Current State of Biomass Technology (BmT) Research in South Korea:
Advanced Biomass R&D Center (ABC)

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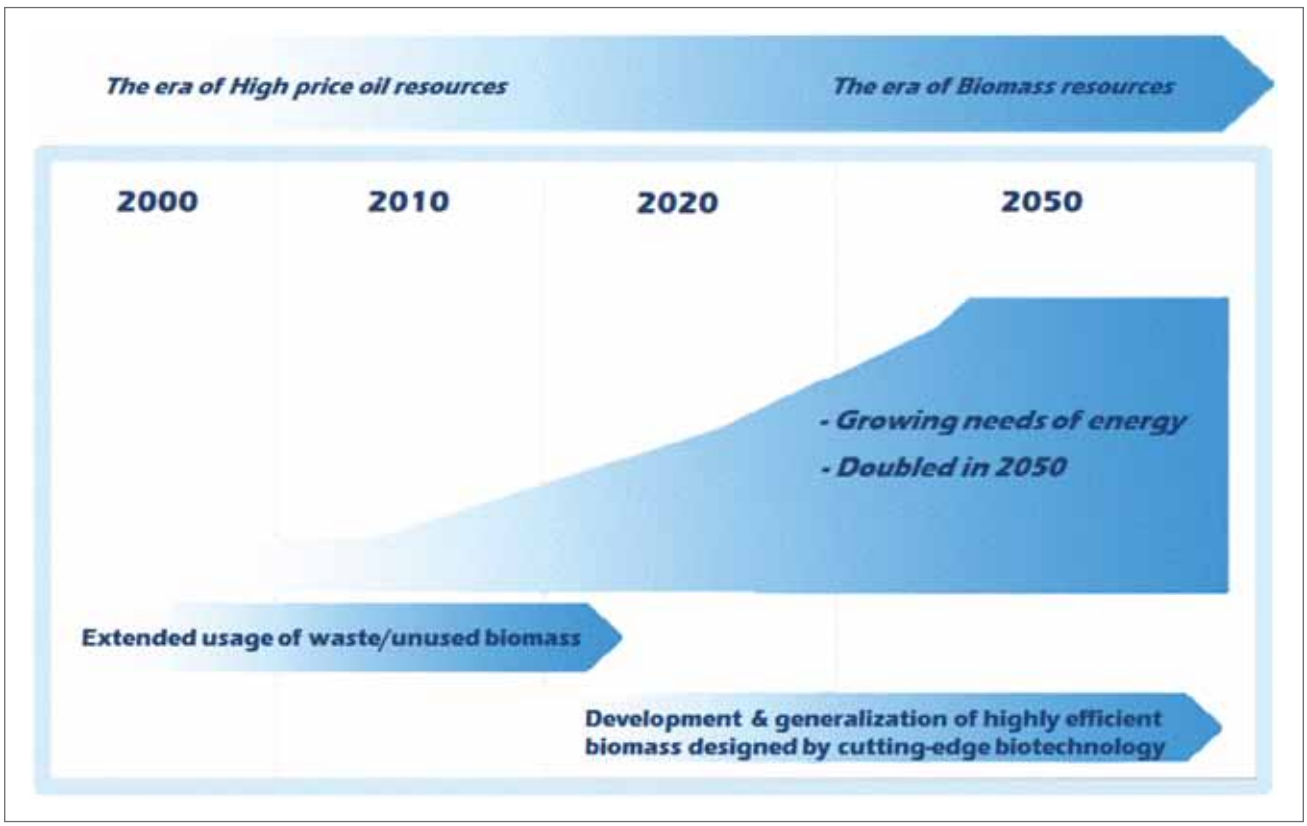

Figure 1. Outlook for future energy source (IEA, 2010)

Introduction

Our society, heavily relying on the fossil energy, has caused environmental problems, as well as energy crisis and, worse yet, this trend is foreseen to continue. The development of renewable energies is not optional any longer, but it represents a mandatory consideration for the survival of human race. Therefore, efforts are being aggressively made to find alternatives to the fossil fuels, which are renewable and without undesirable consequences such as CO_2 emission.

We believe that, among other potential energy alternatives, only biomass can completely replace crude oil. Biomass can be converted into transportation fuels and

chemicals, and also serve as electrical power instead of petroleum. Above all, biomass is carbon-neutral; the amount of carbon released via respiration and burning is well balanced with the amount of carbon absorbed through photosynthesis. Moreover, biomass reserves (or more accurately biomass productivity) worldwide reach 220 billion oven-dry tones (odt) per year and this amount represents nearly ten times higher than the current world energy consumption. In fact, recently meaningful number of green steps in biomass-based energies is observed in industrial sectors; for instance, some of biomass-based materials are expected to replace petroleum-based counterpart materials in the near future. In case of energy, whose consumption is expected to skyrocket in the following years (Fig 1), biofuels will be responsible for 30% of the energy consumption in the transportation sector until 2030 in the USA.

The South Korean government, with a grand motto of low carbon and green growth, puts particular emphasis and efforts to the development of these biofuels and biomaterials. One of such efforts is to launch a long-term research center, named Advanced Biomass R&D Center (ABC).

Advanced Biomass R&D Center (ABC)

Korean Ministry of Education, Science and Technology (MEST), which plays a key role in government-assisted R&D in South Korea, has supported nationwide research projects for decades. Two notable examples are G7 projects in 1990's, whose representative outcomes include Flat TV and cellular phone; and 21C frontier projects in 2000's, which led to the considerable advancement in the areas of bio-pharmaceuticals and nanoscale semiconductor. These mega projects have brought significant momentum and unprecedented growth in South Korea during the last two decades.

The South Korean government wanted to continue these successes and even further spur the growth, so as to poise South Korea as a leader in the strategic fields of science and engineering, such as bioenergy. With this goal in mind, Global Frontier (GF) program

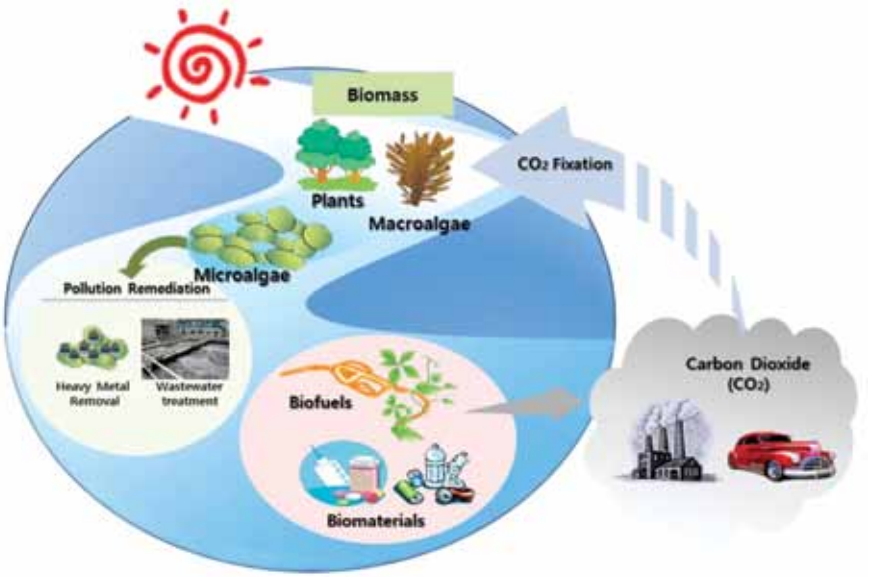

Figure 2. Carbon neutral biomass-based industry

was launched last year, receiving considerable attentions across the world. All of the MEST's planning, management, and assessment experiences accumulated previously (such as in G7 and 21C frontier programs) are anticipated to be wisely practiced for the success of the GF program.

Vision

Biomass-based fuels and chemicals, which will surely and ultimately substitute petroleum-based products, need to go through many obstacles until their commercialization. Therefore, numerous technical breakthroughs are required in time. To this end, Advanced Biomass R&D Center (ABC) was launched in 2010 This specific project is funded with 200 million US dollars for the 9-year period of research with the very best Korean researchers in the related areas including molecular biology, chemistry, and chemical engineering. They take part in ABC, making every effort to achieve the vision of becoming 'Biomass Technology (BmT) global leaders in 2019. ABC is to play a critical role in the realization of the independence from fossil fuel of human beings in general and South Korea in particular.

Objectives

BmT studies that ABC seeks are on the basis of all major biomass as source feedstock. Considering the small land size of the Korean peninsula, surrounded by oceans, microalgae would be the biomass of choice for the country. In fact, microalgae are recognized as biomass feedstock for the production of the 3rd-generation biofuel. At the same time, nearly three-fourths of the peninsula consists of non-agricultural regions, namely mountains, produces substantial amount of cellulosic biomass.

We determined three strategic BmT areas that are of prime importance for the commercialization of biomass-based fuels and chemicals and thus ABC are addressing: i.e. biomass development, cultivation, and bio-conversion. Each specific objective is as follows:

1) Biomass Development: We take aim at producing novel or improved biomass species with desirable features as feedstock for fuels and chemicals by means of classical and modern molecular techniques. In case of plant biomass, we have targeted traits related to the growth through genetic manipulation, such as redistribution of energy, biosynthesis of cellulose and lignin, and reprogramming of cambial activity. We have already gained plentiful information on candidate genes. We are also improving the resistance to environmental stresses including drought and diseases to promote biomass productivity.

To obtain the most desirable microalgae biomass with the features of fast and dense growth, high oil content, oil secretion, and

high resistance to environmental stresses, we are first in search of native novel strains. We have already isolated more than 100 new microalgal strains, some of which showed morphologies of interest. We will continue this endeavor until a sufficiently potent species that can be used as a platform strain for the downstream molecular works. Besides, genetic engineering is also being practiced on a model microalga whose genetic system is well established. Utilizing forward or reverse genetics and proteomics, ABC explores the mechanisms or signaling pathways involved in lipid biosynthesis.

2) Mass Cultivation: Microalgae, even after new strains with the aforementioned desirable characteristics are developed, still have many engineering issues to be addressed for the commercial-level production of microalgal-based biofuel. A high density culture is some of the most critical problems, as phototrophic microbes in general, grow only up to a certain level, mainly due to so-called self-shading effect. The higher culture density, the more economical the downstream processes are. One research direction is to create innovative photobioreactor systems, whose construction and operation are cost-efficient. One noticeable example includes the development of wirelessly powered LED bulbs, which will serve as internal light sources and reduce the self-shading effect.

Necessity of nutrients such as nitrogen and phosphor is another critical factor for economic mass cultivation. One hopeful inexpensive alternative is wastewater. Once proper technologies are developed, we expect to not only greatly reduce biomass production cost, but also to treat nuisance wastes. Other steps of the process for microalgae-based biodiesel production, i.e., biomass harvest and lipid extraction from microalgal biomass are also being studied in order to enhance the overall efficiency.

While the importance of the production of ethanol and/or chemicals from agricultural or wood residues has increasingly been recognized, the level of our technologies is far from their commercialization. One of the most problematic steps for the land biomass is pretreatment (up to 18% of total production cost) and thus another strategic research target of ABC. In addition to the development of innovative technologies such as cellulose dissolution with ion liquids, computational calculation and modeling based on thermodynamics and enhancers of cellulase activity such as expansin are being studied. The development of highly efficient and cost-effective cellulase systems and all-in-one microbes (called consolidated bioprocessing) are of our interest as well.

3) Bio-conversion Technology: We will also develop breakthrough technologies suitable for high-throughput and economical bio-conversions of raw or pretreated biomass into bioenergy and biomaterials. ABC employs particularly the concept of platform technology, which allows to considerably speed up the development to help further other bio-refinery processes. Platforms compounds of our interest include biofuels (i.e., bioethanol, biodiesel and bioalkene) and bio-materials (i.e, carboxylic acids, amines, fatty acids, and aromatic compounds) .

Metabolic engineering is one of the most intensively practiced molecular techniques. Metabolic engineering has been upgraded to the systems level (thus renamed as systems metabolic engineering) by the integrated use of global technologies of systems biology, fine design capabilities of synthetic biology, and rational–random mutagenesis through evolutionary engineering. By this systems metabolic engineering, production of biofuels and chemicals can be better optimized in a multiplexed way on a genome scale, with reduced time and effort

Eventually, through the development of platform technologies, ABC will be able to establish the foundation for sophisticated on-going bio-conversion technology for the future.

4) Groundbreaking, Group Approach, Global, and Growth and Sustainability are the philosophy of the Global Frontier program and also of ABC. In fact, the term Biomass Technology (BmT) is a redefined biotechnology area that specifically focuses on biomass, basically encompasses all ABC proposes to do. The heart of the BmT concept is innovation and cooperation within a research field and consolidation among different fields, which can be well realized under the large umbrella of ABC. For example, coordination in the fields of molecular biology, population biology, and bioengineering are absolutely necessary to better develop desirable biomass species. Likewise, bioengineering, physical chemistry, and agriculture should be converged to achieve highly efficient technologies for biomass cultivation and harvest. In the case of bio-conversion, knowledge and techniques of bioengineering, biochemistry, biochemical engineering, chemistry and chemical engineering are all required.

Issues of energy and global warming can be more effectively, preferably, tackled by global collaborations among all research institutes or industries in the world. With this in mind, ABC will form and maintain close cooperation with representative biomass research institutes, such as Joint BioEnergy Institute (JBEI) supported by Department of

Figure 3. ABC's strategic research targets

Energy (DOE) in the U.S.A., Core Research for Evolutional Science and Technology (CREST) in Japan and Energy Biosciences Institute (EBI) supported by British Petroleum (BP).

Sustainable growth and development are the mission of human civilization, of current Korean government, and also of ABC. We are fully anticipating that our Advanced Biomass R&D Center (ABC) will make significant contributions to it, so that our societal needs of energy and chemicals will be secured.

Concluding Remark

The South Korean government has bet on biomass-based technology by initiating Advanced Biomass R&D Center (ABC) with immense supports of financial and human resources. Research aims, encompassing biomass development, biomass cultivations, and biomass refinery, have been carefully planned. Target biomasses, which are aquatic microalgae and land plants, were selected to fully take advantage of geological traits of the Korean Peninsula. We are fully anticipating that our research center will produce numerous breakthrough technologies for the production and conversion of biomass that will secure our societal needs of energy and chemicals.

Our earnest desire is to see the coming of biomass-based era, so that carbon is circulated in a closed-loop and, at the same time, the economy, albeit without fossil oil, is still growing. We believe we can see it soon.

About the Authors

Jong-In Han is an Assistant Professor in the Department of Civil & Environmental Engineering at KAIST (Korea Advanced Institute of Science and Technology) and General Secretary of ABC. Dr. Han's research focuses on bioenergy production and has three distinct thrusts. The first one is the microbial generation of electricity from wastewater, called microbial fuel cell. The second one is the bioethanol production from cellulosic biomass. The last one is the biodiesel production via both photoautotrophic and heterotrophic oleaginous microbes. He has published in Environmental Microbiology, Chemosphere, and The Journal of Bacteriology and more.

Han graduated with a BA in Agricultural Chemistry and with a MS in Biochemistry from Seoul National University in South Korea; and a PhD in Environmental Engineering from University of Michigan at Ann Arbor under the tutelage of Jeremy D. Semrau. He joined the faculty of the Department of Civil & Environmental Engineering at KAIST in the winter of 2008 after three and a half years spent as an assistant professor at RPI and two years as a DARPA Postdoctoral Fellow in the laboratory of Jared R. Leadbetter at Caltech. He is now playing a key role in ABC in which more than 50 experts in various research fields including biochemical engineering and molecular biology participate.

Ji-Won Yang is a Professor in the Department of Chemical & Biomolecular Engineering at KAIST (Korea Advanced Institute of Science and Technology) and CEO of ABC. Dr. Yang's current research focuses on the production of biofuel and biomaterials from biomass and has four distinct thrusts. The first one is the development of microalgal strains with high lipid content through genetic engineering. The second one is the high density cultivation of microalgae using photobioreactor. The third one is biological wastewater treatment using microalgae and the last one is microalgal harvest, lipid extraction, and transesterification. Dr. Yang has more than 200 publications with various topics of biotechnology and has supervised more than 50 graduate students.

Dr. Yang graduated with a BS in Chemical Engineering from Seoul National University in South Korea and a PhD in Chemical Engineering at Northwestern University in the USA. He joined the faculty of the Department of Chemical and Biomolecular Engineering at KAIST in 1986, where he now holds a full professorship. He is a recipient of various awards for significant contribution to the research innovations in environmental and microalgal biotechnology from Korean government and many academic societies. He had served as the President of Korean Society of Biotechnology and Bioengineering, and the editor-in-chief for the Korean Journal of Soil and Groundwater. He also served as a judge of national R&D projects for Korean government, a co-chairman of the Green Consumer Network, and the chairman of the Daejeon Green Growth Forum. After serving as Vice President for External Affairs at KAIST for 4 years until 2010, he is now leading ABC in which more than 50 experts in a wide variety of research fields including biochemical engineering and molecular biology take part.