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DIRECTORATE FOR SCIENCE, TECHNOLOGY AND INNOVATION
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Working Party on Biotechnology, Nanotechnology and Converging Technologies

"Genomics for Sustainable Development in Emerging Economies: Food, Environment, and Industry"

WORKSHOP REPORT

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NOTE BY THE SECRETARIAT
This report partially fulfils the requirements of Module 3.1 on bio-production, in Intermediate Output result 5.3 of the Programme of Work and Budget (PWB) of the BNCT for Biennium 2015-2016 (see Figure 1 of [DSTI/STP(2014)39]).

Delegates to the BNCT are requested to:
- Note and comment on the paper at the meetings of the Working Party on BNCT of May 18-20, and;
- Submit written comments by June 15, 2015.

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EXECUTIVE SUMMARY

1. Since the 2009 publication of the OECD report *The Bioeconomy to 2030: Designing a Policy Agenda* the concept of a bioeconomy has gathered momentum and now several countries and the EU have written national bioeconomy strategies. The concept has at its origins the realisation that the virtually total dependence on fossil resources such as oil, coal and gas is not only unsustainable, but is resulting in serious global problems, such as climate change. However, a bioeconomy is not by definition sustainable if food and industrial uses of biomass fail to be reconciled. In other words, there is a potential competition for land use between food security and industrial production.

2. With a growing human population the growing need for more food calls for intensification of agriculture if the prospects for extensification are limited. Across many crop and animal species, great strides in yield and quality improvements have been made by breeding programmes. One of the great lures of genomics technologies is that they can bring faster and more accurate results to breeding programmes, making animal and plant breeding more efficient without resorting to genetic engineering.

3. The OECD has an on-going relationship with the Human Genome Organisation (HUGO), and at the annual HUGO conference of 2015, an OECD satellite event, a workshop entitled "*Genomics for Sustainable Development in Emerging Economies: Food, Environment, and Industry*" (see Annex 3) was staged specifically to look at how genomics may help enable the development of bioeconomy strategies in Asia. To date, Malaysia is the only ASEAN country to develop its own bioeconomy strategy, which is far-reaching in its economic and social ambitions for the country.

4. South East Asia is quite different in bioeconomy terms from many developed economies with regard to biomass. A large amount of global biodiversity resides in some countries of South East Asia, much more so than in many OECD nations. Nevertheless, these countries have a similar deeply complex problem to wrestle with – how to exploit this biodiversity and biomass in a sustainable manner that does not cause unintended social and environmental problems. In addition, many of these Asian economies have a very different agricultural model from most OECD countries. The value added per agricultural worker tends to be much lower than in the OECD, and farmer aging and poverty are central issues in food security.

5. Also in common with many OECD nations, these nations of Asia spend a relatively large proportion of GDP on imports of oil, coal and gas, making energy security fragile. Some of these countries are in the front-line of the effects of climate change, while population demographics are also changing. In particular an explosion in the size of the middle classes may be about to happen. Rising wealth brings more consumption, which increases greenhouse gas emissions. An important objective of the bioeconomy is to decouple economic growth from emissions. Therefore the bioeconomy concept should be of huge importance for Asian countries.

6. Typical of bioeconomy strategies is the vision of new bio-based industries which use biomass as the feedstock for the production of fuels, electricity, chemicals, plastics and textiles instead of fossil resources. There are many difficulties in achieving this. It was not the intention of the workshop to look at the scientific and technical difficulties of industrial biotechnology and bio-based production. Rather the focus was on the difficulties in achieving this goal without compromising food security. This is a far more relevant focus in Asian countries with large populations than it is in OECD countries. The mantra of a

bioeconomy strategy must be "food first", and only when food security, by domestic production and imports, can be demonstrated should industrial use be contemplated.

7. The workshop focused on three extremely important crops of the bioeconomy in Asia and by extension in subtropical and tropical climate zones – rice, banana and oil palm. Often the production of the first two is consumed without any export i.e. they are absolutely essential to local food security. The only ways that they can be considered for industrial feedstock is to improve yields and efficiencies, and to adapt waste by-products for industrial processes. In both cases, genomics clearly has major roles to play in the future.

8. Rice and banana make interesting cases for comparison. In the case of rice, the workshop focus was on how selection of rice strains that are tolerant to flooding and its incorporation into the Asian rice crop can greatly add to food and income security. Flooding is a frequent occurrence in a large acreage of the rice crop globally, and most rice crops are rapidly killed by submergence. The development of submergence-tolerant rice strains and their deployment is a major success for both genomics and public policy.

9. Banana, on the other hand, is perhaps the most important of all "orphan crops" in the respect that it receives relatively little research attention. And yet it is essential to food security in a number of Asian and African countries. Compared to rice, little is known about its genetic origins and other critical genetic information is lacking. The genome sequence of banana is important, but without more genetic background information it is of limited utility. This is, of course, important in any economically important animal or crop, but banana stands out – it is also the most popular fruit in industrialised countries. It is beset by serious threats, particular among them fungal diseases.

10. The discussion on these two cases gave rise to a first message for policy makers. The allure of genomics is very tantalising as it is constantly in the news and appears to offer a 'quick fix' in that it can mistakenly be construed as a panacea for agricultural problems. Speakers stressed the need for commensurate research funding for animal and plant genetics, but also for agronomical and breeding research, which is in danger of being viewed as old fashioned and unnecessary. It was repeatedly mentioned that the potential of genomics can only be unleashed when combined with genetics and breeding. Banana stands as an important corroboration.

11. The other exciting Asian bioeconomy crop identified was oil palm as it not only provides 45% of the world's edible oil, but also provides an oil that is well-suited to use as biodiesel. Therefore the central issue of food *versus* energy security is graphically illustrated in this one crop, of particular importance in Malaysia. And palm oil also provided a powerful illustration of the potential of genomics. The discovery of the role of the *Shell* gene which controls oil yield in the oil palm was accompanied by the realisation that *oil yield may be boosted by one-third*. That is a massive amount of economic benefit for a small investment in genomics R&D.

12. Less well developed than these areas is forest genomics. Forest cover is critical to the well-being of the planet, and for some countries forestry is a major source of trade. In a bioeconomy, logging and/or harvesting of forestry residues have large contributions to make. Again the problems of over-exploitation are apparent, and the same lessons as for crops apply: genomics can contribute to yields and breeding efficiency without genetic engineering. For a country like Malaysia, which has forest types from mountain to mangrove, there are additional issues that can be addressed through, for example, DNA barcoding to investigate provenance and authenticity of high-value timber species.

13. Less central to the workshop were other applications of genomics that nevertheless have bearing on the development of a bioeconomy. Animal species are assuming more importance to the Asia

bioeconomy due to the tremendous increase in protein consumption in developing countries in the last few decades directly related to growing incomes. Chicken is a food source of great significance as it can be produced cheaply with low greenhouse gas emissions and lower primary inputs than beef, pork or lamb. Applying genomics to selective breeding is set to revolutionise selection of relevant economic and sustainability traits such as feed conversion efficiency and disease resistance – again without resort to genetic engineering. *Tilapia* is cited as a fish that is farmed widely in ASEAN countries where genomics has already been applied to improve farming efficiency. There are many other examples and many more still to be developed. In bioeconomy terms, yield improvements from animal and crop species mean more land may be available to grow biomass for industrial uses.

14. An unintended outcome of the discussions following the presentations was the potential role of agricultural wastes, or by-products, in an Asian bioeconomy. Traditionally there is hardly any waste in banana agriculture, although there are specific examples where progress can still be made. However, rice production presents a very different picture. Rice straw has very little nutritional value (low crude protein, high in oxalates and low digestibility due to the high silica content) and this makes it a waste material in many Asian countries. What is more, the quantities are so vast (hundreds of millions of tonnes per year in Asia alone) that its disposal is a major problem, and often results in burning at the field. Not only is this extremely wasteful, it is a source of carbon emission and the smoke has been implicated in human health problems.

15. Meanwhile, perhaps the greatest focus in industrial biotechnology over the past decade has been in perfecting lignocellulosic ethanol as an advanced biofuel. The most difficult and expensive technical step has been the initial breakdown of the plant matter into fermentable sugars. With the arrival of the first lignocellulosic biorefineries, this may help solve the problem of rice straw. If so, this would not only solve a health problem, but it would also give farmers an additional income stream. At the workshop it was also mentioned several times that solving Asian farmer poverty should be a top priority. Providing another market opportunity for farmers by turning rice straw into a tradable commodity might not only improve their income and food security, but might also prompt them to increase investment.

16. Asian countries, like all others facing the need to develop a bioeconomy, face a bewildering array of policy challenges. Malaysia helps set the standard for others. The ambitious aspirations of its bioeconomy strategy are being backed by early successes. Particularly striking is the early foreign investments into Malaysian biotechnology, which are being showcased at a very high level politically. Among the many policy issues facing bioeconomies are also its global aspects.

17. This resonates with the foreign investment into the Malaysian biotechnology industry. Many OECD countries will face possibly insoluble problems with biomass supply without imports. Many Asian countries are strong candidates as biomass exporters. That creates conditions in which over-exploitation of biomass could occur. However, the levels of international cooperation and technology transfer evident in Malaysia are a very good sign. The transformation of Asian economies from being natural resource providers to also being solutions providers could have far-reaching consequences for agriculture and the global bioeconomy in creating economic growth that is both environmentally sound and socially equitable.

INTRODUCTION: WHY A BIOECONOMY IN ASIA?

18. In the wake of the worst financial crisis in living memory, a new, sustainable economy must be created. This coincides with a time in our history where there are several grand challenges to be faced that make the task much more difficult. The increasing certainty of climate change means that, for the first time ever, we need to build an economy in which economic growth is decoupled from increasing emissions. This philosophy is at the heart of the OECD (2009) publication, *The Bioeconomy to 2030: Designing a Policy Agenda* (2009).

19. That same publication envisaged a future bioeconomy in which biotechnology could be responsible for 2.7% of GDP in OECD countries, a number that excludes the potential of biofuels. It goes on to predict that, well before 2030, biotechnology will be used in the development of all pharmaceuticals and most new varieties of large market crops.

20. Since its publication, several countries and regions have developed bioeconomy strategies, among them Belgium, Canada, Denmark, Finland, Germany, Ireland, the Netherlands, Sweden, the United States, the European Union and South Africa, many foreseeing a gradual replacement of fossil-derived materials with bio-based. Very few Asian countries have thus far followed. A notable exception is Malaysia (Bioeconomy Malaysia, 2014), which has produced a plan for a very ambitious bioeconomy. Japan does not formally have a bioeconomy strategy (Bioökonomierat, 2015), but has many policies consistent with a desire to build a bioeconomy.

21. The need for new forms of renewable energy and sustainable manufacturing has never been more urgent. However, if a future bioeconomy is seen as one way to achieve this, it will be necessary to reconcile agricultural and industrial needs for biomass and land (Jiménez-Sánchez and Philp, 2015). It is clear that there is much capacity for progress as the age of practical application of genomics to societal problems other than human health is still in its infancy.

22. 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 (Philp and Pavanan, 2013). 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 co-ordination and co-operation will be necessary.

23. The economic impact already being experienced from the Human Genome Project (HGP) has far-reaching consequences for human development. An initial investment of USD 3.8 billion is estimated to have driven close to a trillion dollars in economic impact and generated over 300 000 jobs in the United States economy (Battelle Technology Partnership Practice, 2011). An update has moved this assessment upwards. The original study estimated a return-on- investment of USD 141 per dollar invested. The update estimates this to be USD 178, 26% greater than the original (Wadman, 2013).

24. More than this, the HGP launched the genomics revolution. What is more, the human genome sequence, unlike most other major science investments, is permanent. Not only does it pave the way to unprecedented understanding of biology, it opens up the possibilities of understanding human health from the top down, thereby potentially bringing cures to hitherto unfathomable human disease at rates that have

been otherwise impossible. The HGP, in addition, gave an enormous boost to technology development. More efficient and cheaper technologies for DNA sequencing, DNA synthesis or high throughput technologies and others are now used throughout all parts in life sciences.

25. The implications of the HGP go much further. In a sustainable society, development must meet the needs of the present without compromising the ability of future generations to meet their needs. The grand challenges facing our society have created a need to rapidly move towards sustainable development. Plenty of evidence speaks to the ability of genomics and related technologies to act as platform technologies in diverse environmental protection applications.

THE PERFECT STORM: THE CONVERGENCE OF KEY GRAND CHALLENGES

> "Grand Challenges priority should be to address global inequalities; secondly how to rapidly decarbonise the global economy. The world needs to save the biosphere as well as the banks!"
>
> Anthony Costello, Professor of International Child Health and Director of the UCL Institute for Global Health. https://www.ucl.ac.uk/intercultural-interaction/For_2website_Grand_Challenge_review_event_report.pdf

26. At this point in time, several societal grand challenges are interacting with each other to create one of the most difficult periods in human development. Because these grand challenges are truly global, one of the main problems has been achieving consensus of action across countries with different starting points and levels of economic development.

27. The key to the enormity of the challenge is in the word 'interacting'. Food and water security obviously interact with each other, and measures to improve the security of one may negatively affect the security of the other. Therefore the challenges are of a planet-wide nature that interacts very much like a global ecosystem (see Box 1).

Human population dynamics: asymmetry and uncertainty

28. Ultimately, there is huge uncertainty about what the eventual equilibrium number of people alive will be, and when it will occur. It is expected that there will be over 9 billion people living on the planet by 2050. The implications for Asia are different than for Western countries due to demographics. For many European nations the ratio of European working people-to-elderly is changing quickly (Braconier et al., 2014; Carone and Costello, 2006): in Denmark, for example, the ratio will change from currently 4:1 to 2:1 by 2050 with serious economic consequences (IMF, 2008). The ageing of populations will have large repercussions for OECD labour markets, economic growth, and public finances. The population of the more developed regions is expected to change minimally, passing from 1.24 billion in 2011 to 1.34 billion in 2100, but with the population inexorably ageing.

29. Meanwhile, 95% of the burden of population growth will be in developing countries (UN Department of Economic and Social Affairs, 2011). Across Asia population growth is also asymmetric. By 2021, the population of India is likely to surpass that of China and the two will account then for about 36% of the world population. However, China and India have experienced a rapid fall in the average number of children per woman. These Asian giants are also ageing, and as life standards improve, this phenomenon is expected to become even stronger. By 2100, India is projected to have 130 million persons of age 80 or over, and China 107 million (about 11% of the predicted Chinese population). Together the Indian and Chinese over sixties accounted for 34% of the world population in 2011 and they are expected to constitute 38% by 2050 (Chatterji et al., 2008; Kowal et al., 2012).

30. In East Asia several countries, like in Europe today have very low levels of fertility, well below their 'replacement rate', meaning that their populations are ageing even more rapidly and these countries face great challenges in how to care for and support these ageing populations. Projections by the Japanese government indicate that if the current trend continues, the population of Japan will decline from about 127 million in 2014 to about 97 million in 2050 (National Institute of Population and Social Security Research, 2012), a phenomenon which has been termed Japan's "demographic disaster"[1].

[1] http://thediplomat.com/2013/02/japans-demographic-disaster/

Growth of the Asian middle class

31. Of particular relevance to this paper is the predicted growth of the Asian middle class. As of 2010, Asia accounted for less than one-quarter of today's middle class[2]. By 2020, that share could double due to a large mass of Asian households having incomes that currently position them just below the global middle class threshold. More than half the world's middle class could be in Asia and Asian consumers could account for over 40% of global middle class consumption (OECD, 2010). Globally, the middle class could increase to 4.9 billion by 2030, with 85% of the growth coming from Asia.

Shift in the global economic centre of gravity

32. The economic centre of gravity (the average location of economic activity across geographies on Earth) is moving towards Asia (Figure 1). By 2010 Asia accounted for 34% of global activity, but by 2034 it could account for 57% of global output (OECD, 2010). Not only China, India, Korea and Japan will lead this shift, but other large countries like Indonesia, Thailand, Malaysia and Vietnam will have significant economic mass. With a growing middle class and wealth comes growth and consumption, and with growth comes significant environmental costs, e.g. increased greenhouse gas (GHG) emissions. A primary objective of an Asian bioeconomy should therefore be to decouple growth from GHG emissions.

Figure 1. The global centre of economic gravity has shifted east over the past 30 years (black dots), and could well shift even farther east over the next 30 years (grey dots).

Source: Redrawn from CNN (2011). http://globalpublicsquare.blogs.cnn.com/2011/04/07/worlds-center-of-economic-gravity-shifts-east/

Food and water security *versus* land limitations

33. With so many more people alive by 2050, food and water security becomes increasingly important. With 9.1-9.6 billion alive by 2050 as estimated in the medium variant option, food production will need to rise by 50-70%, dependent on the source (UN FAO, 2009).[34] More arable land, or more

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2 Defined as all those living in households with daily per capita incomes of between USD10 and USD100 in PPP terms (OECD, 2010).

3 http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf

efficient use of existing arable land, will be needed to meet the food demands, while less may be available because of changing climate conditions. Using more land for production also impacts biodiversity. With much of the growth in population and economic output in Asia, these challenges are all the more acute. Moreover, developing countries have changed dietary patterns. In the last 30 years meat consumption in developing countries has doubled, and egg consumption has quadrupled. The demand for more meat has significant environmental implications. Beef production is notoriously costly in resources such as water and land, and is also responsible for high GHG emissions compared to some other forms of animal protein. For every kilogram of beef produced, 4-5 kilograms of high energy feed are required, and well over 10 000 litres of water is consumed.

34. Water is a particularly large challenge. As many as two billion people rely directly on aquifers for drinking water, and 40% of the food in the world is produced by irrigated agriculture that relies largely on groundwater. Globally, 70% of all freshwater use is for agriculture (Sophocleous, 2004). Vast territories of Asia rely on groundwater for 50-100% of the total drinking water (UNEP, 2003) and groundwater depletion is accelerating worldwide. Some of the highest rates of depletion are in the world's major agricultural centres, including northwest India, northeast China, and northeast Pakistan (Wada et al., 2010). Also climate change is projected to decrease freshwater availability in central, south, east and south-east Asia, particularly in large river basins. With population growth and increasing demand from higher standards of living, this decrease could adversely affect more than a billion people by the 2050s. Asia has 28% of the world's freshwater resources (UN FAO, 2003) but is using 50% of the world's water (Gore, 2013).

Energy security and resource depletion

35. Many countries are also plagued by energy insecurity as a result of the geography and geopolitics of fossil fuel production. Many of the larger economies within the OECD import most of their oil and gas, much of it from countries and regions that are regarded as unstable. Moreover, a greater proportion of crude oil in future will be from unconventional sources such as tar sands and the deep subsea. These sources are much more expensive and dangerous to exploit. The current price fluctuations do not change the fundamentals and higher prices are most likely to return in the future. Low prices inhibit investment in alternative energies, but also in conventional exploration. There is also a looming danger that prices rebound way beyond what is desired after a slump, causing large detrimental effects on the global economy.

36. Some Asian countries typify the energy security dilemma. Thailand is highly dependent on crude oil imports, accounting for more than 10% of GDP (Siriwardhana et al., 2009). Energy security and rural and economic development led to Malaysian R&D to derive biodiesel from palm oil as early as 1982. Korea has similar needs, as the country imports 97% of its energy, which still comes from fossil fuel reserves. Korea aims to replace 30% of fossil fuel with biofuel to become more energy independent. To achieve this Korea has an important programme to develop biofuel production from algae. Likewise, China also has a huge demand for crude oil that cannot be met through domestic production, but it faces limitations in sacrificing food security for energy. Recently, India has turned to bio-based energy to reduce dependence on imported oils. India has to import approaching 80% 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).

37. No country illustrates the situation better than Japan, the world's third largest economy which is just 16% energy self-sufficient.[5] Japan is the world's largest importer of liquefied natural gas (LNG), the

4 http://esa.un.org/wpp/Documentation/pdf/WPP2012_Volume-II-Demographic-Profiles.pdf

5 www.eia.gov/countries/cab.cfm?fips=JA

second largest importer of coal and the third largest net importer of oil. Japan relied on oil imports to meet about 42% of its energy needs in 2010 and to feed its vast oil refining capacity (some 4.7 million barrels per day at 30 facilities as of 2011), and relies on LNG imports for virtually all of its natural gas demand. Japan consumed an estimated 4.5 million barrels per day of oil in 2011, whilst it produced only about only 5 000 barrels per day (OECD, 2014). Since the oil crises of the 1970s, the Japanese government has embarked on national projects in developing alternative energy resources, including in raising productivity of bioethanol production.

Bioplastics and Asia

38. The bioeconomy goes beyond energy and also involves bioplastics. Thailand is an interesting test case for bio-based production. Thailand has more than 4 000 companies in the petro-plastics industry[6], and is also very rich in biomass. Since 2006, the Thai Government has declared the bioplastics industry to be one of the strategic industries that the government is promoting in its drive towards sustainable growth and development. This resulted in 2008 in a *National Roadmap for the Development of Bioplastics Industry*, developed by the National Innovation Agency (Ministry of Science and Technology of Thailand, 2008). This action plan for 2008-2012 was focused on four main strategic areas:

- Sufficient supply of biomass feedstock;
- Accelerating technology development and technology co-operation;
- Building industry and innovative businesses;
- The establishment of supportive infrastructure.

39. Several other Asian countries (e.g. Malaysia, Japan, Korea, Singapore and China), offer attractive tax reductions to companies that want to research and invest in the bioplastics sector (OECD, 2013d). Both Japan and Korea have well-developed policy frameworks for the development of bioplastics industries.

40. The mitigation of resource depletion objective of developing a bioplastics industry is exemplified by Japanese policy. Following the ratification by the Japanese Government of the Kyoto Protocol in June 2002, the Government announced (December 2002) two measures: the *Biotechnology Strategic Scheme* and the *Biomass Nippon Strategy*. The main objective of the two measures was to promote the utilisation of biomass and to reduce the consumption of fossil resources and to mitigate global warming through the use of biotechnology. The policy objective stated in the *Biotechnology Strategic Scheme* is to replace approximately 20% (2.5 to 3 million tons per year) of conventional plastics with plastics from renewable resources by 2020. This stimulated some major Japanese corporations into sourcing bioplastics for their products e.g. Toyota.

41. Similarly, in 2012 the Korean government announced a *Strategy for Promotion of Industrial Biotechnology*, with the goal of establishing a mid- to long-term strategy to develop related technology and devise detailed measures for implementation, contributing to lowering the existing dependence of the economy on crude oil. By 2020, this effort is expected to result in replacing 4.8% of crude oil imports with biochemical product manufacturing, reducing CO_2 emissions by approximately 10.8%, and generating at least 43 000 new jobs.

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6 http://www.unescap.org/sites/default/files/43.%20CS-Thailand-Bioplastics-Companies.pdf

Climate change and global warming

42. UNEP (2010) calculated that a doubling of wealth leads to an 80% increase in emissions. An important objective of building a bioeconomy is to help break this vicious cycle so that economic growth can be achieved without increasing the threats of climate change induced by greenhouse gas emissions.

43. Among papers expressing a position on anthropogenic global warming (AGW), an overwhelming percentage endorses the scientific consensus on AGW, with a very small number rejecting it (Cook et al., 2013). To date 167 countries have signed up to the Copenhagen Accord[7], in trying to limit the temperature rise, compared to pre-industrial levels, to 2ºC by limiting greenhouse gas emissions from fossil resources. And yet, taking into account the impact of measures already announced by governments to improve energy efficiency, support renewables, reduce fossil fuel subsidies and, in some cases, to put a price on carbon, the world seems on a trajectory consistent with a long-term average temperature increase of 3.6°C (IEA, 2013).

44. As greenhouse gas emissions reflect a mobilisation of more fossil carbon and are the primary cause of the climate change, the emissions from fossil resources should be limited and the use of circulating or non-fossil carbon favoured. The implication of limiting the greenhouse gas effect is that most of the known and projected fossil fuel reserves may be unburnable (Meinschausen et al., 2009; Carbon Tracker, 2013). This has recently been quantified: a third of oil reserves, half of gas reserves and over 80% of current coal reserves should remain unused from 2010 to 2050 in order to meet the target of 2°C (McGlade and Elkins, 2015). What is worse, achieving a 2°C scenario means only a small amount of fossil fuels can be burned unabated after 2050. In the view of Friedlingstein et al. (2014), two thirds of the CO_2 emission quota consistent with a 2°C temperature limit has already been used, and the total quota will likely be exhausted in a further 30 years at the 2014 emissions rates. By century end, the IPCC (2014)[8] has warned that GHG emissions need to be close to zero to achieve the 2°C obligation.

45. Many of the worst effects of climate change are expected to affect developing nations. This includes a large number of Asian countries. Bangladesh, for example, is a ‘frontline state’ of climate change[9], predicted to be one of the first and the hardest hit countries to face the adverse impacts of warmer global temperatures e.g. glacier melt or increased flooding from the sea, which is very often accompanied by outbreaks of infectious diseases.

Drought, temperature and crop yields

46. One important impact of climate change concerns agriculture. Agricultural productivity is ultimately defined by crop yield. Elevated temperatures have long been known to affect plant growth. Schlenker and Roberts (2009) demonstrated for three major US crops that an increase in temperature above the optimum for each resulted in a very rapid decline in yield. Their modelling suggested that average yields could be predicted to decrease by 30–46% before the end of the century under the slowest warming scenario and decrease by 63–82% under the most rapid warming scenario. The US Environmental

7 http://unfccc.int/meetings/copenhagen_dec_2009/items/5262.php

8 IPCC (Intergovernmental Panel on Climate Change) (2014), “IPCC: GHG emissions accelerate despite reduction efforts”, Press Release, 14 April, 2014. http://www.ipcc.ch/pdf/ar5/pr_wg3/20140413_pr_pc_wg3_en.pdf

9 http://www.oxfordresearchgroup.org.uk/publications/briefing_papers_and_reports/climate_change_drivers_insecurity_and_global_south

Protection Agency (EPA) has predicted that by mid-21st century, crop yields could increase up to 20% in east and south-east Asia. In the same period, yields could decrease up to 30% in central and south Asia[10].

47. The 1988 drought in the Midwestern United States resulted in a 30% reduction in the US corn production and cost about USD 39 billion (Mishra and Cherkauer, 2010). The US has just experienced its most widespread drought in more than half a century (Reardon and Hodson, 2013), and the drought in 2014 in California was perhaps the worst ever recorded (*National Post*, 2014). In Brazil, the three most populous states are currently experiencing their worst droughts since 1930[11]. As agriculture accounts for around 70% of all water use, measures that conserve water are of the utmost social and economic importance.

48. High temperatures in many cases can be expected to be accompanied by drought conditions. Evidence suggests that heat and drought stress can cause disproportionate damage to important crops compared with either stress individually (Atkinson and Urwin, 2012). Therefore, improvement of dual stress tolerance to heat and drought in crop plants has become a top priority for the development of agricultural biotechnology for both food and bioenergy markets. In addition, the number of crop varieties may be expanded to varieties that are better adapted, and to include orphan crops. Another consideration is that increasing temperatures may also be beneficial for areas that are now too cold. In this discussion, consideration should also be given to the fact that changing climate zones may not only have negative effects, there may also be a positive outcome as regions that were too cold for production, may now become primary production areas. In addition, a higher biodiversity is accompanying warmer climate zones. In any case the traditional crops that were used thus far within a specific climate zone, may need to be replaced by other crops or varieties that are adapted to the current conditions.

Soil destruction

49. Finally, and often overlooked in policy making, soil is the ultimate genetic resource; soils are the critical life-support surface on which all terrestrial biodiversity depends. More than 99.7% of all food is derived from cropland (Gore, 2013). But soil is being destroyed at unprecedented rates due to soil erosion (e.g. through deforestation), pollution and salination. About 2.5% of arable land in China is too contaminated for agricultural use (Chen and Ye, 2014).

50. It takes around 500 years to form 25 mm of soil under agricultural conditions, and about 1 000 years to form the same amount in forest habitats[12]. Therefore soil should be treated as a non-renewable resource. In the bioeconomy and sustainability context, soil accounts for some 20% of the capture of human CO_2 emissions (European Commission, 2007).

51. In the EU, the annual cost of soil degradation alone is estimated at some EUR 38 billion (European Environment Agency, 2007). The overall message is clear – our society is utterly dependent on maintaining the global stock of healthy soil. Any plans for a future bioeconomy dare not ignore this. An increasing rate of soil degradation must be reversed. In the face of soil destruction, more crops will have to be grown more efficiently, while methods should also be explored to halt or limit soil destruction.

10 http://www.epa.gov/climatechange/impacts-adaptation/international.html

11 http://www.bbc.com/news/world-latin-america-30962813. January 24, 2015

12 Food and Agriculture Organisation (FAO), www.fao.org/sd/epdirect/epre0045.htm

WHAT CAN GENOMICS OFFER ?

52. What can genomics offer to these global challenges? The potential of genomics is so great that most of the applications are as yet not thought of. For a continent as vast as Asia, it is beyond the scope of this paper to cover the potential of genomics in detail. There are an increasing number of techniques that have been termed 'omics' technologies. Annex 1 describes the main ones in use.

Selection or genetic modification?

53. Although very powerful, it should be stressed that genomics does not necessarily involve genetic modification (GM) or synthetic biology, and the negative societal issues that have haunted GM in many applications can be avoided. Rather, omics technologies can be applied to animal and plant breeding to greatly improve the efficiency of selection of traits. In the case of trees, this is especially important given the long timescales needed for tree growth and trait expression

54. To use the full potential of genomics there is a need to link genomics information to phenotypic characteristics. The availability of well-defined linkage maps and the extent of genetic studies conducted on them vary among different crops, and this influences the feasibility of any MAS (marker assisted (or aided) selection)[13]-related activity. MAS allows to reduce the breeding cycle time significantly (e.g. for cassava from five to two years) and is much more accurate (Ly et al., 2013).

55. The yield increase of the so-called green revolution in modern agriculture, characterised by the use of heterosis[14] and agrochemicals after the Second World War, is flattening out. In addition, current agricultural practices with higher inputs, such as pesticides and fertilisers to ensure high yields, are not considered environmentally sustainable. For further yield improvement of commonly used crops or for so-called orphan crops, the use of advanced breeding methods, using MAS and increasing germplasm will be essential. Today many orphan crops have not yet been pushed to their limits and will still benefit from traditional and advance breeding.

56. During the workshop, banana was referred to as "effectively an orphan crop", and indeed, perhaps the most important orphan crop of all. Because of the fact that banana reproduces mostly vegetative, breeding and increasing the gene pool within a species is more complicated. These crop species may benefit more readily from genetic modification arising from direct introduction of genes isolated from other species or organisms. The *Musa* Germplasm Information System (MGIS)[15],[16] contains key information on *Musa* (banana) germplasm diversity, including: passport data; botanical classification; morpho-taxonomic descriptors; molecular studies; plant photographs, and; GIS information on 2281 accessions managed in 6 collections around the world. This is the most extensive source of information on

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13 Marker assisted selection or marker aided selection (MAS) is a process whereby a marker (morphological, biochemical or one based on DNA/RNA variation) is used for indirect selection of a genetic determinant or determinants of a trait of interest (e.g. productivity, disease resistance, abiotic stress tolerance, and quality).

14 Heterosis is the improved or increased function of any biological quality in a hybrid offspring. An offspring exhibits heterosis if its traits are enhanced as a result of mixing the genetic contributions of its parents. These effects can be due to Mendelian or non-Mendelian inheritance (http://en.wikipedia.org/wiki/Heterosis).

15 http://www.crop-diversity.org/mgis/

16 https://www.bioversityinternational.org/research-portfolio/conservation-use-of-bananas-tree-crops/international-musa-germplasm-transit-centre/

banana genetic resources globally. However, information on the wild ancestors of the current banana varieties in Asia is still unknown. Having access to the full germplasm is important to address the pathogen attacks that many banana cultures are facing. This complete germplasm is likely to lead to new pathogen resistance genes.

57. Meanwhile, industrial applications often involve making novel production strains from standard, non-pathogenic microorganisms for post-harvest biomass processing for industrial use. These applications cause far less controversy, however, as they are usually covered by contained use regulations as they are used in bioreactors where their growth and death can be controlled.

58. It should also be stressed that in a world of interacting grand challenges, omics technologies represent part of the solution, not a magical technical fix. One of the great strengths of omics, however, is that there is so much capacity for interactive problem solving compared to a chemical or physical technology. This is elaborated in Box 1.

Box 1. The grand challenges ecosystem

> "*In an era of increasingly pervasive human influence on physical and biological components of the Earth system, what are the most effective strategies for maintaining the integrity of natural systems and the services they provide?*"
>
> NAS (2010). Research at the intersection of the physical and life sciences. National Academies Press, Washington DC. ISBN-13: 978-0-309-14751-4

Whenever humans intervene in a system, from the level of genetics to whole community, all the way to globally, there are interactions with other components of the system, and new consequences. The 'behaviour' of these grand challenges is assuming characteristics of an ecosystem: an intervention in one location results in changes there but also elsewhere. Single human interventions are unlikely to work. There are some such interactions that are quite clear. There will be many more that are subtle and unforeseen.

Growing more crops on more land, or increasing the productivity of crops on the existing land addresses food security, but maybe only temporarily. This strategy is likely to negatively affect soil health, and will require more water, which is already stressed in many locations. It may decrease biodiversity. And people still want wild places to visit (e.g. national parks). Higher yields will require more artificial fertilizers, which mean more emissions and agriculture becoming even more dependent on the fossil industry. More agro-chemicals can lead to further pollution while production increase reaches a maximum that cannot be further increased. Bioenergy, biofuels and bio-based materials produced from biomass instead of fossil resources addresses GHG emissions reductions, central to the mitigation of climate change. But this requires more biomass, which can impinge on food security, and can interfere in many of the ways highlighted above. The interferences can partly be ameliorated by, say, using algae as a source of biomass, or using waste industrial gases as the feedstock for fermentations. Deliberately increasing the production of algae, or removing existing stocks unsustainably, inevitably affects other parts of the marine ecosystem, and may interfere with local, traditional industries and practices. It could be that the best locations for growing, harvesting and processing algae are not served by infrastructure, such as road and rail transport. The costs of developing marine biotechnology to an extent that will significantly address global challenges are very high, so a lot of attention has to be paid to consequences.

For policy makers, these are either dream or nightmare scenarios. Faced with constrained finances, the policy challenges are long-term and there are no quick fixes. Ultimately the goal is interacting solutions to interacting grand challenges. This calls for multi-disciplinary research and systems innovation. There is no simplistic technological fix, and genomics is merely one part of the jigsaw. But it is a very important part because genomics can offer interactions. Many of the on-going R&D activities in crop science make some of these interactions foreseeable. For example, the combination of drought/heat tolerant traits with the ability of a plant to make its own fertilizers addresses several grand challenges: water security, food security, resource depletion, climate change. Unfortunately, creating such a crop is a gargantuan task. Therefore, although genetic modification and gene editing offers the possibilities to address many of the ambitions ahead, negative interactions have to also be considered, not least of them the possible public reaction to such a strategy.

Crop genomics

59. There are many applications of genomics and genetic engineering/synthetic biology to increase crop production that will be utilised in the future bioeconomy e.g. pest resistance, more "efficient" plants that use less water, resistance to environmental stresses, the development of crops that can fix nitrogen to replace synthetic fertilizers or the change C3 plants into C4 plants.[17] Heat and drought stress are used as examples of the potential of the application of genomics to agriculture. On the other hand, too much water can also lead to crop destruction.

Dual heat and drought tolerance

60. Genomics can be used in conjunction with either modern techniques of plant breeding or genetic engineering to improve the accuracy and efficiency of selection. For example, the most obvious dilemma for agriculture posed by climate change is the dual stress of heat and drought. A subset of target genes that constitute a novel transcriptional regulatory cascade that controls plant responses to the combined stress has been identified (Huang, 2013). In laboratory conditions, *Arabidopsis* and canola plants with mis-sense expression of these regulatory genes were able to tolerate independent higher temperature or drought treatment. More importantly, these plants produced higher seed yield comparing to their controls when both stresses were applied simultaneously. The dual stress tolerance and yield enhancement properties of the transgenic plants were further confirmed by large-scale, multiple season and location field trials. These results represent a significant breakthrough in crop improvement and technologies derived from this research could enable farmers around the world to maintain higher yield and productivity over variable and adverse environmental conditions.

Genetic engineering and synthetic biology, food security and new crops

61. An important point to make here is that modern plant breeding techniques that do not necessarily involve transgenes, although genetic modification may also refer to up or down regulation of genes to induce an advantage of interest (i.e. modifying their activity). Modern plant breeding techniques, including genetic engineering (Annex 2) improve the efficiency of plant breeding.

62. More controversial than genomics in selection, genetic engineering and synthetic biology could transform future agriculture under conditions of grand challenges. There are many studies regarding the risk associated with genetic modification, most of them indicating low risk (e.g. European Commission, 2010). Nevertheless some parts of the world reject genetic modification for a variety of societal and economic reasons, and thereby also reject potentially beneficial sustainable solutions. A balanced risk-benefit analyses could be a useful way forward in this context, particularly when combined with foresight studies. Genetic modification may be among the most sustainable approaches in a future with many more mouths to feed, and a situation where climate effects may negatively interact with crop growth and yield. It provides the potential to adapt crops to warmer and drier climates and to increase the net yield of harvests on less land, with less input of water and agrochemicals, so that also the impact on biodiversity should be as limited as possible.

63. Again it is not within the scope of this paper to be comprehensive. Given the need for more crops and higher yields with improved nutritional qualities, there are other serious problems that may be posed

[17] C3 refers to the Calvin cycle that plants use for photosynthesis. The C4 pathway is an alternative of the Calvin cycle. The latter pathway has an advantage because it fixes more carbon dioxide and can operate under low carbon dioxide concentrations, without inhibitory effects of oxygen or sunlight as is the case for C3 photosynthesis. In addition, C4 plants do not energy and carbon to photorespiration and exhibit better water-use efficiency than C3 plants.

by grand challenges e.g. new and migrating plant pathogens (such as the fungal banana diseases), multiple stresses (such as drought and heat already discussed), flooding, increased salination of soil. Further, new stresses are likely to arise more frequently, driving a need for faster approaches to crop development and adaptation. This is how a future synthetic biology could be very beneficial, if its 'design and engineering' expectations come to fruition. This would remove much of the trial-and-error from crop design, allowing targeted modifications in more rapid time frames.

Crops that make their own fertilizer

64. Several efforts are on-going in this tantalising research area. A collaborative project with UK and US scientists aims to design and build a synthetic biological module that could work inside a cell to perform the function of fixing nitrogen[18]. The cyanobacteria are able to fix nitrogen using solar energy via specialised cellular machinery. This project aims to re-engineer this machinery so that it can be transferred into a new host bacterial chassis as a first step towards transferring the machinery, and thus the ability to fix nitrogen, into plants themselves.

65. If successful, the significance of crops of the future that make use of atmospheric nitrogen rather than using synthetic fertilizers needs to be appreciated. The reliance of artificial nitrogen fertilizers for food crop production and their damaging environmental effects are often underestimated. For example, the Haber-Bosch process for the production of ammonia, which is used to produce agricultural fertilizers consumes 3 to 5% of the world's natural gas production and releases large quantities of CO_2 to the atmosphere (Licht et al., 2014). Therefore it may be possible to decouple agriculture from the fossil fuels industry[19]. Other effects of intensive fertilizer use, such as the concerns about nitrates in water and vegetables, and eutrophication of water bodies, have been recognised for decades (e.g. UN FAO, 1972). Nevertheless, such a strategy is likely to meet with resistance from the public if the necessary safety research has not been conducted, and communicated, to minimise other environmental effects.

66. Another project illustrates the power of smart design to address the fertiliser issue (Lòpez-Arredondo and Herrera-Estrella, 2012). Phosphate is the most limiting nutrient in natural and agricultural ecosystems; 70% of cultivated soils have low phosphate availability. Worldwide, over 70 million tons of phosphate fertiliser are applied yearly to achieve high productivity. In 1998, a phosphite assimilation operon was characterized in *Pseudomonas stutzeri* WM88 (Metcalf and Wolfe, 1998). This operon allows this bacterium to use phosphite as a sole source of phosphorus. When introduced in plants, also the plants were able to use phosphite as the sole source of phosphorus. In fact, when using phosphite as a fertiliser, a reduction of 50% of phosphorus input was possible. More important, fertilisation and weed control can be achieved with a single compound at a lower cost, because when using phosphite as the sole phosphorus source, weeds cannot overgrow the transgenic plants. As phosphite is not present naturally in the soil, accidental gene transfer should not have a negative effect on natural ecological systems. Moreover, phosphite is naturally oxidised into phosphate in a few months guaranteeing that there are no long term residual effect. Replacing phosphate by phosphite as a fertilizer in agriculture would in addition reduce the ecological problem caused by toxic algal blooms.

Golden Rice

67. The story of Golden Rice is interesting beyond the science. It speaks to the geographical divisions on attitudes to GM technologies, and on their regulation. The story is concisely summarised by

18 http://www.bbsrc.ac.uk/news/food-security/2013/130822-pr-uk-usa-collaborate-to-design-crops.aspx

19 When the price of Brent crude oil rose from around USD 50 per barrel to about USD 110 by January 2013, the prices for ammonia in western Europe and the mid-western corn belt in the United States roughly tripled

Potrykus (2013). Vitamin A deficiency is a serious health problem in rice-dependent populations, which are often poor. Genetic engineering provided a solution to produce beta-carotene in the endosperm of rice. Beta-carotene is converted to vitamin A in the intestine. Only 40 grams of GM Golden Rice a day (modified for the production of vitamin A) are sufficient to prevent the severe health consequences of vitamin A deficiency. However, the deployment of this technology was delayed for 12 years by regulation. More recently however, it seems that Golden Rice is gaining better acceptance.[20]

Genomics and sustainable forestry

68. Major global economic models tentatively suggest that ambitious climate change mitigation need not drive up global food prices much if the extra land required for bioenergy production is accessible or if the feedstock, such as wood, does not directly compete for agricultural land (Lotz-Campen et al., 2014). What is not clear, however, is what will be the long-term effect on wood prices. Increasing demand for wood pellets is likely to drive up the price of biomass significantly in a market constrained by supply, not demand (Deloitte, 2012). Such price rises have already started. Pellet prices in Germany, for example, have seen substantial increases at around 18% year-on-year (Wood Pellet Information Resource, 2013). There is a danger in this that the demand for pellets overcomes the sustainable production of wood, and this could affect Asian countries directly through deforestation and its attendant problems e.g. soil erosion.

69. A new approach to forest development and exploitation, particularly regarding the sustainability of new forestry, is also critical to second generation biofuels development (OECD, 2013b). As well as the woody energy crops, some fast-growing tree species have also shown promise for biofuels production. Important attributes include the relatively high yield potential, wide geographical distribution, and relatively low levels of input needed when compared with annual crops (Smeets et al., 2007). However, the lignin, a major component of plant secondary cell walls in woody plants, makes the sugar molecules that build the cellulose microfibrils less accessible to enzymatic depolymerisation and fermentation and thus limits the conversion of biomass to bioethanol. Down-regulation of one of the central genes in the lignin biosynthetic pathway in poplar trees produces wood that contains about 20% less lignin and more cellulose per gram of wood. Lab and greenhouse experiment indicated that at least 50% more bioethanol can be produced by this low-lignin wood. Results from field trials largely confirm these experiments although when the lignin level is too low there is a significant reduction of yield of wood (Van Acker et al., 2014).

70. The forest products sector is looking for new opportunities to produce value-added products while securing access to emerging carbon capture markets (Sheppard et al., 2011) and the example of lowering lignin content in wood may open new opportunities, especially as the approach although classified under GM is not using transgenic expression of poplar foreign genes.

71. Extending the limits of conventional breeding, which is a very slow and inefficient process in tree development, to give faster and more accurate trait improvement for application in plantation forests (including faster growth, improved pest and disease control) has the potential to allow easier and cheaper development of bioenergy and second generation biofuels.

Metabolic engineering and industrial production

72. Although bio-based production was not a focus of the workshop, this is included because, in a resource-constrained future world, bioenergy, biofuels and bio-based chemicals and plastics will use biomass as the feedstock, thus competing directly for land with food and feed. A clear interaction of energy security, food security and climate change is visible here.

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20 http://www.goldenrice.org/

73. Metabolic engineering of (primarily) microbial strains is increasingly being used to make both natural and synthetic organic chemicals. In mass production of the scale of bulk chemicals and transportation fuel, biotechnology processes have been notoriously inefficient, and unable to compete with the petrochemicals industry. The biocatalyst usually lacks the industrial robustness that is required to synthesise products at high yield under industrial conditions (Olson et al., 2012). Part of the vision for synthetic biology in the bio-based industries is to improve on these inefficiencies. Another part of that vision is to improve on greenhouse gas (GHG) emissions savings in bio-based production, which are already viewed as significant in comparison to the equivalent petrochemically manufactured products (e.g. Weiss et al., 2012).

74. The bio-based industries are placed in a position of competition for biomass and land in the production of food. Another frontier for synthetic biology in the future bioeconomy, then, will be applications that alleviate the strain on sustainable biomass production in the face of an increasing global population, when the primary focus must be on food (Pavanan et al., 2013). For example, fermentation of waste industrial gases takes pressure from land as the source of carbon for bio-based chemicals production (e.g. Bomgardner, 2012).

Replacing fossil fuels

75. The arguments discussed above regarding climate change and the need to leave large amounts of oil, gas and coal unburned has been a significant spur for R&D on liquid biofuels and bio-based chemicals and plastics. To be consistent with renewability, sustainable development and a future low-carbon society, a reality check relates to how much change in lifestyle society will tolerate. The Milken Institute (2013) estimated that 96% of all manufactured goods in the US contain at least one chemical, and businesses dependent on the chemical industry account for nearly USD 3.6 trillion in US GDP. The only feasible source of carbon to continue making chemicals is renewable, bio-based carbon.

76. To make the plethora of chemicals synthesised in the petrochemicals industry directly from metabolically engineered microbes is unrealistic. What is more realistic is to make bio-based intermediates, and use these as the basis for further production through (green) chemistry. It is estimated that over 30 different intermediate chemicals could be manufactured sustainably and economically from inexpensive sugar in the future (Burk, 2010). Now it has been shown that entirely unnatural chemicals can be synthesised in metabolically engineered microbes (Yim et al., 2011). An objective of future work at the OECD is to examine in more detail the feasibility of replacing fossil fuels in chemicals production in the long term.

RICE, THE ICONIC CROP OF ASIA

77. Rice is the major staple food for almost half of the world's population. Perhaps more than any other, rice is a defining crop of Asia. It has naturally been the model cereal for genetic, breeding and agronomic research. This is a fortuitous choice: rice has a small genome, it is easily transformed and there are similarities of its gene order and gene sequence with other cereals (Upadhyaya and Dennis, 2010).

78. Conventional breeding over the last three decades has resulted in a doubling of rice production. However, breeders are in need of new tools and resources with which they can address the major production constraints such as pests, pathogens, submergence, salinity and drought in order to provide the required increase in the rate of production. Rice genomics has the potential to provide such tools and resources in the form of molecular markers for genes and gene control sequences determining the desired traits or as genes and gene control sequences *per se* for use in transformation breeding.

79. Regarding climate change and other abiotic threats to crop production, a major challenge is identifying genes involved in complex traits of agronomic significance. It is likely that there will be many genes with some effect in abiotic stress, and pinpointing critical genes will require inputs from all aspects of genetics and genomics. These characteristics will be of critical importance in altered environments caused by changing climate.

80. Major success has been achieved in using genomics to select rice strains to tolerate submergence, an abiotic effect of increasing importance due to increasing instances of flooding as a consequence of climate change.

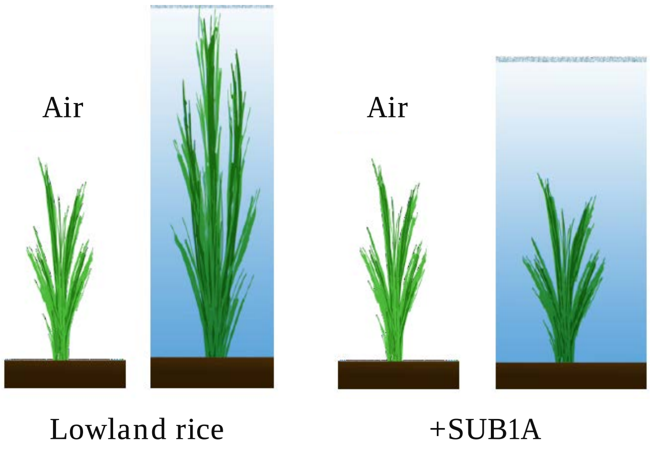
Rice and submergence tolerance

81. Rice is a crop well adapted to wet, monsoon climates and allows farmers to produce food in flooded landscapes. Of the lowland rain-fed rice farms worldwide, over 22 million hectares are vulnerable to flash flooding, representing 18% of the global supply of rice. In total, some 30-40 million hectares get submerged, and this happens roughly every three years. Most rice varieties can tolerate only a few days of submergence and die after about a week.

82. Success in fine mapping of SUBMERGENCE 1 (SUB1), a robust quantitative trait locus (QTL) on chromosome 9 from the submergence tolerant FR13A landrace, has enabled marker-assisted breeding of high-yielding rice capable of enduring transient complete submergence (Bailey-Serres et al., 2010). It provides protection from complete submergence for 3-18 days. SUB1 belongs to the Ethylene Responsive Family (ERF) transcription factors (Xu et al., 2006). It functions by slowing down growth, preserving chlorophyll and conserving energy reserves.

83. With traditional lowland rice, when flooded the plant reacts by spurring growth to get above the water, continues to grow when the flooding continues, and finally runs out of nutrients and dies (Figure 2). Variety SUB1A does not grow while flooded and starts growing again after the flooding has subsided. In this case a single mutation is involved in tolerance.

Figure 2. Submergence tolerance in SUB1A

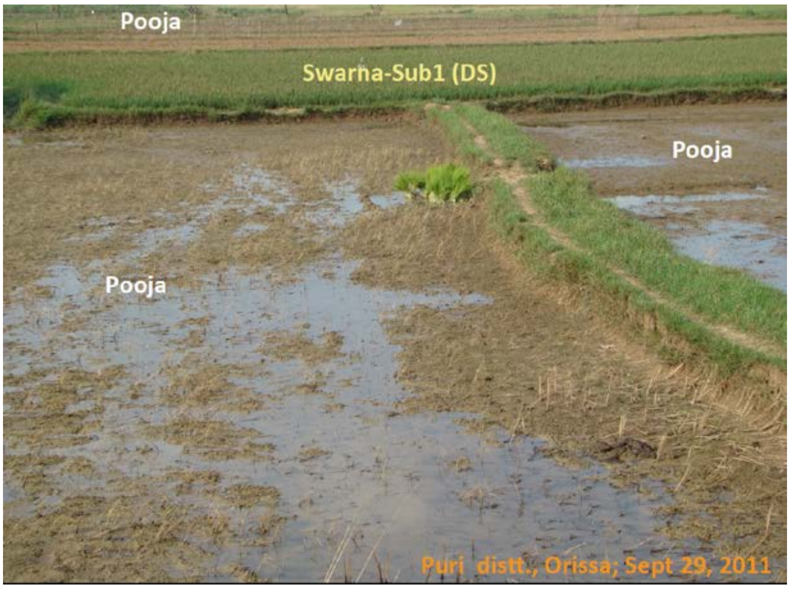


Source: Ismail, S. (2015). Presentation at the OECD workshop "Genomics for Sustainable Development in Emerging Economies: Food, Environment, and Industry"

84. The success of the SUB1A variety is graphically illustrated in Figure 3.

Figure 3. SUB1 enhances recovery after severe flooding damage.

Immediately after flooding | Three months later



Submergence resistant rice field *versus* the normal variety.

Source: Ismail, S. (2015). Presentation at the OECD workshop "Genomics for Sustainable Development in Emerging Economies: Food, Environment, and Industry"

85. SUB1 has been introduced into several mega-varieties of rice through marker assisted selection (MAS) and backcrossing[21] (MABC). Under submergence for 7-14 days these tolerant cultivars have an average yield advantage of 1.5 tonnes per hectare over intolerant cultivars, with no reduction in yield under non-submerged conditions. SUB1 is gradually being introduced to all varieties developed for lowland ecosystems by the International Rice Research Institute (IRRI)[22], and several national programmes are also introducing the gene into locally-adapted varieties. To date, over 4 million farmers have been reached with seeds of SUB1 varieties with the cooperation of the private sector.

Social impacts

86. About 90% of the world's rice is produced and consumed in Asia. Over 70% of the world's poor are in Asia. In Asian countries with subsistence rice farming, when submergence occurs and the rice crop fails, the first most obvious effect is that the farmers' income decreases. Almost the first knock-on effect is that the farmers attempt to save money by taking their children out of school. They may be forced to sell land. Continuing poverty leads to people migrating off the land to find jobs in cities. So the cycle of poverty in the countryside continues.

87. One of the difficult issues encountered is to convince farmers to switch from their traditional varieties to the submergence resistant rice varieties. The strategy taken by IRRI was to convince single farmers to use the sub resistant varieties on one field and when flooding happened the result of this is so convincing (Figure 3) that most farmers around were convinced to switch.

21 Backcrossing is a crossing of a hybrid with one of its parents or an individual genetically similar to its parent, in order to achieve offspring with a genetic identity which is closer to that of the parent.

22 www.irri.org

88. There is evidence that the introduction of submergence tolerant rice strains is now decreasing these negative social effects, and efforts are underway in the International Rice Research Institute to try to quantify these effects.

How governments can help

89. Some of the critical steps that governments can take of are:

- To characterise stress-prone areas and share information with central and state governments for targeted dissemination;
- To map domains to predict seed needs of a particular variety and feedback to partners in the seed chain;
- To monitor progress to identify gaps and needs for process adjustments;
- To assess impacts on farmers' livelihoods and social conditions.

90. There are, of course, other threats to rice crops, and some of these will be complex factors that are not addressable through single gene mutations. Rice is subject to many bacterial, viral and fungal diseases. Without resorting to GM technologies, governments should ensure effective international communication so that advances can be shared where possible.

91. Genomics will only make a difference when closely tied to breeders, and ultimately the involvement of the farmers is needed. Empowering subsistence farmers in this way is likely to optimise the process from discovery to field deployment. By doing so in a timely manner, farmers may be spared from subsequent flooding events and disease episodes.

BANANA: A CRITICAL CROP WITH MANY THREATS

> "The Musa genome sequence is therefore an important advance towards securing food supplies from new generations of Musa crops…"
>
> D'Hont et al. (2012).

Banana and food security

92. Banana as a crop for food security is often overlooked and yet it is the fourth most important food crop in the world. It is a staple in many diets. A large number of people in East Africa consume 1 kg or more per person per day. India and Uganda are the largest producers, but none are exported: the whole crop is required for food security. More than 70 million people in West and Central Africa are estimated to derive more than one-quarter of their food energy requirements from plantains. Banana is the most popular fruit in industrialised nations (Lescot, 2011). But this is all from one variety – Cavendish – and in global terms it is relatively minor. In 2012 the volume of global gross banana exports reached a record high of 16.5 million tonnes, but this represents only some 15–20% of total banana production.

93. However, various pathogens and pests threaten banana crops and its attendant food security (De Lapeyre de Bellaire et al., 2010; Dita et al., 2010). The race against pathogen evolution is particularly critical in clonally propagated crops such as banana. For example, *Fusarium* wilt, known as Panama disease, is a lethal infection caused by the fungus *Fusarium oxysporium*. Once infected, the plant is effectively doomed (Figure 4). *Fusarium* destroyed the Gros-Michel banana plantations in Central America in 1950s. A new strain, Tropical Race 4, identified first in Malaysia, has spread to other South East Asian countries. It is now also in the Middle East and southern Africa. In Queensland, Australia, it threatens to make the AUD 600 million banana industry extinct.

Figure 4. Fusarium wilt

Source: Volkaert, H. (2015). Presentation at the OECD workshop "Genomics for Sustainable Development in Emerging Economies: Food, Environment, and Industry"

94. Tropical Race 4 attacks not only the Cavendish cultivar, but also many other cultivars grown widely in subsistence farming systems in Africa. What is worse, *Fusarium* spores can persist in soil for many years, so eradication of TR4 will require an approach similar to Ebola outbreaks – tracing all possible infection paths and quarantine.

95. Pest control is also expensive. Up to 50 pesticide treatments a year are required in large plantations against black leaf streak disease (also known as Black Sigatoka), a recent pandemy caused by *Mycosphaerella fijiensis*. The situation is not helped by monoculture: every Cavendish is genetically identical, and all have the same susceptibility to disease. Other major threats for banana include banana bunchy top virus (BBTV), burrowing nematode and banana weevil. More recently, banana *Xanthomonas* wilt (BXW) has emerged as an important bacterial disease that apparently originated in Ethiopia and caused a major disease epidemic in much of East Africa in the last decade. Breeding for resistance to these diseases and pests is one of the major goals in Africa and Asia.

The banana genome and breeding

96. Due to several reasons banana breeding is exceptionally difficult. Very few new varieties have been obtained by crossing (e.g. FHIA-01 Goldfinger, FHIA-03 Sweetheart). A few new varieties have been obtained by mutational breeding (e.g. GCTCV-218 Formosana). But acceptance of the new varieties has been low because of different taste, ripening, cooking qualities. Among the difficulties are:

- Banana is seedless and most clones are also pollen sterile;
- It is very difficult to obtain seed from cultivars;
- It is very difficult to germinate viable seedlings;
- They are relatively large plants with long cycles;
- Inadequate germplasm collection, and vitally;
- The understanding of the genetic mechanism of parthenocarpy[23] and unreduced gametogenesis is completely lacking.

97. The reference *Musa* genome sequence is considered a major advance in the quest to unravel its complex genetics. Having access to the entire *Musa* gene repertoire is a key to identifying genes responsible for important agronomic characters, such as fruit quality and pest resistance (D'Hont et al., 2012). In Southeast Asia, at its origin, wild *Musa* still remains, although the global gene pool information is still missing. Access to wild varieties could lead to identification of resistance markers that can be used against pest attacks through breeding or breed more nutritious hybrids.

98. The potential of natural resistance is very well illustrated in the banana variety Yangambi km5 (Hölscher et al., 2013). This variety is resistant to the nematode *Radopholus similis*, a roundworm that infects the root tissue of banana plants. This roundworm infects banana crops worldwide. The nematodes are invisible to the naked eye, but they can penetrate the roots of banana plants by the thousands. Once infected, these plants absorb less water and nutrients, resulting in yield losses of up to 75%. Lesions in the roots also make the plant more susceptible to other diseases. Eventually, the roots begin to rot. In the final stage of the disease, the plant topples over, its fruit bunch inexorably lost. Analysis of Yangambi km5

23 In botany and horticulture, parthenocarpy (literally meaning virgin fruit) is the natural or artificially induced production of fruit without fertilisation of ovules. The fruit is therefore seedless.

indicated this variety produced nine metabolites that are toxic for nematodes. The popular Grande Naine is very susceptible to the nematode infection although it also produces these metabolites, be it much more slowly and in lesser quantities. These findings open new perspectives to use in plant protection.

More information is needed

99. It was emphasised that genomic information on its own is not going to solve problems with bananas, and this should be a general point for policy makers – a large amount of background knowledge is needed before the benefits of genomics can be unleashed. With banana, the issues are:

- There is still an outstanding need to find the relevant populations in the wild;
- Thorough phenotyping is still lacking;
- Making crosses among seeded bananas still has to be done;
- A thorough search for interesting segregating variants is yet to be done e.g. disease resistance, drought resistance, improved yield, unreduced gametes, parthenocarpy.

100. Only then is it useful to apply molecular tools to understand the genetics and developmental mechanisms. Together these measures create the toolbox to create new banana cultivars. This is important intelligence to maintain food security with banana. The tools of genomics are an enormous step forward, but alone they cannot solve the specific problems of the banana crop. It is the marriage of the new and the old that is all-important – the new genomics and the ages-old breeding technologies.

OIL PALM GENOMICS AND SIGNIFICANCE TO THE MALAYSIAN BIOECONOMY STRATEGY

101. Oil palm illustrates a classic bioeconomy dilemma. It is the most productive oil-bearing crop, accounting for one-third of all vegetable oil and 45% of edible oil worldwide. Although it is planted on only 5% of the total world vegetable oil acreage, increased cultivation competes with dwindling rainforest reserves. Global production of palm oil more than doubled between 2000 and 2012 (FAO, 2013). Thus the competing imperatives of a bioeconomy are clear to see: creating economic growth while reining in detrimental environmental effects to create a future economy that is sustainable.

102. Palm oil production is central to the economy of Malaysia, employing close to half a million people. Historical statistics indicate that Malaysian palm oil yields have typically appreciated over time, until 2009, when an unexpected break in the long-term national growth pattern occurred which has persisted to the present day. Explanations for the abrupt change are varied, which include a combination of adverse weather, ageing trees and plant disease (USDA Foreign Agriculture Service, 2012).

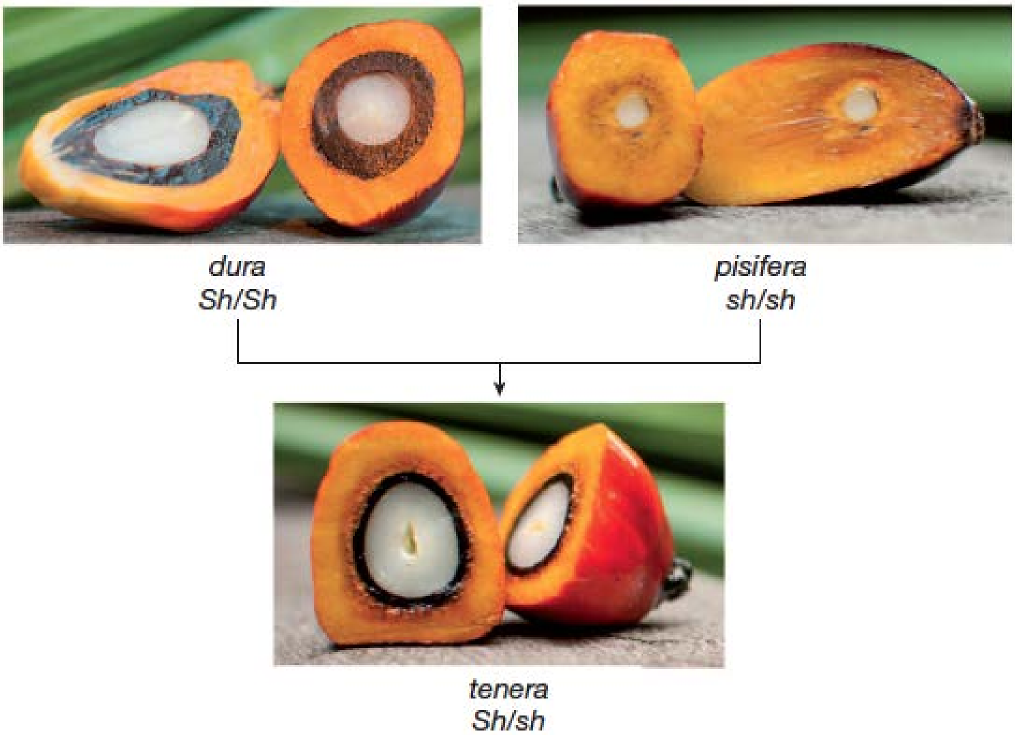
103. Data indicate that the vast majority of trees have already reached or passed through their peak yielding years. A small but growing problem is a lethal fungal disease. *Ganoderma* has the capacity to cause significant yield losses well before it has actually killed an oil palm, while its spores can spread to ever increasing areas of a plantation once it has been introduced. Therefore very obvious targets for genomics applications would be increasing oil yield and disease resistance. With growing needs for edible and biofuel uses, increasing yield would reduce the rainforest footprint of oil palm.

The oil palm genome and oil yield

104. The oil palm genome sequence was published by Singh et al. (2013b). The sequence enables the discovery of genes for important traits as well as alterations that restrict the use of clones in commercial plantings. The oil palm is largely undomesticated and is an ideal candidate for genomic-based tools to harness the potential of this remarkably productive crop. The authors claim that the dense representation of sequenced scaffolds on the genetic map will facilitate identification of genes responsible for important yield and quality traits.

105. The modern oil palm tree *Elaeis guineensis* has three fruit forms: *dura* (thick-shelled); *pisifera* (shell-less); and *tenera* (thin-shelled) (Figure 5). The *tenera* palm yields far more oil than *dura*, and is the basis for commercial palm oil production in all of South East Asia. In 2013 a remarkable discovery was made. The *Shell* gene has proven extremely challenging to identify in oil palm, given the large genome, long generation times and difficulty of phenotyping in experimental populations. Singh et al. (2013a) identified the gene and determined its central role in controlling oil yield. Regulation of the *Shell* gene will enable breeders to boost palm oil yields by nearly one-third, which presents excellent news for the industry, the rainforest and its champions worldwide, and also for bioeconomy policy makers.

Figure 5. Oil palm tree fruit forms



Note: The Shell gene is responsible for the oil palm's three known shell forms: dura (thick); pisifera (shell-less); and tenera (thin), a hybrid of dura and pisifera palms. Tenera palms contain one mutant and one normal version, or allele, of Shell, an optimum combination that results in 30% more oil per land area than dura palms.

Source: Singh et al.(2013a)

106. Seed producers can now use the genetic marker for the *Shell* gene to distinguish the three fruit forms in the nursery long before they are field-planted. Currently, it can take six years to identify whether an oil palm plantlet is a high-yielding palm. Even with selective breeding, 10 to 15% of plants are the low-yielding *dura* form due to uncontrollable wind and insect pollination, particularly in plantations without stringent quality control measures (Cold Spring Harbor Laboratory News, 2013).

107. Accurate genotyping such as this has a critical implication for a bioeconomy. Enhanced oil yields will optimise and ultimately reduce the acreage devoted to oil palm plantations, providing an opportunity for conservation and restoration of dwindling rainforest reserves (Danielsen et al., 2009).

FORESTRY AND GENOMICS

108. Figures vary, but one estimate is that 62.3% of Malaysia is forested. Of this 18.7% is classified as primary forest, the most biodiverse and carbon-dense form of forest. However, between 1990 and 2010, Malaysia lost about 8.6% of its forest cover. Forests are very diverse in Malaysia, covering the ecosystem spectrum from mountain forests to mangroves. About 4.2 million cubic meters of timber are harvested annually from the forest in Peninsular Malaysia. The timbers consist of about 900 different species. As with all tropical rainforest systems, the main threats are global warming, loss of biodiversity and deforestation.

109. As in most countries, Malaysian forest genomics research and development is at an immature stage. At the workshop it was stated that without much prior knowledge, genomics information in itself is not useful. Much other genetic knowledge is required to unleash the potential of genomics. However, future work is likely to fall into one of two (inter-related) categories: conservation of forest genetic resources, and; sustainable utilisation of forest genetic resources.

110. The Forestry Research Institute Malaysia (FRIM[24]) is one of the leading institutions in tropical forestry research in the world. FRIM research activities are organised into the following topics:

- *Forestry and Environment*: To develop technologies and provide solutions to support and ensure the sustainable management of resources and ecosystem services of the natural, urban and recreational forests.
- *Forestry Biotechnology*: To develop technologies and products based on biodiversity resources for forests and herbal plantations for related industries through biotechnological approaches.
- *Forest Products*: To focus on the development of R, D and C towards improvement on durability, service life and utilisation of wood resources and ligno-cellulosic materials available for producing various high quality/value-added products.
- *Forest Biodiversity*: To provide and develop key scientific knowledge to safeguard biodiversity and ecosystem services in Malaysia for their wise management and sustainable utilisation.
- *Natural Products*: To support the national bio-economy agenda via the empowerment of natural product based industries through bioactive feedstock security.
- *Economic and Strategic Analysis*: To conduct socio-economic research and strategic analysis on forestry and environmental issues for national development.

111. Regarding genomics, the early development of this area is divided into five topics:

- Microsatellite marker;

[24] www.frim.gov.my

- Genetic diversity of timber species;
- Optimum population size for conservation;
- Effects of logging on plant species, and;
- Full genome sequence of *Shorea leprosula*, a very important timber species.

112. Many of the Malaysian timber types are of high value, and the business is susceptible to both fraud and over-exploitation of rare species. Timber tracking is therefore very important on the international stage, and DNA barcoding is rising in importance. DNA barcodes are also important in the authentication of the many Malaysian medicinal plants.

113. It is worth comparing these approaches in Malaysia to another large country with a relatively large dependence on forestry in its economy – Canada. Recognised as a sector of economic importance in British Columbia, the forest sector has benefitted from significant investment from Genome Canada and Genome BC. To date, over CAD 92 million has been invested in capacity-building discovery research along with a number of more applied research projects such as the:

- Development of genomic tools to identify forest fungi and understand forest ecosystems;
- Genomic resources for beetle-fungal-tree host interactions;
- Exploration of genome organisation and structure of spruce and pine trees;
- Understanding the genomic diversity of forests;
- Identification of genes activated during fungal infection;
- Developing tools to forecast mountain pine beetle outbreaks;
- Testing of genomic markers for utility in management of climate change.

114. Outputs of these projects are finding application in government ministries responsible for the management of forest health and sustainable harvesting, including reforestation.

115. It is clear that the two countries share similarities in its expectations from genomics research and the impact on forestry and the concomitant economic development.

INDUSTRIAL USES OF BIOMASS WITH REFERENCE TO AN ASIAN BIOECONOMY

116. There is a large existing body of literature on the increasing number of crops and waste materials that can be used in bio-based production of fuels, electricity, plastics, chemicals and textiles. Indeed many of the crops being considered in OECD nations as non-food ‘energy crops’ have Asian or tropical origins. For example, the plant *Jatropha* is widely grown in tropical and sub-tropical regions for the oil it produces. *Jatropha* incentives in India are a part of the national goal to achieve energy independence (Biswas et al., 2014) and the plant is also grown in Africa as a promising alternative for biodiesel production.[25] For a long time however, optimisation of production has been neglected, while yields can be significantly improved in agronomy studies.[26] In addition, the right variety for the right environment needs to be selected. Breeding to develop cultivars that have high yield and result in a stacking of desirable traits are essential. Results from field trials in India demonstrated that yield can be significantly increased.

117. *Arundo donax*, the giant cane, is native to eastern and southern Asia, and is another promising crop for energy production (Lemons e Silva et al., 2015) in the Mediterranean climate of Europe and Africa that could benefit from selection breeding.

118. However, a detailed discussion is beyond the scope of this report. Here, the discussion is limited to rice and banana and their potential for non-food uses. What is quite clear from this report already is that both of these crops are absolutely essential in food security for many people, especially in Asia and Africa. And in bioeconomy strategies food security is the top priority. Therefore it may seem unjustified in discussing the industrial use of these crops. However, in keeping with the ethos of the circular economy[27], it is paramount for society to start using waste materials as resources. This is highlighted by recent announcements in the UK to start mining old landfill sites[28], an extreme version of waste-to-resource utilisation.

119. In this regard, both rice and banana can also produce materials other than the edible components that can be used in a bioeconomy for industrial production. Whereas all of the banana plant is in current use (Figure 7), and therefore using it as biomass for industrial production may be seen as a competing use, a component of rice, the straw, currently represents a difficult waste disposal problem. More widely, it is important to realise that more than half of all absolutely dry matter in the global harvest is in cereal and legume straws; in tops, stalks, leaves, and shoots of tuber, oil, sugar, and vegetable crops; and in pruning and litter of fruit and nut trees (Smil, 1999). On the global scale, the non-edible part of crop production is a vast, untapped resource for utilisation in a bioeconomy.

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25 https://www.cde.unibe.ch/News%20Files/BIA_policy_brief_jatropha_grows.pdf

26 http://www.jatropha.pro/PDF%20bestanden/Quinvita%20presentation%20June%202011.pdf

27 http://ec.europa.eu/environment/circular-economy/

28 “Landfill mines to produce UK energy 'in 15 to 20 years', says minister”, http://www.bbc.com/news/uk-politics-25731026

Rice straw: a difficult waste product

120. Rice farming results in two types of residues – straw and husk – that are attractive in industrial use. Rice husk, the main by-product from rice milling, accounts for roughly 22% of paddy weight, while the rice straw to paddy ratio ranges from 1.0 to 4.3. Although the technology for rice husk utilisation is well-established worldwide, rice straw is sparingly used. One of the main reasons for the preferred use of husk is its easy procurement. In the case of rice straw, however, its collection is difficult and its availability is limited to harvest time.

121. Rice straw is unique relative to other cereal straws in being low in lignin and high in silica (Van Soest, 2006). Silica (up to 12% by weight, Nayar et al., 1977) and lignin in that order are the primary limiting factors in rice straw quality as an animal feed. As a result, widespread burning of rice straw at the field is practiced (Figure 6). The practice has been cited as an air pollution problem, with a possible link to increased instances of asthma (McCurdy et al., 1996; Torigoe et al., 2000).

122. The energy content of rice straw is around 14 MJ per kg at 10% moisture content. The by-products are fly ash and bottom ash, which have an economic value and could be used in e.g. cement and/or brick manufacturing. Straw fuels have proved to be extremely difficult to burn in most combustion furnaces due to engineering difficulties, especially those designed for power generation. Due to recent advances in lignocellulosic conversion, however, the possibility has opened up for the use of rice straw for bio-based chemicals production. There are at least 12 Asia-Pacific countries with biofuels mandates or targets (OECD, 2014), which suggests a unique opportunity. Rice is a huge volume crop, its straw, produced in very large volumes, is not only virtually of no use, its disposal by burning represents a health problem. Its use in bio-based production would therefore represent a new market opportunity for farmers that does not interfere with other markets.

Figure 6. Burning rice straw is a widespread practice with environmental and human health consequences.

(a) (b)

(a) In 2008, about 620 million tons of rice straw and about 125 million tons of husks were produced in Asia alone. In most places, these residues have no commercial value and are disposed of in various ways, very commonly by burning.

Source: International Rice Research Institute (IRRI) http://irri.org/our-work/research/value-added-rice/rice-straw-and-husks.

(b) After the rice harvest each Autumn, a thick layer of smog from burning rice straw spreads across Cairo and the Nile valley for several weeks.

Source: http://english.ahram.org.eg/News/26212.aspx

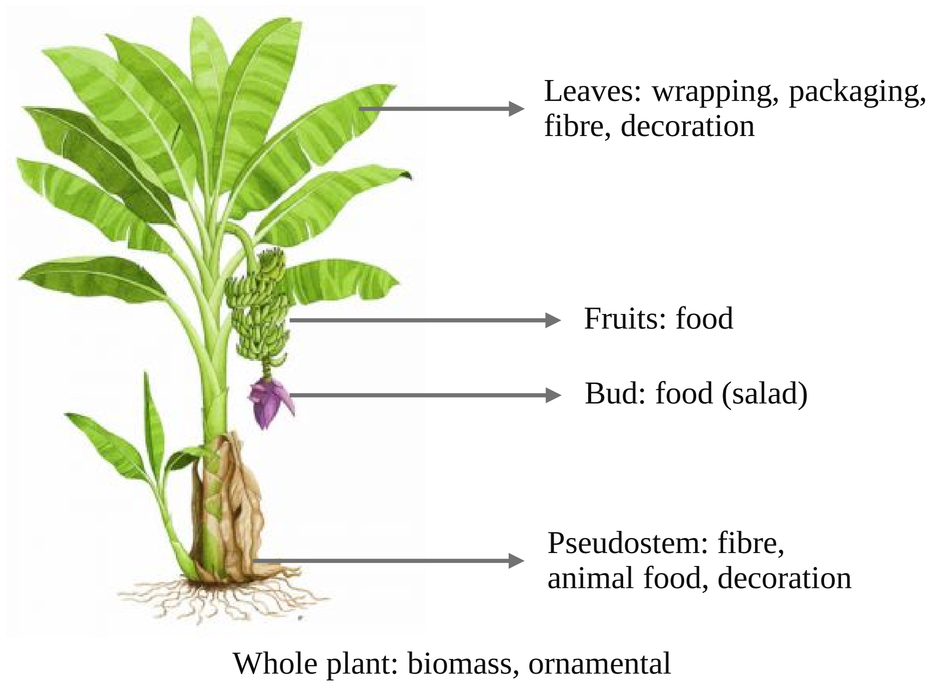
123. Two bio-based production strategies are worth noting. Kim et al. (2010) demonstrated that *Lactobacillus brevis* is able to simultaneously metabolise all fermentable carbohydrates in acid pre-

processed rice straw hydrolysate for the production of high-value lactic acid. More controversially, Oraby et al. (2007) expressed the catalytic domain of the *Acidothermus cellulolyticus* endoglucanase gene in rice (to convert cellulose into fermentable sugars for subsequent fermentation to ethanol as biofuel). This is an alternative to using extracellular enzymes, which remain relatively expensive. They concluded that the approach may be commercially viable.

Banana waste utilisation

124. Figure 7 shows that much of the banana plant, beyond the edible fruit, can be used for a variety of purposes. However, once the banana fruit is harvested in South China, Li et al. (2010) reported that the pseudostems become organic waste and cause environmental pollution.

Figure 7. Uses of the banana plant.



Source: Volkaert, H. (2015). Presentation at the OECD workshop "Genomics for Sustainable Development in Emerging Economies: Food, Environment, and Industry"

125. Cellulosic fibre obtained from the pseudostem of the banana plant is extensively used for paper board, tissue paper, clothing, weaving baskets and natural sorbents (Mohapatra et al., 2010). However, banana sap from the pseudostem is under-utilised. Paul et al. (2013) investigated the manufacture of a bio-based resin from the pseudostem banana sap. They discussed the possible use of such a resin in the automotive industry.

126. By focusing on two critical Asian crops, it is hoped that it can be demonstrated that even food crops that are considered top priority can find a role in bio-based production of industrial materials such as fuels and chemicals without interfering with their primary role in food security. Governments can invest in the R&D required to explore the possibilities for such utilisation at relatively low cost (i.e. R&D subsidy). Many such investigations will prove fruitful in research but will not prove to be commercially viable. But when a commercially viable proposition is discovered, the advantages could include:

- Above all, extra markets are offered to farmers for their produce that may help them escape poverty, or at least improve income security;

- Achieving sustainability in a bioeconomy, and helping to meet national emissions reduction targets;

- In the case of rice straw, a serious air pollutant that causes environmental and human health damage could be removed.

127. A future role of government could be to incentivise collection and make sure that a robust infrastructure is established with the cooperation of the private sector.

128. An important realisation is that in terms of total biomass produced, these by-products of agriculture account for more biomass than the food portion of the crop, pointing to a vast unexplored resource for use in a bioeconomy.

OTHER GENOMICS-RELATED TOPICS RELATING TO FOOD SECURITY IN A BIOECONOMY

129. In keeping with the workshop theme of food security while attending to unwanted environmental consequences of increased food production, this section examines some other opportunities where genomics are making a contribution. Some examples are summarised in OECD (2013c). The specific case of chicken genomics was discussed at the workshop.

130. Increasing incomes in developing economies have contributed to a large increase in meat and milk consumption. From the beginning of the 1970s to the mid-1990s, the increase on consumption of meat in developing countries was almost triple the increase in developed countries, and the increase in consumption of milk was more than twice the increase in developed countries (Delgado, 2003). Naturally, this creates strains on a bioeconomy as yet less biomass can be devoted to industrial uses. Therefore there is clearly a need to find new ways of increasing food production efficiency in these areas.

Chicken as a food source in a bioeconomy

131. Chickens are a major source of protein in the world, with around 20 billion birds alive today, producing around 1.2 trillion eggs[29]. It was the first livestock species to be sequenced and so leads the way for others (Burt, 2005). It is an excellent food source in bioeconomy terms as its production is relatively low in GHG emissions (Table 1), and is cheaper to produce and less energy intensive than rearing lamb, beef or pork.

Table 1. The GHG emissions associated with various meat production systems

Product	CO_2 (eq. per kg)
Beef	44.80
Idaho + Nebraska beef	33.50
Idaho lamb	44.96
Swedish pork	3.3-4.4
Michigan pork	10.16
Chicken	2.0-4.6
Poultry (United States)	1.4
Cod	3.2
Farmed salmon (United Kingdom sea-based)	3.6
Farmed salmon (Canada sea-based)	4.2
Farmed salmon (Norway sea-based)	3.0
Farmed trout	4.5
Capture fish (global average)	1.7

Source: OECD (2013c)

29 http://www.bbsrc.ac.uk/news/food-security/2013/130404-f-what-lives-inside-a-chicken.aspx

132. In parallel with the chicken genome sequencing project (Hillier et al., 2004), a consortium set about identifying single nucleotide polymorphisms (SNPs[30]). When a large number of these are verified, the availability of a standard set of 10 000 or more SNPs holds much promise towards the identification of genes controlling quantitative trait loci (QTL), including those of economic interest.

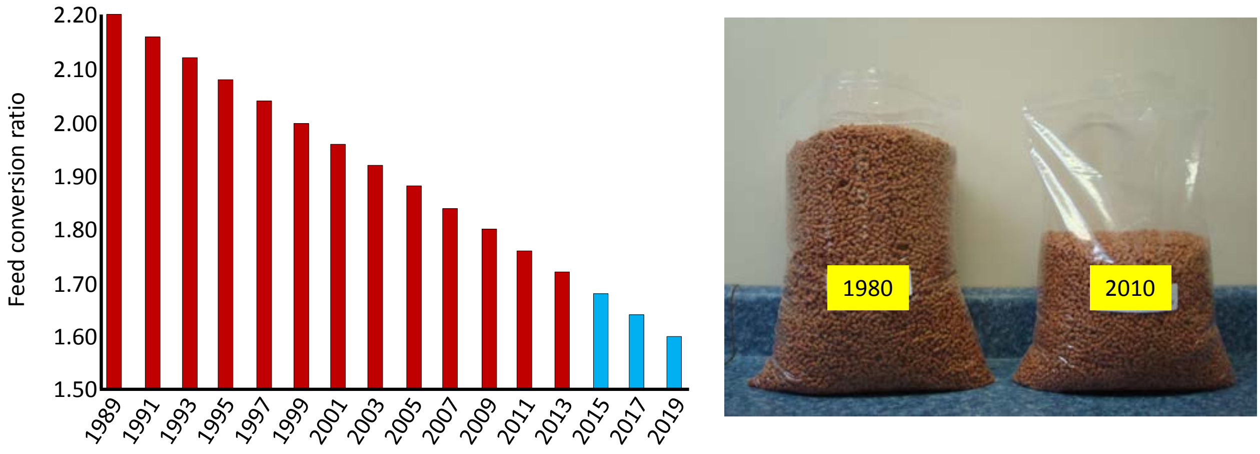
133. During the past 80 years, modern selective breeding has made spectacular progress in both egg and meat production traits. Associated with these successes have been a number of undesirable traits. These impose added costs on the industry which it is striving to control. The consumer wants high-quality products, such as increased egg shell strength. With an increased requirement for food safety, there will be a need to reduce the use of chemicals and antibiotics and increase genetic resistance to pathogens. These new traits are difficult and costly to measure by conventional genetic selection, and the developments in poultry genomics in the last few years promises new solutions to these problems. Therefore genomics research may be expected to be directed at these 'sustainability' criteria.

134. One of the key traits improved every year through selective breeding is feed efficiency – the number of kilos of animal feed needed to produce a kilo of poultry meat (Technology Strategy Board, 2010). Genomic technologies are expected to enhance this trend. Since animal breeding is cumulative, even small enhancements to the rate of improvement can multiply into huge differences for commercial customers over time and have very large impacts. The result of this is that more people can be fed from the same land resources or land resource can be freed up – for example for biomass production for industrial use.

Figure 8. Selective breeding of poultry for higher meat production and more efficient feed conversion

(a) Feed conversion ratio over 30 years in meat-producing broilers at 42 days

(b) Broiler feed to produce a 2.5 kg chicken at 42 days



(a) (b)

Source: Jimenez-Sanchez, G. (2015). Presentation at the OECD workshop "Genomics for Sustainable Development in Emerging Economies: Food, Environment, and Industry"

30 A SNP represents a difference in a single DNA building block, called a nucleotide. http://ghr.nlm.nih.gov/handbook/genomicresearch/snp

135. The Aviagen[31] genomics project, for example, is concerned with identifying naturally occurring markers within the genome of elite birds and using those markers to help breed stronger and more productive birds through the current selective breeding programme, a completely natural process. Aviagen became the first company to include genomic information as a critical additional source of information in a R&D breeding programme.

Beef production

136. Genomics has been propagated as a “paradigm shifting” innovation in livestock production during the last decade. The possibility of predicting breeding values using genomic information has revolutionised the dairy cattle industry and is now being implemented in beef cattle. A challenge in the development of genomic tools for beef cattle selection, however, is in the diversity of breeds represented in the industry.

137. There is large scope for the development of novel applications in the livestock sector, such as selection tools for new traits (meat quality, diseases resistance, feed efficiency, heat tolerance), animal traceability and parentage verification (e.g. McClure et al., 2013). Efforts in sequencing important animals in the global beef industry are underway to identify variants and to associate those variants with the genetic variation observed across beef populations.

138. It is also feasible to postulate that in the near future the artificial reproductive technologies (ART), such as artificial insemination, embryo transfer and in vitro fertilisation, combined with genomic evaluation (GE) approaches will be the driving forces to lead cattle breeding to a finer process than it is nowadays.

Milk production

139. Genomics studies of milk have varied goals, underlining the significance of milk as a human food. Topics include: the capacity of milk to manipulate the gut microbiota; manipulation of bovine milk fat; genetic selection for economically important traits, such as protein content (Raven et al., 2013); and diagnostics for spoilage and pathogens (Marco and Wells-Bennik, 2008).

Genomics and the fishing industry

140. Numerous wild fish populations are either over-exploited or are in precipitous decline. Wild fisheries should therefore be regarded as “not necessarily renewable”. Well-reported universal difficulties associated with wild fisheries are related to fish species identifications e.g. species with limited diagnostic morphological features, cryptic species, juvenile identification, or unavailability of adequate drawings and descriptions. Such problems are probably global, with almost 34% of the world’s fisheries catch from 1950–2002 lacking species level identification.

141. Molecular markers, such as DNA barcodes, can address many such difficulties. In addition to the use of DNA barcodes for species delimitation, the availability of a standardised and globally accessible database (Barcode of Life Data System, BOLD),[32] facilitates numerous related applications, including issues relating to traceability, illegal fishing and fish fraud (Costa et al., 2012).

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[31] http://en.aviagen.com/research-development/

[32] www.barcodinglife.org

Aquaculture and genomics

142. Aquaculture production has continued to grow annually at around 6-8%. Today, farmed seafood production (around 60 million tonnes) exceeds that of wild fisheries and has significant potential for future growth. High priority traits for farmed fish are the development of single sex populations and improving disease resistance. Production of mono-sex female stocks is desirable in most commercial production since females grow faster and mature later than males. Understanding the sex determination mechanism and developing sex-associated markers will shorten the time for the development of mono-sex female production, thus decreasing the costs of farming.

143. Nile *Tilapia* is one of the most important farmed species with a production exceeding 2.8 million metric tonnes in 2010. *Tilapia* farming is increasingly important in Asia, with (at least) Bangladesh, China, Indonesia, Malaysia, Myanmar, the Philippines, Thailand and Vietnam all producing significant tonnages. Most Asian countries do not export significant amounts of *Tilapia*, demonstrating its role in food security.

144. *Tilapia* is unusual in that intensive commercial production generally requires all-male stocks, not only because males grow faster but also to avoid uncontrolled reproduction before harvest. A restriction associated DNA (RAD) sequencing study by Palaiokostas et al. (2013) identified a reduced candidate region for the sex-determining gene(s) and a set of tightly sex-linked SNP markers. Although they could not identify the causative gene(s), no female was mis-assigned using their sex-associated SNPs. This means that those SNPs could be of high practical value towards the production of all male stocks for the *Tilapia* aquaculture industry.

THE MALAYSIAN BIOECONOMY STRATEGY

145. Announced by the Prime Minister in 2012, Malaysia launched its Biotechnology Transformation Programme (BTP) as part of the nation's economic transformation strategies. To do so, Malaysia is providing an incentivised platform for the bio-based industries to contribute to the nation's sustainable development agenda, to improve industry competitiveness, to encourage public-private partnerships and bring socio-economic benefits. Supported by public sector stakeholders such as universities and research centres, economic corridors, financial institutions and inter-ministerial coordination, Malaysia is maximising the possibilities for all participants throughout the bio-based value chains to create and develop commercial growth opportunities nationally and also globally.

146. Spearheaded by the Malaysian Biotechnology Corporation (BiotechCorp[33]), the BTP intends to work towards accelerating Malaysia's passage to the ranks of high-income economies, with very aggressive and ambitious targets for contribution towards Gross National Income (GNI) and job opportunities. Much of the groundwork is already done: at eighteenth position among 189 economies in the World Bank Doing Business Report 2014[34], Malaysia has been placed in the same league as developed nations in ease of doing business.

147. Malaysia is perhaps the first Asian country to launch a fully-fledged bioeconomy strategy. Japan has many policy elements in place but as yet has no formal bioeconomy strategy. For example, the Japanese *Biotechnology Strategic Scheme* and the *Biomass Nippon Strategy,* both of 2002, were launched to promote the utilisation of biomass, and to reduce the consumption of fossil resources and to mitigate global warming through the use of biotechnology.

148. The vision of the Malaysian Bioeconomy Strategy is to be a significant contributor to the nation's economy by 2020 and beyond. It is believed that the bioeconomy has the potential to:

- Make the country more competitive internationally;
- Create value-added jobs;
- Enhance food security and healthcare;
- Create a 'greener' economy as the country shifts towards a low-carbon economy, and;
- Increase the nation's income by sustainably exploiting its biological resources to make high value products using biotechnology.

149. In common with the US strategy (The White House, 2012), it also includes healthcare. An analysis of the G7 bioeconomy strategies (Bioökonomierat, 2015) shows all the elements and philosophy are the same. What sets Malaysia apart from the G7 is the vast biomass and tropical biodiversity resources.

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33 www.biotechcorp.com.my

34 http://www.doingbusiness.org/rankings

This is both of enormous advantage, but also a burden in that the exploitation of these resources must be done in a sustainable way to prevent biodiversity loss.

150. As a measure of the importance of biomass to Malaysia, agriculture accounts for 12% of GDP. But there are key issues facing its major crops:

- Commodity price increases and increasing demand;
- Climate and environmental changes;
- Resource depletion, and;
- Pests and diseases.

151. In response, there is a strong drive in genomics. Projects of the Centre for Marker Discovery and Validation (CMDV) illustrate the importance being placed on genomics. Many of the country's most important crops are involved.

- Rice seed validation;
- Water melon marker discovery;
- Papaya fingerprinting;
- Pineapple fingerprinting;
- Oil palm genotyping;
- Goat and cattle marker discovery and genotyping, and;
- Fish and shrimp fingerprinting.

Key policy areas to enable a genomics-based bioeconomy

152. Policy development for a bioeconomy is extremely complex (Figure 9) as it effectively means a change of the current energy and production regimes. The main areas to be developed in Malaysia are:

- Infrastructure development;
- A conducive regulatory and cultural environment;
- Establishing the necessary policy framework;
- A focus on human capital development;
- Encouraging bio-based investments, and;
- International collaboration.

153. In this last point large successes have already been achieved (Table 2, Figure 8).

Early successes

154. Biocon is setting up bio-pharma manufacturing and research facility located within a 40 acre compound, at Bio-XCell, Johor in Malaysia. The facility will be the largest integrated insulin production plant in Asia. Meanwhile, Stelis Biopharma announced in 2014 the construction of its customised, multi-product, biopharmaceutical manufacturing facility at the same site.

155. Verdezyne, one of the major industrial biotechnology firms, is investing USD 48 million in Malaysia to produce renewable chemicals, a clear demonstration of Malaysia's on-going momentum in attracting bio-based investors. Such is the importance of this investment that President Obama and Malaysian Prime Minister Najib Razak attended the signing of the agreement (Figure 9).

Figure 9. President Barack Obama and Malaysian Prime Minister Najib Razak, participated in the signing of major commercial bio-based chemicals agreements on April 28, 2014.

156. Several other key organisations are investing in a bio-based industry in Malaysia (Table 2).

Table 2. Secured major investments in Malaysia demonstrate a shift towards higher value markets.

Initiative	Partners
Application of biotechnology for lobster aquaculture	Darden
High value chemicals from non-food based, renewable feedstock	Verdezyne
First commercial bio-isobutanol plant in Asia	Gevo
Bio-isoprene production from crude glycerine	GlycosBio
World's first bio-methionine plant and Asia's first thiochemical platform	CJ, Arkema
Integrated biorefinery project	Genting, Elevance
Regional hub for manufacture of biopharmaceuticals and injectables	Stelis Biopharma
Biopharmaceutical manufacturing and development facility	Biocon

Source: Kamal, M.N. (2015). Presentation at the OECD workshop "Genomics for Sustainable Development in Emerging Economies: Food, Environment, and Industry"

Some early targets for the Malaysian bioeconomy

157. The early targets to 2020 and those beyond, are clearly stated and ambitious. Malaysia expects by 2020 a contribution of: USD 15 billion to GNI; the creation of 170 000 jobs, and; investments of USD 16 billion. For comparative purposes, by 2020 the bioeconomy is expected to contribute 8%-10% towards Malaysia's total Gross Domestic Product (GDP), from the current 2%-3%. The OECD (2009) envisaged a

2.7% contribution to GDP, excluding the potential of biofuels. Malaysia expects to achieve this ambitious target by a transition towards higher value downstream activities.

The strategic position of biomass in Malaysia

158. Malaysia is one of the world's 17 megadiverse countries. It therefore has a rich source of biodiversity to tap into in support of its bioeconomy. A large amount of biomass is generated every year across a variety of crops such as palm oil, rubber and rice. Within this sector, by far the largest contributor to GNI is palm oil, contributing about 8% to the national income. While the opportunity is immense, palm oil biomass is also utilised for a variety of additional higher value uses including wood products, energy pellets, bioenergy, biofuel and bio-based chemicals. By year 2020, Malaysia's palm oil industry is expected to generate about 100 million dry tonnes of biomass. This includes empty fruit bunches (EFB), mesocarp fibres (MF) and palm kernel shells (PKS) as well as oil palm fronds and trunks. Moreover, oil palm is not alone in Malaysia's biomass bounty. Other examples are timber waste, paddy waste, coconut trunk fibre, sugarcane waste, kenaf fibre.

POLICY CONSIDERATIONS

Food first

159. As in any bioeconomy, food security has to rank the top priority. Only when it is known that biomass can be spared or shared or imported for industrial applications should sustainable bio-based industries be established. Some Asian economies are more adept at waste prevention than Western economies in that they have remained true to a culture of using as much biomass as possible. In this workshop, it was demonstrated that no biomass from the banana should become a waste material; it is possible to use all of the material in different applications.

Genomics and breeding

160. Research programmes could encourage a combination of genomics with plant and animal breeding. As mentioned during the workshop discussions, genomics without phenotype information does not solve problems. Genomics is new, young and attractive, whereas plant and animal breeding are ages old, and therefore, perhaps not as attractive to young researchers. It would be easy for governments to get caught up with the popularity of genomics. However, in a bioeconomy, governments would be advised to balance both genomics and breeding education and research. The two together are an extremely potent combination for economic growth. Outreach programmes may be necessary to make modern breeding more attractive to entry-level scientists, using the potency of the combination with genomics to capture their imaginations.

161. For example, during the workshop it was stated that a project such as the "200 banana genomes" would fail to solve the scientific conundrums of banana diversity and domestication, unless the proper wild accessions are identified. Therefore it is important that governments do not perceive genomics alone as the panacea, but rather integrate genomics with fundamental genetics and breeding education and research.

Rural regeneration

162. Much of Asia has a very different agricultural model from Western agriculture. In the US, for example, the percentage of people employed in agriculture has fallen to less than 2% (OECD, 2011). Indeed, part of the drive in OECD nations towards a bioeconomy is for rural regeneration. Huge strides in agricultural science and technology has led to the efficiencies that have driven the population out of rural employment. In much of Asia, the situation is quite different. Certainly, agricultural productivity (the value-added per agricultural worker) of many Asian countries is much lower than in developed countries[35]. Farming is characterised by small farms, subsistence farming and high levels of poverty. It was also mentioned that many farmers encourage their children to go to the cities to break out of the poverty trap.

163. Therefore farming populations in Asia tend to be ageing. For example, Japan has a dwindling number of farmers and they are ageing and farming very small plots, which poses problems for agricultural vitality (Karan, 2005). The average age of its farmers was 65.9 years in 2011. In 2012, the agriculture industry employed 2.51 million people, less than 20% of its peak of 14.54 million in 1960 (*The Japan*

35 http://wdi.worldbank.org/table/3.3

Times, 2013), and their offspring do not want to stay in farming. Moreover, a large number of farmers, especially rice farmers, are part-time farmers, who tend not to invest (*The Economist*, 2013). These problems are by no means limited to Japan. In China, for example, the rural population is declining, the average age of farmers is rising, and fewer young people are choosing farming as a vocation (Yang, 2013).

164. It may be worth investigating whether genomics could help reverse the trend of rural degeneration by making agriculture more attractive to young people. Genomics and especially synthetic biology have proven attractive to young researchers. And the technologies are becoming increasingly accessible and less expensive. Governments could investigate the possibility of setting up regional and rural genomics centres. Attracting farming family children into genomics research and technology could help to solve their local and agricultural problems. This could help creating high-technology jobs in the countryside, providing less incentive to young people to abandon country life. It may also be a tool to lower farming poverty, prevalent across much of Asia. A top priority in an Asian bioeconomy must be to greatly reduce poverty in farming communities.

Regional specialisation

165. The Genome Canada set-up is an example of applying genomics to regional problems that might be useful for Asian countries. Canada is a country that relies heavily on natural resources e.g. minerals, oil and gas, forestry, agriculture, fisheries and marine resources. Today, millions of Canadians in over 650 communities from coast to coast depend on natural resource sectors for their livelihoods.

166. Genome Canada[36] is a not-for-profit organisation established in 2000. It was mandated by the Government of Canada to develop and implement a national strategy for supporting large-scale genomics and proteomics research projects for the benefit of all Canadians.

167. To ensure effective management and monitoring of Genome Canada-funded projects and science and technology platforms, regional genome centres have been established in each region across Canada: Genome British Columbia; Genome Alberta; Genome Prairie; Ontario Genomics Institute; Genome Québec; and Genome Atlantic. These centres facilitate access to leading edge technology for researchers; allow for different approaches to project development and fundraising; and provide opportunities for public outreach programmes at a regional level. This allows each region to specialise in genomics issues specific to the region. Given the higher population density of many Asian countries, this also may be a way to capture local talent rather than have them migrate to large centres in cities, which may be divorced from local problems and applications.

A long-term view is needed

168. The very striking differences highlighted by rice and banana in this workshop should raise an awareness of a need for a long-term view. The very rapid and solid success of applying genomics to submergence stress in rice may create an impression that all problems will be solved this way. In reality, many of the crop threats posed by grand challenges, especially those of climate change, will involve many genes interacting in complex ways not yet understood. Therefore it is important that governments use these successes to attract more success, but they must also be cognisant that a long-term approach to genomics funding in bioeconomy strategies is needed.

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36 http://www.genomecanada.ca/

Building national and regional experience

169. An important limitation of large-scale marker applications is the cost involved in marker assays, which may be beyond the capacities of many public plant breeding enterprises. For an effective marker-assisted selection (MAS) activity to facilitate ongoing crop improvement programmes, especially in the context of the developing countries, laboratories with adequate capacity and adequately trained scientific personnel as well as operational resources are required. Assay platforms with significant capital investments including computational capacity are required (FAO, 2007). Therefore it will be a precondition for nations to build up levels of technical expertise to a point where critical mass is achieved to make real differences. Policy makers could attend to the large, expensive facilities at the national level, while investigating the possibilities of smaller, regional facilities that can build rural job capacity.

Genomics need not necessarily mean GM or synthetic biology

170. A previous OECD report (OECD, 2014) highlighted that genomics can be applied to a wide range of issues in a bioeconomy without needing to resort to GM or synthetic biology. This is important for governments faced with societal resistance to GM. This has in recent years focused on Europe. However, it is worth pointing out that US regulators have failed to approve a single genetically modified animal of agricultural importance (Hackett and Carroll, 2015), and most new crop varieties do not make it through governmental review (Miller and Bradford, 2010).

171. Therefore the importance of the ability of genomics to improve the efficiency of selective breeding should be stressed as this does not involve either GM or synthetic biology. This should make bioeconomy strategies less likely to meet public resistance (Jiménez-Sánchez and Philp, 2015). Despite Vietnam and Indonesia in 2014 approving two GM crops for commercialisation, the total number of countries in Asia doing so is only nine (ISAAA, 2014). If successes in genomics in Asia can be publicised, this may make future acceptance of GM and synthetic biology easier.

Cooperation between the public and private sector

172. In the case of submergence-tolerant rice development and diffusion, a good working relationship exists between the public and private sector. In the debates over GM, this relationship is often seen to be at the heart of resistance i.e. many people are not necessarily against the technology itself, but are against monopoly positions of companies.

Industrial uses of food and non-food crops

173. It was demonstrated that even the vital rice and banana crops have by-products that can be used in industrial production with more R&D. In the case of banana, a relatively small-scale application is described, but there will be plenty more given the range of crops and trees in Asia. In the case of rice, the ability to use vast quantities of rice straw for industrial production could solve waste disposal and health problems whilst creating a new industry.

174. The point for policy makers is that not only non-food crops can be considered for bio-based production. With imagination and R&D, other innovative uses of food crop by-products may be put to profitable use. This would give impoverished farmers an extra market for their produce without interfering with the food market. Therefore it may be useful for governments to provide R&D funding for these innovative products from waste or under-utilised materials.

International partnering

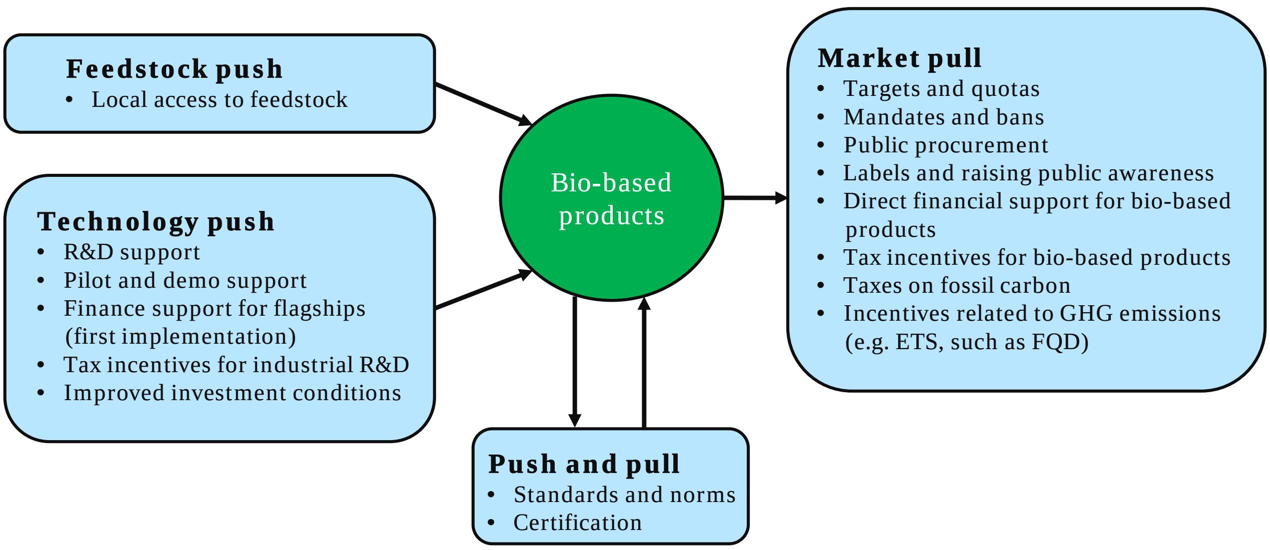
175. In the short period since the publication of the OECD (2009) *The bioeconomy to 2030 – designing a policy agenda*, it has become clear that the bioeconomy is a global phenomenon. It will be necessary for governments to encourage international partnerships, not just in trade, but also in R&D. This is easily done by national research councils. As evidenced by the Verdezyne agreement with Malaysia, this is already happening. It allows technology transfer and gives the technology donors access to large Asian markets.

The complex policy mix for a bioeconomy

176. Good policy design should: ensure competitive selection processes; contain costs and; select projects that best serve public policy objectives, without favouring incumbents or providing opportunities for lobbying (OECD, 2013a). This suggests the need for a portfolio of public investment where funding approaches are tailored to the different stages of technology development. Against a background that no single technology or policy will drive green innovation, Dutz and Pilat (2012) recommended that countries should use a combination of supply- and demand-side policy instruments to achieve policy goals, which may differ from country to country.

177. Given the magnitude of the aspirations of a bioeconomy – to change the energy, food and industrial production systems – then it is hardly any surprise that the policy mix is going to be very complex. Figure 10 offers a summary in general terms of the policy framework that needs to be developed.

Figure 10. A suggested policy framework for bio-based production. In itself, "local access to feedstock" could be extremely complex in the way that it interacts with agricultural policy.



Source: Carus, M.(2014). Presentation at the OECD workshop on bio-based production, October 09, 2014, Turin, Italy.

178. Achieving such a mix clearly involves multiple ministries, including agriculture, environment and energy, and therefore requires active communication and cooperation between them. To date, an opinion that is often expressed is that farmers are not being consulted enough in the process. Given the amount of biomass, as food, feed and by-products that comes from agriculture, this situation will most likely have to change.

CONCLUDING REMARKS

179. It is evident that most of Asia suffers from the same grand challenges of OECD countries which revolve around past and current unsustainable use of both renewable and fossil resources. Therefore it is to be expected that Asian countries will also seek to build a bioeconomy that looks beyond the era of fossil fuels, which may be much more hastened than previously thought if climate change legislation is enacted to make most of the remaining hydrocarbon reserves ‘unburnable’. Whenever it comes, the reining in of fossil resource consumption will inevitably place much more emphasis on the use of renewable carbon resources. The potential threat is obvious – that society swings in the direction of overuse of biomass with attendant threats to soil, water and biodiversity and thus ultimately food and water security.

180. It is into this political maelstrom that the bioeconomy concept was born. It is an exceptionally complex policy agenda that not only has to look to the replacement of fossil materials, but must also look to the foods of the future in the face of a growing human population. Where many Asian economies are blessed compared to OECD economies is with very rich and abundant reserves of biomass. This workshop demonstrated there is plenty of scope for the utilisation of waste products such as rice straw and banana wastes as feedstock for bio-based production. In this way the “food first” rule of a bioeconomy is obeyed – that food security is the top priority and industrial use of biomass only then can be addressed.

181. Malaysia is the first of the ASEAN nations to elaborate a formal bioeconomy strategy. It is extremely ambitious but then Malaysia has many natural advantages, not least of them a massive and well-organised palm oil industry.

182. It seems at first curious to consider the role of genomics in this vast enterprise. But it can be seen that genomics is an enabling technology with very far reaching consequences in a bioeconomy, especially when one asks the critical questions about improving agricultural efficiencies, yields of specific crops, coping with increasingly problematic abiotic issues such as drought and heat, and also pest and disease control. One specific example discussed in the workshop could be the ‘advertising flagship’ for genomics in a bioeconomy. The discovery of the role of the *Shell* gene in control of oil yield in the oil palm was accompanied by a realisation that *oil yield may be boosted by one-third*. That is a massive amount of economic benefit for a small investment in R&D. As yet, the vast majority of ideas for genomics in a bioeconomy have yet to emerge.

183. What should be even more astonishing is that, in its role as an enabling technology, there are huge opportunities that do not involve genetic engineering. It is the marriage of genomics to breeding technologies that are emphasised in this report. For sure, there are virtually boundless opportunities in the future for the deployment of GM and synthetic biology technologies, but governments should gain comfort from the fact that so much economic benefit can be wrought without these technologies. But for this to happen, governments must also realise that the genome sequence in itself is not useful. Genomics is truly unleashed when tied to genetics and breeding technologies. There is a real danger that governments become awed by the ever-increasing outputs of genomics programmes. Traditional breeding then looks old-fashioned, but it is never out-of-date, and more classical genetics and plant and animal breeding education and research is a must if the true unleashing of genomics is to be accomplished.

184. This is a message that should not be overlooked for another crucial reason – farmers put breeders’ technologies into practice. In Asia there is plenty of poverty in farming communities, and hence farming parents often advise their children to seek employment in cities. But in a bioeconomy, rural regeneration is also a priority, not only in Asia but in OECD countries too. A recurring message at the workshop was that one of the prime motivations of a bioeconomy should be to break poverty in Asian

farming. The single example or rice straw shows that if the bioeconomy turns this into a commodity, then farmers' income security is surely enhanced. In the longer term, income security may persuade farmers to invest more in the land and technologies.

185. The other side of a bioeconomy is industrial production. Five years ago there was overwhelming emphasis on biofuels. Today, a realisation has emerged that there is more economic output, as well as a lot of environmental protection, to be gained from making chemicals from biomass instead of oil and gas. This trend can clearly be seen in the Malaysian bioeconomy strategy, where major industrial biotechnology companies have started to make serious investments in bio-based production in Malaysia, as they have also done in Brazil.

186. Above all, the workshop showed the potential of Asia in a global bioeconomy, not just fulfilling a traditional role as a provider of raw materials, but also as source of human talent and home-grown technologies to utilise its most valuable resource of the future – biomass as a feedstock for future food security, energy security and industrial production.

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ANNEX 1: GENOMICS AND –OMICS TECHNOLOGIES DEFINITIONS

Genomics is a discipline that applies recombinant DNA, DNA sequencing methods, and bioinformatics to sequence, assemble, and analyse the function and structure of genomes (the complete set of DNA within a single cell of an organism). Genomics was a relatively unknown discipline until widespread publicity was created around the Human Genome Project (HGP), which was declared complete in April 2003.[37]

Transcriptomics

The transcriptome is the complete set of transcripts in a cell, and their quantity, for a specific developmental stage or physiological condition (Wang et al., 2009). Transcriptomics therefore is the study of genes being expressed at any given time under given conditions.

Proteomics

Proteomics is the large-scale study of proteins, particularly their structures and functions, and the proteome is the entire set of proteins produced or modified by an organism or system. Proteomics lagged behind genomics for a long time due to technical difficulties, but has progressed radically in recent years and is now on a par with most genomic technologies in throughput and comprehensiveness (Mann and Kelleher, 2008).

Metabolomics

This refers to the comprehensive analysis of all low-molecular-weight primary and secondary metabolites present in and around cells growing under defined physiological conditions (Mashego et al., 2007). It is emerging as a rapidly developing field of research with the promise to speed up the functional analysis of genes of unknown function.

The above are listed in order of “information flow”. The metabolome is the final downstream product of gene transcription. Additionally, as the furthest downstream product, the metabolome is closest to the phenotype of the biological system being studied (Horgan and Kenny, 2011).

Metagenomics

Metagenomics is the application of modern genomics technologies to microbial communities in their natural environments, bypassing the need for culturing (Röling et al., 2010). The vast majority of bacterial life, for example, remains unculturable using available methods (Amman et al., 1995). For almost the entire history of microbiology as a discipline, perhaps 90-99% of the diversity of bacteria has been a complete mystery. Metagenomics is uncovering this biodiversity at an unprecedented rate.

New generations of other, lesser-known -omics technologies have also been spawned from the initial genomics technology e.g. fluxomics, epigenomics, pathogenomics, even psychogenomics.

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37 http://web.ornl.gov/sci/techresources/Human_Genome/index.shtml

Synthetic biology

Many definitions of synthetic biology have already been published. A recent operational definition from the European Commission (SCENIHR, 2014) is pertinent as it introduces engineering and the concepts of design, which has been absent from the life sciences.

> "SynBio (i.e. synthetic biology) is the application of science, technology and engineering to facilitate and accelerate the design, manufacture and/or modification of genetic materials in living organisms."

It could be implied from this definition that synthetic biology can be used in manufacturing, and it bears relevance to the OECD definition of biotechnology which envisages "*the production of knowledge, goods and services*" [38].

A simple definition that seems to crystallise the issue without resort to the jargon of either life sciences or engineering is from the Royal Academy of Engineering (2009):

> "Synthetic biology aims to design and engineer biologically-based parts, novel devices and systems as well as redesigning existing, natural biological systems."

The Royal Academy of Engineering definition of synthetic biology sets it apart from systems biology with the use of the terms "design", "engineer" and "devices". Here is an implicit theme that is constantly returned to in synthetic biology, that of rational design.

[38] http://www.oecd.org/sti/biotech/statisticaldefinitionofbiotechnology.htm

ANNEX 2: NEW PLANT BREEDING TECHNIQUES (NPBTS)

This Annex summarises some of the current trends in the use of New Plant Breeding Techniques (NPBTs). All of these approaches depend on molecular techniques from which it is unclear if the resulting product will be subject to existing GMO legislation in different jurisdictions around the world.

Category I: Specific mutations at a targeted site in the genome

Site directed nucleases (SDNs)

These are different types of protein complexes that are able to establish targeted genomic alterations (Podevin et al., 2013). All SDN complexes contain a domain that is able to recognise a specific DNA sequence and a nuclease domain that is able to induce a site-specific double strand break (DSB) in which both complementary strands of DNA are broken. When native cellular mechanisms repair this break, mutations can be induced (deletion, addition or substitution of single base pairs) or a stretch of DNA can be inserted.

Oligonucleotide Directed Mutagenesis (ODM)

This is an approach in which small targeted mutations are established through synthetic oligonucleotides that are homologous to the targeted gene except for a few nucleotides. Once the oligonucleotide hybridises to the targeted gene, it creates a mismatch in base pairing that is corrected by the cells native repair mechanism, giving rise to small, specific mutations (Beetham et al, 1999).

Category II: End-product free of transgenes

RNA-directed DNA Methylation (RdDM), reverse breeding and accelerated breeding are a category of NPBTs that distinguish themselves from classical transgenesis by resulting in an end-product that is free of foreign genetic material, despite the fact that transgenes are used in the process. To date, no commercial applications of RdDM or reverse breeding have been developed.

The accelerated breeding "FasTrack" system[39] has been used to speed up plum breeding by introducing a transgene that stimulates early flowering of the tree, hence reducing the juvenile phase in which the tree cannot reproduce. FasTrack utilises genetic engineering strategies, but the product released for commercial use is not a genetically modified plant. Thus, this technology has the potential for integration into existing breeding programmes.

Category III: Genetic material derived from sexual compatible relatives

A frequently stated concern regarding transgenesis is that it enables the transfer of genes among species that are not cross-compatible, resulting in genomic combinations that would never arise through natural processes. Cisgenesis and intragenesis circumvent this concern by introducing genetic material that is derived from cross-compatible species.

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39 http://ucanr.edu/sites/fastrack/

In both cisgenesis and intragenesis, *Agrobacterium tumefaciens* is used to transform a plant with genetic material derived from cross-compatible species. In cisgenesis the coding sequence of the gene is inserted while being flanked by its native promoter and terminator. For intragenesis, the promoter and terminator can also be derived from other cross-compatible species than that from which the coding sequence originated (Holme et al., 2013).

Category IV: Targeting specific tissues of a plant

This category is distinguished from transgenesis by the introduction of foreign genetic material only to targeted tissues of the plant. Depending on the tissue targeted, this results in plants that neither transfer transgenes to progeny nor possess transgenic materials in the edible parts of the plant.

Grafting

Grafting has been used in agriculture for over 2 000 years. It is a frequently used technique in the breeding of fruit trees in which rootstocks and scions of different lines are combined to obtain a new variety with beneficial traits. The use of genetically engineered rootstocks or scions has the potential to extend the horticultural utility of grafting by combining this ancient technique with the molecular strategies of the modern era (Haroldsen et al., 2012).

Agroinfiltration

In agroinfiltration, transgenes are transiently introduced in a targeted tissue in order to obtain high levels of gene expression. A suspension of *Agrobacterium tumefaciens* is injected into a plant leaf, where it transfers the desired gene to plant cells. The method has seen utility in the production of pharmaceutical proteins (Chen et al., 2013).

ANNEX 3: WORKSHOP AGENDA

OECD - HUGO Joint Session

Saturday, March 14th 2015, Kuala Lumpur, Malaysia, 13:15 - 15:45

"Genomics for Sustainable Development in Emerging Economies: Food, Environment, and Industry"

Chair: Professor Gerardo Jiménez-Sánchez, MD, PhD, Harvard School of Public Health, United States, GBC Group, Mexico.

Programme

13.15 - 13.20: *Welcome remarks* by the Session chair – HUGO Council, Professor Gerardo Jiménez-Sánchez.

13.20 - 13.25: *Welcome remarks* by the OECD Secretariat, Dr. Kathleen D'Hondt

13.25 - 13.50: *The role of genomics in the bioeconomy*. **Professor Gerardo Jiménez-Sánchez**, Programme Director, Genomic Medicine and Bioeconomy, Harvard School of Public Health, United States & Executive President, GBC Group, Mexico.

13.50 - 14.15: *The case of submergence-tolerant rice*. **Dr. Abdelbagi M. Ismail**, Principal Scientist and Coordinator, Stress Tolerant Rice for Africa and South Asia, International Rice Research Institute, Philippines.

14.15 - 14:40: *Unpeeling the banana genome helps in the fight against disastrous fungal diseases*. **Dr. Hugo Volkaert**, Principal Investigator, Kasetsart University, Bangkok, Thailand.

14:40 - 15:05: *Conserving and enhancing productivity of forests in the genomics era*. **Dr. Norwati Muhammad**, Director, Forest Research Institute, Malaysia.

15:05 – 15:30: *Opportunities for the genomics industry in South East Asia*. **Dr. Mohd Nazlee Kamal**, CEO Malaysian Biotech Corporation, Malaysia.

15:30 – 1545: *Roundtable discussion* with the speakers and *wrap up* by the Session Chair.

16:00–18:30: Expert discussion.