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Biofuels, science and society

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Introduction

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The International Energy Agency's New Policies Scenario projects a world demand of 99 million barrels of crude oil per day by 2035, but peak oil production at 68–69 million bpd (http://www.iea.org/press/pressdetail.asp?press_rel_id=402). Something has to fill this gap, even if there are widely enforced efficiency measures and industrial convulsion that might drive oil consumption down. This is simply a resource–demand gap, without factoring in the need to address fundamental issues around greenhouse gas emissions [1]. In the long term, other technologies may replace the present petroleum fuel-driven motor vehicles, heat and power systems, including fuel cells, direct hydrogen, electric vehicles, *inter alia*. However, in the short to medium term, a replacement is needed that will help reduce carbon dioxide emissions and extend petroleum fuel reserve life. Biofuels have been subject to much scrutiny over the past decade [2]. In reality, there are few practical alternatives in terms of delivering substitutes for road transport fuels compatible with existing transport infrastructure. In this issue of *Interface Focus*, we aim to bring together experts from many facets of biofuel production and implementation, across socio-technical approaches, to discuss drivers for the use of biofuels as well as the barriers to exploitation of biofuels.

Although much work has already been done on biofuel production, there are still disconnects between various aspects of the process. The biological control of starch and oil yield, and processing of lignocellulose, is, presently, not fully understood [3]. At the physical sciences level, much work needs to be done drawing engineers, biologists and chemists together to gain a holistic approach to developing biofuel technologies. Furthermore, for example, much of the current life-cycle analysis work is undertaken by experts in that particular mode of study, rather than with experts in the biofuel technology under development.

Furthermore, areas where there needs to be increased understanding are in the disciplines not normally included in life-cycle analysis exercises [4]. For example, in the past, biofuel technologies have failed owing to negative public perception (palm oil), or volatility in feedstock price and supply (waste vegetable oil). There is poor understanding at public and policy level of the risk posed by land-based biofuels to water supply, and also the risk of potential competition with food crops and biodiversity. Indeed, the diversity of biofuels has been in general poorly communicated to the public, with all biofuels seemingly treated using one umbrella term arising mainly from experience of US-origin maize starch ethanol.

In this present issue of *Interface Focus*, biofuels are explored from a variety of viewpoints. From the standpoint of the replacement of demands made by the existing petrochemical platform, Roddy [5] examines the rationale behind the provision of biomass as a petroleum replacement and the areas of the global petrochemical supply chain where biomass can be used, balanced against projected growth in demand for petrochemicals. As well as energy, other sectors will compete for biomass, in the form of man-made textiles for clothing, ubiquitous plastic artefacts, cosmetics, etc. Within the paper, Roddy shows the importance of assigning priority at a societal level for the increase in the production and use of biomass resources, examining biomass component extraction, direct chemical conversion, thermochemical conversion and biochemical conversion routes. In the light of discussions by others around

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biofuel policy, this paper interestingly also identifies a real need for long-range planning for infrastructure and logistics.

Staying with the theme of development of technologies to replace petrochemical-derived resources, Abbott *et al.* [6] examine novel reactor designs for bioprocessing. The authors review the recent interest in the concept of bioprocessing, where complete living cells or any of their components are used for the production of useful products ranging from high-value pharmaceuticals [7] to low-value fuels [8], and show examples of the development of bioprocesses based on renewable and organic feedstocks, with the constraint of maintaining or decreasing current production costs compared with traditional technologies [6]. The authors describe how, in conventional processing, the entire production pathway from feedstock to product requires many stages including pretreatment, production, extraction and purification, and invariably uses traditional batch stirred tank reactors and continuously stirred tank reactors of types that have existed for decades and are still widely used throughout the chemical and bioprocessing sectors for production, owing to their simplicity [9]. Abbott *et al.* describe a recent development in the field of biological processing, the use of oscillatory baffled reactors, in order to address some of the challenges inherent in bioprocessing, for example, how to achieve good global mixing yet low shear, a combination essential for specific bioprocesses including the culture of microalgae, which require mixing to provide illumination and carbon dioxide, but suffer from cell fragility [10].

By extending the broader aspects of biofuel systems, Thornley & Gilbert [11] introduce a framework that can be used to evaluate the environmental risks and benefits associated with biofuel production. The example of Argentine soya bean biodiesel is used to conceptualize trade-offs between different environmental, social and economic impacts of biofuel production. Results are presented that show the greenhouse gas savings and overall life-cycle impact of different 'soy-biodiesel' production methods. The authors show that, even when sufficient knowledge exists to be able to quantify these impacts, the sustainability of supply of a particular biofuel is inextricably linked to values and ethical judgements, which are exceedingly hard to factor into normal life-cycle analysis [11]. The authors conclude that when weighing up the implementation of a biofuel technology, a wide diversity of impacts need to be accounted for, and one of the peculiar challenges associated with bioenergy is that these impacts tend to be far wider than for competing technologies, moreover, coupled with uncertainty in key areas such as soil carbon budgets [12] and nitrous oxide emissions [13].

Such uncertainty is a particular difficulty for investors in biofuel technologies and, in their article, Wells *et al.* [14] report on interviews, and research within the investment community and with established and new renewable energy start-ups, to directly assess some of the barriers present. In many cases, the necessary sustained and long-term funding from the investment community has not been realized at a level needed to allow technologies to become reality. According to global consulting firm Deloitte's [15] recent renewable energy report, many renewable energy projects stalled or were not completed, because of issues including the global economy, the state of government finances, difficulties in funding and regulatory uncertainty. Wells *et al.* [14] identify eight key issues, including a range of barriers and enablers, the role of the government, balance between cost/risk, value/return on investment, investment timescales, personality/individual differences of investors and the level of innovation in the renewable technology. It was particularly notable that in the findings the role of the government was discussed more than other themes and generally in quite critical terms, highlighting the need to ensure consistency and longevity in government funding and policy and a greater understanding of how government decision-making happens.

In terms of governance, the issue of biofuels shows its global reach, as production of certain energy crops may be optimal in countries with low-energy demands, but burgeoning populations with low-income levels. Wu *et al.* [16] examine one such crop, the oil-rich nuts produced by *Croton megalocarpus* [17], which have been shown to yield oil in excess of another species considered for large-scale bioenergy culture, *Jatropha curcus* [18]. Considering the use of this crop in an indigenous context, to address power generation in sub-Saharan Africa, Wu *et al.* outline the development of a 6.5 kWe micro-trigeneration (power, heat and cooling) prototype based on an engine running directly on *Croton megalocarpus* oil (CMO), which has an exceptionally high linoleic acid (C18) content. The direct and local use of CMO instead of *C. megalocarpus* biodiesel converted by a transesterification process [19] minimizes the carbon footprint, owing to the simple fuel production of CMO. The experimental assessment proves that the prototype fuelled with CMO achieves a similar efficiency (76% prime energy) to *C. megalocarpus* diesel. The authors also outline improvements such as preheating that can reduce the environmental footprint of the system.

Within a developing world context, Campbell & Sallis [20] argue that different kinds of bioenergy and different socio-economic contexts of development and poverty present a complex scenario that requires a different approach and present an analysis combining expertise on local socio-economic processes, and appropriate anaerobic digester solutions for an example of energy in development in Nepal. Here, approximately 90 per cent of energy needs are still met by biomass, and the prospect of keeping carbon locked up in the forests overlaps onto the agenda of biodiversity conservation [21] and reducing emissions from deforestation and forest degradation [22]. A 'yak cheese' factory predates the establishment of the national park, and is under pressure to stop using fuelwood for its operation. The state-run cheese factory brings very significant income to an otherwise under-developed district. The study illustrates how clean energy solutions potentially offer new frameworks for collaboration between local livelihood resilience and biodiversity protection.

Thus far, the focus of the discussion has been around terrestrial biomass, and, for example, the Institute of European Environmental Policy estimates that 0.4 billion hectares are needed for additional land-based biofuel crops—an area about the size of the Netherlands [23], albeit spread through the world, some of it in areas with a reputation for high biodiversity. If marginal land and perimeter waters can be used for land-based microalgae culture, this immediately reduces the pressure from land-based biofuel crops production [24]. Similarly, the use of macroalgae (seaweeds) as an energy feedstock also opens up the possibility of using the ocean as an alternative source of biomass for energy applications. In this vein, two further papers are presented detailing some of the issues.

Rowbotham *et al.* [25] looked at the use of macroalgae as a source for thermochemical processing via pyrolysis. Macroalgae represent a novel class of feedstock for pyrolysis but, owing to the nature of the environment in which they grow, coupled with their biochemistry, they naturally possess high-metal content [26]. Although the impact of the presence of metals upon the pyrolysis of terrestrial biomass is well documented, the impact for marine feedstocks is largely unknown [27]. The authors describe the pyrolysis of a carefully selected and readily transferable model compound, copper (II) alginate, together with alginic acid and sodium alginate, to explore the effects of metals upon macroalgae thermolysis. Cu(II) ions were shown to promote the onset of pyrolysis in the alginate polymer, some 14°C lower than alginic acid and 61°C below the equivalent point for sodium alginate. To assess the validity of the model system, samples of wild *Laminaria digitata* seaweed were doped with Cu(II) ions prior to pyrolysis and showed similar behaviour. Traditionally, it has been considered that the use of seaweed has not been viable for thermal conversion owing to large energy requirements for removal of excess water [28], something which studies such as this show can be mitigated by other treatments.

Owing to a variety of desirable traits including rapid growth rates and high oil contents, biofuels production from microalgae attracts much attention [29]. However, owing to high processing costs [30], there has been great interest in genetic modification (GM) of microalgae to produce far higher yields of biofuels components [31]. Flynn *et al.* [32] explore routes to enhance production through modifications to a range of generic microalgal physiological characteristics, showing that biofuels production may be enhanced by an order of magnitude through the GM of factors affecting growth rate, respiration, photoacclimation, photosynthesis efficiency and the minimum quotas for nitrogen and phosphorus (N : C and P : C). Inherent challenges in any GM technology include containment of the GM organisms and realistic analysis of risk to the natural environment, and risk is elevated for micro-organisms such as microalgae. The authors present simulations which, indeed, indicate that the ideal GM microalgae for commercial deployment could, on escape to the environment, become harmful algal bloom species because their accumulation of carbohydrate and/or lipid to high levels is no longer optimal to support their elimination by the zooplankton that normally graze on them.

The diversity of disciplines involved and techniques investigated and used gives insight into the scale of the biofuel debate and its associated research. The area is inherently interdisciplinary and requires consideration at many levels. The outcome of the Biofuels, Science and Society conference, held in Durham University and hosted by the cross-discipline Institute of Advanced Studies, from which these selected papers have been drawn, illustrate the magnitude of the whole bioenergy system. Just some of the key issues arising are (i) to encourage investment, governance should include a trajectory for the sale of sustainable biofuels to 2020 and beyond; (ii) indirect land use change through growing bioenergy and displacement of existing activity is a question that has proved to be extremely complex and there is little consensus as to the real effects on greenhouse gas emissions or on the displacement of food production. For example, the European Commission has now (October 2012) proposed a limitation on support for crop-based biofuels and a reporting structure, with broad factors provided, to cater for indirect greenhouse gas emission impacts; (iii) further support for 'advanced' biofuels should be given. Currently, the EU Renewable Energy Directive contains a clause that gives double rewards for biofuels made from wastes and non-food ligno-cellulosic material to bring on the development and commercialization of 'advanced' biofuels. While used cooking oil and tallow benefit from this provision, the European Commission has recognized that it is ineffective for more complex conversion technologies and has proposed that the rewards for specified feedstocks be given a quadruple benefit; and (iv) at the technical level, current petrol and diesel fuel specifications in Europe do not permit the blending of more biodiesel than 7 per cent (B7) or more bioethanol than 10 per cent (E10). With these limits in place, targets will be difficult to achieve. Note that vehicles in Brazil can run on 100 per cent sugarcane ethanol if needed.

In conclusion, biofuels present technology options to deliver sustainable replacements for petroleum derived resources for fuels, and other chemicals and materials. As a result, research has flourished around biofuels, and bioenergy/biorefining in the widest sense, bringing together many disciplines and delivering highly novel research outputs. However, the complexity of the bioenergy systems still requires considerable research to be able to deliver solutions that are truly sustainable. Critically, governments also need to deliver consistent long-term policy if research is to be converted into commercial production.

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