# CHINA NSFC—US NSF WORKSHOP ON SUSTAINABLE MANUFACTURING

Towards Competitive Sustainable Manufacturing through Collaboration

# PROGRAM BOOK

WUHAN, CHINA

MARCH 13-15, 2014

# CHINA NSFC–US NSF WORKSHOP ON SUSTAINABLE MANUFACTURING:

## Towards Competitive Sustainable Manufacturing through Collaboration

# Program Book

**Wuhan, China**
**March 13-15, 2014**

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| 8:30-8:40 |  | **NSFC opening remarks**<br>Qin Wei, Program Manager, Division for Americas and Australian Affairs, Bureau of International Cooperation, NSFC |
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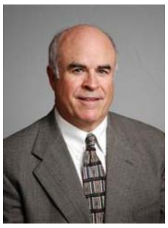
| 8:50-9:20 |  | **Process Energy Systems: Control, Economic, and Sustainability Objectives**<br>Thomas F. Edgar<br>McKetta Department of Chemical Engineering<br>University of Texas at Austin,USA |
| 9:20-9:50 |  | **Energy Efficiency of Machining Systems**<br>Huajun Cao<br>Department of Mechanical Engineering<br>Chongqing University, China |

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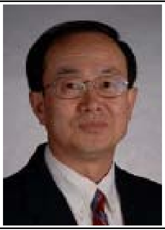
| 16:21-16:33 |  | **Challenges of End-of-Life Electric Vehicle Battery Treatments**<br>Hong C. Zhang<br>Department of Industrial Engineering<br>Texas Tech University, USA |
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| 10:45-11:45 | Group reports on Sustainable Products and Processes and Sustainable Manufacturing Systems |
| | Discussion on U.S.-China Collaboration: Research Areas and Collaboration Strategies |
| | Workshop summary |
| **Closing Ceremony**<br>Chair: **Qin Wei**, Program Manager, Division for Americas and Australian Affairs, Bureau of International Cooperation, NSFC | |
| 11:50-12:00 |  **Yinan Lai**<br>Program Director, Mechanical Engineering Division<br>Department of Engineering and Material Sciences, NSFC |
| |  **Bruce Hamilton**<br>Program Director, Environmental Sustainability<br>US NSF |
| 12:00-13:30 | Break |
| 13:30-17:00 | Local tour |

# 2. PRESENTATION ABSTRACTS

## *Keynote Speech*

### Process Energy Systems: Control, Economic, and Sustainability Objectives

Thomas F. Edgar, McKetta Department of Chemical Engineering, University of Texas at Austin, Austin, TX 78712, USA

Economic, energy, and sustainability metrics are key performance indicators for process operations. The relative importance of these metrics varies from plant to plant, and often some metrics are in conflict with each other (sustainability vs. profitability), so it is important to determine how various metrics can be aligned by focusing on energy efficiency. Power-steam systems are the major energy drivers for most plants, and design changes to enable combined heat and power (CHP), operational changes to improve energy efficiency, and application of process control, sensing, and optimization are key. Managing the interplay of real-time optimization and regulatory control is a challenge for the future, as well as interfacing with the implementation of smart power grids by the utility industry. Combined heat and power along with energy storage presents interesting control and optimization opportunities to maximize energy efficiency and minimize peak power. The broad viewpoint of smart manufacturing encompasses these technologies and bridges the machine to plant to supply chain levels (enterprise perspective).

### Energy Efficiency of Machining Systems

Huajun Cao, Institute of Manufacturing Engineering, Chongqing University，Chongqing 400030, China, E-mail: hjcao@cqu.edu.cn

Energy usage in machining systems is quite huge, and the improvement of energy efficiency is of significantly importance in machining systems. In this presentation, a thorough state of the art review of the layered distribution of energy consumption in mechanical manufacturing systems is proposed. It can be found that there exists great potential for energy saving in machining. Based on our team's researches, we propose several strategies to improve energy efficiency: a) Optimization of NC code of machining processes to reduce unnecessary energy waste; b) Scheduling for energy saving in manufacturing system; c) Improving equipment utilization could significantly improve efficiency of production system by reducing the waste of equipments' productivity; d) Upgrading and re-manufacturing of equipment to improve the efficiency of the old equipments technically. In order to clearly predict the energy consumption and energy efficiency before real machining, an energy consumption prediction model is proposed by our current study. We use the basic data of the machine tools and workpieces, and the process plans to achieve this prediction, so that it is capable to provide supports for evaluating energy efficiency in machining systems, setting work piece energy consumption quota, optimizing the cutting parameters and optimizing the process planning for reducing energy consumption. But for practical application, some problems need to be solved: a) The practical machining process of a work piece consists of a lot of the start-up periods, idle periods and cutting periods, so how to predict for the whole machining process? b) The present methods by modeling and simulating are based on the historical production information and data base of energy consumption, but how to predict the energy consumption of a new workpiece? c) The additional load loss in machining is very complicated and cannot be neglected, which sometimes is more than 20% of the cutting energy, so how to predict the value of the additional load loss? However, the method proposed in this presentation is going to solve all the above problems. Finally, we will provide some useful and constructive suggestions and conclusions.

## Sustainable Product and Process Design

Bert Bras, George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332, USA

The environmental problems from our current products and process systems are probably not solvable by a “silver bullet” technology. Rather, systems-based solutions are needed that require a comprehensive systems approach in which multiple stakeholders from various disciplines like engineering, environmental science, management, economics, and policy all work together.

In this presentation, we emphasize the need for considering sustainable design of products and processes from a systems perspective. Critical elements needed to achieve a systems view and move to sustainability are life-cycle thinking, systems modeling and assessment, inclusion of geospatial locality information and characteristics, and understanding societal and human behavior. We will use examples from past and present projects to illustrate the importance of these elements. Especially proper systems modeling and life-cycle assessments are needed in order to avoid unintended consequences, especially because products are starting to become much more part of larger product systems. For example, an electric vehicle now shares the electrical energy infrastructure with a house. It also connects to telecommunication products. Proper design of products as parts of a larger product system for a consumer may lead to larger sustainability gains than designing the each product separately.

Human behavior may have a much larger effect on overall system sustainability than any engineering decision. The importance of including user behavior in product design for sustainability cannot be underestimated. Over and over we see that affluence leads to greater material and energy consumption. Thus, despite relative gains in product and process design, we are not gaining in absolute sense with respect to reducing environmental impact and increasing sustainability. This applies both to products as well as manufacturing processes.

## Smart Manufacturing through Innovative Knowledge Extraction Methodologies in the "Big Data" Era

Jinsong Zhao, Department of Chemical Engineering, Tsinghua University, Beijing, China

As a pillar industry, the chemical process industry has been growing rapidly in China in the recent years. Fast economic development and slow process safety technology and management advancement have resulted in numerous disasters. For example, on November 22, 2013, a Sinopec's crude oil pipeline in Qingdao, China exploded, which resulted in 62 deaths and 132 injuries. Over ten thousand square meters of the nearby sea water was polluted by the released crude oil. The direct cost was over 700 million RMB. Afterwards, Sinopec announced the permanent shutdown of the pipeline. Manufacturing in the downstream of the pipeline was therefore severely affected. Process safety management (PSM) has been widely recognized as the key to major accident prevention since the U.S. OHSA's PSM standard was promulgated in 1992. However, with the increased complexity and scale of the chemical processes, it is rather difficult for a chemical company, especially a big corporation to fully comply with the PSM standard. Therefore, major chemical accidents such the 2005' BP Texas City refinery accident and the 2005's UK Buncefield oil tank farm explosion accident still occur repeatedly worldwide. How to realize in-time green and safe manufacturing of chemical products still remains a significant challenge to both the academic society and the industry.

HAZOP has been a best practice of risk analysis of chemical processes. However, it is a time-consuming and labor-intensive process. It takes weeks for a HAZOP team to complete the HAZOP analysis of a typical chemical process. Therefore it is hard to keep the consistency of the HAZOP analysis's quality. Potential hazards in some operation modes may be overlooked. Usually the HAZOP reports are more than 100 pages long. Huge data and information are embedded in hundreds of HAZOP reports in a chemical company. Knowledge management tools such as case-based reasoning and ontology are adopted to facilitate the HAZOP knowledge management. Although different versions of intelligent HAZOP software has been developed and deployed, how to manage other tacit PSM knowledge needs further research.

Alarm systems have been stored in almost all of the chemical processes. However, the operators become bewildered when alarm flooding occurs. Chemical process fault detection and diagnosis (FDD) technologies such as principle component analysis (PCA) and artificial neural networks have been studied for more than a half century. However, the chemical industry is still lack of the off-the-shelf FDD tools that can reliably diagnose abnormal situations in a chemical process because the current FDD technologies heavily rely on fault data samples which are very scarce in reality. With the advance of information technology, the chemical industry is going through a dramatic transition from a "data poor" to a "data rich" paradigm. Past approaches developed in a "data poor" era don't work well in the new world. The "big data" era requires innovative knowledge extraction methodologies to address these challenges. The artificial immune systems developed at Tsinghua University are briefly introduced in this regard.

# *Thematic Area 1: Sustainable Products and Processes*

## *Area 1.1. Product Design Innovations for Resource Efficiency and Effectiveness*

### Molecular Modeling as an Enabling Tool in Advanced Material Research

Luke Achenie, Department of Chemical Engineering, Virginia Polytechnic and State University, Blacksburg, VA 24061, USA

In our research, we have developed in silico tools in product and process systems. In addition we have employed these tools for (a) Modeling of Advanced Inorganic-Organic Membranes, (b) CVD Modeling, (c) Computer Aided Molecular and Product Design (CAPD), and (d) Pharmacokinetic Modeling. This presentation will focus on the first two topics that are advanced materials related and also have relevance to sustainability and sustainable manufacturing. We have developed a molecular dynamics (MD) modeling framework for the mechanistic understanding of and development of advanced inorganic-organic membranes. These membranes are employed for separation of gases from fracking (leading to shale gas) and fast pyrolysis. In particular I will discuss the separation of CO2/CH4 in collaboration with membrane experimentalists.

An aspect of our research involves chemical vapor deposition. Zinc sulfide has received a significant amount of attention during the last decade. Compared to other semiconductors, zinc sulfide has a large direct band gap, which makes it useful in a broad range of optical applications. These applications demand high quality zinc sulfide films, which are produced through the chemical vapor deposition method. A common cause of defects in the deposited film is due to the variability in the morphology of adducts in the gas phase and in the deposited film. We have developed a computational approach to predict the size distribution and morphology of the clusters. With this information, we have attempted to explain the link between the cluster size and the morphological defects on the deposited film.

### Method and Application of Sustainable Design for Energy and Material Saving Based on Energy Flow Analysis

Dong Xiang, Department of Mechanical Engineering, Tsinghua University, Beijing, 100084, P.R. China

With the rapid development of manufacturing industry, more and more energy and materials are consumed in the production and usage stages of electromechanical products each year. The concept that using the energy and material saving method and technology in design stage has been accepted by most of the enterprises, but the energy saving method can’t be utilized fully because the conflict often exists between the energy saving measure and performance achievement, the current design for energy saving system can’t conduct to solve the conflict effectively. As the key factor of energy saving design, energy is also an important guarantee for the performance achievement. Reasonable energy flow and distribution can reduce the energy and resource consumption as much as possible, meanwhile the product performance achievement can be fully guaranteed, the energy saving measure and performance achievement can be balanced effectively. Therefore, researching on energy and material saving of typical electromechanical products based on the energy flow analysis has important significance and practical value.

Energy flow element (EFE) is introduced as the basic object of energy flow analysis model, and its modeling process involves three key factors which are energy flow element partition, interface description, and energy change state analysis. The carrying capacity and performance influence style of components can be qualitatively achieved by analyzing the interface relations and energy change states between different energy flow elements, which are the theoretical foundation to address the conflict between the performance constraint and energy saving design measures. Based on the energy flow analysis model, two indicators of performance pertinence (PP) and performance margin (PM) are proposed to quantitatively analyze the effect of energy change and distribution for the final performance achievement. PP of component can be modeled by the numerical calculation and regression analysis of experimental data with the result of concerned parts selection. Calculation model of PM can be achieved by the analysis of expected energy distribution ratio. Considering the calculation results of PP and PM, the conflict solution guideline based on energy flow analysis is presented, which provides a method guarantee for the solution of conflict. The air duct system of split air-conditioner's outdoor unit and vehicle frame of SUV are used as the case study. Based on the energy flow analysis and calculation results, optimal solutions for the two products are proposed to improve the energy efficiency of duct system and lightweight the vehicle frame with their own performance constraint, which also verifies that the method is effective.

## Rethinking Design Scenarios through Concurrent Multi-Dimensional Exploration for Sustainable Decisions

Karthik Ramani, Department of Mechanical Engineering, Purdue University, West Lafayette, IN 47906, USA

The current scientific evidence and trends clearly indicate that our built infrastructure, product and services have to be rethought in a global context. Current climate trends together with future environmental regulations imminent in the United States, manufacturing companies are faced with the need to optimize existing product systems for environmental performance, something that often presents very difficult decision scenarios. Our point of view of manufacturing, supply chain and business decisions is through a design lens, especially at earlier stages where business and sustainability can be integrated and co-designed. The goal in such situations is to improve the environmental efficiency of the product system in question without compromising its performance, quality and deployment. Even after conducting a full-fledged life cycle assessment (LCA), it is still difficult to identify hotspots for appropriate improvements, i.e. balancing cost and operational performance with environmental performance.

Based on current challenges in eco-redesign, we motivate the need to develop new frameworks with ability to explore potential redesign scenarios. The strategy presented is to make data visible during decision-making stages in a manner to promote exploration towards providing new insights and strategies for decisions. Shape-sift: a way to browse part repositories while encoding materials and processes, as well as functionality, is presented as a way to promote energy savings at design time leading to cost savings as well as promoting sustainability. Extending environmental metrics to the system level, weighing eco-related metrics against traditional criteria and exploring alternative eco-impact schemas.

Corresponding to the research needs we also envision educational innovation through embedding sustainable thinking into existing curricula. Although various methods are currently in use for teaching sustainable design, a survey conducted among practicing student engineers shows the presence of significant knowledge gaps. To this end, we propose a problem-based framework for contextualizing sustainability assessment within design engineering curricula. Our framework makes it possible for embedding sustainability related concepts within traditional engineering courses and promote discovery learning among students by means of design exploration.

## Fabrication and Application of Ceramic-supported Polymer Composite Membranes forSustainable Energy

Wanqin Jin, State Key Lab of Materials-Oriented Chemical Engineering, Nanjing University of Technology, Nanjing, PR China

Membrane technology is recognized as an advanced and sustainable technology for water, energy and environment. Among them, pervaporation (PV) is a promising membrane-based technique for the separation of liquid chemical mixtures in the sustainable fabrication process, such as bio-fuels production, VOCs removal, gasoline desulfurization, solvent dehydration, organic/organic separation. The advantage of PV process lies in the energy savings, economic and environmental protection, and so on. For practical applications of PV technology, a composite membrane is generally employed, which has a thin dense skin layer on a porous support, and thus its flux can be increased. Recently, a type of ceramic-supported polymer composite membranes has attracted much attention due to the advantages of ceramic support in stability, mechanical strength and transport resistance.

This presentation will review our progress on the fabrication of polymer composite membranes using porous tubular and hollow fiber ceramic membranes as the support, and their applications in pervaporation process. The effects of ceramic support treatment, polymer solution properties, interfacial adhesion and incorporating inorganic fillers on the membrane structure and separation performance will be thoroughly discussed. Some in-situ characterization techniques developed for the composite membranes are also covered in the discussion. Furthermore, the industrial fabrication and application of the composite membranes for producing biofuels will be introduced. Finally, future trends of the ceramic-supported polymer composite membranes will be prospected.

## Process Safety and Engineering for Sustainable Development

M. Sam Mannan, Mary Kay O'Connor Process Safety Center, Artie McFerrin

Department of Chemical Engineering, Texas A&M University, College Station, Texas 77843, USA

Process Safety Engineering is the science of implementing into everyday engineering procedures, a broad-based understanding of the complex interaction of chemical process technology, mechanical and process design, process control, and Process Safety Management Systems (PSMS). Chemicals play a key role in today's high-tech world. The chemical industry is linked to every technologically advanced industry, and only a handful of the goods and services we enjoy on a daily basis would exist without essential chemical products. However, the use of chemicals is a two-edged sword. Safe use creates a healthier economy and a higher standard of living. Unsafe use threatens our lives, our businesses and ultimately our world.

Process safety is very closely linked to sustainable development. My vision for engineering research brings together elements of manufacturing, design and sustainable engineering in an integrated form. And interwoven through this new paradigm is the consideration of risk in every aspect. An engineer must function as a member of the global community. This means not only competing in the global marketplace, but also acting as a professional who shares the global responsibilities. These responsibilities entail proper account of the finite world resources, sensitivity to the impact on the environment, ethical conduct, process safety, risk consideration and much more. This "extra", but much needed aspect may be called "the sustainability dimension" to engineering education and practice, and can be summarized as, "The design of materials, processes, products and systems to sustain good and safe conditions for human health and environment."

Over the last 30+ years, many catastrophic incidents have grabbed the attention of the public and the media. Companies cannot be sustainable without successful safety and risk management programs. And thus by extension, it is impossible for society to reach the goals for "engineering for sustainable development" without successful safety and risk management programs. Our inability to adapt to the demands of a changing world and eco-system has the potential to take us down the same path as "dinosaurs."

## *Area 1.2: Manufacturing Process and Equipment Design with Minimum Ecological Footprints*

### Sustainable Manufacturing and Closed Loop Systems

Nabil Nasr, Director of the Golisano Institute for Sustainability, Rochester Institute of Technology, Rochester, NY 14623, USA

The growing demand for new products coupled with the rise in consumption in developed and developing economies are straining the environment and posing significant global challenges. The major cause of continued environmental challenges is unsustainable consumption and production, particularly in industrialized countries. However, there is strong evidence that transitioning to a sustainable economy can lead to higher economic growth while reducing the impact on the environment.

Industry is becoming aware that, to meet today's demanding environmental standards; the life-cycle impacts of a production system must be understood and optimized. In response, many designers are focusing on addressing the environmental impacts of products. This presentation will discuss a proposed framework and methodology for sustainable production and highlight initiatives in this area. A discussion of remanufacturing; a key enabling technology to sustainable production, will also be presented outlining industry history, technologies, and practices.

## Low-Carbon Manufacturingof Metal Forming Equipments

Zhifeng Liu and Haihong Huang, Hefei University of Technology, Hefei 230009, China

Exploitation and utilization of a large amount of energy and resource, especially the energy based on fossil fuels, greatly promote the development of modern civilization; meanwhile, they also make the followed "greenhouse effect" and "energy crisis" become serious challenges that international community has faced. Against the background of low-carbon economy, "low-carbon" rushed in all walks of life, while how does traditional manufacturing realize low-carbon development? The purpose of this report is to summarize and analysis domestic and international research status of low-carbon manufacturing, and clarify the connotation and technology system of low-carbon manufacturing. Combined with the research works carried out by our research team, low-carbon manufacturing of high-end metal forming equipments are introduced from four aspects: carbon emissions from the equipment manufacturing processes, the innovative structure design and material- saving design based on the load path of the equipments, the discipline of energy flow and energy loss during the service of equipments, and the mapping relationships between energy consumption and process parameters for typical metal forming processes. Finally, the prospect and future development direction of low-carbon manufacturing are presented in our view.

## Minimum Quantity Lubrication Based On Supercritical Carbon Dioxide

Steve Skerlos, Department of Mechanical Engineering and Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI 48109, USA

The environmental, health, performance, and economic benefits of switching from water-based systems to gas-based MQL systems have been observed in industry and are starting to be documented in the literature. The cost savings arise by eliminating major infrastructure components in the plant, which represent a significant fraction of water-based metalworking fluid (MWF) system costs. To date however, MQL has only been adopted on a limited basis due to the lack of cooling available in MQL systems for challenging machining operations involving advanced materials.

In this presentation we introduce a new type of MQL MWF, patented by the University of Michigan, based on rapidly expanding sprays of supercritical carbon dioxide (scCO2). Carbon dioxide above its critical temperature and pressure ($T_c$ = 31.1°C and $P_c$ = 72.8 atm) effectively dissolves many lubricating oils and forms chilled microparticles of lubricant as it expands out of a nozzle. Therefore sprays of oil carried from scCO2 can extend the reach of MQL technology into more challenging machining domains not achievable today with air-based MQL due to the need for more cooling, chip evacuation, and higher pressure. The scCO2 approach has proven applicable to turning, milling, drilling, and other applications with advanced aerospace alloys.

Advanced applications in grinding and forming are also being pursued.

A full life cycle analysis of air and CO2 MQL systems revealed that the environmental benefits of these MQL systems are significant. It is seen that the environmental impacts of gas-based MWF systems are significantly lower than water-based systems in many impact areas primarily because the systems usually contain only two components: gas and lubricant. By eliminating additives required in water-based systems, including surfactants, MQL processes eliminate much of the environmental footprint and health risks associated with water-based MWFs.

## Numerical Simulation of Multiphase Reactors/Crystallizers and Application for Green Processes and Sustainable Development

Chao Yang, Key Laboratory of Green Process and Engineering, Institute of Process Engineering, Chinese Academy of Sciences, Beijing, China. E-mail: chaoyang@ipe.ac.cn, Fax: +86-10-62554558

Sustainable chemical, metallurgical or pharmaceutical industrial processes should be based on highly efficient reactors and separators. It is necessary to thoroughly study multiphase flow, heat and mass transfer and chemical reaction in reactors/crystallizers and understand the mechanism of transfer and transform of mass and energy, and establish reliable models for these processes. The theory and numerical method of design and scale-up large scale process equipments for multiphase processes are far from sufficiently developed. This is in many cases the bottleneck for transfer of laboratory achievements to commercial production. The traditional methodology of chemical engineering research is largely based on the empirical correlations and semi-empirical models in terms of overall averaged parameters, which is the key reason leading to the difficulty in scaling up chemical processes and equipment and the high consumption of energy and raw materials and pollutions.

Therefore, we focus on the fundamental and applied research in computational reaction engineering approaches and innovated technologies for energy saving and emission reduction in process industries, i.e., green process and engineering for sustainable development. With multi-scale models and numerical simulation methodology, the processes related with flow, transport and reaction in reactors are studied, in order to obtain in-depth understanding on physico-chemical mechanisms and strive for the realization of scientific design, scale-up, diagnosis, optimization and manipulation of multiphase reactors and crystallizers. Multiphase flow, mixing, heat/mass transfer and chemical reaction (kinetics) related to fluids and solid particles, particle assemblages and reactors are studied by analytical and numerical methods. At the meantime, highly efficient processing equipment including stirred tank, loop reactor, crystallizer and bioreactor for mixing, transport, separation and reaction in multiphase systems are improved and innovated. Our studies can provide the details of unit operations for accurate and quantitative evaluation of process sustainability.

With rapid development of various relevant technologies, numerical simulation of multiphase flow and mass transfer in multiphase reactors /crystallizers is being popularized very fast nowadays than ever before. This presentation would embrace our recent fundamental and applied research of mathematical models, numerical methods and experimental techniques for multiphase flow and mass transfer in reactors and crystallizers, operating in gas-liquid, liquid-solid, liquid-liquid, gas-liquid-solid, liquid-liquid-solid and gas-liquid-liquid systems on macro-scale and meso-scale (namely particle scale about solid particles, bubbles and drops). Some recent industrial application of our mathematical models and numerical simulations of reactors/crystallizers havebrought about impressive economic benefit by reducing the materials and energy consumption and pollution emissions and saving of equipment investment, which make the industrial processes more sustainable and profitable.

### Sustainable Process Development and Evaluation

Helen H. Lou, Dan F. Smith Department of Chemical Engineering, Lamar University, Beaumont, TX 77710, USA

The value of sustainable development has been well recognized by the industries and the societies. The quest of incorporating sustainability into process design urges designers to come with process/equipment solutions to radically reduce resource use, while increasing the health, equity, and quality of life for all stakeholders. During the design of chemical/energy production systems, the selection of a sustainable process/equipment design solution at an early stage will help eliminate undesirable routes thus save the designers tremendous amount of time and energy.

Due to the multi-dimensional feature of sustainability, how to account for the impacts of various design factors and the cause-and-effect relationships can be very difficult. This paper will present a sustainability assessment method incorporating economic, environmental, societal and efficiency concerns. A sustainability root cause analysis method will be utilized for identifying sustainability improvement opportunities. This methodology will provide critical guidance to design for sustainability. The efficacy of this methodology will be demonstrated through case studies on syngas to chemical processes, water desalination technologies, and the development of clean combustion technologies.

# *Thematic Area 2. Sustainable Manufacturing Systems*

## *Area 2.1: Smart Manufacturing: Green Production and Management*

### Computational Design Tools for Global Sustainable Product Development

Bryony DuPont, School of Mechanical, Industrial and Manufacturing Engineering, Oregon State University, Corvallis, OR 97331, USA

Designers employ computational design tools, such as computer-aided design (CAD) and analysis (force, flow, etc.) software throughout the design process in order to accurately reflect conceptual ideas as well as to catalog design changes over time. During the early design phase, preliminary CAD models are often employed to illustrate the trade-offs between multiple concepts, to better represent design intent, and to better communicate this intent with the product's stakeholders, such as manufacturers, distributors, and potential users. These tools have become an indispensible means to communicate during the early design phase and throughout the design and production of a product. Though design for sustainability has become a significant driver for innovation in product development in the United States, means by which designers can identify the environmental impact of a product during the early design phase are limited. It is the intent of this work to explore the development of computational design tools that can be applied during the early design phase that will enable designers to make sustainable design decisions during conceptual development. On a global scale, sustainable product design can be highly varied due to the application of international standards related to product development and manufacture; a product manufactured in China for sale in the United States faces different environmental design standards than a product manufactured and sold in Germany. Our work seeks to better understand sustainable design on an international level, and to approach building computational design tools and systems that will facilitate extolling this understanding to engineers and designers. An overview of international design standards related to sustainable manufacturing will be explored, as well as a discussion of existing computational tools that facilitate sustainable design.

## Advances in 3E of Polymer Processing and Sustainable Manufacturing

Weimin Yang, State Key Laboratory of Organic-Inorganic Composites, National Engineering Laboratory of Tire Design and Manufacturing, Polymer Processing and Advanced Manufacturing Center, School of Mechanical and Electrical Engineering, Beijing University of Chemical Technology, Beijing 100029. E-mail： yangwm@mail.buct.edu.cn

Polymer materials including plastics, rubber, fiber and resin matrix composite, are gradually taking place of metals and woods and widely being used in almost everywhere, which greatly changes the life of people all over the world. Most of polymer materials are made from oil by chemical process. Due to the increasing depletion of oil resources and environmental deterioration, the sustainability of polymer processing and manufacturing is becoming a very serious problem. Therefore, new methods should be developed to produce polymer without using oil. We also have to solve the important 3E problems (Efficiency, Energy Saving & Environment Friendly) in polymer producing and processing. During the past decade, we have done a lot of researches on 3E problems of sustainable polymer manufacturing. 1) In order to control the dimensional accuracy of high speed injection molding, the online measurement method and equipment of polymer PVT (Pressure-Volume specific-Temperature) correlation properties was invented. 2) In order to get energy saving polymer processing method, a new vulcanization machine of high performance radial tire was invented; a new concept of polymer melt differential and integral in polymer processing was also proposed, based on which we invented the polymer melt differential injection molding machine, calculus extruder, calculus electro-spinning device, calculus nano-composites cascade machine, etc.. 3) In order to realize green and sustainable producing of polymer from stone instead of oil, a Ring Route PVC Producing Method without mercury pollution was invented.

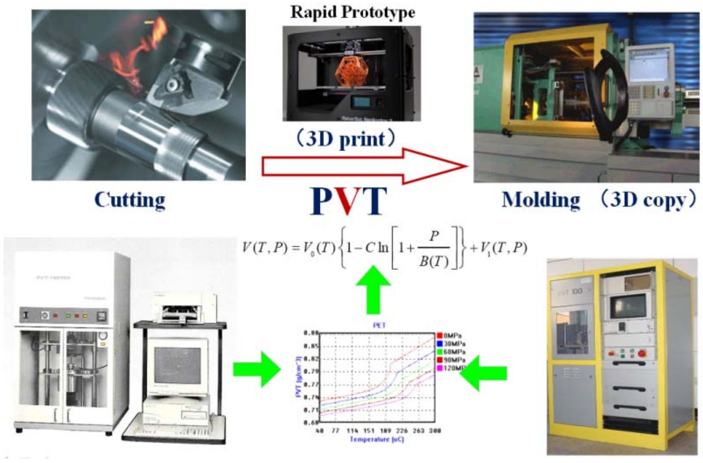



Figure Polymer PVT property and its application in precision molding.

## Multiscale Systems Science and Engineering in Manufacturing Sustainability: Challenges and Opportunities

Yinlun Huang, Department of Chemical Engineering and Materials Science, Wayne State University, Detroit, MI 48202, USA

The quest for engineering sustainability reflects a crucial paradigm shift in the 21st century, i.e., from the traditional techno-economic paradigm to triple-bottom-lines-based sustainable system design, manufacturing, and management at various length-time scales. However, sustainability is an extremely complex area of research and practice in terms of scope, contents, and spatial/temporal aspects, and sustainability science is far from exact today. Manufacturing sustainability needs not only evaluation of the status quo, but also prediction and strategic decision-making for the future, all under the situation of information uncertainty and insufficient knowledge. Thus, how to characterize, analyze, design and restructure manufacturing systems, from the material-product-process level to the large-scale industrial system level, in the context of sustainability, is a new research frontier in engineering that needs much exploration.

In this presentation, the challenges, opportunities and research frontiers in manufacturing sustainability research and practice will be discussed first. Then, a Multiscale Design-Manufacturing for Sustainability (MDMS) methodology will be introduced, which is developed by resorting to basic sustainability science, multiscale complex systems theory, uncertainty theory, and control theory. The methodology is capable of performing hierarchical system modeling, comprehensive sustainability analysis, and multiscale decision making under uncertainty. The methodological efficacy will be demonstrated by a number of applied studies, ranging from sustainable design of nanomaterials and manufacturing, to collaborative profitable pollution prevention in surface coating systems, and to industrial-zone-based technology network sustainability. Finally, an NSF funded academic-industrial collaboration involving eight countries on sustainable manufacturing research, education, and technology development will be highlighted and future directions will be discussed.

## Operational Optimization of Discrete Shop Manufacturing System with High Efficiency and Low Carbon

Xinyu Shao, School of Mechanical Science and Engineering, Huazhong University of Science and Technology, Wuhan, PR China

Facing with global market competition as well as environmental and resource pressure, modern manufacturing needs urgently to increase efficiency and reduce energy consumption. By investing the correlated association of production efficiency and energy consumption, we developed some technologies for the integrated operational optimization of discrete shop manufacturing system with high efficiency and low carbon. These include: (1) An indirect cutting power measurement method based on the spindle motor current is proposed for the machine tools. Experimental results show that accurate predictions are achieved for cutting power monitoring by spindle motor current. (2) A model for evaluating energy consumption of milling process is put forward. The model characterizes the relationship between material removal rate (MRR), spindle speed, feed rate and SEC by fully considering the energy flow of CNC machine tools. Experimental results show that the improved model can provide a higher prediction accuracy of energy consumption. (3) Besides energy consumption, certain other manufacturing activities can also cause environmental impacts, such as the use of cutting fluids, deposition of worn tools, and material consumption. An integrated model for process parameter optimization and scheduling is developed, and the two objectives including efficiency and carbon emissions are considered simultaneously. All these research results above reveal that carbon emission can be employed as a new and overall environment criterion for sustainable manufacturing.

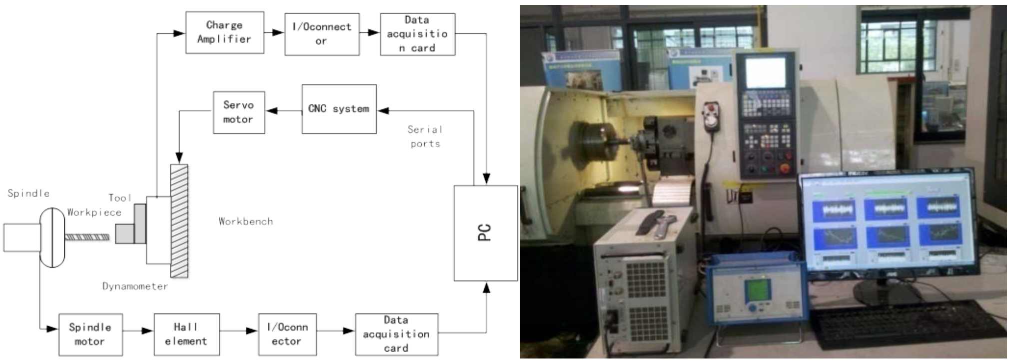



Figure Experimental platform

## Sustainable Production of Feed and Fuel from Micro Algae

Kimberly Ogden, Department of Chemical and Environmental Engineering, University of Arizona, Tucson, AZ 8572, USA

Production of biofuels such as jet fuel and biodiesel from algae has shown a step change in the amount of research in the last 3 years. The field is advancing at a rapid pace, everything from understanding fundamental algal biology to cultivation through conversion to fuels and coproducts. The major technological advances including: algal strain sequence information; molecular biological toolboxes; novel bioreactor strategies; new processes for dewatering, harvesting, extracting, and conversion; and techno-economic models that highlight the advances and remaining challenges. This presentation will focus on integrating technologies to treat wastewater, recycle water and nutrients, as well as the current economics and life-cycle analyses of production of feed and fuel from microalgae. The experiments were done with a freshwater alga, Chlorella sorokiniana that grows well in secondary effluent, tertiary effluent, and centrate. It also grows over a range of temperatures and pH. Production of crude bio-oil from this strain is currently estimated at $6/gallon.

## *Area 2.2: Sustainable Supply Chain and Industrial Ecology*

### Multi-scale Sustainable Manufacturing: Approaches, Implementation and Application Perspectives

Kai Cheng, School of Mechatronics Engineering, Harbin Institute of Technology, Harbin, Heilongjiang 150001, China, Email: kaicheng@hit.edu.cn

The presentation aims to explore the generic nature and fundamental issues in sustainable manufacturing associated with the tooling - machine/process – shop floor - factory - manufacturing supply chains, so as to achieve the comprehensive and scientific understanding of sustainable manufacturing in a multiscale and multi-dimensional context. Furthermore, the approaches towards multiscale sustainable manufacturing are presented using the following five delicate application exemplars with their implementation and application perspectives, including:

(1) Design of internally cooled smart cutting tools, which can be employed for contamination-free machining and ‘dry’ cutting, and thus likely lead to environmentally-friendly machining processes.

(2) Development of the ERWC (energy-resource-waste-carbon footprint) approach to quantitative analysis of energy consumption and carbon footprint of CNC milling machines, its ultimate goal is to implement ERWC-based algorithms onto CNC controllers and lead to development of next generation Eco-CNC machine tools operating in a sustainable manufacturing manner.

(3) Further development of the ERWC approach to quantitative analysis of energy consumption and carbon footprint at automotive paint-shop, and the associated shop-floor processes mapping and optimization.

(4) Development of the energy management system for automotive manufacturing factories, industrial feasible real-time decision makings are the essential research focus by likely applying advanced modeling and big data techniques. The correlation analysis on quality, productivity and energy consumption in a multi-dimensional manner and the associated complexity impose scientific challenge while in manufacturing terms.

(5) Investigation on Point-of-Use (POU) manufacturing systems with application to food industry, the research and development is carried out in close collaboration with industrial companies, particularly on design of POU systems, their use in food manufacturing in light of geographically distributed manufacturing supply chains, and the new business model.

The presentation concludes with a further discussion on the potential, applications and challenges of the approaches in broad manufacturing industries.

## Sustainable Process Design by Hybrid Techno-Economic Models

Bhavik R. Bakshi, Lowrie Department of Chemical and Biomolecular Engineering, The Ohio State University, Columbus, OH 43210, USA

Much effort across engineering disciplines has been focusing on the design of sustainable processes and supply chains. The goal in such efforts is usually to reduce the life cycle environmental impact, while satisfying economic objectives as well. Most such efforts rely on accounting for the life cycle by using life cycle emissions factors for inputs to the process being designed. These factors are commonly obtained from process LCA databases, and enable convenient expansion of the engineering design boundary to its life cycle. Such methods suffer from two major shortcomings: the process LCA boundary used for the emissions factors is prone to errors and captures only 20-50% of the life cycle flows, and considering emissions factors to be constant unrealistically implies that there is no interaction between the designed process and its life cycle. These shortcomings mean that results from current approaches for sustainable process design (SPD) may be sub-optimal at best and perverse at worst due to unintentional shifting of the problem outside the process LCA boundary instead of solving it.

This talk will describe a new framework for integrating engineering process models (equipment scale) with process LCA models (value chain scale) and environmentally extended input-output models (economy scale) to overcome the shortcomings of current methods, while benefiting from advances in hybrid LCA methods. These models vary in their scope and aggregation: EEIO models have the largest scope but are most aggregated, while engineering process models are the narrowest in scope but most accurate. The hybrid model is developed by disaggregating sectors in EEIO models to connect with models at value chain and equipment scales, in a manner analogous to hybrid LCA. However, unlike hybrid LCA, this framework can utilize linear LCA models along with nonlinear process models, and can be used to solve design problems by optimization. The optimization problem can consider multiple objectives including the net present value of the process being designed, and its life cycle impacts. An illustrative example demonstrates the ability of the hybrid framework to provide better results than existing methods. Use of this framework for risk analysis and advancing LCA will also be discussed.

## Innovating Green Chemical Industry to Promote Sustainable Development in China

Shanying Hu, Dinjiang Chen, Bing Zhu, Yong Jin. Center for Industrial Ecology, Department of Chemical Engineering, Tsinghua University, Beijing, 100084.

Today, conventional industries are suffering more and more rigorous environmental limits, market competition and a shock from recently emergent industries. However, it is impossible for China to transform to a new economic pattern in a short period. The conventional industries such as iron and steel industry, nonferrous metals industry, chemical industry, building materials industry will be still a very important part of Chinese economic in the future ten or more years. For satisfying demands of develop and environmental constraint, these industries must be transformed to a green development pattern.

For Chinese chemical industry, we referred successful experiences of advanced countries, made a systematic analysis for current situation and developing trend, proposed green development strategies and policy suggestions. Some key technologies were identified, and four important innovation projects are suggested.

(1) Innovation project for chemical fertilizer industry served modern circular agriculture.

(2) Innovation project for energy chemical industry to solve vehicle fuel and pollution problem.

(3) New technology for thermo-chemical comprehensive utilization of coal.

(4) Innovation project for new coal chemical products.

## Challenges of End-of-Life Electric Vehicle Battery Treatments

Hong C. Zhang, Department of Industrial Engineering, Texas Tech University, Lubbock, TX 79409, USA

Electric vehicle (EV) is deemed as perfect substitute for internal combustion engine vehicle (ICEV) for reduction of pollution emissions. However, most studies on comparisons of environmental benefits of internal combustion engine vehicle ICEV and EV focused on the use phase. EV battery production and end-of-life treatment are very significant and should be included in the analysis to avoid issue of problem shifting. A recent study by EPA indicates EV battery production causes 7.52E-01 kg Sb-Eq./kWh of abiotic resource depletion, 1.12E+02 kg CO2-Eq./kWh of global warming potential, 7.64E-02 kg N-Eq./kWh of eutrophication potential, 4.73E-06 kg CFC 11-Eq./kWh of ozone depletion potential. While end-of-life (EOL) treatments of EV batteries will create additional environmental problems, this presentation will address challenges associated with EOL treatments of the EV batteries. Finding appropriate EOL treatment would not only minimize new materials extraction and processing but also provide huge relief on environmental problems that could be occasioned by EOL of EV batteries. More research is required to improving environmental profile of EV batteries; this presentation will also offer way forward to make EV batteries contribute positively to pollution reduction efforts.

## Life Cycle Assessment and Sustainability of Coal based Energy and Chemical Processes

Yu Qian. School of Chemical Engineering, South China University of Technology, Guangzhou, 510640, China, Email: ceyuqian@scut.edu.cn

Coal is the dominant energy resource in China. Clean and efficient utilization of coal is critical in conserving resource and improving environment, as well as satisfying economic increase. In the background of energy/resources shortage, many new coal based energy and chemical processes were proposed and employed, which are, however, not quantitatively and comprehensively evaluated, neither for long-term effects on the industrial sectors and resource supply chains, nor for social development and ecological environment.

Many of developed approaches for process sustainability are based on four E dimensions: Efficiency, Energy, Economics, Environment/Ecology, respectively. To provide industry and decision makers with better understanding of the benefits and unintended impacts on environment and resources of the large-scale deployment of coal processing/utilizing technologies, life cycle models are established from upstream to downstream of coal processes. In this work, perspective of the four E approaches is expanded to energetic life cycle assessment (ELCA) and life cycle costing (LCC).

Our investigation is to explore methodology for evaluating the efficiency and sustainability of alternative coal-based processes, to rationale and optimize the flow-sheetings, reduce investment and operating costs, raise efficiency and minimize environmental impacts. Our current study takes coal gasification syn-gas centered energy/chemical chains as the bench case. “Technical-economical-environmental-societal” multi-dimensional models are built, simulated and optimized. Mass and energy flow diagrams, life cycle inventory, sustainability indicators are established. Resource/energy utilization efficiency, environmental impact, and economic benefits are quantitatively analyzed. Finally, a platform to support the life cycle analysis and decision is constructed for process evaluation, integrated innovation, and optimization of existing and potential coal processes.

A number of coal based chemical processes were investigated, including coal to methanol (CTM), coal to olefins (CTO), coal to liquid fuels (CTL), coal to natural gas (CTNG). It is found that, CTO is promising and economical feasible in current market condition. In comparing with current OTO, however, it suffers lower energy efficiency, higher water usage, and severe emissions.

Further investigation found that the existing CTO could be improved by integration with alternative feedstock to raise energy efficiency and reduce CO2 release. On the other hand, coal based processes with higher CO2 capture rate and higher purity for commercial use could improve environmental and economic performance a lot.

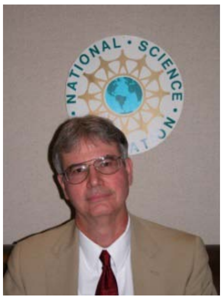
## Improving Industrial Sustainability through Supply Chain Energy and Resource Management

Eric Masanet, Department of Mechanical Engineering and Department of Chemical and Biological Engineering, Northwestern University, Evanston, IL 60208, USA

Energy and resource efficient production technologies are some of the most promising, cost-effective, and reliable sources of sustainability improvement available to the global manufacturing sector. However, best practice technologies for energy and resource efficiencies are still vastly underutilized in most manufacturing plants—despite their proven benefits and low adoption costs—due to a variety of organizational, financial, and knowledge barriers in the manufacturing sector. This presentation will discuss a modeling approach that aims to overcome these barriers by quantifying the best practice energy and resource efficiency potential of industrial supply chains. The approach integrates detailed bottom-up techno-economic modeling approaches with top-down input-output supply chain modeling methods. The model provides insights into how much energy and emissions could be saved through specific technology upgrades to specific energy systems (e.g., steam systems) at specific actors in a complex supply chain, and further estimates what level of capital investment would be required to achieve these savings. Results can be used by manufacturers to set procurement standards to increase best practice technology uptake by suppliers, and by policy makers to design policies for supply chain energy and resource efficiencies aimed at specific industries, technologies, and materials.

# 3. BIOGRAPHICAL SKETCHES AND POSITION STATEMENTS

## US NSF OFFICERS




### Bruce Hamilton, Ph.D.
Program Director, Environmental Sustainability
U.S. National Science Foundation
Arlington, VA22230, USA


### Biographical Sketch

Bruce Hamilton is a program director at the U.S. National Science Foundation (NSF), Arlington, VA. Among various activities at the U.S. NSF, he is a member of the cross-NSF Implementation Group for the Science, Engineering, and Education for Sustainability (SEES) investment area. He also is program director of the Environmental Sustainability program in the Engineering Directorate, and a managing program director in ENG's Emerging Frontiers in Research and Innovation Office (EFRI). Additionally, he is a program director for the Water Sustainability and Climate solicitation (WSC), the Sustainability Research Networks (SRN) solicitation, the Cyber SEES solicitation, the Research Coordination Networks - SEES (RCN-SEES), SEES Fellows, and Cyber-Physical Systems (CPS) activities, the joint DHS/NSF Academic Research Initiative on Domestic Nuclear Detection (ARI), and the Engineering Research Center (ERC) program. In 2012, he received the NSF Director's Award for Meritorious Service in the area of sustainability. Before joining NSF 17 years ago, Bruce held R&D management positions in the chemical and biotechnology industries for 20 years. He has a B.S. in Chemical Engineering and a Ph.D. in Biochemical Engineering, both from MIT.

### Position Statement

The U.S National Science Foundation funds basic research in all areas of science, technology, engineering, and mathematics (STEM). The U.S. NSF encourages international collaborations that advance the frontiers of research in STEM. Research on sustainability, including sustainable manufacturing, is an area of particular focus.


### JoAnn Slama Lighty, Ph.D.
Director, Division of Chemical, Bioengineering, Environmental, and Transport Systems
U.S. National Science Foundation
Arlington, VA22230, USA

## Biographical Sketch

JoAnn S. Lighty, professor and former chair of the department of chemical engineering at the University of Utah, joined the National Science Foundation (NSF) in October 2013 as director of the Division of Chemical, Bioengineering, Environmental, and Transport Systems (CBET) in the Directorate for Engineering (ENG).

At the University of Utah, Lighty served in a variety of leadership capacities. She led the department of chemical engineering from 2007 to 2013 and served as associate dean for academic affairs for the College of Engineering from 1997 to 2004. During the intervening years, Lighty directed the Institute for Combustion and Energy Studies (now the Institute for Clean and Secure Energy).

Lighty's research has focused on the formation of fine particulate matter from combustion systems; the fate of mercury in fossil fuel combustion; carbon capture technologies; and on the formation and oxidation of soot. She received her Ph.D. and B.S. in chemical engineering from the University of Utah. Lighty has authored or co-authored more than 60 publications and 6 book chapters based on her research and expertise. While serving on committees for the Environmental Protection Agency and the National Research Council, she contributed to reports on important national issues including air quality, hazardous waste management, and water quality. Lighty has received numerous honors and recognitions, including educator awards from the Society of Women Engineers and the Utah Engineering Council, and election to Fellow by the American Institute of Chemical Engineers.

## Position Statement

The U.S National Science Foundation funds basic research in all areas of science, technology, engineering, and mathematics (STEM). The U.S. NSF encourages international collaborations that advance the frontiers of research in STEM. Research on sustainability, including sustainable manufacturing, is an area of particular focus.

# <u>US DELEGATES</u>


## Luke E. K. Achenie, Ph.D.

Professor
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## Biographical Sketch

Dr. Luke E.K. Achenie is a Professor of Chemical Engineering at Virginia Polytechnic and State University. He holds a joint appointment as Professor of Health Sciences at the Virginia Tech Faculty of Health Sciences. Dr. Achenie is a member of several major professional societies and has served on several federal peer-review panels. He served as the Program Director of the Reaction and Engineering Program within the NSF Division of the National Science Foundation in the 2012 calendar year.

Dr. Achenie's work is in several different interdisciplinary fields including process design, molecular modeling, multi-scale modeling, bioinformatics, drug-delivery and uncertainty analysis. He is a pioneer in molecular design, a subset of computer aided product design. This is an advanced simulation model that addresses the systematic design of chemical compounds with desired physical and chemical properties, with the goal of producing computer based "designer" compounds. Molecular design is a valuable tool used to aid bench chemists in narrowing down the range of compounds to synthesize for particular applications. Dr. Achenie has also worked to develop new formulations for flexibility analysis that takes into account accuracy of uncertain parameters in physical models. This theory has been applied to the analysis of the direct methanol Proton Exchange Membrane (PEM) fuel cell, an area that has attracted a lot of research interest over the last decade for its use in portable electronics, as well as in stationary and mobile power generators and electric vehicles.

His current research effort is in molecular dynamics (MD) modeling, computational modeling of fast pyrolysis of biomass and systems biology. In systems biology he has collaborative efforts in (1) modeling of oral drug delivery, (2) modeling of drug transport across the blood-brain-barrier, and (3) machine learning algorithms for early diagnosis of autism in little children.

Dr. Achenie is honored by (1) induction into Connecticut Academy of Engineering (2007), (2) Board Member, Scientific Journals International (SJI) (2008 to present), (3) Board Member, AIChE Board of Trustees (2009 to present), (4) AIChE Award for Excellence & Service as Minority Affairs Committee Chair (2004), and (5) The Rogers Outstanding Teaching Award (1992, 1997).

## Position Statement

Energy sustainability, resource sustainability and environmental sustainability are all top concepts in the area of sustainability. Politicians, policy makers, thought leaders, educators/researchers and all world citizens have either bought into the concepts or will in the foreseeable future. Increasingly computational modeling and scientific computing will play an integral part in sustainability research and products.

Dr. Achenie is employing molecular dynamics for the simulation of organic/inorganic membranes and their role in the separation of gas blends (CO2/CH4/H2), which are products/by products of pyrolysis and shale gas processing. Membrane separation is a low energy process; pyrolysis of biomass leads to "green" bio-oil and fracking (shale gas) provides a path to energy independence. Thus all these have implications in green and/or sustainable energy. We have modeled the gas permeation process within four hybrid inorganic-organic membranes at the micro level using molecular dynamics (MD) and at the mesoscale level using a diffusion mechanism. The predicted permeances and relative selectivity of $CO_2$ and $CH_4$ compared very favorably with the experimental data from our collaborator's lab. In the MD simulation a single-pore silica crystal framework model with and without inserted phenyl groups were used to define two membrane structures. To mimic the diffusion of gas across the membrane, a three-region system with a repulsive wall potential on the edge is employed.

We have also studied kinetic modeling of fast pyrolysis under uncertainty induced by (a) incomplete characterization of reacting and product species, (b) incomplete characterization of reactions paths and (c) incomplete knowledge of or varied composition of lignin, cellulose, hemicellulose and other fractions within woody biomass. Here we have used fuzzy-logic modeling and stochastic modeling.

The current workshop addresses Sustainable Manufacturing with the understanding that this is intricately linked to sustainable products and sustainable processes. A good example of the latter is process intensification, for example using a network of micro-reactors to replace conventional reactors. I was involved in the Department of Energy projects associated with micro-reactors only a few years ago. In closing my view is that although leadership in sustainable manufacturing can bring short-term advantages to a given entity, in the long run, globalization will dictate that these technologies be shared and used by the global community. Therefore why not collaborate on sustainable manufacturing right from the onset?

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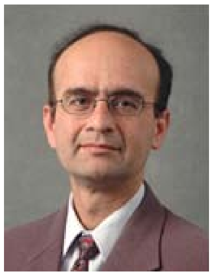

## Biographical Sketch

Bhavik R. Bakshi is a Professor of Chemical and Biomolecular Engineering and Research Director of the Center for Resilience at The Ohio State University. His research is developing scientifically rigorous methods for understanding and enhancing the sustainability of human activities. This includes new methods for analyzing the life cycle of existing and emerging technologies, and developing integrated models of industrial, ecological and economic systems for designing engineered systems and supporting policies. A major focus of his research is on understanding the role of ecosystem services in supporting industrial activities, and on designing integrated networks of technological and ecological systems. This multidisciplinary research overlaps with areas such as thermodynamics, applied statistics, ecology, economics, and complexity theory. Applications include nanotechnology, green chemistry, alternate fuels, and waste utilization in both, developed and emerging economies. He has published extensively and is on the editorial boards of various academic journals. In addition to university courses, Prof. Bakshi offers short courses to practicing professionals on various aspects of sustainability. His work has been recognized through awards from the American Institute of Chemical Engineers, the U.S. National Science Foundation, and several best paper awards at various conferences. Prof. Bakshi received his Bachelor of Chemical Engineering degree from the University of Bombay, MS in Chemical Engineering Practice and Ph.D. in Chemical Engineering from the Massachusetts Institute of Technology. While in graduate school, he also completed a minor in Technology and Environmental Policy and conducted research at Harvard's Kennedy School of Government.

## Position Statement

Two major shortcomings of existing methods for sustainable engineering are (1) their focus on enhancing eco-efficiency, and (2) their ignorance of ecosystem goods and services. Approaches for enhancing eco-efficiency include life cycle assessment and design. These methods tend to encourage continuous improvement by reducing various footprint and life cycle measures. While this may enhance sustainability, it also encourages or prolongs the use of inherently unsustainable systems, as opposed to encouraging breakthrough innovation that is inherently sustainable. This focus on doing "less bad" is not good enough for sustainable development. The ignorance of ecosystem goods and services means that the very foundation of human well-being is ignored by existing methods. Examples of ecosystem goods include water, food, genetic resources and biomass, and services include biogeochemical cycles, pollination, and maintaining soil fertility. Ignoring them can result in perverse decisions that increase reliance on degraded ecosystems. My group's research is motivated by the need to overcome these shortcomings, and has resulted in the approach of Ecologically-Based Life Cycle Assessment (Eco-LCA) that accounts for the role of a large number of ecosystem goods and services. Thermodynamic methods based on the concept of exergy have been used to define metrics that include ecosystem services. A model of the U.S. economy based on this approach is available at http://resilience.osu.edu/ecolca/. This approach quantifies the demand for ecosystem services generated by various economic activities. However, it does not consider the availability or supply of these services. To overcome this shortcoming, we are developing methods for the analysis and design of synergies between networks of technological and ecological systems. This techno-ecological synergy analysis or Eco-Synergy analysis approach quantifies the available ecosystem services in a selected region by using models for ecosystems such as forests, soil, and wetlands. The supply and demand of ecosystem services is compared at multiple spatial scales. If the demand for an ecosystem service at the selected scale is smaller than the supply then the system may be considered to be sustainable for that service at the selected scale. Eco-Synergy design encourages the development of technological systems that operate within local ecological constraints, and benefit from the ability of ecosystems to provide needed goods and services in a manner that is often economically and environmentally superior than systems designed without including ecosystems.


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## Biographical Sketch

Dr. Bert Bras is a Professor at the George W. Woodruff School of Mechanical Engineering at the Georgia Institute of Technology since September 1992. His research focus is on sustainable design and manufacturing, including design for recycling and remanufacture, bio-inspired design, and life-cycle analyses with applications in energy and mobility systems. He has authored and co-authored over 150 publications. His work is funded by the National Science Foundation, Ford Motor Company, General Motors, Boeing, among others. Some of the work done with Ford was featured at the 2013 and 2014 Consumer Electronics Shows (CES). He was named the 1996 Engineer of the Year in Education by the Georgia Society of

Professional Engineers, received a Society of Automotive Engineers' Ralph R. Teetor Award in 1999, and the 2007 Georgia Tech Outstanding Interdisciplinary Activities Award. Over the years, he has also provided consulting services for the Chrysler Corporation, United Technologies, LG Electronics, NASA and Verus Carbon Neutral, among others. From 2001 to 2004, he served as the Director of Georgia Tech's Institute for Sustainable Technology and Development. In 2014, he was named a Brook Byers Professor. Dr. Bras has Master of Science ("Ingenieur") degree in Mechanical Engineering from the University of Twente (The Netherlands) and a PhD in Operations Research from the University of Houston. Prior to his PhD, he worked at the Maritime Research Institute Netherlands (MARIN).

## Position Statement

In sustainable manufacturing, it is very easy to focus on a particular subset of problems and lose sight of the larger picture needed to achieve sustainable development (i.e., "development that meets the needs of the present generation without compromising the needs of future generations"). Already in 2001, a comprehensive global study on Environmentally Benign Manufacturing sponsored by the US NSF and DoE found that there was no evidence that the environmental problems from our production systems are solvable by a "silver bullet" technology. Rather, the need for systems-based solutions was noted, requiring a comprehensive systems approach in which multiple stakeholders from various disciplines like engineering, environmental science, management, economics, and policy all work together.

While there are many researchers working to address important needs in sustainable manufacturing, the cumulative impact of the work is often limited by its fragmented nature, lack of a systems view, and lack of connectivity to industry. For example, moving an entire manufacturing facility from a region with coal-fired electricity generation to an area where hydropower is prevalent may offer more greenhouse gas emission benefits for a company than incremental facility process improvements. Critical elements needed to achieve a systems view and move to sustainability are life-cycle thinking, systems modeling and assessment, inclusion of geospatial locality information and characteristics, and understanding societal and human behavior.

In the end, human behavior may have a much larger effect on overall system sustainability than any engineering decision. Over and over we see that affluence leads to greater material and energy consumption. Thus, despite relative gains in product design and manufacturing, we are not gaining in absolute sense with respect to reducing environmental impact and increasing sustainability. It is therefore dangerous to normalize improvements per unit product and simply assume that this will result in actual benefits. Without fully including and addressing the market dimension, consumer behavior, potential rebound effects, etc., and truly considering sustainable manufacturing as a systems issue, engineering improvements will probably not be enough to reach true sustainability.

**Bryony DuPont, Ph.D.**
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## Biographical Sketch

Dr. DuPont is an Assistant Professor in the Design Engineering Lab in the School of Mechanical, Industrial, and Manufacturing Engineering at Oregon State University. Her work is in computational optimization, specifically the development and application of advanced optimization tools to renewable energy systems and sustainable product development. Dr. DuPont has published work in this area in the American Society of Mechanical Engineers (ASME) Journal of Mechanical Design, and has presented her work at ASME International Design and Engineering Technical Conferences/Computers, and Information in Engineering Conference and the American Institute of Aeronautics and Astronautics (AIAA) SciTech Conferences (ASME Wind Energy Symposium). Her work is funded through the National Science Foundation, the U.S. Department of Energy National Energy Technology Laboratory, and Oregon State University. She is a member of the ASME, AIAA, and the American Society for Engineering Education (ASEE). Dr. DuPont received her Ph.D. in Mechanical Engineering from Carnegie Mellon University in 2013, her master's degree in Mechanical Engineering from Carnegie Mellon University in 2010, and her bachelor's degree in Mechanical Engineering from Case Western Reserve University in 2008.

## Position Statement

Design for sustainability involves the consideration and reduction of the environmental impact of potential design decisions, such as the reduction of energy use during manufacture, reducing the use of hazardous chemicals, and designing products to be recycled or remanufactured. The challenge of sustainable design lies in its complex systemic nature—all phases of a product's life cycle must be properly considered, from the earliest design ideation stage through to reuse, recycle, or disposal. Currently, the environmental impact of a design can be estimated using methods that require design choices to be fully established (the majority of design decisions must be solidified). These a posteriori tools provide the basis for understanding the sustainability of a finalized design by relating design parameters (such as material weight) to values developed from extensive data analyses of the environmental impact of design attributes. However, there is a pressing need to expand the capability of sustainable design tools such that they meet current stakeholder needs. The ecological impact of traditional product design is becoming more apparent, and consumer demand for sustainable products continues to increase. As sustainable design principles become more popular, we must broaden the dissemination of sustainable design theory, making environmentally friendly design more freely accessible.

Dr. DuPont's long-term research goals seek to fulfill these needs by establishing the fundamental design principles through which researchers and product developers can accurately predict the sustainability of a potential product throughout the design process, particularly during the early design phase. This requires (1) the aggregation of quantifiable sustainability measurements and data relating to manufacturing processes and product use, (2) the development of a cohesive set of standards that incorporate these metrics, and (3) the creation of means for analyzing and disseminating this sustainability knowledge in a user-friendly way. These goals will enable the formulation of a multi-objective optimization framework for sustainable design optimization, with standards applied as constraints, for sustainable product development. The ultimate goal is for this framework to provide guiding principles and insights for sustainable design theory that can be readily interpreted during the design process.


## Thomas F. Edgar, Ph.D.

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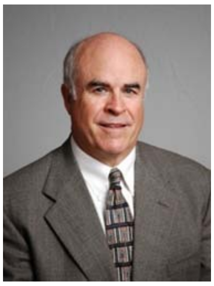

## Biographical Sketch

Thomas F. Edgar is Professor of Chemical Engineering at the University of Texas at Austin and Director of the UT Energy Institute. Dr. Edgar received his B.S. degree in chemical engineering from the University of Kansas and a Ph.D. from Princeton University. For the past 40 years, he has concentrated his academic work in process modeling, control, and optimization, with over 200 articles and book chapters. Edgar has co-authored two leading textbooks: Optimization of Chemical Processes (McGraw-Hill, 2001) and Process Dynamics and Control (Wiley, 2010) and has received major awards from AIChE and ASEE. Dr. Edgar was the 1997 President of AIChE. Tom Edgar is co-founder of the Smart Manufacturing Leadership Coalition (SMLC; https://smart-process-manufacturing.ucla.edu/), which developed a research roadmap to address smart, zero-emission, energy-efficient manufacturing. SMLC recently received an $8 million award from the Energy Efficiency and Renewable Energy program of DOE to develop software for saving energy in two industrial test beds. Another NSF-funded project where Tom is the Co-PI (with Yinlun Huang and others) is to develop a research coordinating network for sustainable manufacturing. This project will develop sustainable manufacturing case studies and disseminate software.

## Position Statement

Process control has become increasingly important in the process industries to address improving energy efficiency, rapidly changing economic conditions, and more stringent environmental and safety regulations. Process control and its allied fields of process modeling and optimization are critical in the development of more energy-efficient processes for manufacturing high value-added products and this is closely coupled with sustainability. Tom is the UT PI on a large U.S. DOE demonstration project on smart grids (www.pecanstreet.org) in Austin, TX, which focuses on new automation techniques and big data analytics for managing distributed solar energy generation and energy storage and involves six faculties from EE, ME, and CAEE departments. This smart grid demonstration is particularly notable because it involves data collection from over 300 homes with solar panels and 60 electric vehicles in one neighborhood, the densest concentration of such users in the U.S. Simultaneously, Tom has been PI of a large NSF IGERT grant, which is connected to the Pecan Street effort. The 20 students work in an interdisciplinary research and educational framework to address sustainable grid integration of distributed and renewable energy systems, a crucial priority for greenhouse gas reduction. Edgar believes private-public partnerships such as Pecan Street and SMLC can push sustainable manufacturing forward, requiring the cooperation of industry, universities, government, and non-government organizations.


## Yinlun Huang, Ph.D.

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## Biographical Sketch

Yinlun Huang is Professor of Chemical Engineering and Materials Science at Wayne State University, where he has been directing the Laboratory for Multiscale Complex Systems Science and Engineering. His research has been mainly focused on fundamental study of multiscale complex systems science and applied study on engineering sustainability, encompassing the development of sustainable (nano) materials, integrated design of sustainable product and process systems, integration of process design and control, sustainable manufacturing, and large-scale industrial system sustainability assessment and decision making under uncertainty. He has published widely in these areas. Dr. Huang is currently directing the NSF funded Sustainable Manufacturing Advances in Research and Technology (SMART) Coordination Network, which involves 13 domestic universities, eight foreign universities in seven countries, and 11 national organizations and university centers. In the past six years, he co-organized/co-chaired three international conferences on sustainability science and engineering in the U.S., and three on sustainable chemical product and process engineering in China. In August 2013, he chaired the SMART CN’s Sustainable Manufacturing Roadmap Development Workshop in Cincinnati, OH. Dr. Huang was Chair of AIChE Sustainable Engineering Forum (SEF) in 2008-09 and ACS Green Chemistry and Green Engineering Subdivision in 2010. Currently, he is Technical Advisor of the AIChE-SEF. Among many honors, Dr. Huang was the recipient of the Michigan Green Chemistry Governor’s Award in 2009, the AIChE Sustainable Engineering Forum’s Research Excellence in Sustainable Engineering Award in 2010, and the NASF Scientific Achievement Award in 2013. He was a Fulbright Scholar in 2008-09. Dr. Huang holds a B.S. degree from Zhejiang University, China, in 1982, and a M.S. and a Ph.D. degree from Kansas State University, in 1988 and 1992, respectively, all in chemical engineering. He was a postdoctoral fellow at the University of Texas at Austin before joining Wayne State University in 1993.

## Position Statement

Engineering sustainability is a science of applying the principles of engineering and design in a manner that fosters positive economic and social development while minimizing environmental impact. The mission can be largely accomplished through designing new systems and/or retrofitting existing systems of various length/time scales that meet sustainability goals. Among these, design sustainability of product and process systems is of upmost importance, but it faces tremendous challenges, mainly due to the complexity in multiscale design and the existence of uncertainties contained in the accessible data and information. At Wayne State University, Huang is leading a group to study multiscale systems modeling, analysis, and decision-making and develop methodologies and tools for design of sustainable physical systems, such as nanomaterials at the microscale, products with needed properties at the mesoscale, process systems at the macroscale. His group has extended an ecological input-output analysis (EIOA) modeling approach through separating the system output into functionally different groups so that sustainability assessment can be more meaningfully conducted, and design modification opportunities can be relatively easily identified. His group has also introduced the Collaborative Profitable Pollution Prevention design methodology, which can advise synergistic efforts among industrial entities to maximize economic gains while minimizing pollutions; the collaboration can be at either the management or the technical levels. It is recognized that one of the most challenging issues in sustainability research is how to deal with uncertainties. This is especially true for future sustainability performance prediction and/or short-to-long-term sustainable development. Recently, Huang's group developed an interval-parameter-based decision-making methodology has been introduced to develop short-to-long-term sustainability improvement strategies for industrial zonal development problems.

**Helen H. Lou, Ph.D., P.E.**
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## Biographical Sketch

Helen H. Lou is a Professor in the Dan F. Smith Department of Chemical Engineering, Lamar University. Her research focuses on sustainable engineering, process systems engineering, process safety and combustion. Dr. Lou was the Chair of AIChE Sustainable Engineering Forum (SEF) in 2010-11. She holds a B.S. in Chemical Engineering from Zhejiang University, Hangzhou, China (1993), then worked four years in SinoPec Luoyang Petrochemical Engineering Corporation (LPEC). She received the following degrees from Wayne State University in Detroit, MI: an M.S. in Chemical Engineering (1998), an M.A. in Computer Science (2001) and a Ph.D. in Chemical Engineering (2001).

## Position Statement

The quest on sustainability reflects a crucial paradigm shift for the 21st century: the transition from environmental management to systems design, coming up with solutions that integrate environmental, social, and economic factors to reduce radically resource use, while increasing health, equity, and quality of life for all stakeholders. Profitable pollution prevention (P3) technologies seek the simultaneous realization of waste reduction and production improvement. It can be realized through fundamental understanding of the process operation and waste generation mechanism. An array of sustainable technologies has been developed, including low-NOx coal grate, low-NOx burner for coal power plant, clean combustion flares, etc.

In the design of chemical/energy production systems, a major challenge is to identify the bottleneck issues and improve its sustainability effectively. Due to the multi-dimensional feature of sustainability, how to account for the impacts of various design factors and the cause-and-effect relationships can be very difficult. Lou's group developed a sustainability root cause analysis method based on the combination of Pareto Analysis and Fishbone diagram. This methodology is able to help the designers focus the attention on the most important fundamental causes, discover opportunities for sustainability improvement and provide critical guidance to design for sustainability. This method has been applied to polygene ration systems, biofuel and syngas-platform chemical conversion technologies.


## M. Sam Mannan, Ph.D., PE, CSP, DHC

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## Biographical Sketch

Dr. M. Sam Mannan is Regents Professor in the Chemical Engineering Department at Texas A&M University and Director of the Mary Kay O'Connor Process Safety Center at the Texas Engineering Experiment Station. Before joining Texas A&M University, Dr. Mannan was Vice President at RMT, Inc., a nationwide engineering services company.

Dr. Mannan is a registered professional engineer in the states of Texas and Louisiana and is a Certified Safety Professional. His experience is wide ranging, covering process design of chemical plants and refineries, computer simulation of engineering problems, mathematical modeling, process safety, risk assessment, inherently safer design, critical infrastructure vulnerability assessment, aerosol modeling, and reactive and energetic materials assessments.

He co-authored the *Guidelines for Safe Process Operations and Maintenance* published by the Center for Chemical Process Safety, American Institute of Chemical Engineers. He is the editor of the 3$^{rd}$ and 4$^{th}$ edition of the 3-volume authoritative reference for process safety and loss prevention, Lees' Loss Prevention in the Process Industries. Dr. Mannan has published 188 peer-reviewed journal publications, 3 books, 7 book chapters, 183 proceedings papers, 14 major reports, and 199 technical meeting presentations.

Dr. Mannan is the recipient of numerous awards and recognitions including the American Institute of Chemical Engineers Service to Society Award, the Texas A&M University Association of Former Students' Distinguished Achievement Award for Teaching, the Texas Engineering Experiment Station Research Fellow, the Texas A&M University Dwight Look College of Engineering George Armistead, Jr. '23 Fellow. In

2003, Dr. Mannan served as a consultant to Columbia Accident Investigation Board. In 2006, he was named the inaugural holder of the T. Michael O'Connor Chair I. In 2007, he was elected Fellow of the American Institute of Chemical Engineers. In December 2008, the Board of Regents of Texas A&M University System recognized Dr. Mannan's exemplary contributions to the university, agency, and to the people of Texas in teaching, research and service by naming him Regents Professor of Chemical Engineering. Dr. Mannan is a Guest Professor at the Nanjing University of Technology and the China University of Petroleum in Qing Dao. In September 2011, the Technical University of Łódź, Poland, conferred the Doctoris Honoris Causa on Dr. Mannan. In 2012, Dr. Mannan was awarded the Bush Excellence Award for Faculty in Public Service. In March 2013, Dr. Mannan was named a Distinguished Honorary Professor at the Rajiv Gandhi Institute of Petroleum Technology.

Dr. Mannan received his B.S. in chemical engineering from Bangladesh University of Engineering and Technology (BUET) in Dhaka, Bangladesh in 1978, and obtained his M.S. in 1983 and Ph.D. in 1986 in chemical engineering from the University of Oklahoma.

## Position Statement

Process Safety Engineering is the science of implementing into everyday engineering procedures, a broad-based understanding of the complex interaction of chemical process technology, mechanical and process design, process control, and Process Safety Management Systems (PSMS) and by virtue of knowledge and experience, evaluates an integrated petrochemical process. Chemicals play a key role in today's high-tech world. The chemical industry is linked to every technologically advanced industry, and only a handful of the goods and services we enjoy on a daily basis would exist without essential chemical products. For example, chemicals are a big business in Texas; where the state's chemical complex is the largest in the world. The industry provides jobs for more than 85,000 Texans, and the state's chemical products are shipped worldwide at a value of $15 billion dollars annually. Chemicals play a similar significant role in most modern economies. However, the use of chemicals is a two-edged sword. Safe use creates a healthier economy and a higher standard of living. Unsafe use threatens our lives, our businesses and ultimately our world. For this reason, working and living safely with chemicals are the ultimate focus of the Mary Kay O'Connor Process Safety Center.

Process safety is very closely linked to sustainable development. Our engineering education today lacks integration of knowledge needed for modern industry practice, and is inadequate in providing students with an understanding of societal impact and global role of engineering. My vision for engineering research brings together elements of manufacturing, design and sustainable engineering in an integrated form. And interwoven through this new paradigm is the consideration of risk in every aspect. An engineer must function as a member of the global community. This means not only competing in the global marketplace, but also acting as a professional who shares the global responsibilities. These responsibilities entail proper account of the finite world resources, sensitivity to the impact on the environment, ethical conduct, process safety, risk consideration and much more. Today's engineering education largely neglects preparing our graduates to meet these challenges. This "extra", but much needed aspect may be called "the sustainability dimension" to engineering education and practice, and can be summarized as, "The design of materials, processes, products and systems to sustain good and safe conditions for human health and environment."

## Eric Masanet, Ph.D.

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## Biographical Sketch

Eric Masanet is the Morris E. Fine Junior Professor in Materials and Manufacturing in the McCormick School of Engineering and Applied Science at Northwestern University. After receiving his M.S. in mechanical engineering from Northwestern in 1996, he spent several years as a practicing design and manufacturing engineer. During that time, he became interested in the intersections between manufacturing, sustainability, and public policy. He returned to graduate school to pursue research in these areas at the University of California (UC), Berkeley, where he received a Ph.D. in mechanical engineering in 2004. He subsequently spent eight years at the U.S. Department of Energy's Lawrence Berkeley National Laboratory (LBNL), where he most recently held the positions of Staff Scientist and Deputy Leader of the International Energy Studies Group. While at LBNL, he also held a joint research appointment at UC Berkeley, where he served as Program Manager of the Engineering and Business for Sustainability Graduate Certificate program.

He currently serves as Editor-in-Chief of Resources, Conservation and Recycling, the leading peer-reviewed journal on materials and resource systems efficiency. He previously served as program co-chair of the International Society for Industrial Ecology Conference (2011) and the IEEE International Symposium on Sustainable Systems and Technologies (2008-2010). His research work on sustainable manufacturing has been published in leading journals such as Nature Climate Change, Environmental Science & Technology, and Annual Review of Environment and Resources and has appeared in major international media like Forbes, Scientific American, and The Guardian. He teaches courses at Northwestern on life cycle assessment (LCA), sustainable manufacturing systems, and sustainability principles. In January, he’ll teach a free Coursera massive online open course (MOOC) on LCA.

## Position Statement

Energy and resource efficient production technologies are some of the most promising, cost-effective, and reliable sources of sustainability improvement available to the global manufacturing sector. Long-term energy and climate studies also suggest that manufacturing energy and resource efficiency are among our largest wedges for reducing society’s dependence on fossil fuels and its associated greenhouse gas emissions. However, best practice technologies for energy and resource efficiencies are still vastly underutilized in most manufacturing plants—despite their proven benefits and low adoption costs—due to a variety of organizational, financial, and knowledge barriers in the manufacturing sector. My research aims to overcome these barriers by developing mathematical models and decision support tools that can be used by manufacturers and policy makers to identify the broad sustainability benefits of efficient technologies and expose such barriers. For example, under funding from the U.S. National Science Foundation (NSF), my lab is developing a robust supply chain technology evaluation model for open use by engineers, plant managers, and policy makers. The model evaluates the supply chain embodied energy and emissions associated with a wide range of materials and goods procured by manufacturers. It then estimates the energy use, resource, and emissions savings that could occur throughout these supply chains if suppliers were to adopt a wide range of best practice energy and resource efficient technologies. The model provides insights into how much energy and emissions could be saved through specific technology upgrades to specific energy systems (e.g., steam systems) at specific actors in a complex supply chain, and further estimates what level of capital investment would be required to achieve these savings. As such, it allows manufacturers to set procurement standards or supply chain energy performance targets to drive improvements throughout their supply chains. It further allows policy makers to identify which specific manufacturers should be given incentives to initiate supply chain standards to most efficiently and substantially reduce national energy use and emissions. My lab also works to overcome knowledge barriers by researching and publishing efficient technology guidebooks for various industries (for the U.S. EPA's ENERGY STAR for Industry Program), to reduce financial barriers by developing plant investment co-benefit models (e.g., water-energy savings model for industrial steam systems), to advocate for efficient technology subsidies by developing models that reveal split-incentives (e.g., materials savings at the manufacturer that deliver large societal environmental upstream of the manufacturer), and to encourage early investment in emerging manufacturing technologies (e.g., additive manufacturing) by developing models that quantify the long-term energy, resource, and economic benefits of advanced manufacturing methods to the nation (for the U.S. DOE's Advanced Manufacturing Office). I am eager to learn how my workshop colleagues are promoting more sustainable manufacturing systems through their research work in our upcoming meetings!


## Nabil Z. Nasr, Ph.D.

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## Biographical Sketch

Dr. Nabil Nasr is the Associate Provost for Academic Affairs and founding Director of the Golisano Institute for Sustainability at Rochester Institute of Technology (RIT). He also founded the Center for Remanufacturing and Resource Recovery at RIT, which has become a leading source of applied research and solutions in remanufacturing technologies. For over 25 years, Dr. Nasr has worked in the fields of sustainable production, remanufacturing, clean production, and sustainable product development and is considered an international leader in research and development efforts in these disciplines. He has developed strong ties to industry through efforts to implement and improve sustainable design and remanufacturing processes at hundreds of companies from diverse sectors. Dr. Nasr chaired the Advisory Expert Group on Sustainable Production and Eco-Innovation with the Organization for Economic Cooperation and Development (OECD). In addition, he also served as an expert delegate for the U.S. government with several international forums, including the Asia Pacific Economic Cooperation (APEC), the United Nations, and the World

Trade Organization. He recently served as an invited expert to the 13th International Resource Panel of the United Nations Environment Programme.

Dr. Nasr served as a member of The National Academies, National Research Council, National Materials and Manufacturing Board (NMMB). He also served a three-year term as a member of the Scientific Advisory Board for Singapore Institute for Manufacturing Technology. He serves as the president of the Center for Environmental Initiatives (CEI) and is a member of the Editorial Board of the International Journal of Engineering Management and Economics, the Editorial Board of the International Journal of Sustainable Manufacturing, a member of ASME's Research Committee on Sustainable Products and Processes, and a member of the Review Committee for the Energy, Engineering and Systems Analysis Directorate (EESA) at Argonne National Laboratory. Dr. Nasr is a member of the executive leadership group of the Remanufacturing Industries Council (RIC), and the Imaging Technology Council (remanufacturing council for the imaging industry). He is also a member of the Advisory Board for the Product Stewardship Institute (PSI). Dr. Nasr is Founding President and member of the board of directors of a start-up company (based on his patented technology) focused on advanced prognostics and system health management for transportation applications. The company currently employs 60 people.

Dr. Nasr has a B.S. in Industrial Engineering from Helwan University, an M.S. in Industrial and Systems Engineering from Rutgers University, an M.Eng. in Manufacturing Engineering from Penn State University, and a Ph.D. in Industrial and Manufacturing Engineering from Rutgers University.

## Position Statement

A major cause of the worsening global environment is unsustainable consumption and production, particularly in industrialized regions. Through partnerships with industry, government, non-governmental agencies and other universities Dr. Nasr and his team at Golisano Institute for Sustainability seek to develop new technologies that will assist in implementing sustainable processes in industry while also disseminating knowledge, education and training in the field.

International Collaboration: Through a partnership with the Clinton Global Initiative, a commitment has been formed to provide assistance to five developing countries (Peru, Dominican Republic, Malaysia, Indonesia, and Egypt) to assist in their development of educational programs in the field of sustainability as well as technology transfer.

## Kimberly Ogden, Ph.D.

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## Biographical Sketch

Kimberly Ogden is a professor of chemical and environmental engineering at the University of Arizona. She received her BS degree from the University of Pennsylvania and her MS and PhD degrees from the University of Colorado. Prior to joining the UA in the fall of 1992 she was a postdoctoral fellow at Los Alamos National

Laboratory. She is currently on the managing board of SBE and recently completed her term as the secretary of AIChE. Kim's research focus includes bioreactor design for production of alternative fuels from algae and sweet sorghum and microbiological water quality. She is the engineering technical lead for the National Alliance for Advanced Biofuels and Bioproducts or NAABB. As the final report is being written for the NAABB consortium, her research in algae to biofuel continues through a Regional Algal Feedstock Test bed program funded by the Department of Energy. The goal of this 4 year project is to obtain long term outdoor algal cultivation data that will be available to the public for use in modeling and other research efforts, and demonstrate the feasibility of year round cultivation. Furthermore, industrial and other universities will be able to use the test beds to test new technologies such as novel harvesting and extraction systems.

Kim is also involved in teacher outreach programs. She has run a NSF Research Experiences for Teachers Program for over ten years, where teams of teachers spend 5 to 6 weeks in the summer doing research in the UA laboratories and transfer what they learn directly to the K-12 classroom through relevant lesson plans. She is also the principal investigator for a NSF GK-12 engineering program. The focus of the GK12 is water and energy sustainability. Graduate students from 7 different engineering disciplines have been GK12 fellows and worked in junior high and high school classrooms in the Tucson area. Some of these school districts have up to 90% of their student population from diverse backgrounds and have 70 to 80% of the students receiving free or reduced meals.

## Position Statement

Kim is interested in the systems approach to sustainability. New industries such as the algal biofuels industry will only be viable if they integrate with existing systems. Co-locating algal cultivation systems near cheap or free sources of carbon dioxide, nitrogen and phosphorous is highly desirable. Water recycle and use of non-potable water sources is required in areas of abundant sunlight like the Southwestern United States. Furthermore, using existing refining infrastructure allows for slow integration of bio-oils. Simultaneous production of high value products such as omega fatty acids, nutriceuticals, and pharmaceuticals; fertilizer; fuel; and food is essential in Kim's opinion. Integration will assure a cost effective and environmentally friendly integrated new industry.

## Karthik Ramani, Ph.D.

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## Biographical Sketch

Karthik Ramani is a Professor in the School of Mechanical Engineering at Purdue University. He earned his B. Tech from the Indian Institute of Technology, Madras, in 1985, an MS from Ohio State University, in 1987, and a Ph.D. from Stanford University in 1991, all in Mechanical Engineering. He has worked as a summer intern in

Delco Products, Advanced Composites, and as a summer faculty intern in Dow Plastics, Advanced Materials. He was awarded the Dupont Young Faculty Award, the National Science Foundation (NSF) Research Initiation Award, the NSF CAREER Award, the Ralph Teetor Educational Award from the Society of Automotive Engineers, Outstanding Young Manufacturing Engineer Award from the Society of Manufacturing Engineers, Ruth and Joel Spira Award for Outstanding contributions to the Mechanical Engineering Curriculum, Kos_Ishii Toshiba Award for Design for Manufacture and Lifecycle. In 2002, he was recognized by Purdue University through a University Faculty Scholars Award and 2005 the Discovery in Mechanical Engineering Award for his work in shape search. In 2006 he won the innovation of the year award from the State of Indiana. He developed many successful new courses - Computer-Aided Design and Prototyping, Product and Process Design and co-developed an Intellectual Property course. In 2007 he won the only Research Excellence Award throughout the College of Engineering at Purdue University. He is a co-founder of Imaginestics, a knowledge-based software company that has launched the world's first on-line search engine for the global supply chain. He recently founded ZeroUI. He serves in the editorial board of Elsevier Journal of Computer-Aided Design. In 2008 he was a visiting Professor at Stanford University (computer sciences) as well as a research fellow at PARC (formerly Xerox PARC). He is also serving on the Engineering Advisory sub-committee for the National Science Foundation (Industrial Innovation and Partnerships) since 2007.

While his research lies at the intersection of mechanical engineering and information science and technology, the areas span design and manufacturing, shape understanding using machine learning, geometric computing and human-computer interaction and interfaces with shapes and sketches. A major area of emphasis in his group is computer support for early design, shape searching, sketch-based design, cyber and design learning, sustainable design and manufacturing, and natural user interfaces for shape modeling. In 2006 and 2007, he won the Most Cited Journal Paper award from Computer-Aided Design and the Research Excellence award in the College of Engineering at Purdue University. In 2009, he won the Outstanding Commercialization award from Purdue University.

He is a co-investigator in the NSF IGERT on sustainable electronics at Purdue, as well as two other NSF sustainable design grants in design education and engineering.

## Position Statement

Growing and realistic environmental concerns, coupled with public pressure and stricter regulations, are fundamentally impacting the way companies design and launch new products across the world. In particular, early design decisions can have a very significant impact on sustainability. Our contributions in this area include methodologies considering materials and manufacturing choices during early design where the impact on the environment can be the highest. We are developing design frameworks using cases to help companies to systematically develop appropriate and profitable design for environment strategies for their product systems. In addition, since most curricula are already saturated, we developed a new design critique method to embed sustainable thinking into design of products, processes and services. Our study indicates that integration of a critique-based module within an existing design project is an effective medium for teaching sustainable product design. We also demonstrated visual frameworks in early design for sustainability explorations. We developed an example multi-dimensional visualization that encodes part similarities as well as a calculated environmental sustainability indicator. By merging sustainable thinking into traditional design methods, our review provides a framework for ongoing research, as well as encourages research collaborations among the various communities interested in sustainable product realization.


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## Biographical Sketch

Professor Steve Skerlos is Arthur F. Thurnau Professor at the University of Michigan (UM). He is a tenured faculty member in Mechanical Engineering and Civil and Environmental Engineering, and serves as a UM Distinguished Faculty Fellow in Sustainability. He received his B.S. in Electrical Engineering with Highest Honors and his Ph.D. in Industrial Engineering from the University of Illinois at Urbana-Champaign.

Professor Skerlos is Director of the U-M Program in Sustainable Engineering which launched in 2013 and has 80 students enrolled. He is also Co-Director of the Engineering Sustainable Systems Program and Chief Technical Officer of Fusion Coolant Systems. Professor Skerlos has gained national recognition and press for his research, teaching, and impact in the fields of technology policy and sustainable design. He has co-founded two start-up companies: Accuri Cytometers and Fusion Coolant Systems, and has served as Director of the UM Graduate Program in Mechanical Engineering (2009-2012), and served as associate or guest editor for four different academic journals.

His Ph.D. students in the Environmental and Sustainable Technologies Laboratory have addressed sustainability challenges in the fields of technology systems design, technology selection, manufacturing, and water. From 2005-2012, he served as Principal Investigator for a $2M National Science Foundation Award to study the Optimization of Greenhouse Gas Policies in the Automotive Sector. Since 2003 Professor Skerlos has served as founder and faculty advisor to BLUElab, a 150 member student organization that serves as an incubator for sustainable design projects at home and abroad. BLUElab also organizes educational events to raise awareness of development issues and the critical role engineers play in tackling these technical problems in a socially responsible way.

In 2014, the U.S. National Academy of Engineering published his paper on the use of Cognitive Agents to Advance Sustainable Manufacturing in the Winter issue of The Bridge.

## Position Statement

Sustainable manufacturing has been defined by the US Department of Commerce as the creation of manufactured products using processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers, and are economically sound. Written as a mathematical optimization, and altered to place economic performance as the objective and environmental and social performance targets as constraints, the sustainable manufacturing definition might be expressed as:

MAX Profit = (unit revenue – unit cost) * production volume

Subject to Environmental targets

Social targets

Throughout his career, Professor Skerlos has used this view of sustainable manufacturing as an innovation driver for technology development, particularly in the area of manufacturing fluid systems. He has created novel membrane filtration applications, nanoemulsions, supercritical carbon dioxide-based process fluids, and bio-detection systems, all of which are manufacturing solutions that protect the environment, protect the health of workers, and increase profitability relative to business as usual.

Professor Skerlos has applied life cycle and economic modeling tools to evaluate the sustainability of various manufacturing applications, including lightweight materials substitution and laser-based additive manufacturing. His laboratory has recently extended the boundaries of life cycle assessment to include deeper economic integration, namely through a methodology called consequential life cycle assessment with market driven design (cLCA-MDD). The approach improves the utility of LCA in a policy and design context by combining engineering models with firm-level models and game theoretic strategy to understand how new technologies or policies in the manufacturing sector directly impact environmental emissions. cLCA-MDD played a significant role in recent discussions regarding the potential for unintended market consequences and rebound effects resulting from increases in the U.S. Corporate Average Fuel Economy standards.

**Hong C. Zhang, Ph.D., P.E.**
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## Biographical Sketch

Dr. Hong-Chao Zhang is E.L Derr Endowed Professor of Industrial Engineering at Texas Tech University. Dr. Hong-Chao Zhang is also the National “Qian-Ren” Endowed Chair Professor at the school of Mechanical Engineering, Dalian University of Technology, Dalian, China. Dr. Hong-Chao Zhang was Chang-Jiang visiting professor at Hefei University of Technology, Hefei, China in 2004-10. Dr. Hong-Chao Zhang serves as the Chief-Scientist of China 973 Fundamental Science Research Project focusing on scientific research of heavy-duty mechanical equipment remanufacturing. At Texas Tech University, he founded Advanced Manufacturing Laboratory (AML), where he and his research group are conducting research on the development of new innovative technologies, processes and methods to improve products’ sustainability, new material processing and lifecycle assessment, environmentally benign end-of-life (EOL) strategies, and development of tools to assess and enhance sustainable manufacturing practices. He has published more than 200 papers and served as over 50 major invited speakers for industry and government agencies. He established wide collaborative linkages with industry and served as chairs for conferences. Dr. Zhang has raised $14,793,327 research funding from NSF, Texas ATP, NIST, SME and other government and industry agencies, in which about $4.9 million are cash funds from US agencies, and 9.15 million from Chinese agencies (all cash funding are all competitive research grants), and $0.7 million are in-kind capital equipment funds. He is associate editor in three international journals and serves as advisory board member in the International Journal of Advanced Manufacturing and Technology (IJAMT). He was elected as a Fellow of American society of Mechanical Engineers (ASME) in 2008 and as a Fellow of the International Academy for Production Engineering (CIRP) in 2010. Dr. Zhang finished his B.S. degree of mechanical engineering from Tianjin University of Science and Technology, China, 1976, and his M.S., Ph.D. degrees of mechanical engineering from University of Aalborg, Denmark and Technical University of Denmark, 1986, 1989 respectively. He was research scientist at University of Texas, El Paso before he joined Texas Tech University in 1990.

## Position Statement

Sustainable manufacturing is the creation of manufactured products through economically-sound processes that minimize negative environmental impacts while conserving energy and natural resources. The aims of sustainable manufacturing can be achieved by developing new innovative processes, materials and technologies to enhance existing manufacturing practices, and to design new practices and products. Making innovation a continuous process for new and advanced manufacturing of new and existing products is major challenge Dr. Hong-Chao Zhang's research groups have been working on both in US and China. The groups have been redesigning end-of-life (EOL) strategies for many products such as heavy-duty equipment remanufacturing, and developing new materials technologies to make sustainable products. Dr. Hong-Chao Zhang's groups developed new processes for delaminating, recycling of printed circuit boards using a supercritical carbon dioxide process. The groups carried out microstructural transformation of materials such as shape memory polymer nanocomposites for active disassembly (AD) applications. Dr. Hong-Chao Zhang's groups have also extended literature on product innovation and sustainable manufacturing by developing sustainability index and metric for 3D assessment of product's sustainability. Recently, Dr. Dr. Hong-Chao Zhang's groups start research on development of innovative processes for remanufacturing of electric vehicle (EV) batteries.

# CHINA NSFC OFFICERS


## Guobiao WANG, Ph.D.

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### Biographical Sketch

Guobiao Wang is the director of Mechanical Engineering Division, NSFC. His main areas of research interest include modern design theory and methods, vehicle engineering and micro-nano manufacturing. He is also the executive director of the tenth council of Chinese Mechanical Engineering Society, and the committee member of academic council in the State Key Laboratory of Mechanical System and Vibration (Shanghai Jiao Tong University, SJTU), the State Key Laboratory of High Performance Complex Manufacturing (Central South University, CSU), and the State Key Laboratory of Digital Manufacturing Equipment and Technology (Huazhong University of Science and Technology, HUST). He is also the associate managing editor of "*Chinese Journal of Mechanical Engineering*", the editor of "*China Mechanical Engineering*", and "*China Surface Engineering*".

### Position Statement

Mechanical Engineering Division supports fundamental research and applied fundamental research in the areas of mechanical and manufacturing science. The major areas supported by the Division are listed as follows:

(1) The fundamental research oriented to national strategic requirements, the frontiers of disciplinary development, as well as potentials for industrial applications.

(2) The research oriented to environment-friendly, resource-saving, and high energy efficient integration of sustainable design and manufacturing.

(3) The research on the innovative design, manufacturing principle, measurement theory for the ultra, high-precision, high-tech and especially large/heavy equipment and instrument, including processing mechanism, prototyping theory and technology.

(4) The development on the methodology of design and manufacturing for the extreme working conditions, for instance, from macro to meso, micro, nano, and even multi-scale sizes, and from conventional to extraordinary or extreme parameters.

(5) The multi-disciplinary research, multi-physics coupling analysis, and design method covering mechanical sciences, electronics, hydraulics, acoustics, optics, magnetism, information science and other subjects.

## Yinan LAI, Ph.D.

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### Biographical Sketch

Ms. Yinan Lai joined the National Natural Science Foundation of China (NSFC) in 2011 as the program director of Mechanical Engineering Division. She obtained a Ph.D. in Mechanical Engineering from Harbin Institute of Technology in 2004. Before joining NSFC, she was a full professor of mechanical engineering at Harbin University of Science and Technology, and awarded New Century Excellent Talents in University, Ministry of Education, China (2010).


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### Biographical Sketch

Mr. Qin WEI joined the National Natural Science Foundation of China (NSFC) in 2007 as program manager of the Division for Americas and Australian Affairs, Bureau of International Cooperation, National Natural Science Foundation of China (NSFC). He has been actively involved in NSFC-CIHR, NSFC-FRQs, and NSFC-RFBR bilateral programs. He obtained his M.A. in English Language and Literature from the School of English and International Studies, Beijing Foreign Studies University in 2007.

### Position Statement

The Division for Americas and Australian Affairs is responsible for administering international cooperation in all areas of basic science with science funding agencies in the Americas and Oceanian countries, such as the National Science Foundation and the National Institutes of Health in the U.S., and the Australian National Health and Medical Research Council etc. International programs managed by the division include international personnel exchange projects, joint research projects, bilateral workshops, and other academic activities. Besides, the division is charge of policy research on the promotion of international S&T cooperation and exchange.

## Guojun ZHANG, Ph.D.

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## Biographical Sketch

Dr. Guojun Zhang joined the National Natural Science Foundation of China (NSFC) in 2012 as the program director of Chemical Engineering Division. Before joining NSFC, Dr. Zhang is a full professor of chemical engineering at Beijing University of Technology (BJUT). He received his PhD degree from Chinese Academy of Sciences in 2002. Dr. Zhang had worked as an Environmental Engineer at Chinese Research Academy of Environmental Sciences from August 2002 to February 2003. Since March 2003, he joined the National University of Singapore (NUS) as a Research Fellow (A). After working at NUS for two years, he moved to BJUT and was promoted as a professor on December 2010. Dr. Zhang was awarded Beijing NOVA Program (2006), and New Century Excellent Talents in University, Ministry of Education, China (2012). He is now on the Editorial Boards of Membrane Water Treatment and Membrane Science and Technology (Chinese). He has published more than 70 journal papers and applied 27invention patents.

## Position Statement

The Chemical Engineering Program supports the research in chemical engineering and industrial chemistry focusing on the dynamics, mass and energy transfer, reactions and interrelationships in the physical, chemical and biological conversion of matter. Its tasks are to recognize the phenomena and rules underlying mass transfer in these conversion processes and their effect on the reactions and the properties of the products. New technologies and equipment for the clean and highly effective conversion of substances, and the establishment of theories and methods of design, scale-up and regulation and control for industrial applications are also involved. Research areas encouraged include basic chemical engineering data measurement, computation and simulation, multi-phase flow and transfer processes, separation and purification engineering, process engineering of chemical reactions, system engineering, inorganic chemical engineering, fine organic engineering, bio-chemical engineering and food chemical engineering, energy chemical engineering, chemical engineering and materials, chemical engineering and metallurgy, chemical engineering and environment, and chemical engineering and resources.

## CHINA DELEGATES


### Huajun CAO，Ph.D.

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### Biographical Sketch

Dr. Huajun Cao is a full professor of Mechanical Engineering, and deputy director of the Institute of Manufacturing Engineering (IME) in Chongqing University, China. His research focuses on green manufacturing, including efficient and effective resource utilization of manufacturing system, modeling and optimization for low carbon manufacturing system, clean and high efficient manufacturing processes, end-of-life engineering for high-duty equipment(machine tools, diesel engine power train, turbo machinery, etc.).He has authored and co-authored over 80 academic papers and a book of *Green Manufacturing Theory and Technologies* in 2005 by China Science Press. His work is funded by the National Science Foundation of China, Ministry of Science and Technology (MOST) of China, Chongqing Machine Tool Works, and others. He was hired as the expert panel member of the national "Twelfth Five-Year" Green Manufacturing Major Project (2012-2015), and also the technology director of the National High and New Technology Industrialization Base for Green Equipment Manufacturing located in Chongqing in 2012. As principal writers, he drafted three national technical standards on green manufacturing( GB/T 28612-2012,GB/T 28613-2012and GB/T 28615-2012）.He won four scientific or technical achievement awards related to green manufacturing by Chongqing Government in recent years. He was also named as the 2013 New Century Excellent Talent by Ministry of Education, China. Dr. Cao had Master degree in mechanical engineering from the Chongqing University, China and got his PhD in mechanical engineering also from Chongqing University in 2004. From 2007 to 2008, he was in charge of a machining shop for mould design and fabrication. As visiting scholar in 2009, he was engaged in the research work in UC Davis and UWM-Milwaukee, USA. Afterwards, as a delegate of China Green Manufacturing Global Investigation Group organized by MOST, he also had short visits to the Lab for Manufacturing and Sustainability (LMAS) at UC Berkeley, the Fraunhofer Institute for Machine Tools and Forming Technology (IWU) at Chemnitz of Germany, and DMG Factory in Hanover，Caterpillar Remanufacturing Plant at Corinth in USA, etc. As a research affiliate (RA), he also attended the CIRP January Meeting in Paris in Jan 21-25, 2014, and participated the meeting of STCA of Life Cycle Engineering and Assembly, and the forum of CWG of Efficient and Efficiency of Resource Utilization (EERU).

### Position Statement

Sustainability is beyond the responsibility for protecting the planet and the human being healthy, and should be the driving force for innovation of technology, product and service. Manufacturing activities dominate industrial energy consumption, responsible for 84% of energy-related industry $CO_2$ emissions and 90% of industry energy consumption. However, the resources in the earth are limited and needs of energy and material resources are exploding in the past ten years, especially in developing countries, such as China. Production will have to do with much fewer materials and energy to guarantee the future prosperity. An assessment by expert scientists showed that at least a 10-fold improvement in resource and energy efficiency over the next 50 years is essential. Particularly in China, it is more imperative and practicable. Meanwhile, due to the increasing energy cost, in the coming future the embedded energy in products would be balanced and evaluated accurately in industry and energy-efficient product and production technology would lead the innovation and application. Our group, Institute of Manufacturing Engineering (IME) of ChongqingUniversity has been engaging in the research on resource and energy efficiency since 1980s initiated by Prof. Fei Liu. Our research group have published extensive publications on energy efficiency and also developed some practical methods and tools. An optimized material cutting system for multi-raw material and multi-workpiece was developed to improve the efficiency of material utilization, while reduce the rough machining allowance and the related energy as well. A series of practical energy consumption prediction models for machine tools were established to assess the potential energy consumption based on design drawings of parts and process planning sheet. To optimize energy efficiency in machine shop, energy-saving process planning was conducted, including micro planning, macro planning and scheduling as well. Manufacturing execution system considering energy efficiency (e-MES) was developed, in which the power information was used to acquire the information of production progress automatically, and monitor the condition of machine tools for sake of predictive maintenance. Since the machine tools in Chinese machine shop usually run in bad condition, machine tool remanufacturing and updating were widely conducted as technical service for many factories to improve the machining effectiveness and energy efficiency. However, production system is a very complex system and varied with products and processes. There are still a lot of problems for research. To face the challenge of the shortage of resource and energy, the theory and technical innovation must achieve break-through progress for the production systems.

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## Biographical Sketch

Professor Kai Cheng holds the Qian-Ren professorship in Manufacturing Systems at Harbin Institute of Technology. His current research interests focus on multiscale sustainable manufacturing and systems, precision and micro manufacturing, and design of high precision machine tools. Professor Cheng has published over 90 papers in learned international journals, authored/edited 4 books and contributed 6 book chapters. Professor Cheng is a fellow of the CSME, IET and IMechE. He is heading the Sustainable Manufacturing Research Center at Harbin Institute of Technology, which consists of 6 academics and over 20 PhD students. The Centre is currently working on a number of research projects funded by the NSFC, MOST, 863 Program, UK-China GSM network and the industry. The Center is also actively collaborating and engaging with a number of manufacturing companies from China, South Korea, Europe and USA. Professor Cheng is the associate editor for the International Journal of Advanced manufacturing Technology, and a member of the editorial board of International Journal of Machine Tools and Manufacture. Prof. Cheng was awarded the BEng in Mechanical Engineering and MSc in Manufacturing Engineering at Harbin Institute of Technology respectively, and a PhD in Precision Manufacturing at Liverpool John Moores University.

## Position Statement

My team at Harbin Institute of Technology has been working in multiscale sustainable manufacturing and systems since September 2009. The research activities have been primarily projects driven while with some focuses on:

(1) Design of internally cooled smart cutting tools, which can be employed for contamination-free machining and 'dry' cutting, and thus likely lead to environmentally friendly machining processes.

(2) Development of the ERWC (energy-resource-waste-carbon footprint) approach to quantitative analysis of energy consumption and carbon footprint of CNC milling machines, its ultimate goal is to implement ERWC-based algorithms onto CNC controllers and lead to development of next generation Eco-CNC machine tools operating in a sustainable manufacturing manner.

(3) Further development of the ERWC approach to quantitative analysis of energy consumption and carbon footprint at automotive paint-shop, and the associated shop-floor processes mapping and optimization.

(4) Development of the energy management system for automotive manufacturing factories, industrial feasible real-time decision makings are the essential research focus by likely applying advanced modeling and big data techniques. The correlation analysis on quality, productivity and energy consumption in a multi-dimensional manner and the associated complexity impose scientific challenge while in manufacturing terms.

(5) Investigation on Point-of-Use (POU) manufacturing systems with application to food industry, the research and development is carried out in close collaboration with industrial companies, particularly on design of POU systems, their use in food manufacturing in light of geographically distributed manufacturing supply chains, and the new business model.

Recently, the research interest is started to move onto investigating the generic nature and fundamental issues of tooling - machine/process – shop floor - factory - manufacturing supply chains in sustainable manufacturing in a multiscale and multi-dimensional context. It aims to achieve the comprehensive and scientific understanding of sustainable manufacturing, i.e. approaches/ methodologies/tools, which can be utilized effectively and efficiently by manufacturing industries in the 21$^{st}$ century.

## Shanying HU, Ph.D.

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### Biographical Sketch

Professor HU Shanying received PhD (Chem Eng) from the Tsinghua University in 1989. He has been a staff in department of chemical engineering since 1990, became Professor in 2003. Before that he visited at the Denmark Technical University (Denmark) as a visiting scholar and at the University of Manchester Institute of Science and Technology (UK) as a British Royal Society Research Fellow. His research interests include industrial ecology, circular economy and process system engineering. More than 80 research projects were finished and 25 planned eco-industrial parks were set as national demonstrations. More than 300 academic papers were published in international and Chinese journals. Dr. Shanying Hu also won 8 scientific and technology prizes.

### Position Statement

Aiming to demand of sustainable development in China, the center for industrial ecology at department of chemical engineering, Tsinghua University was established in April, 2001, which is the first research center on eco-industrial theory and practice in China. The center is also a branch of united eco-industry key laboratory of State Environment Protection Ministry. Dr. Hu's group focus on analysis, planning, integration for eco-industrial parks and circular economy systems, especially on developing soft science methods to help building sustainable chemical industry in China. The group has finished a lot of research projects for supporting decision-making on circular economy development for Chinese government departments, and also finished more than 50 eco-industrial parks and circular economy parks.

## Haihong HUANG, Ph.D.

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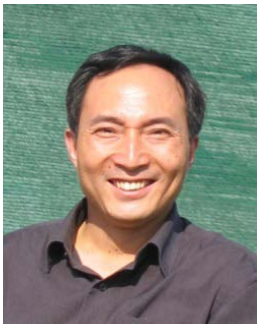
### Biographical Sketch

Haihong Huang is a professor of School of mechanical and Automotive Engineering at Hefei University of Technology. His research is focusing on green design and manufacturing, remanufacturing and recycling process and technology, and non-destructive testing for remanufacturing. He has authored and co-authored over 60 publications, 8 invention patents. His researches have been supported by a number of programs from national 863 and NSFC. His work has been recognized through several awards, and he has received Anhui Science and Technology Progress Award first prize, and Shanghai Science and Technology Progress Award second prize.

## Position Statement

Manufacturers around the globe have been increasingly pressured to create products that are as ecological as possible, which has led to ever more attention to green design and manufacturing. It has been noted that a major proportion of the environmental impact is determined in the product design process. Dr. Huang has developed green design methods and tools to support this innovative design. At the same time, wasted products are becoming a serious environmental problem. Dr. Huang is focusing on the product end-of-life (EOL) technologies for many products and materials such as household appliances, automobile, construction machinery, automotive tires and fiber-reinforced composites. These EOL strategies include disassembling, remanufacturing and recycling. His group has developed equipments and tools for disassembling and recycling to make the recycling process efficient and clean. He is developing new nondestructive testing method and instrument for remanufacturing of ferromagnetic components to evaluate their residual life. Recently, Dr. Huang starts research on development of innovative processes and equipment for recycling of carbon fiber-reinforced composites.

## Wanqin JIN, Ph.D.



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## Biographical Sketch

Dr. Wanqin Jin is professor of Chemical Engineering at Nanjing University of Technology, the Deputy-director of the State Key laboratory of Materials-oriented Chemical Engineering and the Chief-scientist of the National Basic Research Program (973 plan) of China. He received his Ph.D. from Nanjing University of Technology in 1999. He was a research associate at Institute of Materials Research & Engineering of Singapore (2001), an Alexander von Humboldt Research Fellow (2001-2013), and visiting professors at Arizona State University (2007) and Hiroshima University (2011, JSPS invitation fellowship). His currently research focuses on the development of membrane materials, membrane processes and membrane reactors. He has published over 170 international refereed journal papers with over 2600 citations. He edited 4 books and had 22 Chinese authorized patents. He has given over 20 plenary and keynote lectures in international conferences. He is now on the Editorial Boards of *J.Membr. Sci.*, *J.Nanomater.*, *Asia-Pacific J. Chem. Eng.* and *Chinese J. Chem. Eng.*, and is a council member of Aseanian Membrane Society (AMS).

## Position Statement

Membrane technology is recognized as an advanced and sustainable technology for water, energy and environment. Professor Jin's group applied catalytic membrane reactors (CMR) based on dense mixed oxygen-ionic and electronic conducting (MIEC) ceramic membranes for energy and environment applications. His research aims at promising industrial processes, such as syngas production from methane; sustainable hydrogen production from bioethanol, resource utilization of carbon dioxide. He leads a number of creative fundamental researches to address the challenges and difficulties for the practical application of MIEC membrane and CMR, from the development of high performance MIEC membrane materials, to design of advanced membrane geometric configuration, and finally to the construction of new membrane reactors. The goal of his research is to establish the bridge between lab-scale research of MIEC membrane and their practical application for highly effective and sustainable industrial processes. Another significant research of his group is focusing on pervaporation membranes and processes for renewable energy utilization. Pervaporation is an emerging membrane technology that could realize molecular-level separation for liquid mixtures with advantages of high-efficiency, cost-effective and eco-friendliness. His research is conducted in the rational designing and engineering of advanced pervaporation membranes that can be used for biofuels recovery and purification, as well as developing pervaporation-intensified processes. His ultimate pursuit is to push the state-of-the-art pervaporation technology into biofuels production.

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## Biographical Sketch

Dr. Yu Qian is Pearl River Chair Professor of Chemical Engineering, Director of the Center for Process Systems Engineering at South China University of Technology. His field involves modeling, simulation, and integration of the energy and chemical processes.

Dr. Qian is currently directing a China NSF funded key project on sustainability and life cycle assessment of coal based energy/chemical processes. This research is developing scientific methodologies for understanding and enhancing the sustainability of recent blooming coal based chemical processes in China, especially focusing on IGCC, coal to gas/syngas, coal to methanol/olefins, coal to liquid fuel, hopefully further to shale oil/gas processing. The research aims analyzing the life cycle of existing and emerging technologies, developing integrated models for industrial processes, and supporting policies, in consideration of multi-objective technological–economic -environmental-ecological performance.

In the past six years, he co-organized/co-chaired two international conference series on sustainable chemical product and process engineering. Currently, he is the deputy director of the Institute of Computer Aided Chemical Engineering, Chinese Society of Chemical Engineers. Among many honors, Dr. Qian was the recipient of China NSF's Outstanding Young Scientist Award in 2003, and the Outstanding Academic Award of Chemical Systems Engineering from the Chinese Society of Chemical Engineers in 2011.

Dr. Qian holds a B.S., a M.S., and a PhD degree, from Tsinghua University, in Beijing, in 1982, 1984, and 1987, respectively. He was a postdoctoral fellow at the Norwegian Institute of Technology in 1989, then a Research Associate Fellow at the University of British Columbia, in Vancouver, before joining South China University of Technology as a full professorin 1994. He has served as the Dean of the School of Chemical Engineering there since 2002.

## Position Statement

In the background of global energy/resources shortage, many alternative energy and chemical processes were proposed, which are, however, not quantitatively and comprehensively evaluated, neither for long-term effects on the industrial sectors and resource supply chains, nor for social development and ecological environment.

Coal is the dominant energy resource in China for a long period. Clean and efficient utilization of coal is critical in conserving resource and improving environment as well as satisfying economic increase. With increasing knowledge of negative effect of industrial process development on environment and human livelihood, many of developed approaches for process sustainability are based on four E dimensions: Efficiency, Energy, Economics, Environment/Ecology, respectively.

To provide industry and decision makers with better understanding of the benefits and unintended impacts on environment and resources of the large-scale deployment of coal processing/utilizing technologies, our investigation aims establishing life cycle models from upstream to downstream phases, to explore methodology for evaluating the efficiency and sustainability of alternative coal-based processes, to rationale and optimize the flow-sheetings, reduce investment and operating costs, raise efficiency and minimize environmental impacts.

Although economic measures are not the first concern of our research, it is necessary to ensure economic benefit of a process prior to process design. Inspired from LCA, a variety of life cycle approaches are developed by expanding the perspective of the four E approaches, including exergetic life cycle assessment (ELCA), material life cycle efficiency, and life cycle costing (LCC). The key task for sustainability assessment and design is not to invent more taxanominors, but to select and utilize the existing indicators in appropriate and systematic manners.

Our current study takes coal gasification syn-gas centered energy/chemical chains as the bench cases. "Technical-economical-environmental-societal" multi-dimensional models are to be built, simulated, and optimized. Mass and exergy flow diagrams, life cycle inventory, sustainability indicators are to be established. Resource/energy utilization efficiency, environmental impact, and economic benefits are quantitatively analyzed. Finally, a platform to support the life cycle analysis and decision will be constructed for process evaluation, integrated innovation, and optimization of existing and potential alternative coal based chemical processes.

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## Biographical Sketch

Dr. Shao Xinyu is a Professor in the School of Mechanical Science and Engineering at Huazhong University of Science and Technology (HUST). He is also Executive Vice President of HUST, and Director of the State Engineering Research Center for the Digitization of Manufacturing Equipment, as well as Dean of the Dongguan-HUST Institute of Manufacturing Engineering (Dongguan, Guangdong Province). His research interest has been focused on digital and intelligent manufacturing, including low carbon and sustainable manufacturing. He has been honored by(1) The Ministry of Education 'The Chang Jiang Scholars Program' Professor (2004), (2) National Science Fund for Distinguished Young Scholars (2008), (3) Second-grade State Scientific and Technological Progress Prizes 2001, 2008, and 2012 respectively).

Dr. Shao once served as Dean of the School of Mechanical Science and Engineering, HUST from 2002 to 2007, and has been Vice-President of HUST since 2008. He is currently PI of the NSFC Key Project 'Theories and key technologies of operational optimization for manufacturing system with high efficiency and low carbon'. In 1998, he received his PhD degree in mechanical engineering from HUST, and from 1995 to 1998, he was studying in the Department of Industrial and Manufacturing Systems Engineering at the University of Michigan-Dearborn, USA as a visiting PhD candidate.

## Position Statement

Facing with global market competition as well as environmental and resource pressure, modern manufacturing needs urgently to increase efficiency and reduce consumption. Following this trend, one of our efforts supported by NSFC has been focused on the study of some basic theories and key technologies of operational optimization for manufacturing system with high efficiency and low carbon (i.e. low energy consumption). We investigated the correlated association of production efficiency and energy consumption, builta multi-dimension and multi-level optimizing model for complex manufacturing system, andproposed the technology for the integrated operational optimization of discrete shop manufacturing system with high efficiency and low carbon. By developing the integrated software-hardware architecture for shop floor production planning and control with necessary functionalities in prediction, monitoring, and simulation optimization, our work helps to enrich the body of knowledge for production management regarding energy consumption, and will develop a new platform of manufacturing execution with coincided objectives in high efficiency and low carbon. Another effort supported by MOST has been on the reverse logistics and remanufacturing of used products from the engineering machinery industry. Our focus has been on the systematic design of the recycling system for the used products, including planning of the service facilities and logistics network for the collection and transportation as well as remanufacturing operation. Special interest has been given in this to the life-cycle material tracking and information management for the process control and optimization in product recovery. In almost all of these studies and practices, we've observed that smart manufacturing based on advanced ICT (especially the Internet of Things, Internet of Service, and the so-called cyber-physical system) will pave a broad avenue to the new paradigm of sustainable manufacturing and green supply chain.


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## Biographical Sketch

Dong Xiang is an associate professor of mechanical engineering at the Tsinghua University. His research focuses on sustainable design and manufacturing, life-cycle assessment, e-waste recycling process and equipment and fatigue reliability of mechanical products. He has authored and co-authored over 100 publications. His work is funded by the National Science Foundation of China, Ministry of Science and Technology of China, Ministry of Industry and Information Technology of China, Top search Ltd., Sichuan Changhong and so on. He is a vice secretary general of National Technical Committee 337 on Green Manufacturing Technology of Equipment Manufacturing Industry of Standardization Administration of China.

## Position Statement

Growing and realistic environmental concerns, coupled with public pressure and stricter regulations, are fundamentally impacting the manufacturing industry of China. Sustainable manufacturing has been considered to be one of the most important ways to future manufacturing. The aims of sustainable manufacturing can be achieved by developing innovative processes, materials and technologies to enhance existing manufacturing practices, and to design new practices and products.

Dr. XIANG Dong is the head of Green Manufacturing Laboratory of Department of Mechanical Engineering. Green manufacturing laboratory has been involved in the active research activities in the area of Green Manufacturing and Green Education since 1998. In the past 16 years, green manufacturing laboratory has achieved fruitful research results on green design, green manufacturing process and recycling technology and some of them have been put into industrialization. Up to now, we have cultivated 7 post-doctoral, 4 visiting scholars, 18 PhD candidates and 35 masters. We have completed about 15 national and international projects, applied 30 patents and 10 software copyrights and issued about 150 papers. Taking 'Technological Innovation, Promoting Education and Service to the Society' as the target, we will contribute our best to support the sustainable development of China's manufacturing industry. The representative research includes:

(1) Theory, methodology and application of green design: Green design is the main method to achieve product's green characteristics. The environment, security, energy and resource factors are integrated into product by green design activities using the system point of view. Our researches concentrated on the green design theory and methodology, disassembly planning theory, energy and material saving of typical electromechanical products based on energy flow analysis. A green design integrated design platform concept and prototype had been proposed aiming at the shortcoming of temporary researches. Its key technology, systematic infrastructure and utilization in design process are studied and a green design oriented product system integrated model has been proposed.

(2) Green manufacturing process: In the study on galvanic attack problem in immersion silver technique of printed circuit board, Immersion Silver (I-Ag) is the major alternative lead-free surface finishes, but galvanic attack exists in I-Ag surface finish, which seriously erodes copper under solder mask. According to the analysis to the results of about sixty experiments, which are divided to three groups, the effect regulation and the significance of every factor to galvanic attack fault are decided. We optimize the parameters of the major factors. The optimization makes average galvanic attack degree decrease from 0.1839mil2 to 0.0761mil2. In the study on photoresist ultrasonic atomizing coating technology, it is necessary to use a new coating technology to deal with the problems of photoresist waste and environmental pollution, reduce the cost of the spin coating process. Based on the transfer matrix of the vibration rod, a new model of decomposing vibration system into vibration elements is proposed to solve the vibration performance of the ultrasonic atomizing nozzle's vibration system.

(3) Recycling process and technology: The main research activities include disassembly process and equipment, e-waste recycling and reusing, scrap rubber regeneration and reverse logistics theory and technology. We develops the concept of disassembly energy and sets up disassembly energy models for different kinds of components to describe removal force and separating displacement of components on PCB. In the study on reutilization technology of waste printed circuit boards, a multi-level crushing and pulverizing technology have been developed and got well separated PCB particles. A multistage separation technology that combines wet air-classification, filtration and shaking table was designed. The separation process could control the particles of pulverizing in more uniform concentration and got 95% separation rate. The PCB nonmetals were used to make sewer grates and surfboat in amusement park. In order to realize rubber resource sustainable development, we developed an energy-saving and environmental friendly waste rubber regeneration technology at room temperature by the studies of selective cleavage of C-S and S-S linkage of waste rubber's three dimensional networks.

(4) Study on fatigue reliability design and evaluation method of wind turbines: With the rapid development of wind power industry, it is very urgent to improve the reliability of wind power equipment so as to reduce the resource and energy consumption. Taking transmission system as the studying object, the energy transferring model was built based on energy analysis, which was used to study the mapping mechanisms between failure mode and reliability and build multidimensional reliability model. Then, the reliability of system and parts were built based on the study of correlation rules between components of transmission system. Bayes method was used to build reliability model based on performance degradation analysis and

real-time reliability evaluation method was studied. This research will provide theoretical and technical support for the reliability improvement during the whole lifecycle of wind equipment.

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## Biographical Sketch

Dr. Chao YANG is a Professor of Chemical Engineering, a group leader and deputy director of Key Laboratory of Green Process and Engineering at Institute of Process Engineering, Chinese Academy of Sciences. Prof. Yang was born in 1971 and received his Ph.D. and B.Sc. degrees in 1998 and 1993, respectively, both from Nanjing University of Technology. He was a postdoctoral fellow at Institute of Chemical Metallurgy, Chinese Academy of Sciences from 1998 to 2000, and a visiting scientist at Cornell University from 2005 to 2006. He has published about 140 papers in peer-reviewed journals, and holds 30 patents and 8 computer software copyrights. Prof. Yang has received numerous honors and recognitions, including the Asia Research Award from the Society of Chemical Engineers, Japan, and the HouDebang Chemical Science and Technology Award both in 2012, the National Award for Youth in Science and Technology and the Young Scientist Award of Chinese Academy of Sciences in 2011, the Mao Yi-Sheng Science and Technology Award in 2010, and the second prize of China State Natural Science Award and the first prize of Technological Invention Award from China Petroleum and Chemical Industry Association, both in 2009. He was awarded the National Science Fund for Distinguished Young Scholars in 2010. In 2013, he was selected into the National Talents Project and awarded the title of “Young and Middle-aged Experts with Outstanding Contributions” by Ministry of Human Resources and Social Security of China. He has supervised 16 Ph.D. students and 12 M.S. students. To meet the demands of the “green” upgrade and sustainable development of chemical and metallurgical industries in China, his research interests include numerical and experimental study of multiphase flow and transport phenomena in various multiphase reactors such as stirred tanks, loop reactors, micro-reactors and membrane reactors, and modeling diagnosis and innovation of industrial chemical reactors, in addition to development of new technologies for high-efficiency, clean and comprehensive utilization of low-grade mineral resources and pollution control of solid wastes by bioleaching and environmental biochemical engineering.

## Position Statement

Chemical, petrochemical, metallurgical and material industries are heavily related with the national sustainable and ecological development, which is subject to successful operation of reaction and separation in multiphase systems and multiphase reactors. Thus, a sustainable industrial process should be based on highly efficient reactors and separators. It is necessary to thoroughly study multiphase flow, heat and mass transfer and chemical reaction in these complex multiphase systems and understand the mechanism of transfer and transform of mass and energy, and establish reliable models for these processes. The theory and numerical method of design and scale-up large scale process equipment for multiphase processes are far from sufficiently developed. This is in many cases the bottleneck for transfer of laboratory achievements to commercial production. The traditional methodology of chemical engineering research is largely based on the empirical correlations and semi-empirical models in terms of overall averaged parameters, which is the key reason leading to the difficulty in scaling up chemical processes and equipment and the high consumption of energy and raw materials and pollutions. Therefore, we focus on the fundamental and applied research in computational reaction engineering approaches and innovated technologies for energy saving and emission reduction in process industries, i.e., green process and engineering for sustainable development of Chinese industry and economy. With multi-scale models and numerical simulation methodology, the processes related with flow, transport and reaction in reactors are studied, in order to obtain in-depth understanding on physico-chemical mechanisms and strive for the realization of scientific design, scale-up, diagnosis, optimization and manipulation of multiphase reactors, crystallizers and other process equipment. Multiphase flow, mixing, heat/mass transfer and chemical reaction (kinetics) related to fluids and solid particles, particle assemblages and reactors are studied by analytical and numerical methods. At the meantime, highly efficient processing equipment including stirred tank, loop reactor, crystallizer and bioreactor for mixing, transport, separation and reaction in multiphase systems are improved and innovated. Our studies can provide the details of unit operations for accurate and quantitative evaluation of process sustainability. Our fundamental works have promoted the applications of models and simulation in industrial production, e.g., recently we helped SINOPEC to optimize and renovate 16 industrial reactors successfully, which brought about impressive economic benefit (more than 100 million CNY/year) by reducing the materials and energy consumption and pollution emissions and saving of equipment investment, which make the industrial processes more sustainable and profitable.

Besides, biotechnologies have been involved increasingly in the utilization of natural resources. For example, bioleaching and bio-oxidation have been successfully used in extraction of metals such as Cu, U and gold from some low grade and refractory ores. These industrial practices have proved the application of biotechnology being promising and prospective in the sustainable development of mineral and metallurgy industries. However, in spite of many successful implementations, the potential of this strategy is underestimated seriously by some industrialists for its poor efficiency. To overcome this shortcoming, we are developing novel processes and designing new reactors to improve the rates of bioleaching and bio-oxidation by chemical reaction engineering methods. On the other hand, based on biohydrometallurgy processes, we are developing some new methods for remediation of contaminated soil by heavy metals and acid mineral drainage for mine environmental protection. Recently we are trying to develop a novel technology to remove and fix arsenic through formation of scorodite (crystalline ferric arsenate) based on a bioprocess, as arsenic is widely distributed throughout rocks, soil and natural water and commonly associated with some base and noble metals in the sulfide ores in mineral and metallurgy industries.

## Weimin YANG, Ph.D.

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## Biographical Sketch

Weimin Yang is Professor of Mechanical and Electrical Engineering at Beijing University of Chemical Technology, and directing the Polymer Processing and Advanced Manufacturing Center. He is also a Distinguished Professor of Chang Jiang Scholars Program, China Ministry of Education. His research interest is polymer processing and advanced manufacture technology, mainly focused on green process of polymer producing, plastics precision molding, energy saving in tire manufacturing, nano-fiber electrospinning and enhanced heat transfer in polymer processing, etc. His research group has undertaken over 30 projects supported by National Science and Technology Support Plan, National Science Foundation of China, and industrial company. Based on the research results, he has applied more than 200 invention patents (82 items authorized to present), published 8 books (English: ***Advances in Polymer Processing***, published by Wood head in UK and CRC in USA ) and more than 300 journal papers. He has received numerous honors and recognitions, including 2 Awards of China National Science and Technology Progress,10 China Provincial Awards and Houte Pang Chemical Science and Technology Award. Dr. Yang holds a B.S. degree of Mechanical Engineering, and a M.S. and a Ph.D. Degree of Chemical Process Equipment from Beijing University of Chemical Technology in 1987 and 1990, and 1998, respectively. From Oct. 2000 to Sept.2002, he was a postdoctoral fellow at Polymer Processing Yokoi Lab. of the University of Tokyo, Japan. In the recent years, Dr. Yang has been serving on editorial board of some important journals related to polymer processing, and also selected to Vice Chairman of the Experts Committee of China Plastics Processing Industry Association, and Advisor Experts of China Rubber Processing Industry Association.

## Position Statement

Polymer Processing and Advanced Manufacturing Center is an interdisciplinary research group in Beijing University of Chemical Technology (BUCT). This center is related with 2 national key laboratories in BUCT: State Key Laboratory of Organic-Inorganic Composites and National Engineering Laboratory of Tire Design and Manufacturing. There are 15 faculties and about 80 students in this research center. Their vision is to develop Efficiency, Energy Saving & Environment Friendly Technology in Polymer Processing.

Dr. Yang as former dean of School of Mechanical and Electrical Engineering of BUCT, he set up this interdisciplinary research center on polymer processing from 2003. During the past ten years, the center has got some great achievements, such as, 1) In order to get high efficiency technology of making micro polymer products and nano-fibers, we proposed a new concept of polymer melt differential and integral in polymer processing, and invented polymer melt differential injection molding machine, calculus extruder, calculus electro-spinning device, calculus nano-composites cascade machine, and etc. 2) In order to control the dimension accuracy of polymer molding products, we invented online measurement method and equipment of polymer PVT (Pressure- Volume specific -Temperature)correlation properties. 3) In order to get green and sustainable method of producing polymer from stone instead of oil, we invented a Ring Route PVC Producing Method without Mercury Pollution.

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## Biographical Sketch

Jinsong Zhao is a Professor and the Chairman of Department of Chemical Engineering at Tsinghua University. His researches are mainly focused on designing inherently safer chemical processes with increased operability and controllability, developing knowledge management systems for process safety management (PSM), and building intelligent systems for abnormal situation management (ASM). Before he came back to teach in China in 2005, he had worked at Purdue University as a postdoctoral and at AET as a Senior Engineer in Indiana, U.S.A. for eight years. The intelligent software platform PSM Suite developed by his research group at TsinghuaUniversity has been deployed in about 40 big petroleum/petrochemical/pharmaceutical companies in China. Dr. Zhao has published more than 90 peer reviewed papers in national and international journals. In addition to university courses, Prof. Zhao has offered short training courses to about 10,000 practicing professionals on process safety, HAZOP and risk management. His work has been recognized through awards from the China Petroleum and Chemical Industry Federation (CPCIF) and the Ministry of Education of China. He provides expert consulting services for the Ministry of Environment Protection (MEP) of China, the State Administration of Work Safety (SAWS) of China, and the United Nations Environment Programme (UNEP). Prof. Zhao received his Bachelor, Master and Ph.D. degrees in Chemical Engineering from Tsinghua University in Beijing.

## Position Statement

The promotion of sustainable industrial development in harmony with Earth's natural resources is of utmost importance, particularly in rapid growing economies such as China. Many countries have acknowledged that a comprehensive management of chemical hazards is a key contributor to achieve progress towards sustainable industrial development. Despite significant advancements in recent years, industrial accidents involving hazardous chemicals still pose a global problem. Their accidental release to the environment may result in the death or injury of workers; damage to the environment including death of wildlife or long-term damage to sensitive habitats; impacts on the surrounding neighborhood as well as economic losses and damage to infrastructure. Inherently safer design (ISD) proposed by Late Prof. Trevor Kletz decades ago has been recognized as the most effective risk reduction method. However, the ISD principles are still mostly qualitative and descriptive. We are developing methods for quantitative operability and controllability analysis which facilitates designing inherently error-tolerance chemical processes. Process fault detection and diagnosis (FDD) are critical for early warning of abnormal situations in chemical processes. Even though they have been studied for about a half century, off-the-shelf process FDD technologies are hardly reported. We are studying artificial immune systems (AIS) combined with artificial neural networks targeting online industrial applications.

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