significant substitution credits and alternative end-users for cake eg. Co-firing?
Evidence of insufficient current funding or investment ("additionality")
Commercial waste research focus on AD and incineration (composting) as these are available technologies. U.S. focus shifted away from waste to biofuels? Landfill tax (not R&D) drives approaches to waste management.
Potential for results to contribute economic value in the UK
High. All co-products have high (ethanol) or low but high volume (cake) markets. If process can be made to work at smaller scales, technology is highly exportable.
Strength of UK research capability relative to the rest of the world
Significant. Academic and industrial strengths in fermentation biology Expertise in advanced enzyme biology Imperial, York, Rothamstead, Norwich Brewing industry – strong waste management (funding, logistics??)

Comments:

AD of mixed wastes?

Expose microbes to test conditions then allow natural selection

AD itself needs much more R&D

APPENDIX 2 – WORKSHOP PROGRAMME

Bioenergy directed research: opportunities for the Carbon Trust & the bioenergy community 12th and 13th November 2007, Lady Margaret Hall, Oxford

A 2-day residential workshop to explore bioenergy research opportunities which could benefit from financial support from Carbon Trust using its new directed research approach

Day 1 Monday 12th November

- 9:30 *Registration and welcome refreshments*
- 10:00 **Welcome and overview of the workshop**
Garry Staunton, Carbon Trust &
Sarah Keay-Bright, UKERC Meeting Place
- 10:25 **Carbon Trust 'directed research' approach: Photovoltaics as a case study**
Robert Trezona, Carbon Trust
- 11:10 **The UKERC bioenergy landscape and roadmap**
Gail Taylor, University of Southampton/UKERC
- 11:40 *Refreshment break in the Bear Pit room*
- 12:10 **Carbon Trust framework for selecting topics for directed research and current state-of-play**
Robert Trezona, Carbon Trust
- 13:00 *Lunch in the Jerwood Room*
- 14:00 **Plenary brainstorm**
Sarah Keay-Bright, UKERC Meeting Place
- 14:30 **Syndicate sessions**
Participants to work in parallel groups, focusing on the following topic areas:
1. Bioenergy feedstock development
2. Thermal and chemical conversion
3. Biologically-enabled conversion
4. Concepts for biorefineries
5. Options for novel biofuels and other valuable biomass products
6. Challenges in utilisation of waste biomass
7. System perspectives (including end use) and sustainability
- Refreshments served at 15:45 in the Talbot Hall; poster marketplace.*
- 16:30 **Discussion on proposals developed**

- 17:30 Close
- 19:00 *Pre-dinner drinks, St Anne's College.*
- 19:30 *Dinner, St Anne's College*
After dinner speaker: Sir Ben Gill

Day 2 Tuesday 13th November

- 8:30 *Refreshments available from 8:30 in the Bear Pit room.*
Groups welcome to reconvene before 9am to incorporate feedback into proposal.
- 9:00 **Syndicate groups**
Syndicate groups to prepare a presentation for plenary to include:
- Why should we do this?
 - What would it look like?
 - Who would be involved?
 - What will we get at the end that we don't have now (what am I buying?)?
 - Who (else) might pay for this?
- 10:15 *Refreshment break in the Bear Pit*
- 10:45 **Syndicate group presentations in plenary**
Sarah Keay-Bright, UKERC Meeting Place.
- 12:05 **Voting session**
Vote on which proposal is the most appropriate for the Carbon Trust to support, followed by plenary discussion on this and proposals of merit that could attract support from other funders
Sarah Keay-Bright, UKERC Meeting Place.
- 12:40 **Next steps**
Robert Trezona, Carbon Trust
- 13:00 *Lunch in the Jerwood Room*
- 14:00 Close

APPENDIX 3 - Bioenergy Directed Research workshop attendee list

First name	Surname	Email	Organisation
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