



Journal of Applied Sciences

ISSN 1812-5654

science
alert

ANSI*net*
an open access publisher
<http://ansinet.com>

A Feasible Pathway for Energy and Development

Ying Jian Chen

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

Abstract: In the last decade, ever increasing energy and environmental problems such as fossil fuel depletion and global warming are ringing the alarm bell to human society. Many proposals have been put forward to mitigate and adapt such situations. Synthetic biology is a set of tools and techniques which mix engineering and biology and support the development of new applications. New applications may be found in energy, medicine, environment and materials. In this study, 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 renewable energy and the relations between sustainable energy and sustainable development are discussed. Finally, several key points to achieve sustainable development are summarized.

Key words: Synthetic biology, sustainable energy, sustainable development

INTRODUCTION

The world currently faces a systematic energy and environmental problem of increased CO₂ emissions, decreased soil-carbon content and global-climate change. To solve the massive global energy and environmental sustainability problem, it likely requires a comprehensive portfolio of R and D efforts with multiple energy technologies.

The field of advanced biofuels, such as photo-synthetic biomass energy, may represent one of the major R and D areas that have the potential to provide renewable clean energy, in additions to the other renewable energy technologies, including nuclear energy, geothermal, wind, solar and hydropower. Photosynthesis captures more CO₂ from the atmosphere than any other processes on Earth capture.

Each year, land-based green plants capture about 440 gigatons (Gt) CO₂ (equivalent to 120 Gt Cy⁻¹) from the atmosphere into biomass (Geider *et al.*, 2001). That is, about one-seventh of all the CO₂ in the atmosphere (820 GtC) is fixed by photosynthesis (gross primary production) every year. Theoretically, if there is a technology that could translate as small as 7.5% of the annual terrestrial gross photosynthetic products (120 Gt Cy⁻¹) to a usable biofuel to substitute fossil fuels that would be sufficient to eliminate the entire amount (nearly 9 Gt Cy⁻¹) of CO₂ emitted into the atmosphere annually from the use of fossil fuels.

In this study, we propose a biological pathway for energy and development. In the following we particularly focus on 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” (OECD, 2010). 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

On the other hand, Murray (2010) did place the technologies comprising “synthetic biology” into four categories:

- **Advanced genetic engineering:** Engineering bacteria to produce a precursor of artemisinin, a front-line malaria drug, epitomizes 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 (Suppan, 2007).

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 (<http://www.easac.eu/>). 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 (Kwok, 2010):

- **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
- **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
- **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, geo-thermal resources and bio-fuels and hydrogen derived from renewable resources (Janssen, 2002). 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 (Fortman *et al.*, 2008) 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.

For biofuel production, 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* (Alper *et al.*, 2009).

Synthetic biology might accelerate the development of second-generation biofuels (UNCTAD, 2008a, b) 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 hydro-carbon 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 (Lee *et al.*, 2008).

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 (UNBC, 1987).

According to UNEP/SEFI/NEF (2009), 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 (>50 MW) 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 (Goldemberg, 2007).

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 CO₂ 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 CO₂ emissions from transport can be achieved by using available and emerging energy-saving vehicle technologies and switching to alternative fuels such as biofuels (for instance, 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 CO₂ 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 CO₂ 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. It is based on the concept of creating more goods and services while using fewer resources and creating lesser waste and pollution (WBCSD, 2000).

WBCSD has pointed out seven major elements in considering eco-efficiency of developing environmental friendly products or processes for reducing environmental impacts (DeSimone and Popoff, 1997):

- 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

CONCLUSION

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: (1) Radical 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, 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 developed, renewable energies can provide many benefits, including job creation, increased energy security, improved human health, environmental protection and mitigation of climate change
- Universal access to electricity and cleaner cooking fuels and stoves can be achieved by 2030; however, this will require innovative institutions, national and local enabling mechanisms and targeted policies, including appropriate subsidies and financing. The necessary technologies are available, but resources need to be directed to meet these goals. Universal access is necessary to alleviate poverty, enhance economic prosperity, promote social development and improve human health and well-being. Enhancing access among poor people, especially poor women, is thus important for increasing their standard of living. Universal access to clean cooking technologies will substantially improve health, prevent millions of premature deaths and lower household and ambient air pollution levels, as well as the emissions of climate-altering substances

REFERENCES

- Alper, H. and G. Stephanopoulos, 2009. Engineering for biofuels: Exploiting innate microbial capacity or importing biosynthetic potential? *Nat. Rev. Microbiol.*, 7: 715-723.
- DeSimone, L.D. and F. Popoff, 1997. *Eco-efficiency: The Business Link to Sustainable Development*. MIT Press, Cambridge, MA.
- Fortman, J.L., S. Chhabra, A. Mukhopadhyay, H. Chou, T.S. Lee, E. Steen and J.D. Keasling, 2008. Biofuel alternatives to ethanol: Pumping the microbial well. *Trends Biotechnol.*, 26: 375-381.
- Geider, R.J., E.H. Delucia, P.G. Falkowski, A.C. Finzi and J.P. Grime *et al.*, 2001. Primary productivity of planet earth: Biological determinants and physical constraints in terrestrial and aquatic habitats. *Global Change Biol.*, 7: 849-882.

- Goldemberg, J., 2007. Ethanol for a sustainable energy future. *Science*, 315: 808-810.
- Janssen, R., 2002. Renewables-policy and market design challenges. IEA Renewable Energy Working Party, Paris, France, pp: 9.
- Kwok, R., 2010. Five hard truths for synthetic biology. *Nature*, 463: 288-290.
- Lee, S.K., H. Chou, T.S. Ham, T.S. Lee and J.D. Keasling, 2008. Metabolic engineering of microorganisms for biofuels production: From bugs to synthetic biology to fuels. *Curr. Opin. Biotechnol.*, 19: 556-563.
- Murray, T.H., 2010. Society must weigh massive potential benefits against risks of synthetic life. Brian Vastag, Washington, DC., November 16, 2010.
- OECD, 2010. Symposium on opportunities and challenges in the emerging field of synthetic biology: Synthesis report. OECD and The Royal Society, Pages: 48.
- Suppan, S., 2007. Patents: Taken for granted in plans for a global biofuels market. Institute for Agriculture and Trade Policy. October 17, 2007.
- UNBC, 1987. Report of the world commission on environment and development: Our common future. UN Documents Gathering a Body of Global Agreements, General Assembly Resolution 42/187, December 11, 1987.
- UNCTAD, 2008a. Biofuel production technologies: Status, prospects and implications for trade and development. United Nations Conference on Trade and Development, Geneva, Switzerland.
- UNCTAD, 2008b. Second-generation biofuels are those made from land-based non-edible lignocellulosic biomass, either residues of food crop production (such as corn stalks or rice husks) or whole-plant biomass (such as grasses or trees). United Nations Conference on Trade and Development, Geneva.
- UNEP/SEFI/NEF, 2009. Global trends in sustainable energy investments 2009. UN Environment Programme: Sustainable Energy Finance Initiative, New Energy Finance, Nairobi.
- WBCSD, 2000. Eco-efficiency: Creating more value with less impact. World Business Council for Sustainable Development, August 2000.