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Perspectives

Bio-based Production in a Bioeconomy

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We recently co-authored a series of policy-based articles for *Trends in Biotechnology* on various aspects of bio-based production and bioeconomy matters (see Shaklee 2013). When we discuss bio-based production we mean biofuels and bio-based materials (largely bio-based chemicals and plastics). One of the things that emerged from that exercise was that if a bioeconomy is to succeed in virtually any country, then it relies on international trade and cooperation, which is becoming global. The drivers behind the development of bio-based production are also global: climate change, energy security and independence, the creation of new jobs allied to rural regeneration. At the same time, food security is a grand challenge facing society, and there are ways in which energy and food production come into direct competition (Seidenberger *et al.* 2008).

Energy Security

Some Asian countries typify these dilemmas. Thailand has to fuel growth whilst in the grip of high dependency on crude oil imports, accounting for more than 10 per cent of GDP (Siriwardhana *et al*. 2009). Energy security and rural and economic develop drove Malaysian R&D on biodiesel derived from palm oil as early as 1982. Japan is the world's third-largest oil consumer, whilst having to import almost all of its crude oil needs. Since the oil crises of the 1970s, the Japanese government has embarked on national projects in developing alternative energy resources with the purpose of

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raising productivity of bioethanol production. Korea has similar needs. Likewise, China has a huge demand for crude oil that cannot be met through domestic production. But as an agricultural country, China cannot sacrifice food security for energy. Currently, India has turned to biobased energy to reduce dependence on imported oils. India has to import approaching 80 per cent of its crude oil requirements (Ministry of Petroleum and Natural Gas, Government of India, 2009). India leads the way in planting and cultivating the non-food Jatropha plant on an industrial scale for biodiesel production (Wonglimpiyarat 2010).

Many other countries have biofuel policies in place or in formulation. REN21, the Renewable Energy Policy Network for the 21st Century, reported that 73 countries (many of them developing countries) had bioenergy targets as of early 2009 (REN21 2009). In 2012 the Biofuels Digest released its annual review of biofuels mandates[1], stating that there were 52 countries with mandates or targets, mostly in the EU, but also 13 in the Americas, 12 in Asia-Pacific and 8 in Africa. So clearly, energy security is a global issue, and an issue with serious consequences for the future of Asia.

Food security

The impact of bio-based production on food supply is very much a live debate. The international food prices increases that were experienced in 2008 ignited controversy over biofuels production, the so-called food versus fuel debate (e.g. IFPRI, 2010; Mueller et al., 2011). Evidence links first-generation biofuels to the price spike, but the actual extent of the linkage will probably never be known. Next-generation lignocellulosic ethanol production has, as a primary driver, the breakage of this link between land requirements for food and fuel. Due to the much smaller production volumes (and in some cases higher land area efficiency) compared to fuels, bio-based materials production has far smaller consequences for land use, and therefore the potential impacts on food supply are concomitantly lower (see, for example, Endres and Siebert-Raths, 2011).

Opportunities Beyond Biofuels

In most countries the focus has been to a great extent on biofuels. However, bio-based chemicals and plastics offer exciting opportunities for future manufacturing. For example, 96 per cent of all US manufactured goods use some sort of chemical product, and businesses dependent on the chemical industry account for nearly $3.6 trillion in US GDP (Milken Institute 2013). Unusually for a biotechnology sector, the objective is the replacement of existing fossil-based materials with bio-based, therefore, contributing to green house gas (GHG) emissions reductions. Green credentials, however, are not enough to justify their place in the market. The technical, economic and social performances of these materials have to be considered. Bio-based production also promises high-value jobs. Carus *et al.* (2011) have estimated that materials use of biomass can directly support 5-10 times more employment and 4-9 times the value-added compared with energy uses, principally due to longer, more complex supply chains for material use. A report commissioned for The Blue Green Alliance estimated that shifting 20 per cent of current plastics production into bioplastics would create a net 104,000 jobs in the US economy (Heintz and Pollin 2011).

Bio-based plastics production, whilst dwarfed by petro-plastics, has seen a revolution in recent years. The market of around 1.2 million tonnes in 2011 may rise to 12 million tonnes by 2020, mainly driven by developments in the production of bio-based thermoplastics. Asian countries are both making demand, and setting up conditions for increased future production capacity. The Japanese automotive industry, for example, is creating demand for bio-based plastics for vehicle interiors, prompted by the Biomass Nippon Strategy of 2002.

Thailand has more than 4,000 companies in the plastics industry, and the bio-based plastics industry is considered to be strategic. Thai government initiatives and incentives have led to several investments in bio-based production facilities by both international and domestic firms. The government has also encouraged Thai companies to engage with international bioplastics companies and has promoted close collaboration with international partners. In return, Western bioplastics companies gain access to local expertise and to the large Asian markets. In addition to investment incentives, other government policies have promoted the use of bioplastics and the development of Thai industrial standards for bioplastics and consumer awareness (Ministry of Science and Technology of Thailand 2008).

The bio-based chemicals sector, whilst also small, has been growing much more rapidly than the petrochemicals sector in recent years, and several sources indicate that this trend will continue into the future (Philp *et al.* 2013). Modern techniques of synthetic biology have opened up the possibilities for the replacement of many fossil-based chemicals with bio-based equivalents. There are developing centres of excellence in synthetic biology in China (Pei *et al.* 2011), Japan (Mori and Yoshizawa 2011) and Korea (Lee *et al.* 2011).

There is also a compelling case for bio-based materials manufacturing in integrated biorefineries. The economics of full-scale fossil fuels production, with very small margins that can be toppled out of profit by increases in crude oil price, demonstrate that the production of higher value plastics and chemicals at the same site is a way to improve refinery economics. There is a very marked industry trend in refining and petrochemicals towards integration of the two. There is a lesson here for bio-based production as well – the long-term economics of biofuels production are likely to be similar to fossil fuels production, and it may be necessary to make bio-based materials at the biorefineries to keep them economically viable. Japan has been developing research expertise in biorefining following this concept of multi-purpose facilities, e.g. The Kobe University Biorefinery Center.[2]

Sustainability and Biomass

The final article in the series (Pavanan *et al.* 2013) was concerned with the most critical aspect of all, the sustainability of biomass. For example, Koizumi (2013) stressed that the most crucial task for Japanese biofuels development is establishing sustainability criteria for biofuels, which must pay close attention to biodiversity, food availability, and social consequences, as well as GHG emissions.

All of bio-based production is dependent on a stable supply of biomass. There are still many unknowns: just how much biomass can be grown sustainably (Batidzirai *et al.* 2012); how to measure biomass sustainability (van Dam and Junginger 2011), and; how to deal with the inevitable biomass disputes (Taanman and Einthoven 2012) are all huge problems still to be reconciled.

Sustainable feedstock supply has to be addressed nation-by-nation. It is an imperative for countries that have bioenergy targets. For example, one study (Silalertruksa and Gheewala 2010) assessed the security of feedstock supply to satisfy the increased demand for bioethanol production in Thailand. They identified cassava is as the critical feedstock and a need to reduce cassava exports to cope with domestic consumption. Waste materials are rapidly being recognised as an under-utilised source of biomass. Waste biomass is potentially the most sustainable form of biomass of all due to its ability to relieve pressure on land use. The potential for the utilisation of waste biomass has been recognised in India (Singh and Gu 2010). However, there remain issues around the sustainability of collecting the waste biomass. In Japan, it costs more to collect and transport waste biomass than using virgin feedstocks (Kuzuhara 2005).

Water supply is obviously another crucial factor in sustainability of biomass production. The scale of its importance is worth highlighting. As many as two billion people rely directly on aquifers for drinking water, and 40 per cent of the food in the world is produced by irrigated agriculture that relies largely on groundwater. Vast territories of Asia rely on groundwater for 50-100 per cent of the total drinking water (UNEP 2003). Whilst bio-based production has great potential for GHG emissions savings (e.g. Weiss *et al.* 2012), the production of extra non-food biomass requires a great deal of water, thus potentially putting it in competition with other vital water uses. For example, one study (Gerbens-Leenes *et al.* 2009) found that, for biodiesel production, soybean and rapeseed (crops mainly grown for food) had the best water footprint. Jatropha, often cited as a great future hope for biofuels production, had the least favourable.

Biomass disputes cover a very wide range of issues: some relate to human rights (land rights, workers' rights, and local economies), environmental issues (effects on soil, land, air, biodiversity, and climate) and economic issues (international trade, market distortions, property rights, and business-to-business conflicts). Recent controversies surrounding the large scale investments in palm oil plantations serve as examples of sustainable biomass disputes in Asia. With Malaysia and Indonesia accounting for more than 90 per cent of global palm oil production (Lam *et al.* 2009), exploration of sustainability issues in the industry would give valuable insights into how to increase yields while maintaining and monitoring sustainable plantations. The analyses of Koh and Wilcove (2008) indicated that oil palm plantations in Malaysia and Indonesia have replaced forests and, to a lesser extent, pre-existing cropland.

The global sustainable biomass governance system is a patchwork of many voluntary standards and regulations. Standards and regulations for dispute settlement sometimes exist. However, these regulations are weakened by poor monitoring and with low access or absence of channels to lodge complaints. It is thought that a dispute settlement facility would lend credibility and legitimacy to the current situation.

Closing Remarks

For many OECD countries it is clear that to establish and maintain a bioeconomy will require international trade in biomass. Many European countries are densely populated and have relatively little free land for dedication to non-food biomass purposes. Several Asian countries will be key to this trade. And this is where sustainability is a real life issue. For these countries, this represents a large new business opportunity, but one which must be balanced with domestic necessities, such as food and water security, and good agricultural practice to prevent soil quality deterioration and deforestation.

Our perspective on bio-based production shows the great difficulties in assessing the overall advantages compared to fossil-based production. For Asia, it is perhaps an even more difficult equation. A huge driver in Asia is energy security to fuel future economic growth. But with a large population, food and water security have to come first. At the international level the lack of harmonised tools for measuring sustainability is a major hurdle to be cleared. Life cycle analysis (LCA) is widely believed to be flawed as it overwhelmingly concentrates on environmental criteria, which are more easily calculated than others, especially social criteria.

Asia clearly has a leading role to play in future bioeconomy plans. In everything from research and development to full-scale implementation and biomass production, Asian countries are likely in the long-term to be leaders in bio-based production. With growing commitments to climate change mitigation, Asia can reap the benefits of economic growth, jobs and environmental improvements that bioeconomy plans promise. But careful international coordination and cooperation will be vital.

Endnotes

1 http://www.biofuelsdigest.com/bdigest/2012/11/22/biofuels-mandates-around-the-world-2012/

2 http://www.eng.kobe-u.ac.jp/en/research/biorefinery_center.html

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