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Synthetic biology, sustainable energy and sustainable development

Ying Jian Chen

Research Center for Strategic Science and Technology Issues, Institute of Scientific and Technical Information of China, Beijing 100038, (CHINA)

ABSTRACT

Synthetic biology is a set of tools and techniques which redesign of existing biological systems to perform specific tasks. New applications may be found in energy, medicine, environment and materials. In this paper, we first focus on the definition of synthetic biology as well as the potential applications and key challenges, then the role of synthetic biology in producing biofuel and the relations between sustainable energy and sustainable development are discussed. Finally, several key points to achieve sustainable development are summarized.

KEYWORDS

Synthetic biology;
Biofuel;
Energy efficiency;
Sustainable development.

INTRODUCTION

The world is becoming increasingly interconnected and the ability to generate, share and interpret data on a massive scale is accelerating our ability to understand highly complex systems. The emergence of synthetic biology as a distinct discipline through the first decade of this century is a clear example of this trend.

Synthetic biology represents a quantum advance on biotechnology, and goes beyond transferring genes between species to constructing entirely new, self-replicating microorganisms that have the potential to convert any biomass or carbon feedstock into any product. In other words, from the perspective of synthetic biology, the resource base for the development of marketable *renewable* materials is not the world's commercialized 23.8 % of annual terrestrial biomass[1], but also the other 76.2 % of annual terrestrial biomass that has remained outside the market economy.

Potential applications of synthetic biology arise wherever biological systems play a role. Fields of increasing interest at individual and societal levels include *well-being* (such as prediction and prevention of diseases, personalized healthcare, improved lifestyle, employment), *security* (including food, water and energy security) and *sustainability* (meeting the challenges of managing natural resources, reducing dependence on non-renewable resources and finding ways to mitigate climate change). Objectives for envisaged synthetic biology applications in these fields include reduction in costs, extended or novel functionality and greater selectivity.

In 2012, the synthetic biology industry evolved into a global, well-financed and rapidly expanding sector with products already in the marketplace[2].

- **Growing fast**

According to BCC Research, global synthetic biology product sales were around $1,600 million in 2011 and are expected to rise to $10,800 million by 2016.

- **Switching focus**

Three quarters of the activity has so far been energy and chemical companies (such as BP, Shell, DuPont, Total) developing and marketing artificial microbes that produce next generation biofuels, bioplastics and commodity chemicals. However, the industry is now rapidly switching focus to primarily produce materials formerly sourced from natural plant products – such as rubber, food flavours, fragrances and essential oils as well as natural medicinal products.

- **Already on sale**

Examples of synthetic biology products already on the market include maize-based bioplastics, biosynthesized 'natural' grapefruit flavour, as well as cane sugar-based biodiesel.

Synthetic biology is still at an early stage of development and relatively unproven, but its potential is widely considered to be great. It is a platform technology with an extensive range of possible applications. In this paper, we discuss the role of synthetic biology in producing renewable energy and achieving sustainable development.

Synthetic biology

Potential applications and key challenges

Synthetic biology is an emerging field combining biology with engineering but lacks a coherent and agreed definition. Synthetic biology is perhaps best understood in relation to its aims, which are described by the OECD as being "to design and build new biological parts and systems or to modify existing ones to carry out novel tasks"[3]. In other words, synthetic biology is

- the design and construction of new biological parts, devices and systems, and
- the redesign of existing, natural biological systems for useful purposes.

Instead of inserting genes from one species into another, synthetic biology aims to create life from scratch with synthetic DNA or without the use of DNA entirely. DNA is synthesized on a computer and "printed" out, which can then be shipped anywhere in the world through the mail[4].

On the other hand, Thomas H.Murray did place the technologies comprising "synthetic biology" into four categories[5].

- **Advanced genetic engineering**

Engineering bacteria to produce a precursor of artemisinin, a front-line malaria druge, pitomizes this category.

- **DNA-based device construction**

The BioBricks project applies the principles of electronics engineering to biology, aiming to one day build functional nano devices *de novo* from genes and proteins.

- **Creating a minimal cell**

Venter's achievement of synthesizing a complete, functional genome for Mycoplasma mycoides is the leading indicator.

- **Creating a protocell**

According to Murray the goal is to create a new form of life. A genuinely new living entity, not based on the biology we've known thus far. This goal remains distant, but may lead to radical advances such as silicon-based life.

Research studies in synthetic biology are still only a decade old. The first department of synthetic biology at a major research institution – the US Lawrence Berkeley National Laboratory – was opened in 2003, and American scientists dominated much of the early research.

Synthetic biology has been praised as a technology-based response to a range of societal challenges. For instance, the US Department of Energy has stated that the successful application of synthetic biology will replace a third of U.S. transport fuel usage by 2030 and increase ethanol production capacity 12-fold to 60 billion gallons by 2030[6].

For the wider community the importance of synthetic biology lies in its social and commercial potential. One estimate suggests that the global market for synthetic biology could reach US$2.4 billion by 2013, with applications ranging from medicine to agriculture[7]. Possible uses of synthetic biology include the following areas.

- **Energy**

Custom-built microbes for generating hydrogen and other fuels, or for performing artificial photosynthesis. And the development of new pathways for producing fuel.

- **Medicine and health**

The manufacture of drugs, vaccines and diagnostic agents, and the creation of new tissue. Also including enhanced drug production and delivery.

- **Environment**

The detection of pollutants, and their breakdown or removal from the environment, and including engineered dispersants and environmentally friendly materials.

- **Chemical industry**

The production of fine or bulk chemicals, including proteins to provide an alternative to natural fibres or existing synthetic fibres.

- **Agriculture and food**

Including engineered or optimized crops, and novel food additives.

Which of these applications will be first to make an impact in the marketplace is a matter of speculation, although many commentators foresee biofuel products as a likely frontrunner.

However, challenges loom at every step in the process, from the characterization of parts to the design and construction of systems. It has been pointed out that there are five key challenges[8].

- **Many of the parts are undefined**

A biological part can be anything from a DNA sequence. The problem is that many parts have not been characterized well. They haven't always been tested to show what they do, and even when they have, their performance can change with different cell types or under different laboratory conditions.

- **The circuitry is unpredictable**

Even if the function of each part is known, the parts may not work as expected when put together. Synthetic biologists are often caught in a laborious process of trial-and-error, unlike the more predictable design procedures found in other modern engineering disciplines.

- **The complexity is unwieldy**

As circuits get larger, the process of constructing and testing them becomes more daunting. For example, the researchers had to test many part variants before they found a configuration.

- **Many parts are incompatible**

Once constructed and placed into cells, synthetic genetic circuits can have unintended effects on their host.

- **Variability crashes the system**

Synthetic biologists must also ensure that circuits function reliably. Molecular activities inside cells are prone to random fluctuations, or noise. Variation in growth conditions can also affect behavior.

Synthetic biology for renewable energy

In this section, we focus on the definition of renewable energy and discuss the role of synthetic biology in producing renewable energy.

The renewable energy is defined by International Energy Agency(IAE) as: Renewable energy is derived from natural processes that are replenished constantly. In its various forms, it derives directly from the sun or the heat generated deep within earth. Included in the definition is electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and bio-fuels and hydrogen derived from renewable resources[9]. Major reasons for exploring renewable resources are continuity of energy supply for future generations as well as reducing hazardous impacts on environment while using the energy.

As the fossil fuel economy grows increasingly unsustainable, it becomes more and more important that humanity develops alternative energy solutions. Climate change is occurring at an alarming pace, disrupting the biosphere, facilitating international conflicts over finite resources, and destabilizing the global economy. Synthetic biology, the integration of multiple scientific disciplines, provides scientists with a path towards rapid development of renewable fuels via biological systems. For instance, the most widely used biofuel is ethanol produced from corn or sugar cane[10], however, the heavy agricultural burden combined with the suboptimal fuel properties of ethanol make this approach to biofuels problematic and limited. Microorganisms engineered with optimized biosynthetic pathways to efficiently convert biomass into biofuels are an alternative and promising source of renewable energy. These strategies will succeed only if their production costs can be made to compete with, or even outcompete, current fuel production costs. Similarly, there are many drugs for which expensive production processes preclude their capacity for a wider therapeutic reach. New synthetic biology tools would also greatly advance the microbial production of biomaterials and the development of novel materials.

Synthetic biology is being used in two different processes for biofuels production, first is using synthetic enzymes to break down biomass into sugars for fuel, and second is creating microbes that produce fuel directly. Enzymes are being engineered into microbes that can break down biomass much quicker than traditional methods. Synthetic DNA that codes for these enzymes is inserted into microbes that then produce these synthetic enzymes. These enzymes can now be tailored towards specific types of biomass, such as woodchips or corn stalks, and increase the rate at which they are broken down into sugars that can then be fermented into ethanol or other types of fuels. The second approach being used to produce biofuels is through creating organisms, largely algae, that produce biofuels directly. Synthetic algae or other microbes do not necessarily require biomass to produce fuel, unlike organisms with synthetic enzymes, and instead can produce lipids that are processed into fuels from sunlight, water, and fertilizers.

It is noteworthy that certain microorganisms have evolved to be proficient in converting lignocellulosic material to ethanol, biobutanol and other biofuels. These native isolates possess unique catabolic activity, heightened tolerances for toxic materials and a host of enzymes designed to break down the lignocellulosic components. Unfortunately, these highly desired properties exist in pathways that are tightly regulated according to the host's evolved needs and therefore may not be suitable in their native state for production scale. A longstanding challenge in metabolic and genetic engineering is determining whether to improve the isolate host's production capacity or whether to transplant the desired genes or pathways into an industrial model host, such as E. coli or S. cerevisiae[11].

Synthetic biology might accelerate the development of second-generation biofuels[12] that can be prepared from agricultural waste and plant residues, so avoiding competition with crops grown for food. Synthetic biology involves engineering microbes to produce specifically desired fuels, especially hydrocarbon fuels that are "drop-in" replacements for petroleum diesel and gasoline. The work that has been done thus far has been targeting the development of microbes that "eat" sugar molecules and excrete diesel-like fuel[13].

However, for fuel production, the choice is not just between dirty fossil fuels and products from synthetic organisms. Instead of turning to biofuels to save the environment, investments can be made in clean energy technologies and updating the energy grid so it can be connected to wind turbines, solar panels, and electric cars across the country. Investments in energy efficiency can reduce the strain on energy resources. There wouldn't be a need for synthetic bacteria to eat up oil spills if no one was using dirty oil for energy and if the corporations that contaminate the environment were held accountable. Oil created from synthetic organisms that mimics the structure of natural oil only deepens dependence on an out-dated energy infrastructure. And as a recent study has shown, biofuels from algae may not even reduce overall emissions[14].

Sustainable energy for sustainable development

In this section, we first discuss the definitions of sustainable energy and sustainable development, then we focus on the concept of eco-efficiency.

The most appropriate definitions of sustainable development are as, Development that meets the needs of the present without compromising the ability of future generations to meet their own needs, the ability to meet the needs of the present while contributing to the future generations' needs[15].

According to UNEP/SEFI/NEF[16], sustainable energy includes solar, wind, biofuels, biomass and waste to energy, marine and small-hydro, geothermal, efficiency, and other low-carbon technologies/services. It excludes large-scale hydro (>50MW) and all nuclear power. Sustainable energy is to provide the energy that meets the needs of the present without compromising the ability of future generations to meet their needs. It has two components,renewable energy and energy efficiency.

Renewable energy

It uses renewable sources such biomass, wind, sun, waves, tides and geothermal heat. Renewable energy systems include wind power, solar power, wave power, geothermal power, tidal power and biomass based power. Renewable energy sources, such as wind, ocean waves, solar flux and biomass, offer emissions-free production of electricity and heat. For example, geothermal energy is heat from within the earth. The heat can be recovered as steam or hot water and use it to heat buildings or generate electricity. The solar energy can be converted into other forms of energy such as heat and electricity and wind energy is mainly used to generate electricity. Biomass is organic material made from plants and animals. Burning biomass is not the only way to release its energy. Biomass can be converted to other useable forms of energy, such as methane gas or transportation fuels, such as ethanol and biodiesel (clean alternative fuels). Renewables are less polluting, both in terms of local emissions (such as particulates, sulfur, and lead) and greenhouse gases, carbon dioxide and methane, that cause global warming. They are also more labor intensive, requiring more workforce per unit of energy than conventional fossil fuels[17].

Energy efficiency

Sustainable energy systems also include technologies that improve energy efficiency of systems using traditional non renewable sources. Improving the efficiency of energy systems or developing cleaner and efficient energy systems will slow down the energy demand growth, make deep cut in fossil fuel use and reduce the pollutant emissions. For examples, advanced fossil-fuel technologies could significantly reduce the amount of CO_2 emitted by increasing the efficiency with which fuels are converted to electricity. Options for coal include integrated gasification combined cycle (IGCC) technology, ultra-supercritical steam cycles and pressurized fluidized bed combustion. For the transportation sector, dramatic reductions in CO_2 emissions from transport can be achieved by using available and emerging energy-saving vehicle technologies and switching to alternative fuels such as biofuels (biodiesel, ethanol). For industrial applications, making greater use of waste heat, generating electricity on-site, and putting in place more efficient processes and equipment could minimize external energy demands from industry. Advanced process control and greater reliance on biomass and biotechnologies for producing fuels, chemicals and plastics could further reduce energy use and CO_2 emissions. Energy use in residential and commercial buildings can be substantially reduced with integrated building design. Insulation, new lighting technology and efficient equipment are some of the measures that can be used to cut both energy losses and heating and cooling needs. Solar technology, on-site generation of heat and power, and computerized energy management systems within and among buildings could offer further reductions in energy use and CO_2 emissions for residential and commercial buildings.

According to definition of sustainable energy, damage of environment is another major concern for sustainable energy development. Environmental efficiency is closely linked to working of sustainable and renewable energy development concerns.

The term eco-efficiency was coined by the World Business Council for Sustainable Development (WBCSD). It is based on the concept of creating more goods and services while using fewer resources and creating lesser waste and pollution[18].

WBCSD has pointed out seven major elements in considering eco-efficiency of developing environmental friendly products or processes for reducing environmental impacts[19].

- Reduce the material intensity of its goods and services.
- Reduce the energy intensity of its goods and services.
- Reduce the dispersion of any toxic materials.
- Enhance the recyclability of its materials.
- Maximize the sustainable use of renewable resources.
- Extend the durability of its products.
- Increase the service intensity of its goods and services.

CONCLUSIONS

The development of cleaner and efficient energy technologies and the use of new and renewable energy sources will play an important role in the sustainable development of a future energy strategy. In order to achieve sustainable development the following points are crucial.

A sustainable future requires a transformation from today's energy systems to those with ①radical improvements in energy efficiency, especially in end use, and ② greater shares of renewable energies and advanced energy systems with carbon capture and storage(CCS) for both fossil fuels and biomass.

Efficiency improvement is proving to be the most cost-effective, near-term option with multiple benefits,

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such as reducing adverse environmental and health impacts, alleviating poverty, enhancing energy security and flexibility in selecting energy supply options, and creating employment and economic opportunities.

The share of renewable energy in global primary energy could increase from the current 17% to between 30% to 75%, and in some regions exceed 90%, by 2050. If carefully developedr, enewable energies can provide many benefits, including job creation, increased energy security, improved human health, environmental protection, and mitigation of climate change.

REFERENCES

[1] Helmut Haberl et al.; Global Human Appropriation of Net Primary Production (HANPP), The Encyclopedia of the Earth, 29 April 2010. See, http://www.eoearth.org/view/article/153031/, **(2010)**

[2] BCC Research, Synthetic Biology, Emerging Global Markets, November 2011. http://www.bccresearch.com/report/global-synthetic-biology-markets-bio066b.html, **(2011)**.

[3] Secretary-General of the OECD Synthesis Report, Symposium on Opportunities and Challenges in the Emerging Field of Synthetic Biology, OECD & the Royal Society, **(2010)**.

[4] Extreme Genetic Engineering: An Introduction to Synthetic Biology. Ottawa, ON. ETC Group, **(2007)**.

[5] H.Thomas; Murray:Society Must Weigh Massive Potential Benefits Against Risks of Synthetic Life, See http://www.aaas.org/news/releases/2010/1116hitachi_synth_bio.shtml, **(2010)**.

[6] S.Suppan, Patents; Taken for Granted in Plans for a Global Biofuels Market. Institute for Agriculture and Trade Policy, October **(2007)**.

[7] See http://www.easac.eu, the European Academies Science Advisory Council, January **(2011)**.

[8] R.Kwok; Five Hard Truths for Synthetic Biology, Nature, **463(7279)**, 288-290 **(2010)**.

[9] R.Janssen; IEA Renewable Energy Working Party. Renewable Energy… into the main stream, **9**, **(2002)**.

[10] J.L.Fortman, Swapnil Chhabra, Aindrila Mukhopadhyay, Howard Chou, Taek Soon Lee, Eric Steen and Jay D.Keasling, Biofuel Alternatives to EthanolÿPumping the Microbial Well. Trends Biotechnol**, 26**, 375–381 **(2008)**.

[11] H.Alper, G.Stephanopoulos; Engineering for Biofuels, Exploiting Innate Microbial Capacity or Importing Biosynthetic Potential. Nature Rev.Microbiol. **7**, 715–723 **(2009)**.

[12] Second-generation biofuels are those made from land-based non-edible lingocellulosic biomassÿeither residues of food crop production, such as corn stalks or rice husks, or whole-plant biomass, such as grasses or trees, UNCTAD (2008). UNCTAD(2008) Biofuel Production Technologies, Status, Prospects and Implications for Trade and Development, prepared by E. D. Larson. United Nations Conference on Trade and Development(UNCTAD)Geneva, Switzerland.

[13] S.K.Lee, H.Chou, T. S.Ham, T.S.Lee, J.D.Keasling; Metabolic Engineering of Microorganisms for Biofuels Production, From Bugs to Synthetic Biology to Fuels. Current Opinion in Biotechnology, **19**, 556-563 **(2008)**.

[14] Andres F.Clarens, Eleazer P.Resurreccion, Mark A.White, Lisa M.Colosi; Environmental Life Cycle Comparison of Algae to Other Bioenergy Feedstocks, Environmental Science and Technology, **44(5)**, 1813-1819 **(2010)**.

[15] United Nations. Brundtland Commission. Report of the World Commission on Environment and Development. General Assembly Resolution 42/187. 11 December (1987). See also http:// www.un.org/ , **(1987)**.

[16] UNEP/SEFI/NEF; Global Trends in Sustainable Energy Investments 2009. UN Environment ProgrammeÿSustainable Energy Finance Initiative, New Energy Finance, Nairobi, **(2009)**.

[17] J.Goldemberg; Ethanol for a Sustainable Energy Future. Science, **315(5813)**, 808–810 **(2007)**.

[18] World Business Council for Sustainable Development (WBCSD). Eco-efficiency, Creating More Value with Less Impact. ISBN, 2-940240-17-5 **(2000)**.

[19] Livio D.DeSimone, Frank Popoff; Eco-efficiency, The Business Link to Sustainable Development, MIT Press, **(1997)**.