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Second-generation biofuels: exploring imaginaries via deliberative workshops with farmers

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Abstract

Second generation biofuels derived from agricultural lignocellulosic waste represent what is hoped to be a significant technological, but also socio-economic advance beyond the shortcomings of first generation biofuels (chiefly bioethanol). The development of advanced catalytic techniques is a central part of making such technologies viable. However, assessing the potential socio-economic significance of the socio-technical arrangements necessary to translate such fundamental techniques into mature technologies is also a central part of shaping the development of second generation technologies in a way that both avoids the shortcomings of first generation fuels and ensures that future developments are genuinely responsive to social needs. A pilot project is described in which a deliberative workshop with farmers in Wales is used to explore the potential societal impacts of novel nanocatalysis methods for the production of lignocellulosic biofuels developed by members of the research team. Using risk- and benefit-ranking/issue mapping methodologies, the workshop examined the potential future role of bioeconomies of different scales, in which second generation biofuels play a significant part, in transforming rural communities. Grounded scepticism from workshop participants delineated key socio-technical issues that will be highly consequential for the development of second-generation technologies, thus laying the ground for subsequent planned work on responsible innovation and nanocatalytic methods of biofuel production.

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Introduction

Biofuels are being promoted as one of the sustainable alternatives to fossil fuels, mainly for transportation uses. As well as reducing greenhouse gas (GHG) emissions, they are surrounded by promissory rhetoric that depicts them as a potential source of energy security, as well as catalyst for rural regeneration through the creation of 'bioeconomies' that will lead to increased prosperity for farmers and more agricultural jobs (Nuffield Council on Bioethics 2011). Typically, biofuel development is prospectively mapped through foresight studies across several distinct 'generations', beginning with specific crops (such as sugar cane) grown specifically for conversion to bioethanol. These current, 'first generation' technologies are expected to be superseded by the development of lignocellulosic biofuels (LBs), based on the conversion of agricultural wastes (such as straw or corn stover) or fast-turnover crops (like switchgrass or miscanthus). Subsequently, it is expected that other feedstocks (such as algae or crops bioengineering to sequester increased amounts of carbon) will be developed in 3rd and 4th generations. The move away from first generation crops is seen as necessary for reasons of efficiency and cost, but also because of the wide criticisms of first generation biofuels for the ways in which they compete with food crops (thus contributing to higher food prices) and lead to the displacement of small farmers in the developing world.

Research to date on the potential social desirability, as well as future technical viability of emerging biofuel technologies remains scanty. In this paper, we make a contribution to remedying this deficit by reporting on results from a small deliberative pilot study connected to an interdisciplinary collaborative project based at the universities of Cardiff and Bangor in the UK that is developing novel nanocatalytic methods for the production of chemicals, including biofuels, from lignocellulosic biomass derived from agriculture waste. The promise of these methods lies in the ways in which they can reduce the need for conversion of wastes to be carried out at high temperatures, thus reducing the costs to producers of setting up and running a biorefinery. Although our study is a pilot one, it represents an attempt to show, in contrast to the largely extractive methodologies applied to date to study public and farmer opinions of biofuels, a responsible research and innovation (RRI) approach, working closely with groups of farmers as part of upstream deliberation, can make a major contribution to exploring the viability and desirability of LBs. In particular, it can leverage lay expertise

to explore the specificities of socio-economic relationships within which LB technologies will need to be embedded. We report on findings from a deliberative workshop held in July 2016 with farmers in mid Wales in the UK that add to existing scholarship on the social assessment of LBs by setting out how fossil fuel markets, current uses of agri-waste and the complexities of environmental regulations will influence the viability and desirability of further developments in LBs.

Second generation lignocellulosic biofuels

The development of biofuels has been widely framed as essential for helping to address two aspects of the 'energy trilemma' – by reducing carbon emissions from the production of transport fuel, and also (particularly in the USA) by enabling nations to free themselves of dependence on the international trade in fossil fuels, thus achieving greater energy security (Ribeiro 2013, 79). Biofuels are commonly classified as belonging to one of two (or sometimes three or four) generations or waves of development, of which only the first has so far seen wide deployment. First generation biofuels are chiefly sourced from crops like sugar cane, corn or soybeans, which are processed to provide ethanol. Second generation biofuels, which are yet to see largescale commercial deployment, rely on a variety of physical, biological or chemical processes to produce fuels (and other useful chemicals) from lignocellulosic biomass (typically, 'woody' agricultural waste, but also from specially grown crops like switchgrass or miscanthus). At this time still largely speculative technologies, third and fourth generation biofuels are expected to be developed, respectively, through the exploitation of algae-based feedstocks and the genetic engineering of plant feedstocks that exhibit e.g. enhanced capacities to capture CO₂ from the atmosphere (Dutta, Daverey, and Lin 2014, 116-17). Rhetoric surrounding second generation or lignocellulosic biofuels (hereafter, LBs) is marked by often highly promissory language. In particular, the technologies required to produce the fuels are seen as offering a way to deal with the much-discussed negative social and environmental impacts of first generation fuels, as laid out in what have become known as the 'food vs fuel' debate and controversies over their contribution to anthropogenic global warming (AGW).

Ceding arable land for growing first-generation fuel crops, and appropriating additional land by clearing forest means a reduction in the amount of land for growing food, potentially contributing to rising food prices worldwide (a contribution first noticed in the worldwide food price spikes of 2008-09). This impact is particularly serious when the land taken is appropriated in the developing world through the activities of developed-world corporations. The prospects for first generation fuels as a tool in decarbonising fuel production are also questionable. Biofuels are hoped to reduce the amount of greenhouse gases in the atmosphere because they lock in CO₂ during photosynthesis to balance

CO₂ produced while they are processed and burned in combustion engines. Biofuels are generally hoped to be carbon neutral, not carbon negative, overall. But first generation fuels face various problems. Reduction of forest cover through land use change (as in Brazil, for example) leads to lower capacity of vegetation to absorb CO₂, as well as leading to increased CO₂ emissions through the use of fossil fuels in producing fertiliser for large-scale crop cultivation. Further, use of fertilisers in crop production leads to production of nitrous oxide which stays in the atmosphere for 100-150 years and is 300 times as potent a GHG as CO₂. Accounting for the 'carbon debt' incurred through first generation fuel production indicates it may take between 100 and 1000 years to cancel out the total CO₂ produced during their cultivation alone (Kim, Kim, and Dale 2009). In addition, although first generation fuels have created rural employment in places like Brazil, they have also brought soil erosion, river basin contamination, air pollution, human respiratory diseases and extremely poor working conditions (Antizar-Ladislao and Turrion-Gomez 2008).

LBs are hoped to avoid these kinds of issues, in particular avoiding the problem of carbon debt (Fargione et al. 2008). The use of agricultural waste from existing crops (like straw or corn stover) is expected to avoid the problem of needing to replace food with fuel crops. Where additional quick turnover crops like switchgrass might be used, the use of marginal land rather than higher-quality soils is anticipated, again hopefully avoiding the use of food growing land. Nonetheless, such hopes are exactly that: hopes, through which the meaning of LBs in the present is constructed by anticipating what a future shaped by optimally successful versions of them might be like. Discussions of the desirability and potential viability of LBs here and now therefore inevitably involve assessments of the plausibility of promises (Selin, 2011), as well as discussion of the possibility of the unintended consequences of innovation (Beck, 1992).

These discussions may be rooted in bodies of scientific evidence relating to agricultural and broader environmental process, and to social scientific models of technological and socio-economic change. But such discussions are beset by fundamental difficulties. The very act of trying to 'improve' the world by introducing new objects and artefacts into it is, by definition, an opening up of possibilities, some of which may be unforeseeable before these artefacts are out 'in the wild'. Understandings of risk, in the narrow sense of quantified probabilities of determinate harm, must feed into processes of societal assessment of the desirability of an emerging technology. But they are by no means sufficient. Making the world more complex by creating new situations that are potentially unprecedented in human knowledge and experience (a condition typified by technological innovation) means that the past (represented by archived data) is not necessarily a reliable guide to the future (Groves 2009).

Understanding potential impacts of new technologies thus needs to bring in viewpoints additional to those of experts directly engaged in developing them, in order to explore the diverse ways in which new technologies may create unforeseen ‘interference’ effects (Hacking 1986), some of which may go far beyond quantifiable economic, health or environmental impacts. In particular, the value to social technology assessment of ‘lay’ stakeholder perspectives on technologies has been repeatedly emphasised in recent years by a range of commentators (Grove-White, Macnaghten, and Wynne 2000, Wynne 1996). In addition, the ways in which new technologies may help rewrite the implicit (e.g. cultural norms) and explicit (e.g. law) rules of social life (Feenberg 1999) mean that the tacit ‘legislative’ role of technological innovation should be open to democratic scrutiny (Tallacchini 2004). There are thus instrumental, substantive and normative rationales for extending the assessment of new technologies beyond expert assessments of risks and benefits (Fiorino 1990).

The concept of responsible research and innovation (RRI) is a response to this ‘post-normal’ condition of expert knowledge. The need to expand the range of perspectives used to understand potential future impacts of new technologies, together with the need for scrutiny of the ways these impacts may include a rewriting of societal norms, demand the exercise of reflexivity towards promises about the potential value of a new technology, and also towards how the problem to which it is believed it might be part or all of the solution has been hitherto defined (Stilgoe, Owen, and Macnaghten 2013). Defining what energy security means, for example, leads to a particular understanding of the problem of energy *insecurity*. But energy security for a nation might be compatible with, for example, energy insecurity for sections of its population (Hildyard, Lohmann, and Sexton 2012). Questions of desirability cannot therefore be limited to weighing up what the extant scientific corpus defines as reliable data on risks or benefits (Preston and Wickson 2016). Further, as time goes on, discussions of what are to count as pressing problems, priorities and purposes are inevitably shaped by selections between potential technical responses, just as choices between emerging technological options are shaped by identified priorities (Mol 2008, Verbeek 2011). Innovation processes tend to be framed as linear ‘top-down’, technology-led ones which generate products in response to pre-given, consensual social needs which are then purchased by consumers who realise their value. Framing innovation more inclusively as a ‘bottom-up’ process which must include a variety of perspectives in order to shape technologies and embed them more sensitively in evolving social relationships is thus a central aspect of RRI.

Part of understanding how new technologies will be developed as part of complex socio-economic relationships and will, in turn, help to reshape these relationships is understanding how the

expectations and promise which circulate through and around technologies are already rewriting social relationships, and what scientific research gets done here in the present (Borup et al. 2006), as well as thinking about how these will interact with ongoing social processes to shape outcomes. Hope and anxiety around promises provide powerful conduits for the formation of social coalitions in the present (Brown, 2005), and thus for the reordering of power relations. The dynamics of promising, including hype and disappointment cycles (Brown & Michael, 2003), can be conditioned by assessments of plausibility in ways that aim to establish the relative pedigree of different promissory rhetorics (Grunwald, 2011). Social assessment of technologies, in bringing in a variety of perspectives, therefore needs to happen *ex ante*, indeed, 'upstream' (Wilsdon and Willis 2004), before the exploration of techniques begins to decisively coalesce into path-dependent selections of technology options. It has been proposed that critical, reflexive exploration of the assumptions and values inherent in promises is an essential part of RRI (Simakova and Coenen 2013), as this creates 'second order reflexivity' (van de Poel and Zwart 2010), including not only the prospect of opening up alternative paths of technology development, but also potentially using these reflections to open up potential redefinitions of the problems to which technologies are framed as solutions (Stirling, 2014). Participatory forums of various kinds intended to provide opportunities for this kind of critical exploration open up a route for multi-sided dialogue intended to create transparency around subjects of deliberation as well as to open up routes to effective influence decisions relating to technology development or regulation (Rowe and Frewer 2005).

Relatively little attention has so far been paid in literature on emerging technologies to bioenergy and biofuels in particular. There is some evidence that public opinion, especially in the USA, where debate over the economic and environmental effects of first-generation technologies has been at times intense, is inclined to view second generation biofuels more favourably (Delshad et al. 2010). Beyond this, relatively little has emerged regarding public views of LBs, though evidence tends to support this finding of support (Rohracher 2010, Cacciatore, Scheufele, and Shaw 2012). In the field of RRI, some scholarship has explored the promissory rhetoric surrounding biofuels and bioenergy, along with some participatory research into lay stakeholders' perspectives.

Visions and imaginaries surrounding bioenergy in the UK have been investigated by Levidow and Papaioannou (2013), who identify three main visions within contemporary policy discourse relating chiefly to combined heat and power (CHP) and anaerobic digestion (AD) as ways of dealing with waste: localisation, agri-diversification and oil substitution. *Localisation* is seen, within discussions of the energy trilemma, as a way of increasing accountability as well as material benefits on a place-based

community level. It is also expected to deal, especially in the case of AD, with the costs of transporting waste for processing. *Diversification* is seen as both a way of dealing better with waste and of enhancing the sustainability of rural communities and the farming industry, as well as producing skilled 'green-collar' jobs. *Oil substitution* is seen as a priority to effectively reduce GHG emissions from the transport sector, particularly in response to more stringent EU regulations on GHG emissions, as well as providing economic advantages through the generation of intellectual property.

These imaginaries gather together shared promissory beliefs about how technical developments will be embedded within social relationships, and how they will transform the spatial and economic relationships between urban and rural. In addition, the promissory imaginary of a 'bioeconomy', in which bio-based goods, including wastes, form the basis of new economic relationships in which rural communities are involved, has become much discussed as a way of making sense of the potential of recent technical developments. In particular, the 'knowledge-based bioeconomy' (KBBE) is an imaginary that is increasingly influential at the level of national and regional policy in Europe. Articulated at the level of EU policy, this holds out the prospect of technology-led development which

can maintain and create economic growth and jobs in rural, coastal and industrial areas, reduce fossil fuel dependence and improve the economic and environmental sustainability of primary production and processing industries. (Schmidt, Padel, and Levidow 2012)

This promises integration of technological and social innovation in response to a set of particular problems, of which (global) resource depletion and climate change are just two. Uncompetitive rural economies and declining populations in these areas are also seen as problems that a growing bioeconomy can help to solve (Levidow and Papaioannou 2013, 46). In relation to biofuels, the envisaged future is one in which circular economies are created around agricultural and food wastes, and biofuel production is expanded through 2nd, 3rd and 4th generations, incorporating biotechnological techniques to improve feedstocks. From within these and related visions, farmers tend to be seen instrumentally in policy discourses about biofuels as actors who will help bring about planned change through the adoption of technological products.

Drawing on the literature on RRI and the sociology of expectations suggests that the credibility and pedigree of these visions and the promises entangled with them need to be tested, and that the perspectives of farmers will be vital to achieving this. Without such an approach, a number of difficulties that can be traced within contemporary imaginaries of 'the bioeconomy' will remain unaddressed. For example, viewing bioeconomies as products of solely technological change of which

farmers will be largely passive beneficiaries (Schmidt, Padel, and Levidow 2012, 51) may be seen as both implausible and as neglecting values and priorities which are of signal importance in just and equitable rural development, such as the effects of bioeconomy development on rural unemployment or the effects of biofuel exploitation on public goods, such as water availability and quality or soil health (Schmidt, Padel, and Levidow 2012, 54). Asking questions about such issues has immediate significance for technical explorations and technology choices. Depending on whether one prioritises public goods or not, for example, the concept of productivity and efficiency one then goes on to employ will be different – from maximising outputs per unit inputs, from a more industry and technology-led perspective, to reducing inputs while maintaining quality of outputs, from a more public goods perspective (56).

Further, the possibility that bioeconomies, in practice, may well take on different forms, shaped by the geographical, political and economic characteristics of particular regions, needs to be considered. This may be missed by research on farmers' opinions that often assumes that the meaning of a bioeconomy, in terms of its scale and defining structures, can largely be treated as given (e.g. Tyndall, Berg, and Colletti 2011). We could, for example, envisage a future in which 'small' and 'large' bioeconomies exist, perhaps interconnected in different ways across or within regions (Henry and Trigo 2014). The difference between these two forms of assemblage lies in where to locate infrastructure for processing biomass into energy and other chemical byproducts, and what relationships between farmers and others need to exist in order to set up markets in either case and to keep them working. The distinction has chiefly to do with the structure of value chains, and the degree to which process is characterised by forward integration and on-farm or localised processing, which reduces transportation needs and thus also reduces costs to farmers (Sanders et al. 2007).

In a small-scale bioeconomy, processing infrastructure is owned by individual farmers or cooperatives. Biomass collected from individual farms could be refined as locally as possible, with products then sold and transported to fuel distribution hubs or other points. This implies both particular technology choices and also societal innovations to maximise cooperation, allowing farmers to negotiate effectively with other actors in the value chain and also to mobilise investment in infrastructure and equipment necessary to harvest and process crop residues.

In a large bioeconomy, refining facilities would be more concentrated, perhaps at county or regional level. Farmers would then harvest and sell on crop residue waste, either individually, or once again, as part of cooperatives. Wastes would need to be harvested and collected from individual farms, and

transported a relatively long distance, which might lead to more heavy traffic on rural roads, additional costs (including road repairs), as well as potentially increasing emissions from transport. But at the same time, the economies of scale involved might result in LBs becoming more economically viable more quickly. A knock-on effect might then be to stimulate additional research and innovation to improve the efficiency of production. It might result in significant numbers of direct and so called flow-on jobs added to rural areas where refineries were located. On the other hand these job opportunities might not materialise, should large refineries be run more efficiently and profitably with more automation.

Beyond the imaginaries of the bioeconomy, localisation, oil-substitution and diversification, other concerns, which reflect some aspects of the controversies over first generation fuels, also need to be reflected upon in assessing LB imaginaries. Even if LBs do not promise competition between fuel and food uses of land in the same way as first generation fuels, questions of land use and ownership remains important. In the developing world in particular, the use of specially grown crops may create conflicts relating to the operational definition of 'marginal land' and the ways in which this definition may expand in practice to deny access to and use of traditionally available land (Nuffield Council on Bioethics 2011).

This may particularly be the case if LB penetration increases. Unintended consequences could follow, such as the possibility of wastes of sufficient quality for conversion becoming scarce. Similar issues have been encountered already in relation to anaerobic digestion and waste to heat incinerators, where companies and local councils run out of waste streams in the quest to hit profit targets, and so have to encourage more wastage rather than less or ship waste in from elsewhere (Alexander and Reno 2014). Further, impacts on public goods such as water and soil health need to be considered. Clearing crop residues for biofuels may reduce incidence of some pests and allow the soil to warm more quickly in the spring, enabling greater productivity. On the other hand, removal of residues reduces the amounts of nutrients available for soil conditioning, which may lead to increased use of fertilisers and thus both to higher GHG emissions associated with their production and also to water pollution through runoff (Marshall and Sugg 2009).

Research methodology

Assessing the pedigree of imaginaries is not just about debating shared visions, values and assumptions, however. Imaginaries are always anchored around particular techniques or technologies, whose credibility and viability they assist in establishing (Rip & Kemp, 1998). The socio-

technical complexities which surround the assessment of imaginaries are not separable from particular techniques. Instead, they are shaped by the affordances of technologies themselves, just as technologies are themselves responses to socio-technical problems. In this paper, we focus on a particular technique for the production of LBs, the design of which is already a socio-technical process, shaped by considerations of the comparative efficiency and cost-effectiveness of different methods, as well as by the need to avoid the negative social and environmental impacts of first generation fuels,

The development of new techniques therefore represents a process of technology assessment based on socio-technical criteria, although of a relatively limited range. Against this limited set of criteria, current technologies which fit broadly into a second generation frame have been seen as problematic. Fuels based on non-edible vegetable oils, for example, tend to fail the cost-effectiveness test. The high oxygen content (up to 50%) of these fuels renders them immiscible with fossil fuels (unlike first generation bio-ethanol), and makes them both more viscous and less likely to combust reliably, thus decreasing their efficiency as fuels and their economic value (Mohammad *et al.* 2013). Where techniques for direct conversion of lignocellulosic biomass into fuel are available, such as liquefaction, pyrolysis and gasification, these bring their own difficulties. Some of these achieve much higher efficiency in terms of outputs. But this tends to come at a cost, such as the need to perform conversion at high (e.g. >400°C) temperatures in the case of pyrolysis or high-temperature gasification, or to use catalysts (such as noble metals) which are expensive.

A possible alternative to these methods which seeks efficiency gains without increasing associated costs is to use catalysts for conversion reactions which employ nanoscale-versions of particular elements or compounds, including noble metals (Akia *et al.* 2014). Nanoscale versions of familiar materials often possess enhanced properties, such as a much higher reactivity due to a surface area that is relatively much larger than that of macroscale materials. The use of nanoscale noble metal catalysts has been proposed as a technique that promises considerable efficiency gains while also avoiding the need for higher temperatures and expensive infrastructure as part of the conversion process. These nanocatalysts are also much less costly, by weight and volume, than their macroscale versions. Members of our team based at Cardiff and Bangor Universities are developing catalytic techniques using monometallic and bimetallic nanoparticles which are stabilised at the water-oil (generic term) interface. Recently, the catalytic properties of these nanoparticles have been studied by the team for the first time. In this technique, compounds (derived from lignocellulosic biomass based feedstock) are dissolved in a water layer, with catalytic hydrodeoxygenation reactions being

performed using the metal nanoparticles at the water-oil interface. Useful products would automatically move to the oil phase from the aqueous phase.

The research question posed by this technique is then to what extent can it articulate with imaginaries of the bioeconomy in ways that may promise genuine social value in relation to visions of decentralisation, diversification and oil-substitution. This requires moving from assessment based primarily on a limited range of technical criteria to a broader degree of reflexivity in which the implications of imaginaries and visions, together with this technological approach, are opened up to societal reflection. A variety of different approaches have been developed in recent years to extend the degree of reflexivity realised by social technology assessment, drawing on a substantial corpus of research into modes of participatory research (Rowe and Frewer 2005). Issue mapping uses digital tools to map and track the emergence of particular framings of issues and concerns relating to new technologies via the internet and social media (Marres 2015). A more directly participatory methodology explicitly designed to allow stakeholder participation to shape innovation is deliberative mapping. Deliberative mapping employs public workshops, often iteratively and over an extended period, to open up a wider range of concerns and aspirations surrounding social issues and technological promises than is typically admitted by expert assessments. The emphasis is on creating opportunities for extended deliberation without approaching issues via too restrictive a framing early on. This is often paired with multi-criteria analysis to reflexively expand expert assessments beyond narrow risk-benefit framings to consider other dimensions of value and impact not necessarily typically examined.

Currently, empirical research with farmers and publics on the assessment of LB visions is fairly limited in scope. Studies with farmers often restrict themselves to considering whether or not they see themselves as playing a part or not in a bioeconomy shaped by new waste harvesting technologies (Tyndall, Berg, and Colletti 2011). A smaller number of studies position farmers as actors whose own perspectives should make a contribution to assessing the viability of these changes (Rossi and Hinrichs 2011). More broadly, RRI-based studies of public views of LBs using deliberative methodologies have shown that support for LBs exists, but also that this support may be dynamic and highly conditional, depending on trade-offs between different priorities and values (Capurro et al. 2015), a pattern which has been found elsewhere in relation to support for 'green' technologies, such as renewable energy (Pidgeon & Demski, 2012).

Our study was designed to address this research need, drawing on research seedcorn funding to set up an upstream pilot study early on in the development of the new catalysis techniques mentioned above, which are currently at around technology readiness level (TRL) 2-3. We employed a stripped-down variant of deliberative mapping to create an upstream engagement opportunity with farmers, with the goal of framing issues which could then be explored further in a subsequent research project, alongside the development of techniques into demonstrator installations at TRL 4-5. The importance of selecting participants with maximum relevant information was a key consideration, as was allowing participants themselves to specify discussion topics as far as possible within the limited time available, in order to identify important overlooked topics and issues (Rowe and Frewer 2005, 268-69). Overall, the topics and themes for discussion at the event were framed in way to achieve structured debate covering the socio-technical context as defined in extant literature on biofuels, as well as in the nanocatalysis research itself. Via an intermediary who had worked with the Welsh Government rolling out training for Welsh farmers in farm management (and who, as a farmer, also participated), we recruited nine Welsh farmers who owned their own land, and who engaged in combinations of livestock and arable farming. Two of these farmers had experience of working with small AD systems on their own farms.

In line with the broad framing we adopted, the deliberative workshop began by discussing issues relating to sustainability and farming in general with the group, before introducing the topic of biofuels, along with the distinctions between different generations of biofuels technologies, and then talking about the specific nanocatalytic technologies currently being developed jointly by the Cardiff Catalysis Institute at Cardiff University and Bangor University. These techniques were then discussed in relation to potential socio-technical options for developing them further into mature technologies, and the different scales of bioeconomy in which they might be embedded. Presented with two posters on which were shown possible LBs risks and benefits (drawn from scholarly literature on LBs) in three categories (general, large-scale bioeconomy, small scale bioeconomy), participants were given four coloured stickers for each poster (green, yellow, blue, red) and invited to use these to score these risks and benefits (green=most significant/most concerning, yellow next most, then blue, with red being used for any risk or benefit that participants felt should not be treated as being at all significant and could be ignored). Eight participants mean a maximum score of 24 for any one risk or benefit. Participants had five minutes with each poster to rank benefits and risks. Once risks and benefits had been identified, participants were asked if they felt anything had been left out, and whether they had experienced any difficulties with the exercise, before the main group was split into two. Each group and a facilitator had twenty minutes with each poster to explore the reasons people had for ranking

positives and negatives as they had done, and then to explore within the group how risks or benefits might eventuate or be prevented from eventuating.

Findings

Topics and themes discussed touched on potential differences between large-scale and small-scale bioeconomies, but also expanded to cover issues which could be said to cross scales.

Cross-scale issues

Understanding the possibilities which surround prospective technologies inevitably draws on past experiences, and debates then often turn around which experiences are most relevant. Farmers in each breakout group were keen to draw on colleagues' experience of AD and other biofuel crops, along with solar photovoltaic panels (PV), in developing analogies for helping the group make sense of and assess potential risks and benefits.

One additional risk to those with which we presented on the posters during the ranking exercise was identified by participants as the possibility of significant conflict between farming practices generally and the production of LBs. This related specifically to current uses of agricultural waste (wheat straw), such as for animal feed and bedding and soil conditioning. Within the pre-given list of risks, this was most closely related to the risk of soil nutrients being lost due to waste being diverted to LB production, a problem noted within the academic and policy literature on LBs (Marshall and Sugg 2009, Nuffield Council on Bioethics 2011, 48).

This was one area where a comparison with AD was directly made, and specifically with the way in which digestate, as the product of the process, may be used again to enrich soil. LBs, by contrast, were seen by some participants as creating a gap that could not easily be filled, rather than closing a loop.

P[articipant]: Well it's like baling up the straw to feed you know the power stations or you know burning that, it's gone and that's it there is no return but whether your crops are going off to the AD plant you've got the digestate coming, its potentially going to come back haven't you which is actually, it's recycling and putting the organic matter back into the soil.

P: Yeah and you're not losing the P [phosphorous] and the K [potassium] you're getting that back

No matter what scale future LB infrastructure might take, participants were concerned that LBs might impose additional costs by diverting ‘wastes’ that were already defined as important resources, making them scarce and potentially expensive to replace.

P: All the straw that's being used is being used for bedding and sold as bedding, if you use it in a bio refinery you've still got to find bedding [...]

This scarcity of ‘waste’ was already part of the rural economy.

P: And there is a fair percentage of straw because there is not enough straw grown locally that we're buying which comes from over that end of the country [East Anglia] anyway you know there is a lot, you know you'll see the, in another six weeks' time there will be lorries flying up these roads.

In terms of the frequency of participants ranking this as significant, and in terms of its overall score, this risk was close behind the risk participants associated with the need for farmers to invest significant capital in equipment for LB production as well as in subsequent running costs. Investing in equipment initially to get production off the ground was seen by more people as a significant risk, but overall the additional costs of labour and equipment associated with sorting and grading waste were scored as a higher priority for concern than these set-up costs.

In discussing prospective problems resulting from diverting already-useful resources redefined as ‘waste’, participants moved to discuss specially-grown crops as an alternative (with miscanthus as an example).

P: It needs it, you can't keep taking off and taking off. That's what some of the animal farmers have done in the East and they've got soil with no organic matter in it and those sort of things so you've got to find a balance somewhere. I mean if it's wood it doesn't matter, that's not going back on the land anyway is it?

With specially grown crops for biofuels, issues relating to marginal land come into play. As noted previously, definitions of what counts as marginal land are expected to play a significant part in shaping the political process around where and how second generation biofuels are exploited (Nuffield Council on Bioethics 2011, Ribeiro 2013). Whereas developing world contexts raise issues around neo-colonial exploitation and appropriation of resources, in developed world locations like mid Wales, where fertile lowland and upland areas are already extensively cultivated and sustainability is part of agricultural policy discourse, the problem of how to define marginal land is different. Two participants opened discussion in relation to conservation policy.

P: I would have said that we said in the corner about marginal land, there is no marginal land in Wales because we have woolly bears [tiger moth larvae].

P: That's not quite true, up on the hilltops.

P: Yeah but sheep still graze it don't they?

P: Not in some parts no, it's been abandoned.

The definition of marginal land has thus been altered, one participant suggests, because of the presence in upland areas of species that are listed in UK biodiversity protection legislation. Where land passes to non-marginal status thanks to concerns about conservation, the only areas left are hilltops used for sheep. The status of these areas is also contested, however, thanks to the intersection of traditional farming practices and newer ones associated with the promotion of biodiversity that have been developed in tandem with non-governmental organisations (NGOs).

P: We've been talking to RSPB [Royal Society for the Protection of Birds] and they're having to sort of crop and we have been looking at artificially cropping some of the uplands and we've been looking at charring some of those uplands.

P: I'm working with two groups of farmers and they all say uplands there's just, there's no cattle up there anymore or a few sheep

P: But without sheep grazing the biodiversity is changing.

P: Soon we'll have a forest again I expect.

In addition, the difficulty of accessing hilltop marginal land will likely raise the costs of harvesting waste.

P: Well there's purple moor grass, the sheep don't really like it much, it's only cattle that will graze it and there's no cattle so it's spreading and that could be, that's one potential for biomass but then getting access up on top of the uplands there's no road infrastructure to get it from there.

Whether existing 'wastes' are used, or fast-turnover crops grown specifically for LBS, participants had significant concerns about the additional costs of LBs production. The cost of additional equipment or services needed to separate waste products and thus to produce waste of a quality sufficient for LB production was seen as a significant problem. Problems of this kind with AD, leading to unintended feedback effects (such as competing with other processors for waste of sufficient quality or 'purity') have been noted by other researchers (Alexander and Reno 2014). Participants wondered if similar problems might emerge around LBs used for biofuels.

This was compounded by concerns about the existence and stability of market demand for LBs, whether produced from agri-waste or from specialised crops. A central problem with the production

of biofuels, small or large scale, was seen as the difficulties, at least in the short to medium term, in competing with fossil fuels.

P: And the oil price you wouldn't believe it, it was sort of \$30 a barrel and now it's creeping up now you know two years ago it was over a 100 wasn't it so that sort of dictates what's, that's the competition isn't it? That's the competition you're up against.

P: That's the kind of benchmark you are sitting across if you want to be, if you want your business to be sustainable.

The volatility of oil prices and the capacity of producers to lower prices when strategically useful made participants doubtful about the capability of LBs, even with subsidies, to become competitive. Specially-grown crops like miscanthus brought additional uncertainty given that they are not, unlike 'wastes', obviously resources with other uses.

P: [...] miscanthus or any other thing you might get enticed into there is always a higher risk in it because what you do with it if it doesn't go to that specific job? I think with your farm crops or your bits of wood you've got about the place or whatever you can do things with it, you've always got that haven't you?

Where participants ranked benefits, there was hope that, for smaller farmers facing an increasingly difficult economic climate, new technologies based around agri-waste might make a positive contribution both to farm income and to the intergenerational sustainability of individual farms and rural economies more generally. The scepticism around the viability of using agri-waste primarily for fuels was countered with enthusiasm for other potential uses for residues, particularly the production (using advanced nanocatalysis-based biorefineries) of speciality chemicals.

P: I think you need to aim for different markets and different end products rather than ethanol. We started off looking at ethanol and it was like, you know it's the cheapest any of us know so you go for things that have higher added value that's why we're looking at lactic acid because you can make plastics from lactic acid, succinic acid, the market for succinic acid is massively growing and has been over the last...

Participants discussed how these considerations might have direct implications for technology development and choices between different production methods and infrastructures.

P: The other thing that if you are looking at any time of biorefinery what my conclusion is that it has to be relatively flexible because you don't know what feedstock we've been talking about or at least be able to chop and change depending on what feedstock you've got available based on your geographical regions supply chains, whether it's wheat, straw, whether it's miscanthus, whether it's more woody material..

Promised environmental benefits were seen as contingent on the economic success of LBs or other agri-waste derived products. While the potential impact on climate change was seen as fairly significant, other potential impacts (e.g. on biodiversity) were largely seen as unimportant. Questions were raised as to how biorefinery facilities used to produce LBs or other products were to be powered, with concerns that without significant wider commitments to renewable electricity and grid upgrades, any GHG reduction benefits might be cancelled out through increased demand for power. Overall, though, the most significant concerns remained economic – in particular, the additional costs for individual farmers that might be created by any move around LBs towards a bioeconomy. Discussion around issues relating to different scales of bioeconomy explored these issues further, and in particular, how farms could be cushioned against these costs.

Large scale bioeconomies

Most participants appeared sceptical of a larger scale bioeconomy, based for example on farmers harvesting and selling agri-waste for processing at a central biorefinery run by a separate company. Once again, economic viability was a concern, with participants pointing to the instability and power inequalities of the relationships between buyers and sellers of waste. Cooperation between farmers as sellers was seen as a necessity, but also as leading to problems of its own.

P: I was involved in a few meetings buying poultry feed through a cooperative and that fell flat on its face because the companies that they were talking to didn't really want us to do it because we'd have too much clout so to speak if we're buying 5000 tonnes a year as against ten farmers at 400 tonnes each you know it was and they were really not, not wanting it you know because it was they were almost having a strong company coming up against them and they didn't like it.

The amounts of waste required to supply larger scale operations were not seen as available within areas where mixed farming predominated. Only larger arable farms (such as those found in East Anglia or East Yorkshire) were seen as being able to provide enough to make an economic relationship with a larger biorefinery viable.

P: Well for us over here it would be when you're looking at, for me, looking at straw it would be the viability of it of you know to source enough straw to go into a large plant or to be part of a large plant whether you were in a cooperative or not.

Larger arable farms would also be able to sustain trading straw at a price low enough to out-compete smaller suppliers in mixed farming areas like mid-Wales, even if smaller suppliers were part of a

cooperative. Some experiences within the group suggested that similar outcomes might occur with specially-grown crops like miscanthus.

I have spoken to farmers down in Pembrokeshire who were tied in with the [development] that was developed there and they were persuaded to sort of grow miscanthus on the promise that they would get a set price for their miscanthus over the next few years. A farmer that I spoke to said he was lucky if they were offering him about £10 a tonne and I know [development] are actually bringing in chip now, the only miscanthus that they're using is actually on their own farms.

The likelihood of price volatility meant that long-term commitments from buyers would have to be sought.

P: You've got to have long term contracts to say you supply straw for 15 years at this price because....

P: But then you're not going to know what the fuel price that you're producing at the end of it is going to be for 15 years are you?

The unintended environmental consequences of expanding a larger-scale LB bioeconomy, mainly due to the requirement for biorefineries to reach further afield to gather enough waste to produce fuel, were seen as potentially very negative. The intensity of exploitation of agri-waste might increase to the point where even larger scale waste producers (such as the 'east of England boys') could face difficulties in making up for the loss of waste as soil conditioner (discussed earlier), leading to an increase of fertiliser use across large tracts of land and attendant financial and environmental costs.

Another possibility could be that companies involved in waste processing engage in agreements that displace existing farming enterprises from the land, particularly if tenant farmers were involved. Once again, participants drew analogies with larger AD plants and economic practices that had emerged around them.

P: [...] it's basically happened with AD plants in Cheshire where they want say a thousand acres per AD plant and they have taken all the rented ground from the dairy farmers that rent so that they are getting priced out [...]

P: [...] a few years ago the potato trawlers were driving the land prices and giving 2 or £300 an acre well then the digesters come in and they gave £500 an acre well that knocks all other farmers out [...]

Small scale bioeconomies

Small scale bioeconomies were seen, by contrast with large ones, as offering significant benefits for farmers choosing to work cooperatively, these being rooted in the greater degree of influence over trading relationships available within a cooperative where

P: [...] the farmer has a proper stakehold in it so it's a proper farming cooperative, rather than just providing the feedstock

as well as smaller scale bioeconomies being generally less costly for farmers, given that the lignocellulosic waste produced on farms is best suited to being processed on site or at least locally.

P: How do you gather it all up and use it on a small scale because that sort of stuff is not viable to shift anywhere because it's so bulky, you couldn't haul it anywhere for it to be viable really could you?

Realising such benefits was not thought to be easy, however. Cooperative approaches are often promoted as a way to bolster farmer capacity to respond to new technological opportunities. Not all cooperative structures are appropriate for this purpose, however, and not all are able to exert comparable influence (Downing, Volk, and Schmidt 2005). Participants saw the potential benefits of cooperation as very important – indeed, as only slightly less significant than the top-ranked possibilities of increased farm income, or of greater intergenerational farm stability. They gave various reasons, however, for being somewhat sceptical of the prospect of these benefits being realised.

A degree of cultural aversion to the kinds of relationships between farmers that characterise cooperative working was seen as characteristic of agricultural life in Britain, mirroring Rossi and Hinrichs (2011, 1425) findings from the USA among farmers growing switchgrass.

P: The thing is we have no real history of cooperative working, a difference to say Ireland or France, we've had a go at it once or twice it's quite difficult because there is no, people aren't used to it. It takes a long time to get farmers to work together. [...]

Several participants had either had direct experience of cooperative working or had close contacts with others who had set up cooperatives that had run into difficulties, especially in livestock or milk farming.

You know locally there has been, there was a little cooperative where people were asked to put money into the local abattoir and it fell by the wayside and that's left a lot of sour taste with a lot of folk locally.

These experiences were reflected in a shared distrust within the group of the stability and viability of cooperative ventures in general, in the face of potentially unstable financial returns.

P: There just isn't a culture of it here, of cooperative working. It would just have to be a proper business relationship rather than a cooperative venture.

This latter remark opened up some discussion about alternative business models more generally. Another alternative mentioned was to move towards share or contract farming approaches, given that these often lead to forms of 'combined business rather than a cooperative' that allow the pooling of resources (share farming) or the use of secure contracts with buyers of crops (contract farming, in which buyers invest to help support growing and supply). Through such forms of social innovation, it was suggested that purchase of new technologies such as those necessary for LBs could be effectively supported.

Such forms of support were thought to potentially be more effective than government subsidies used to kickstart investment, although it was thought some government support would be necessary to make any investment work in the longer term. Analogies with solar PV were drawn to explore the question of how the adoption of new technologies at the small scale might be supported by public policy and possibly by subsidy, as traditional sources of credit capital are often risk averse in relation to new technologies: 'when we go to the banks with anything that's what they're wanting is security you know they're not going to lend it to us on a whim.'

Comparisons with PV and feed-in tariffs (FiTs) or renewable obligations certificates (ROCs) were made in order to draw attention to the difficulties associated with stabilising market environments to encourage farmers to invest capital in new technologies, some of which derive from the short-termism and instability of public policy itself:

P: Well it is the tariffs isn't it really?

P: Yeah well but then they keep changing them don't they so...

P: Yeah as soon as you get in with them, 12 months later they're axing them.

Some participants with experience of AD tended to see technological push creating markets as more of a factor.

When you went first into anaerobic digestion nobody knew about it and they used to laugh at us and it's taken years and years and now people can see that it works and it will be the same with these other things won't it you see?

At the same time, the degree of availability of waste for AD meant that the viability of these facilities was not always assured, and some were run solely on waste from one farm intermittently rather than taking any waste from further afield,

P: [...] there's two digesters closed because they can't, they can't compete because obviously they have now been pulled out and they've been pushed out and they've had to close them and they were dealing with domestic home waste.

In such circumstances, it appears that the socio-economic need for the facility and the relationships necessary to support and maintain it (a societal 'pull' as contrasted with a technology push) had not been created.

Discussion

As we have seen, in making sense of the technological promises which have come to circulate around LBs and their connection to concepts of the bioeconomy, comparisons with anaerobic digestion and solar PV were used by participants throughout their conversations to frame interpretations of potential outcomes, particularly around questions of economic viability. These questions of viability themselves turned on issues relating to diversification, individual farm incomes, and intergenerational sustainability of these farms. In addition, experiences with cooperatives and also with incentivising regulatory instruments (like feed-in tariffs) were used by participants to frame discussion of LBs.

Price volatility of crops reaching into the longer term has long been recognised as a problem affecting the attractiveness of biofuels to farmers (e.g. Levidow and Papaioannou 2013, 44). Our pilot study offers some confirmation that competition between LBs and fossil fuels in the short- to medium term presents, in the view of farmers, a major challenge to the viability of LBs. Rossi and Hinrichs' (2011) participants see more potential value in promised products that remain more speculative, their realisation further off in the future even than the promised fuel-based bioeconomy. Some of our participants too pointed to the added value of e.g. specialty chemicals that might become a technical possibility through the development of novel methods of nanocatalysis such as that which formed the technological focus of our workshop. Our participants associated these other products with higher

value because of their views on the potential vulnerability of markets in agri-waste and in biofuel markets to high degrees of price volatility, which drew to some extent on experiences with AD.

Comparisons with AD were again significant when discussions turned to the volumes of agri-waste that might actually be available in different areas of the country, and how this would affect the emergence of distinct forms of bioeconomy. The amount of waste needed to produce LBs on a scale able to provide returns sufficient to offset the costs of investing in new technology and in setting up and running cooperative or other business models would be high. This need for volume in turn means that the production of biowaste is embedded within a set of fragile relationships that govern how waste is already used and influence how it might be produced and distributed in the future. Existing needs for waste for soil conditioning or for animal bedding affect precisely how much could be given over to fuel production. As other research has shown (Rossi and Hinrichs 2011), agri-waste is not simply a resource standing by to be used. It is already part of other processes and relationships which contribute not only to farm viability but also to public goods like soil health (Schmidt, Padel, and Levidow 2012). Further, focus group data confirms findings from elsewhere that farmers are concerned about environmental conditions on their farms (and especially soil condition), to the extent that additional income streams from biofuels may be seen less favourably, given their potential environmental externalities (Chouinard et al. 2008).

Expanding and diversifying beyond agri-waste from existing crops to growing specialist crops is a potential development which, again, is replete with promissory significance – holding out the prospect of preparing agriculture for subsequent developments towards 3rd and 4th generations of bio-engineering crops. However, farmers indicated that this socio-technical pathway would also face specific obstacles. They expressed scepticism, once again, based on the lack of economic or regulatory structures that could shield producers against price volatility, and anticipated that other farmers, more widely, would also be sceptical.

Expanding the range of uses to which agri-waste can be put, even as part of optimised technical systems, requires farmers to put in place new socio-economic relationships that are potentially fragile, whether as part of a small or a large scale bioeconomy. The amount of waste available to mixed farmers to sell may be small, again raising questions about the possibility of creating stable relationships between cooperatives of farmers as sellers of waste and larger, mainly fuel-producing biorefineries. On the other hand, the difficulties of forming cooperatives as a way of supporting small-scale bioeconomies based on nanocatalysis technologies were seen as associated with the cost of

investment (and with the difficulties of securing loans to help), as well as with deeply embedded cultural expectations regarding how farmers should manage their relationships with other farmers.

Overall, concerns about the fragility of rural economies which participants expressed during initial discussions at the beginning of the workshop around the general theme of sustainability can be seen reflected in the more specific discussions of potential LB futures. These demonstrate that upstream reflection on the viability and desirability of LBs can locate the promissory rhetoric surrounding these technologies in relation not only to general concerns, but also to what participants felt were the most significant socio-economic relationships that would affect future LB viability. In this way, the somewhat abstract promises of efficiency, cost-effectiveness and environmental enhancement that circulate around LBs are made sense of in relation to a set of concrete socio-economic relationships within which the technologies connected to these promises would need to be embedded.

Conclusions

The small-scale nature of this pilot research inevitably means that its findings cannot easily be generalized to agricultural contexts elsewhere. Our findings do, however, offer insights into emerging concerns and aspirations around biofuels that will be of wider practical and scholarly significance. This will particularly be the case for other developed countries as biofuel policies that reflect imaginaries of energy security, decarbonisation and agricultural diversification continue to be developed. In particular, our participants' reflections underscore the need for the social assessment of LBs to focus in a much more detailed fashion on the ways in which LBs may, as currently envisaged, represent something of a blunt 'technical fix' instrument for improving rural economies. Sensitivities to the specific and different situations of farmers who may be future participants in a bioeconomy of whatever scale will be vital to making LB innovation responsive to the needs of rural communities as well as to wider factors that may affect the future viability of LBs, and preventing developments that may actually be harmful. In particular, the ways in which fossil fuel markets, current uses of agri-waste and the complexities of environmental regulations may affect viability are factors that require further and deeper investigation, bringing in other stakeholders to include not only a broader range of voices from farming, but also regulators, SMEs and larger organisations, and broader publics.

Our pilot project can therefore be seen as laying the groundwork for future deliberative research around LBs that could draw on the kinds of distributed and longitudinal forms of engagement and deliberation on biofuels discussed by Entradas (2014) to examine the prospects for regulatory and socio-economic innovation that could respond to vulnerabilities of the kinds identified in our

workshop. The promises of cost-effectiveness attaching to the new nanocatalysis methods for producing biofuels cannot, as we have shown, be seen in isolation from the broader socio-economic and environmental contexts in which they are implicitly embedded. Rendering these contexts more explicit has been one of the major contributions of our participants to debates over LBs. In particular, the already existing bio-economy of waste trading and husbandry provides a setting for further developments that will play an active role in shaping how the promises of new methods of value-production from agri-waste are interpreted, acted upon, and realised or not. The use of upstream deliberative methods as a way of identifying unanticipated vulnerabilities and needs provides a way of realising the 'extended peer review' (Funtowicz & Ravetz, 1990) of the implicit problems and priorities which underlie innovation. Employing a wide and socio-technical risk-benefit frame that explicitly relates particular emerging technologies to wider imaginaries, we suggest, makes it possible to explore more systematically the wider social meaning of currently evolving techniques by mapping future possibility and issue spaces (Burg, 2014; Selin, 2014).

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