

Biochem. Eng. & Pilot Plant Research & Dev. Unit (Eng)

Biochemical Engineering

and

Pilot Plant Research and Development Unit

(BEC)

Background

The Biochemical Engineering and Pilot Plant Research and Development Unit (BEC) was established in 1986 under cooperative program between the National Center for Genetic Engineering and Biotechnology (BIOTEC) and King Mongkut's University of Technology Thonburi (KMUTT). The Unit serves as a center for research and development in biochemical engineering and pilot plant design, with a strong emphasis on applications suitable to local industrial needs. During the initial phase, BEC became one of a number of independent satellite research units of BIOTEC. This allowed the research group to work independent of the bureaucratic system.

During Phase II, (1995-1999), BIOTEC became an autonomous organization and a large number of their graduate scholarship researchers trained overseas returned to Thailand to work in collaboration with the satellite units. Also during this period, administration of the units was undertaken by university staff assigned by BIOTEC for this purpose. BEC's first 5-year plan was implemented during this phase emphasizing collaboration between researchers from both BIOTEC and KMUTT who worked together in the laboratory facilities at KMUTT. This concept of shared resources has proven to be a successful innovation for research programs in Thailand, producing a win-win for both parties.

The second 5-year plan was implemented during the third phase (2000-2005). The formal signing of a Memorandum of Understanding on 23 December 1999 had helped to better define the activities and clarify the expected support and roles of both partners. The second 5-year plan provided a framework for research, development and engineering that focuses on the activities of four major research groups; Algal Biotechnology, Sensor Technology, Microbial Bioprocess Development and Waste Utilization and Management. At the end of this 5-year plan, BIOTEC and KMUTT agreed to restructure the scope of BEC's works by spinning-off the Waste Utilization and Management Research group to be Excellence Center of Waste Utilization and Management (ECoWaste).

The fourth phase (2006-2010) is currently being implemented with the formal Memorandum of Understanding started from 1st October 2005. The framework of the third 5-year plan of BEC focuses on the activities of five major research groups including Algal Biotechnology, Sensor Technology, Microbial Bioprocess Development, Food Technology and Engineering, and Systems Biology and Bioinformatics. Apart from BEC as collaborative research and development unit, KMUTT and BIOTEC have signed a new Memorandum of Understanding to set up the Excellence Center of Waste Utilization and Management (ECoWaste), spun-off R&D group from BEC, at KMUTT.

Dr. Solot Suwanayuen has guided BEC as its Director since the establishment of the Unit in 1986.

{mospagebreak heading=Background&title=Mission
Vision}

Vision

To be a leading research, development and engineering center in biochemical engineering and pilot plant design in the region in order to develop relevant knowledge as well as technologies to serve the needs of society and the country.

Mission

- To carry out R, D&E to generate knowledge and provide products and processes according to industry needs.
- To strengthen and support the competitive position of small to medium enterprises (SMEs) through the application of BEC expertise, developed technologies and human resources.
- To establish and foster university-industry partnerships for mutual benefit.
- To promote / facilitate new entrepreneurs and business development.

{mospagebreak title=Management}

R&D Cluster Management

In cooperation with Industrial Park Center (IPC), Pilot Plant Development and Training Institute (PDTI) and School of Bioresources and Technology (SBT) at KMUTT, BEC manages its research work through the specialized research group under the concept that the strength of any research development system needs two-way communication between demand pull (the technology needs from industry) and supply push (the innovation/ knowledge developed from research institute and academic side). The conventional management system usually found in the universities does not currently facilitate such linkages. One of the essential factors regarding the success of IPC depends on the strength and innovation of research and development (on-going research and maintaining the currently and relevance of R&D). The scope of BEC as a part of R&D Cluster covers research activities to produce high quality R&D, technical services, technology transfer and consultancy, in order to strengthen and support competitive position of SMEs through the application of BEC expertise, developed technologies and human resources.

{mospagebreak title=Funding}

Funding

BEC is operated by funds from various sources: KMUTT, BIOTEC, research grants, contract research, technical services including consultancy, training, pilot plant design, incubators hiring and analytical services

{mospagebreak title=Research
Direction}

Research Direction

Specialized research projects can be initiated through the Unit, with strong scientific and technical support from KMUTT research program. Multidisciplinary project teams can be selected for their relevance to specific research and development projects being undertaken with the research groups.

1) Algal Biotechnology (link to PDTI Lab data)

Research in this group emphasizes the development of mass cultivation techniques and processes, with the aim of obtaining high-value compounds such as phycocyanin and gamma-linolenic acid (GLA). The goal is to enhance cell growth and maximize the production of high-value chemicals in *Spirulina platensis*. Researchers have focused on finding the correct substrate and environmental conditions for the cultivation of different strains of *Spirulina platensis*. For example, CO₂ could be used to replace NaHCO₃ in microalgae cultivation, with substantially lower production costs. In addition, the effects of light and temperature on the productivity and photosynthesis of the algae in an outdoor environment have also been investigated. The group also focuses on understanding the gene expression and regulatory mechanisms by which *Spirulina* produces high-value compounds such as phycocyanin and GLA at a molecular level, in order that we can develop new strains with higher contents of such compounds. Recently, spirulina genome sequencing project has been initiated. The information obtained will be used to develop new generation of research and would be great help for scientists to unveil many novel genes that are involved in biosynthesis of high value compounds that are produced by this organism.

2) Sensor Technology (Bio sensor s and chemical sensor s technology) ([link to PDTI Lab data](#))

Advances in electrochemistry and sensor (bio sensor s and chemical sensor s) research and development have come about due to the need to meet the indigenous demands of the food industry, for environmental analysis, and for biomedical applications. Research is carried out in three areas, for which there is a need to develop existing approaches for better performance of the sensor s, improve analytical methods and explore possible new applications. The bio sensor s and chemical sensor s technology group can be sub-divided into the following lines of study:

- Biosensors: Microbial BOD sensor s, phenol enzyme bio sensor s, screen-printed glucose oxidase electrodes, and simultaneous determination of glucose and sucrose.

- Chemically modified electrodes: Biocompatible redox polymer membrane, metal microparticles in polymer films, inorganic film modified electrodes, and nafion-coated probe in viscous/resistive media.

- Electroanalytical techniques: Pulse amperometric detection, artificial neuron networks for interpreting voltammetric data, and stripping analysis.

3) Microbial bioprocess development (MBD) ([link to PDTI Lab data](#))

The research in microbial bioprocess development involves working in a group of specific laboratories: Animal cell culture, Microbial Fermentation, Solid State Fermentation, Fungal Biotechnology, Pilot Plant Fermentation; that emphasize microbial metabolism and molecular physiology relevant to the metabolic networks of microorganisms and the modification of pathways. An understanding of the genetic and metabolic networks as well as their regulation and interaction will be used to form rational models of biological production systems. These systems in turn will be used as a device to transfer the technologies in question into efficient, industrial-scale processes. The group also focuses on animal cell culture and microbial fermentation technology for the production of biological products at a pilot scale, and production orders and process development for the private industrial sector.

Examples of research conducted by the MBD group are the development of alkaline protease from a filamentous fungus *Aspergillus oryzae* using a solid state fermentation technique, the production of γ -linolenic acid (GLA) from *Mucor rouxii*, the production of Baculoviruses for biopesticide application, pilot scale production and application of probiotic microorganisms, and process development for the production of bioactive compounds for animal feed.

4) Food Technology and Engineering (link to PDTI Lab data)

This group emphasizes on food properties production improving, food thermal processing and aseptic processing.

5) Systems Biology and Bioinformatics (SBI) (link to PDTI Lab data)

This multidisciplinary research group has applied systems biology and bioinformatics approaches to analyze the –omics data of various organisms such as *Saccharomyces cerevisiae*, Cassava, *Plasmodium*, and Tuberculosis. The aim of such research is to understand the biology of these organisms at the systems level, with applications to strains improvement and antibacterial targets identification. The group has at its disposal various tools including mathematical modeling, bioinformatics tools and databases, along with its molecular biology and fermentation laboratories. With these resources, the group is able to build and improve on in silico models, and verify them experimentally to study cellular behaviors under changing environmental, physiological and genetic conditions on a personal computer. We hope to generate a better understanding of how these systems work, and our admittedly ambitious goal is to be able to apply the knowledge thus gained to provide better tools for other scientists and engineers, and to work with these scientists and engineers to solve problems relating to agricultural and medical biotechnology in Thailand.

{mospagebreak title=Staff}

Staff

The multidisciplinary team gathered from the R&D cluster research group has been working under the BEC umbrella and is comprised of 20 staff from BIOTEC, including 12 Ph.Ds. and 8 M.Sc.s., while there is 55 staff (Full Time Equivalent) from KMUTT, including 28 Ph.Ds. and 27 M.Sc.s.. In addition, there are also 16 Ph.D. students and 54 M.Sc. students who are undergoing researches under the supervision of the Unit's researchers. Assoc.Prof.Dr.Solot Suwanayuen has

guided BEC as a Director since the establishment of the Unit in 1986.

{mospagebreak title=Achievements-
Technology}

Achievements

1. Technology transferred or ready to be transferred to industry

Algal Biotechnology

• **Mass Cultivation Technology:** Mass cultivation of Spirulina technology has been developed from local strain selection to pilot and industrial scale cultivation. The research involved the use of tapioca starch waste water as substrate for Spirulina cultivation in order to reduce production costs. Four pilot concrete raceway-type ponds equipped with paddle wheels provided encouraging results: the harvested slurry was sun-dried, the final product containing 55% protein and 7% moisture. The investment and annual production cost for Spirulina biomass was estimated for a plant covering a total production area of 1.5 hectares with a productivity of 40 tons per year; the operating cost was between \$6,000 and \$7,000 per ton. After the completion of the project, the technology developed was transferred to the private sector where dried Spirulina is produced as high-protein feed for animals (e.g. shrimp and fish). As Spirulina biomass can be used either as a food supplement for direct human consumption or as feed supplement for animals, commercial production is likely to increase for the health product market.

Microbial Bioprocess Development and Pilot Plant Fermentation

• **Pilot Scale Fermentation for microbial production, Baker's Yeast, Bacillus subtilis :** Local strains with high yield have been selected and cultivated from laboratory experimentation to commercial scale with an extensive range of fermentors from 5 litres up to 1,500 litres. Using locally designed pilot plant fermentation facilities, the Unit has enabled potential private sector clients to carry out small-scale production runs for feasibility testing, cost predictions or optimization of processing steps and production of prototype products for market testing.

Sensor Technology

• Screen-printed electrodes for blood-glucose determination: Screen-printing seems to be one of the most promising technologies which will enable biosensors to be produced on a large scale in the near future. This method boasts several advantages, including compactness, versatility and low cost, thus holding out the possibility of mass production. In this research, screen-printed electrodes have been constructed based on hydrogen peroxide-sensing electrodes. Commercially available rhodium-on-carbon was used as the electrode base material. In addition, glucose oxidase was mixed with catalytic ink to form "biocomposite" ink, which was then screen-printed onto the substrate, producing glucose biosensors in a single, one-step procedure. This existing technique offers greater speed and simplicity in the manufacturing process.

Food Technology and Engineering

• Development of thermal processing: A sterilization process for canned food production by retort has been developed. This involved the development of design software using experimental data. A heat penetration database of Thai canned food has been developed following systematic collection of data. This standard database will help reduce the expensive and time-consuming procedure to determine the optimal thermal process for new products. The prototype still retort with over pressure that has been developed will help SMEs to develop their new products with more attractive packaging through the sterilization of pouches, bottles and other plastic packaging using the special retort to maintain their shape and seal during processing.

Systems Biology and Bioinformatics

• Development of software: As lipids have become interesting compounds in biotechnological industries because of their broad functions applicable to medical, pharmaceutical, and oleo-chemical industries, the insightful understanding into the lipid biosynthesis of the producer strains will lead to the rational strain improvement. A prototype of user-friendly genome-scale model of *Saccharomyces cerevisiae* was developed using systems biology and bioinformatics approach and used to simulate the effect of genes/enzymes on the cellular growth and lipid productions. This in silico approach would enable rational metabolic pathway alterations at the genetic level for improved cellular properties especially the overproduction of certain lipids and essential fatty acids then cut down the time used for laboratory validation experiments.

{mospagebreak title=Achievements-
Services
Patents/Awards}

2. Technical Services and Industrial Linkages

In recognizing the importance of agro-industry and the biotechnology industry as a basis for development in Thailand, particular attention has been given to research and development and transfer of in-house research in these specific areas. BEC has initiated several successful linkages between government and the private sector through contract research, technology transfer and technical services. Technical services offering include design and construction of pilot/industrial scale processes, technical and administrative consultancy, feasibility studies, training and analytical services. BEC has transferred some of the developed technology and provided some technical services to interested private entrepreneurs. Examples are:

- Pilot scale production of pressed yeast for Bioman Co.Ltd.
- Pilot scale production of Bacillus subtilis for probiotics market trial in animal feed industry for Grand Siam Co.Ltd.
- Pilot Plant fermentation services for microbial production applied to waste water treatment in the shrimp farming industry: Grandness Integration Co. Ltd., Allvet Co. Ltd. and T.C. Union Co. Ltd.
- Incubator hire service for Mighty International Co. Ltd. for yeast production testing.
- Cooperative research with Biowealth Co. Ltd. to conduct fungal fermentation for enzyme production to be applied for probiotics in the animal feed industry.

3. Training and Workshops

BEC offers high quality technical training, seminars and workshops at both the national and regional levels whereby participants have the opportunity to get hands-on experience and to design experiments suitable to their needs. Those attending these courses are from both the government and private sector. Some of the successful activities and continuing programs are:

- Mass Cultivation of Spirulina
- Regional mini-symposium on bio sensor and chemical sensor technology
- Bioinformatics as a Tool for Gene Manipulation
- Metabolic Engineering and Functional Genomics
- Advanced Fermentation Technology
- Practical approach to fermentation technology workshop
- Comparative microbial genomics workshop
- Animal Cell Culture and Applications

4. Human Resource Development

During the period 2000-2007, there were 246 graduates (12 Ph.D. and 234 M.Sc. students) affiliated with BEC research groups. At present there are 74 students who are working in the laboratories, 16 Ph.D. and 54 M.Sc. students. BEC expects to maintain a ratio for the number of students to Ph.D. research staff as 4:1 for M.Sc. students and 2:1 for Ph.D. students.

5. Patents

To date, BEC has filed for 6 patents as follows:

- DNA probes specific to Methanogens (1999). [link to ECoWaste]
- Nucleotide and Amino Acid Sequence of D 12 desaturase of *Mucor rouxii* ATCC 24905 (2000).
- Nucleotide and amino acid sequences of D 6 -desaturase gene of *Mucor rouxii* ATCC 24905, Thai Patent Filed: September, 2000.
- Nucleotide and amino acid sequences of D 6 -desaturase isoform II of *Mucor rouxii* ATCC 24905, Thai Patent Filed: January, 2004.
- Development of D 6 -desaturase isoform II enzyme of *Mucor rouxii* involved in synthesis of essential fatty acids, gamma-linolenic and stearidonic acids by site-directed mutagenesis, Thai Patent Filed: 28 September, 2005.
- Production of Gamma-linolenic acid (GLA) and alpha-linolenic acid (ALA) using the delta-6-desaturases and delta-12-desaturase genes from *Spirulina platensis* in yeast cells, *Saccharomyces cerevisiae* , Thai Patent Filed: October, 2006.

6. Awards

- The Thailand Toray Science Foundation (TTSF) Science and Technology Award in 2003 in recognition of the BEC unit on outstanding achievements in science and technology works.
- "High Rate Anaerobic Fixed Bed Reactor for Agro-Industrial Wastewater Treatment"; Research Award in Industrial Research and Engineering field from National Research Council of Thailand. [link to ECoWaste]
- "Thai Biogas Plants - High Rate Anaerobic Fixed Film Technology for Agro-industrial Wastewater"; The Best Program on New and Renewable Sources of Energy (Off-grid) in Year 2003 from Department of Alternative Energy Development and Efficiency, Ministry of Energy. [link to ECoWaste]

{mospagebreak title=Achivements-
Publications
Conference}

7. Publications and Conference Proceedings

During 1993-2003, BEC has published 76 international publications, 5 national publications, 76 international proceedings and 66 national proceedings. The list of international publications is as follows.

- Cohen, Z.; Ruengichatchawalya, M.; Siangdung, W.; Tanticharoen, M. “Production and partial purification of g - linolenic acid and some pigments from *Spirulina platensis* ” *Journal of Applied Phycology* 1993, 5:109-115
- Tanticharoen, M.; Bunnag, B.; Vonshak, A. “Cultivation of *Spirulina* using Secondary treated starch waste water” *Australasian Biotechnology* 1993, 3:223-226.
- Cohen, Z.; Ruengichatchawalya, M.; Siangdung, W.; Tanticharoen, M.; Heimer, Y.M. “Herbicide-resistant Lines of microalgae: growth and fatty acid composition” *Phytochemistry* 1993, 34 (4):973-978.
- Chanawongse, L.; Lee, Y.K.; Bunnag, B.; Tanticharoen, M. “Productivity of the cyanobacterium *Spirulina platensis* in cultures using sunlight” *Bioresources Technology* 1994, 48:143-148.
- Tanticharoen, M.; Ruengichatchawalya, M.; Bunnag, B.; Vonktaveesuk, P.; Vonshak, A.; Cohen, Z. “Optimization of g - linolenic acid (GLA) production in *Spirulina platensis* ” *Journal of Applied Phycology* 1994, 6:295-300.
- Vonshak, A.; Chanawongse, L.; Bunnag, B.; Tanticharoen, M. “Physiological characterization of *Spirulina platensis* isolates: Response to light and salinity” *Plant Physiology* 1995, 14:161-166.
- Vonshak, A.; Kancharaksa, N.; Bunnag, B.; Tanticharoen, M. “Role of light and photosynthesis on the acclimation process of the cyanobacterium *Spirulina platensis* to salinity stress” *Journal of Applied Phycology* 1996, 8:119-124.
- Somasundrum, M.; Kirtikara, K.; Tanticharoen, M. “Amperometric determination of hydrogen peroxide by direct and catalytic reduction at a copper electrode” *Analytica Chimica Acta* 1996, 319:59-70.
- Vonshak, A.; Chanawongse, L.; Bunnag, B.; Tanticharoen, M. “Light acclimation and photoinhibition in three *Spirulina platensis* (cyanobacteria) isolates” *Journal of Applied Phycology* 1996, 8:35-40.
- Somasundrum, M.; Tanticharoen, M.; Kirtikara, K. “H₂ O₂ from an oxidase enzyme can be detected cathodically using metal-dispersed conducting polymer film” *Journal Electroanalytical Chemistry* 1996, 407:247-251.
- Somasundrum, M.; Tongta, A.; Tanticharoen, M.; Kirtikara, K. “A kinetic model for the reduction of enzyme - generated H₂ O₂ at a metal-dispersed conducting polymer film” *Journal Electroanalytical Chemistry* 1997 , 440:259-264.
- Kiattipoomchai, M.; Somasundrum, M.; Tanticharoen, M.; Kirtikara, K. “Measurement of sulfite at oxide-coated copper electrodes” *Analytica Chimica Acta* 1998 , 123:2017-2019.
- Nomsawai, P.; Tanticharoen, M.; Cheevadhanarak, S. “Light regulation of phycobilisome structure and gene expression in *Spirulina platensis* C1 (*Arthrospira* sp. PCC9438)” *Plant Cell Physiol o gy* 1999, 40(12):1194-1202.
- Surareungchai, W.; Worasing, S.; Sritongkum, P.; Tanticharoen, M. “Dual electrode signal-subtracted bio sensor for simultaneous flow injection determination of sucrose and glucose.” *Analytica Chimica Acta* 1999 , 380:7-15.
- Samarntarn, W.; Cheevadhanarak, S.; Tanticharoen, M. “Production of alkaline protease by genetic ally engineered *Aspergillus oryzae* U1521. ” *Journal General Applied Microbiology and Biotechnology* 1999, 45:99-103 .

- Arjsriwat, S.; Tanticharoen, M.; Kirtikara, K.; Aoki, K.; Somasundrum, M. “Metal – dispersed Conducting polymer – Coated Electrode used for Oxidase – based Bio sensor .” *Electrochemistry Communication* 2000, 2:441-444.
- Laoteng, K.; Monnontara, R.; Tanticharoen, M.; Cheevadhanarak, S. “Delta 6 desaturase of *Mucor rouxii* with high similarity to Plant delta 6–desaturase and its Heterologous Expression in *Saccharomyces cerevisiae* .” *Biochemical and Biophysical Research Communications* 2000 , 279:17-22.
- Passorn, S.; Laoteng, K.; Rachadawong, S.; Tanticharoen, M.; Cheevadhanarak, S. “Heterologous Expression of *Mucor rouxii* D 12 Gene in *Saccharomyces cerevisiae* .” *Biochemical and Biophysical Research Communications* 1999 , 263:47-51.
- Deshniun, P.; Paitoonrangsarid, K.; Suphatrakul, A.; Meesapyodsuk, D.; Tanticharoen, M.; Cheevadhanarak, S. “Temperature-independent and dependent expression of desaturase genes in filamentous cyanobacterium *Spirulina platensis* C1 (*Arthrospira* sp. PCC9438)” *FEMS Microbiology Letter* 2000, 184:207-213.
- Surareungchai, W.; Kasiwat, D. “Electroanalysis of tert-Butylhydroquinone in Edible Oil at a Nafion – Coated Probe.” *Electroanalysis* 2000, 12(14):1124-1129.
- Laoteng, K.; Anjard, C.; Rachadawong, S.; Tanticharoen, M.; Maresca, B. “ *Mucor rouxii* D 9 Desaturase Gene is Transcriptionally Regulated during Cell Growth and by Low Temperature.” *Molecular Cell Biology Research Communications* 1999 , 1:36-43.
- Jaturapat, A.; Isaka, M.; Hywel-Jones, NL.; Lertwerawat, Y.; Kamchonwongpaisan, S.; Kirtikara, K.; Tanticharoen, M.; Thebtaranonth, Y. “Biosanthracenes from the Insect Pathogenic Fungus *Cordyceps pseudomilitaris* BCC 1620. I. Taxonomy, Fermentation, Isolation and Antimalarial Activity.” *The Journal of Antibiotics* 2001 , 54(1):29-35.
- Isaka, M.; Jaturapat, A.; Kladwang, W.; Panya, J.; Lertwerawat, Y.; Tanticharoen, M.; Thebtaranonth, Y. “Antiplasmodial compounds from wood-decayed fungus *Xylaria* sp. BCC 1067” *Planta Medical* 2000, 66:473-475.
- Meesapyodsuk, D.; Reed, D.W.; Cheevadhanarak, S.; Deshniun, P.; Covello, P.S. “Probing the mechanism of a cyanobacterial D 9 Fatty acid desaturase from *Spirulina platensis* C1 (*Arthrospira* sp. PCC9438)” *Comparative Biochemistry and Physiology Part B* 2001, 129:831-835.
- Thammarongtham, C.; Turner, G.; Moir, A.J.; Tanticharoen, M.; Cheevadhanarak, S. “A new class of glutaminase from *Aspergillus oryzae* .” *Journal of Molecular Microbiology and Biotechnology* 2001, 3(4) (Oct):611-617.
- Surareungchai, W.; Deepunya, W.; Tassakorn, P. “Quadruple-pulsed amperometric detection for simultaneous flow injection determination of glucose and fructose” *Analytica Chimica Acta* 2001 , 448:215-220.
- Chaiprasert, P.; Bhumiratana, S.; Tanticharoen, M. “Mesophilic and Thermophilic Anaerobic Digestion of Pineapple Cannery Wastes” *Thammasat International Journal of Science and Technology* 2001 , 6 (2):1-9.
- Ruengitchatchawalya, M.; Chirasuwan, N.; Chaiklahan, R.; Bunnag, B.; Deshniun, P.; Tanticharoen, M. “Photosynthetic characteristics of a mutant of *Spirulina plantensis* ” *Journal of Applied Phycology* 2002 , 14:71-76.
- Posayapisit, N.; Pumputsa, K.; Mekvichitsaeng, P.; Techkarnjanaruk, S. “Phylo genetic analysis of Baculovirus chitinase sequence” *Chitin Enzymology* 2001, 343-350.
- Suriyawattanakul, L.; Surareungchai, W.; Sritongkum, P.; Tanticharoen, M.; Kirtikara, K. “The use of co-immobilization of *Trichosporon cutaneum* and *Bacillus licheniformis* for a BOD sensor ” *Applied Microbiology and Biotechnology* 2002, 59:40-44.
- Na Nakon P., Suphantharika M., Udomsopagit S., and Surareungchai W. "Poly (vinylferrocene)-Polyethylene Glycol Glutamate Oxidase Electrode for Determination of Glutamate in Commercial Soy Sauces." *Journal of Microbiology & Biotechnology* 2003, 19, 479-485.
- Khunyoshyeng, S.; Cheevadhanarak, S.; Rachdawong, S.; Tanticharoen, M. “Differential expression of desaturases and changes in fatty acid composition during sporangiospore germination and development in *Mucor rouxii* .” *Fungal Genetics and Biology* 2003 , 37, 13-21.

- Laoteng, K.; Pongchuachidthai, R.; Rueksomtawin, K.; Dandusitapunth, Y.; Tanticharoen, M.; Cheevadhanarak, S. “A *Mucor rouxii* mutant with high accumulation of an unusual trans -linoleic acid (9c, 12 t -C18: 2)” FEMS Microbiology Letters 2003, 10993, 1-7.
- Suvajittanont, W.; Chaiprasert, P. “Potential of biogas recirculation to enhance biomass accumulation on supporting media” Bioresource Technology 2003 , 88(2) , 157-162.
- Chaiprasert, P., W. Suvajittanont, B. Surarak, M. Tantichroen, and S. Bhumiratana. “ Nylon fiber as supporting media in anaerobic hybrid reactors: its effects on system's performance and microbial distribution .” Water Research , 2003, 37, 4605-4612.
- Devahastin, S.; Suvarnakuta, P.; Soponronnarit, S.; Mujumdar, A.S. “A Comparative Study of Low-Pressure Superheated Steam and Vacuum Drying of a Heat-Sensitive Material,” Journal of Drying Technology – An International 2004, 22(8).
- Namsanguan, Y.; Tia, W., Devahastin, S.; Soponronnarit, S. “Drying Kinetics and Quality of Shrimp Undergoing Different Two-Stage Drying Processes,” Journal of Drying Technology – An International 2004, 22(4), pp. 759-778.
- Wiyarath, W.; Somasundrum, M. and Surareungchai, W. “A voltammetric sensor for general purpose organohalide at picogramper-litre concentrations based on a simple collector-generator method” Journal of Analytical Chemistry 2004, Vol.76, pp.859-862.
- Ngamchana, S.; Surareungchai, W. “Sub-millimolar determination of formalin by pulsed amperometric detection” Journal of Analytica Chimica Acta 2004, Vol. 510, pp.195-201.
- Hongsthong, A.; Subudhi, S.; Sirijuntarat, M. and Cheevadhanarak, S. “Mutation study of conserved amino acid residues of *Spirulina r 6* - acyl-lipid desaturase showing involvement of histidine 313 in the regioselectivity of the enzyme” Journal of Applied Microbiology and Biotechnology 2004, 66:74-84
- Hongsthong, A.; Paithoonrangarid, K.; Prapugrangkul, P.; Deshniem, P.; Sirijuntarut, M.; Subhudhi, S.; Cheevadhanarak, S. and Tantichroen, M. “The expression of three desaturase genes of *Spirulina platensis* in *Escherichia coli* DH5 alpha.” Journal of Molecular Biology Reports 2004, 31:177-189
- Ruengjitchatchawalya, M.; Kovács, L.; Mapaisansup, T.; Sallai, A.; Gombos, Z.; Ponglikitmongkol, M. and Tanticharoen, M. “Higher plant-like fluorescence induction and thermoluminescence characteristics in cyanobacterium, *Spirulina* mutant defective in PQH 2 oxidation by cyt b 6 / f complex” Journal of Plant Physiology 2005, 162: 1123-1132.
- Wiyaratn, W.; Somasundrum, M. and Surareungchai, W. “Votammetric detection of organohalides by redox catalysis: Improved sensitivity by immobilisation within a cubic phase liquid crystal” Journal of The Analyst, (2005), 130:626-631 and Also highlighted as a Hot Paper on The RSC website and highlighted in Chemical science 2005, 2:C41
- Wiyaratn, W.; Hrapovic, S.; Liu, Y.; Surareungchai, W.; Luong, J.H.T. “Light-assisted synthesis of Pt-Zn porphyrin nanocomposites and their use for electrochemical detection of organohalides” Analytical Chemistry 2005, 77:5742-5749.
- Rijiravanich, P.; Aoki, K.; Chen, J.; Surareungchai, W. and Somasundrum, M. “Electrode reactions of catechol at tyrosinase-immobilized latex suspensions” Journal of Electroanalysis 2004, 16:605-611.
- Loetanantawong, B. ; Suracheep, C. ; Somasundrum, M.; Surareungchai, W. “Electrocatalytic Tetracycline Oxidation at a Mixed-Valent Ruthenium Cyanide-Modified Glassy Carbon Electrode and Determination of Tetracyclines by Liquid Chromatography with Electrochemical Detection” Journal of Analytical Chemistry , 2004, 76: 2266-2272
- Laoteng, K.; Ruenwai, R.; Tanticharoen, M. and Cheevadhanarak, S. “Genetic modification of essential fatty acids biosynthesis in *Hansenula polymorpha*” Journal of Microbiology Letters 2005, 245:169-178.
- Na-Ranong, S.; Laoteng, K.; Kittakoop, P.; Tantichareon, M. and Cheevadhanarak, S. Substrate specificity and preference of r 6 –deaturase of *Mucor rouxii* . Journal of FEBS Letters 2005, 579:2744-2748.
- Laoteng, K.; Cheevadhanarak, S.; Tanticharoen, M. and Maresca, B. “Promoter analysis of *Mucor rouxii* 9-desaturase: Its implication for transcriptional regulation in *Saccharomyces cerevisiae* ” Journal of Biochemical and Biophysical Research Communications 2005, 335 :400-405.

- Meechai, A.; Pongakarakun, S.; Deshniem, P.; Cheevadhanarak, S. and Bhumiratana, S. “Metabolic flux distribution for g -linolenic acid synthetic pathways in *Spirulina platensis* ” *Journal of Biotechnol. Bioprocess Eng* 2004, 9(6):506-513.
- Jupraputtasri, W.; Cheevadhanarak, S.; Chaiprasert, P.; Tanticharoen, M. and Techkarnjanaruk, S. “Use of Fluorochrome-Labeled rRNA Targeted Oligonucleotide Probe and Tyramide Signal Amplification to Improve Sensitivity of Fluorescence in situ Hybridization. *Journal of BioScience and Bioengineering* 2004, 98(4):282-286.
- Jupraputtasri, W.; Cheevadhanarak, S.; Chaiprasert, P.; Tanticharoen, M. and Techkarnjanaruk, S. “Use of an Alternative Archaea -Specific probe for Methanogen Detection” *Journal of Microbiological Methods* . 2005, 61:95-104.
- Kurdrit, P.; Subudhi, S.; Hongsthong, A.; Ruengjitchatchawala, M. and Tanticharoen, M. “Functional expression of *Spirulina* - D 6 desaturase gene in yeast, *Saccharomyces cerevisiae*” *Journal of Molecular Biology Reports* 2005, 32: 215-226.
- Wachiraphansakul, S. and Devahastin, S. “Drying Kinetics and Quality of Soy Residue (Okara) Dried in a Jet Spouted Bed Dryer” *Journal of Drying Technology*, 2005, Vol. 23, No. 6, pp. 1229-1242.
- Na-Ranong, S.; Laoteng, K.; Kittakoop, P.; Tanticharoen, M. and Cheevadhanarak, S. “Targeted mutagenesis of a fatty acid D 6 -desaturase from *Mucor rouxii* : Role of amino acid residues adjacent to histidine-rich motif II” *Journal of Biochemical and Biophysical Research Communications* 2005, 339:pp.1029-1034.
- Jeennor, S.; Laoteng, K.; Tanticcharoen, M. and Cheevadhanarak, S. “Comparative fatty acid profiling of *Mucor rouxii* under different stress conditions” *Journal of FEMS Microbiol Lett* 259 2006, pp.60-66.
- Kurdrit, P., Subudhi, S., Cheevadhanarak, S. Tanticharoen, M. and Hongsthong, A . 2006. Effect of two intermediate electron donors, NADPH and FADH 2 , on *Spirulina delta* 6 desaturase co-expressed with two different immediate electron donors, cytochrome b5 and ferredoxin, in *Escherichia coli*. *Journal of Molecular Biology*, Oct 2006 published on-line.
- Hongsthong, A., Subudhi, S., Sirijuntarut, M., Kurdrid, P., Cheevadhanarak, S. and Tanticharoen, M. 2006. Revealing the complementation of ferredoxin by cytochrome b 5 in the *Spirulina* - D 6 -desaturation reaction by N-terminal fusion and coexpression of the fungal-cytochrome b 5 domain and *Spirulina* - D 6 -acyl-lipid desaturase. *Journal of Applied Microbiology and Biotechnology* . 72 (6), 1192-1201.
- Hongsthong, A., Sirijuntarut, M., Thammathorn, S., Prommenate, P., Bunnag, B., Cheevadhanarak, S., and Tanticharoen, M. 2007. Revealing differentially expressed proteins in two morphological forms of *Spirulina platensis* by proteomic analysis. *Journal of Molecular Biotechnology* . 36(2), 123-130.
- Rijiravanich, P., Aoki, K., Chen, J., Surareungchai, W. and Somasundrum, M. Micro-cylinder bio sensor for phenol and catechol based on layer-by-layer immobilization of tyrosinase on latex particles: Theory and experiment. *Journal of Electroanalytical Chemistry* 589 (2006) 249-258.
- Punbusayakul, N., Ci, L., Talapatra, S., Surareungchai, S. and Ajayan, P.M. 2007. Double-Walled Carbon Nanotube Electrodes for Electrochemical sensing. *Journal of Electrochemical and Solid-State Letter*, 10(5) F13-F17.
- Chiewchan, N., Pakdee, W., and Devahastin, S., 2007, Effects of Water Activity and Hot Air Drying on Thermal Resistivity of *Salmonella krefeld* on Rawhide Surface , *International Journal of Food Microbiology* , Vol. 114, No. 1, pp. 43-49. (February 28).
- Pimpaporn, P., Devahastin, S., and Chiewchan, N., 2007, Effects of Combined Pretreatments on Drying Kinetics and Quality of Potato Chips Undergoing Low-Pressure Superheated Steam Drying , *Journal of Food Engineering* , Vol. 81, No. 2, July, pp. 318-329.
- Nimmol, C., Devahastin, S., Swasdisevi, T., and Soponronnarit, S., 2007, Drying of Banana Slices Using Combined Low-Pressure Superheated Steam and Far-Infrared Radiation , *Journal of Food Engineering* , Vol. 81, No. 3, August, pp. 624-633.
- Kerdpi boon, S. and Devahastin, S., 2007, Fractal Characterization of Some Physical Properties of a Food Product under Various Drying Conditions, *Drying Technology* , Vol. 25, No. 1, pp. 135-146.
- Thomkapanich, O., Suvarnakuta, P., and Devahastin, S., 2007, Study of Intermittent Low-Pressure Superheated Steam and Vacuum Drying of a Heat-Sensitive Material, *Drying Technology* , Vol. 25, No. 1, pp. 205-223.

- Wachiraphansakul, S. and Devahastin, S., 2007, Drying Kinetics and Quality of Okara Dried in a Jet Spouted Bed of Sorbent Particles , LWT - Food Science and Technology , Vol. 40, No. 2, March, pp. 207-219.
- Panyawong, S. and Devahastin, S. “ Determination of Deformation of a Food Product Undergoing Different Drying Methods and Conditions via Evolution of a Shape Factor ” Journal of Food Engineering , 2007, Vol. 78, No. 1, January, pp. 151-161.
- Kerdpi boon, S.; Kerr, W.L.; Devahastin, S. “ Neural Network Prediction of Physical Property Changes of Dried Carrot as a Function of Fractal Dimension and Moisture Content ” Journal of Food Research International , 2006, Vol. 39, No. 10, December, pp. 1110-1118.
- Kongsoontornkijkul, P.; Ekwongsupasarn, P.; Chiewchan, N. and Devahastin, S. "Effects of Drying Methods and Tea Preparation Temperature on the Amount of Vitamin C in Indian Gooseberry Tea” Journal of Drying Technology , 2006, Vol. 24, No. 11, pp. 1509-1513.
- Leeratanarak, N.; Devahastin, S. and Chiewchan, N. “ Drying Kinetics and Quality of Potato Chips Undergoing Different Drying Techniques ” Journal of Food Engineering , 2006, Vol. 77, No. 3, December, pp. 635-643.
- Srisamran, C. and Devahastin, S. “ Numerical Simulation of Flow and Mixing Behavior of Impinging Streams of Shear-Thinning Fluids ” Journal of Chemical Engineering Science , 2006, Vol. 61, No. 15, August, pp. 4884-4892.
- Devahastin, S.; Tapaneyasin, R.; and Tansakul, A. “ Hydrodynamic Behavior of a Jet Spouted Bed of Shrimp ” Journal of Food Engineering, 2006, Vol. 74, No. 3, June, pp. 345-351.
- Devahastin, S. and Pitaksuriyarat, S. “ Use of Latent Heat Storage to Conserve Energy during Drying and Its Effect on Drying Kinetics of a Food Product ” Journal of Applied Thermal Engineering , 2006, Vol. 26, No. 14-15, October, pp. 1705-1713.
- Laoteng, K.; Jitsue, S.; Dandusitapunth, Y. and Cheevadhanarak, S. “ Ethanol-induced changes in expression profiles of cell growth, fatty acid and desaturase genes of *Mucor rouxii* ” Journal of Fungal Genet Biol, April 2007 published on-line.
- Nookaew, I. ; Meechai, A.; Thammarongtham, C.; Laoteng, K.; Ruanglek, V.; Cheevadhanarak, S.; Nielsen, J. and Bhumiratana, S. “ Identification of Flux Regulation Coefficients from Elementary Flux Modes: A new tool in systems biology for analysis of metabolic networks” Journal of Biotechnology and Bioengineering . 2007, 97(6), 1535-1549.

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Performance
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Key Performance Index (KPI)

Key Performance Indicators have recently been introduced to BEC as a means to help measure the efficiency, effectiveness, productivity and sustainability of the Unit and its work. Data is generated to provide KPI indicators that demonstrate effectiveness in research and development work. This includes amount and source of research funding, contract research and number of publications, which better helps to show the efficient use of research funds per Full Time Equivalence (FTE) Ph.D. research staff and publications per FTE Ph.D. research staff, although it should be

emphasized that BEC is not a publications-driven research unit. Performance indicators such as total income per total salary and number of M.Sc./Ph.D. students per FTE Ph.D. research staff are also used to measure the productivity and sustainability of the Unit.