Overview

Plant biotechnology: a key technology in the 21st century

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Abstract Although we enjoy convenient and happy lives as a result of using large amount of fossil fuels, this convenience comes at a steep price: global warming, pollution, and destruction of the environment. It took more than a hundred million years for the Earth to accumulate its current reserves of fossil fuels. It is sure that the earth will confuse, if we exhaust it within 1-2 centuries.

Solar energy supports all life on the earth, and plants are able to use this energy. Annually, plant biomass produces 8 times as much energy as we consume globally. Therefore, if we could harness 12% of plant biomass for the production of energy and industrial materials, in place of fossil fuels, we could establish a sustainable world. Plant biotechnology is progressing rapidly, and research aimed at producing both fuels and plastics from plant biomass is already underway. Because carbon dioxide generated from plant products will ultimately be consumed by other plants, the recycling system is built in. Our future therefore may not so dark after all.

Global warming

The famous Swedish scientist Svante A. Arrhenius (1859–1927) was the 3rd Nobel Chemistry Prize Winner in 1903. To him, we owe the acid-base definition and reaction rate equations that bear his name. He gave a lecture in December 1895 to the Conference of Physics in Stockholm, entitled "On the influence of carbonic acid in the air upon the temperature of the ground"; in 1896 he published a paper with the same title in the Philosophical Magazine and Journal of Science. Global coal consumption in 1895 was 5 million tons, and atmospheric CO2 was increasing 0.1% per year. Based on detailed experiments, Arrhenius predicted that if the world continued to use fossil fuels, global warming would become serious. In 2004, fossil fuels equivalent to 80 million tons of coal were being used per year; it now appears that Arrhenius' warning was correct.

Renewable energy

It is essential that we replace fossil resources with renewable energy sources. Energy produced from fossil fuels in 2004 was 12 terawatts (TW) globally.[1)] The largest source of renewable energy is the sun, which could provide up to 100,000 TW; the next largest source is plant biomass, which could yield as much as 100 TW. Other renewable energy sources, such as geothermal, wind, tides and currents, and hydroelectric power, are not nearly as large. (Figure 1) Although solar energy is so abundant, current technology for converting it into available energy (i.e, electricity) is inefficient. Therefore, the most promising source of energy is plant biomass. Of the 100 TW generated by plant biomass, 7 TW is used to produce energy, such as foods, feeds, woods, textile, and pulp; another 33 TW is required for the maintenance of the world's forests. The remaining 60 TW is unused biomass. (Figure 2) However, unused natural biomass, such as the jungle, weeds, and fallen leaves, is difficult to collect. The available agricultural, forestry, and animal husbandry biomass generates 7.6 TW.[2)] Production of fuel ethanol from corn starch and sugar cane is very active in the US and Brazil, respectively, but fuel production competes with production of food supplies.

Increase of plant biomass production

The world population will reach nine billion by 2050. The economic growth of developing countries will require more and more energy. Therefore, by 2050 we need to be producing at least 1.5 times as much energy and plant biomass as we are at present; ideally, we would like to be producing 3 times as much. Strategies for increasing plant biomass production include 1) increasing of the amount of agricultural land; 2) increasing

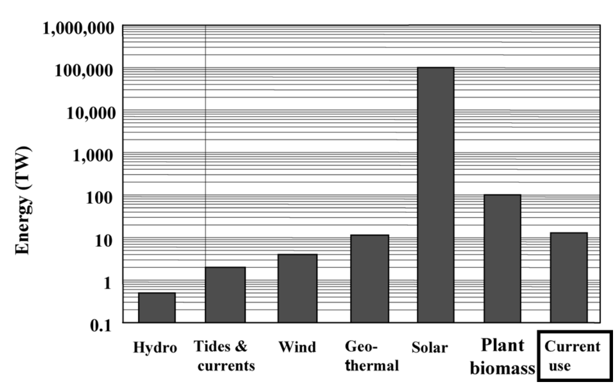

Figure 1. Potential of underused renewable energy sources. TW (tera watt) = 1,000 Billion watt.

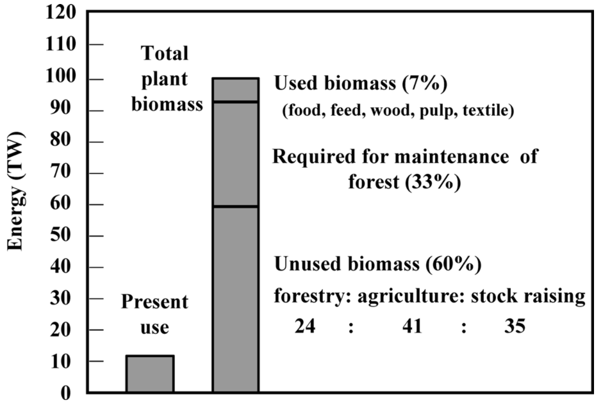

Figure 2. Plant biomass energy.

production per unit of land; and 3) plant breeding to optimize energy yield. Currently, agricultural land in the world is decreasing because of drought and increasing salinity. Production per unit area has reached a maximum in the developed countries as a result of widespread use of irrigation, chemical fertilizer, insecticides and herbicides. One remaining possibility is using recombinant DNA technology to breed plants for high growth and stress resistance.

The productivity of plants is significantly reduced by many environmental stresses, such as viral and microbial infection, insects, salinity, drought, extremes of temperature, reactive oxygen species, and so on. Even in the US, the agricultural yields are less than a quarter of their theoretical maximum.[3] To date, virus-, insect-, or herbicide-resistant crops have been produced by introduction of a single gene, resulting in significant improvements in productivity. Many kinds of stress-resistance gene have been isolated; their mechanisms of resistance have been elucidated mainly in *Arabidopsis thaliana*. Genes improving plant growth in acidic or alkaline soil and salty land have also isolated. It is predicted that plant productivity could be increased several fold by conferring multi-stress resistance.

Yokota A (personal communication) succeeded in increasing CO2 fixation in tobacco by a factor of 1.8, by introducing a key gene into the chloroplast carbon cycle. Tamaki et al.[4] has introduced a gene responsible for producing florigene (a phytohormone that controls flowering) into rice, thereby reducing the flowering period to 60% of the wild type. It has been suggested that this gene might bring forward the date for producing seeds and fruits, thereby increasing the number of harvests per year in a unit of agricultural land. Recombinant DNA technology has the potential not only to reduce the yield losses due to environmental stresses, but also to increase the maximum productivity of plants.

Plant science and plant biotechnology

At present, plant science is mainly studied in a several model plants, including *Arabidopsis*, tobacco, and rice; many important genes, including transcription factors and regulatory elements, have been isolated in these species. These results must be applied to agriculturally useful plants. The most important technology required in plant biotechnology is the establishment of a transformation system in these useful plants, allowing application of basic research from model plants. At present, no universal transformation system has been established. The highest-quality genetically modified-plants will be resistant to multiple stresses and also contain a novel metabolic pathways; therefore, many transcription and translation elements must be ligated into each gene. Since a convenient ligation technique is required to construct vectors containing many multi-gene fragments, we have developed the *in vitro* ligation robot. This robot allows construction of a vector containing 30 genes in just a few days (Takita E, personal communication). Another technology required for application of basic research to plant biotechnology is the quantitative control of gene expression. We have isolated many elements that control gene expression, including promoters, novel terminators, translation enhancers, and optimum nucleotides around the initiation codon. Combining these elements can provide the optimum gene expression system.

We believe that plant biomass is a key energy source that could be substituted for fossil fuels. We hope that parallel progress in basic plant science and plant biotechnology will lead to the establishment of a sustainable world in the near future.

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