The 51st William Blum Lecture
Presented at NASF SUR/FIN 2014
in Cleveland, Ohio
June 9, 2014

Surface Finishing Sustainability: Technology Pathways

by
Prof. Yinlun Huang
Recipient of the 2013 William Blum
NASF Scientific Achievement Award

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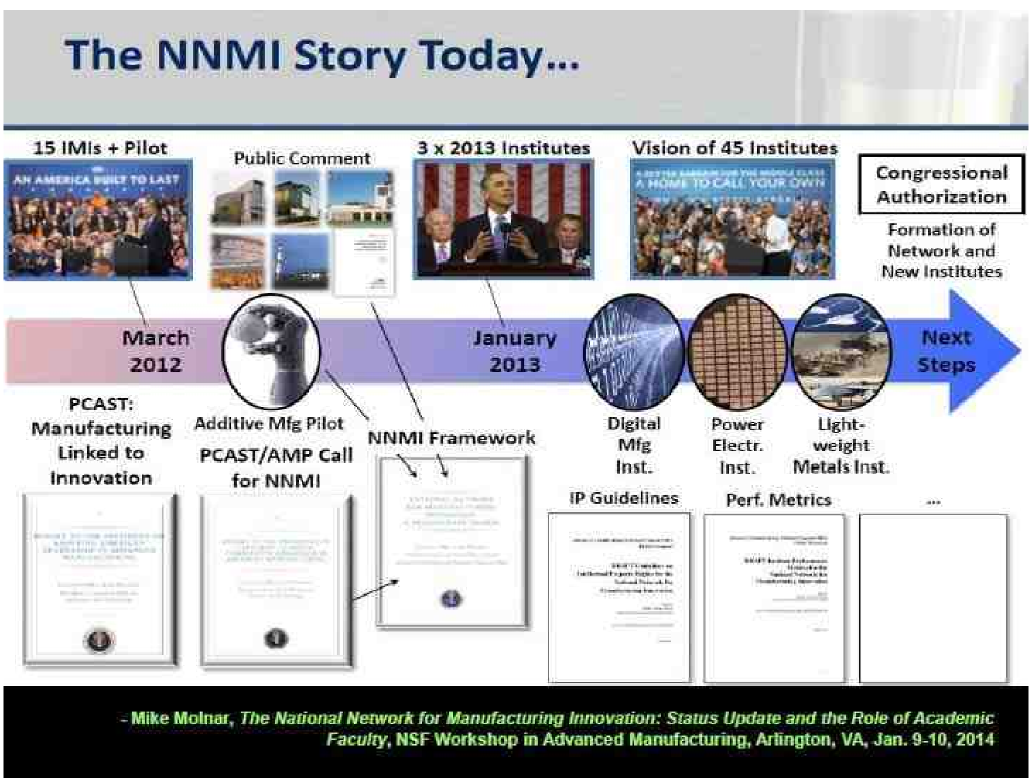
Editor's Note: The following is the Powerpoint presentation by Dr. Huang in delivering his William Blum Memorial Lecture at SUR/FIN 2014, in Cleveland, Ohio on June 9, 2014.


Outline
♦ Advanced, Sustainable Manufacturing – A National Priority
♦ Surface Finishing Sustainability: Questions and Tasks
♦ Technology Sustainability Study – A Wayne State University Approach
♦ Sustainable Manufacturing – An International Effort
♦ Concluding Remarks

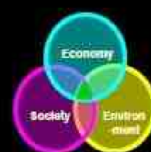

The NNMI Story Today…
15 IMIs + Pilot
AN AMERICA BUILT TO LAST
Public Comment
3 x 2013 Institutes
Vision of 45 Institutes
A HOME TO CALL YOUR OWN
Congressional Authorization
Formation of Network and New Institutes
March 2012
January 2013
Next Steps
PCAST: Manufacturing Linked to Innovation
Additive Mfg Pilot
PCAST/AMP Call for NNMI
NNMI Framework
Digital Mfg Inst.
Power Electr. Inst.
Light-weight Metals Inst.
IP Guidelines
Perf. Metrics
…
- Mike Molnar, The National Network for Manufacturing Innovation: Status Update and the Role of Academic Faculty, NSF Workshop in Advanced Manufacturing, Arlington, VA, Jan. 9-10, 2014


Advanced Manufacturing in the Civil, Mechanical and Manufacturing Innovation (CMMI) Division
Research leading to transformative advances in manufacturing and building technologies, with emphases on efficiency, economy, and sustainability
- M. Toney, NSF CMMI/MEP Prog. Director, presented at the NSF Workshop in Advanced Manufacturing, Arlington, VA, Jan. 9-10, 2014
NSF's No. 1 Science &Technology Priority for the FY 2014 Budget: Advanced Manufacturing
- Z.J. Pei, NSF CMMI/MME Prog. Director, presented at the NSF Workshop in Advanced Manufacturing, Arlington, VA, Jan. 9-10, 2014


Industrial Sustainability
• Sustainability is a new key driver of innovation
• Only companies that make sustainability a goal will achieve competitive advantage in the future
• An urgent need to rethink business models as well as products, technologies, and processes development
-- Prahalad et al., Harvard Business Review, Sept. 2009

Development Sustainability

- Surface finishing
  - Continuously vital to the national manufacturing and economy
  - Drivers: regulation, technology, and economics
  - Must find ways to prosper
- Manufacturing sustainability
  - Economic prosperity
  - Environmental compatibility
  - Social responsibility



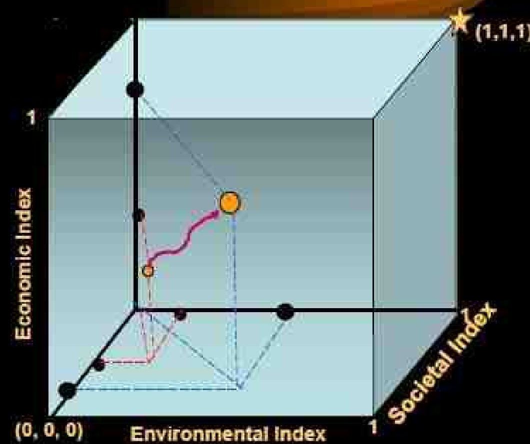
Important Documents

- Haveman, M., *Profile of the Metal Finishing Industry*, WRITAR, Minneapolis, MN, 1997.
- Chalmer, P., *Benchmarking Metal Finishing*, NCMS, Ann Arbor, MI, Jun. 2000.
- Chalmer, P., *The Future of Finishing*, NCMS, Ann Arbor, MI, Jan. 2008.
- Durkin, B., *Sustainability in Surface Finishing Today & Future*, Convetya, Inc., Oriskany, NY, 2014. (http://www.coventya.com/assets/Documents/RD-Sustainability-at-Coventya-2014.pdf)

Surface Finishing Sustainability: Key Questions to Answer

We need to know:

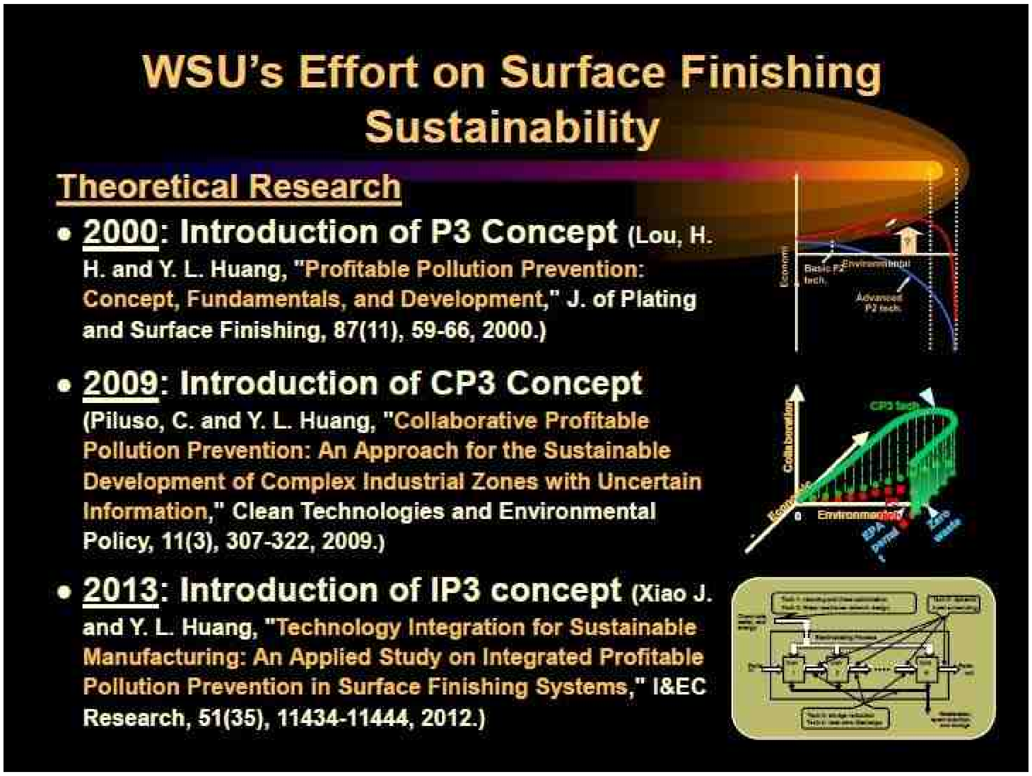
- where we are?
- what the next goal is?
- what the path is?
- what the investment and ROI will be?
- how long it will take to get there?

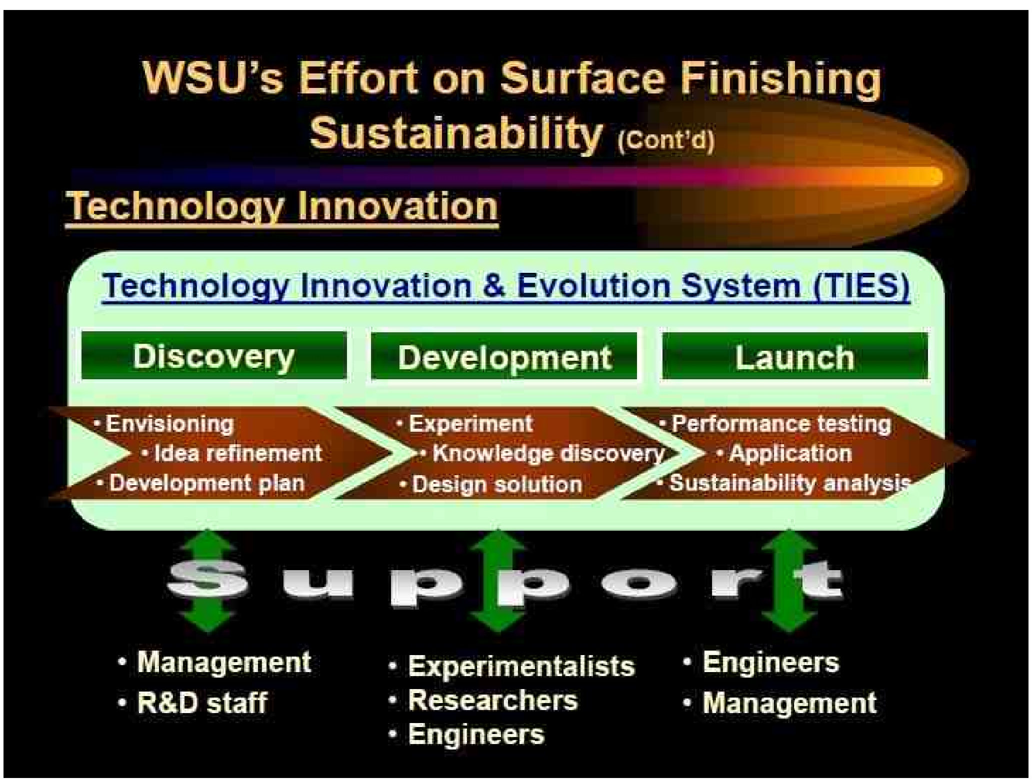


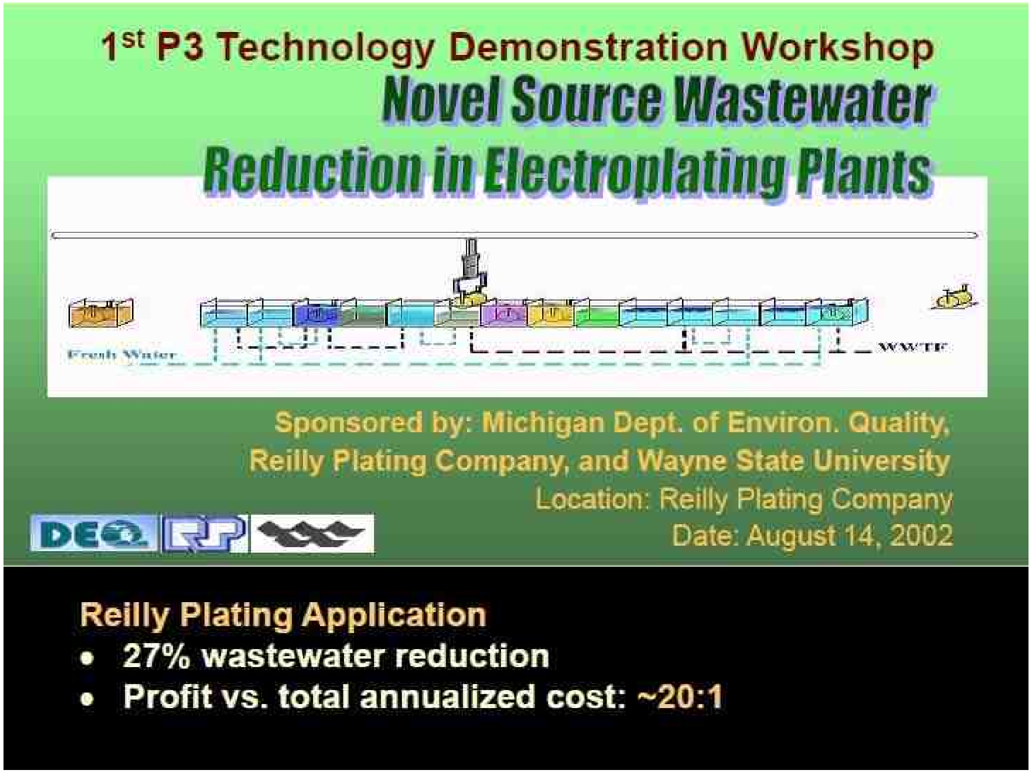
More Fundamental Questions

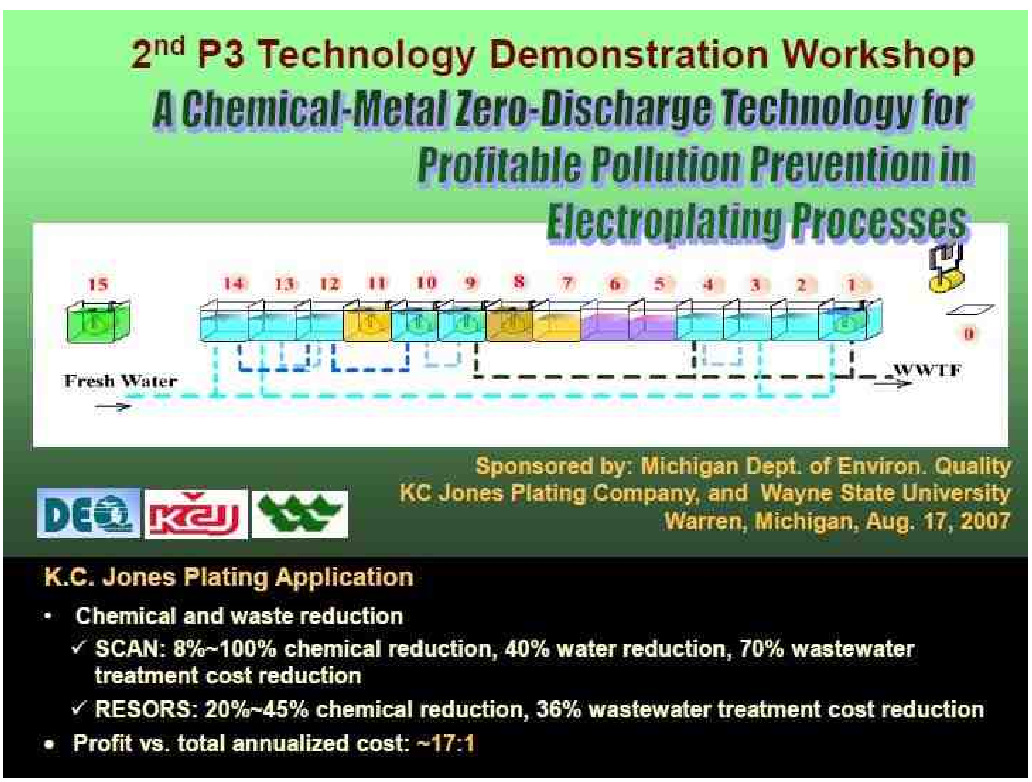
- Questions to be answered:
  - How much do we consider the challenges as a sustainability problem?
  - Do we have a sustainable development roadmap?
  - Are we able to conduct sustainability assessment?
  - Do we have tools to help surface finishers to evaluate their business sustainability and suggest short-to-long-term business strategies?

Serious, persistent efforts on sustainability study are urgently needed.


WSU's Effort on Surface Finishing Sustainability
Theoretical Research
• 2000: Introduction of P3 Concept (Lou, H. H. and Y. L. Huang, "Profitable Pollution Prevention: Concept, Fundamentals, and Development," J. of Plating and Surface Finishing, 87(11), 59-66, 2000.)
Basic P2 tech.
Advanced P2 tech.
• 2009: Introduction of CP3 Concept (Piluso, C. and Y. L. Huang, "Collaborative Profitable Pollution Prevention: An Approach for the Sustainable Development of Complex Industrial Zones with Uncertain Information," Clean Technologies and Environmental Policy, 11(3), 307-322, 2009.)
CP3 tech.
Collaboration
Economic
Environmental
EPA permit
Zero waste
• 2013: Introduction of IP3 concept (Xiao J. and Y. L. Huang, "Technology Integration for Sustainable Manufacturing: An Applied Study on Integrated Profitable Pollution Prevention in Surface Finishing Systems," I&EC Research, 51(35), 11434-11444, 2012.)


WSU's Effort on Surface Finishing Sustainability (Cont'd)
Technology Innovation
Technology Innovation & Evolution System (TIES)
Discovery
Development
Launch
• Envisioning
• Idea refinement
• Development plan
• Experiment
• Knowledge discovery
• Design solution
• Performance testing
• Application
• Sustainability analysis
Support
• Management
• R&D staff
• Experimentalists
• Researchers
• Engineers
• Engineers
• Management

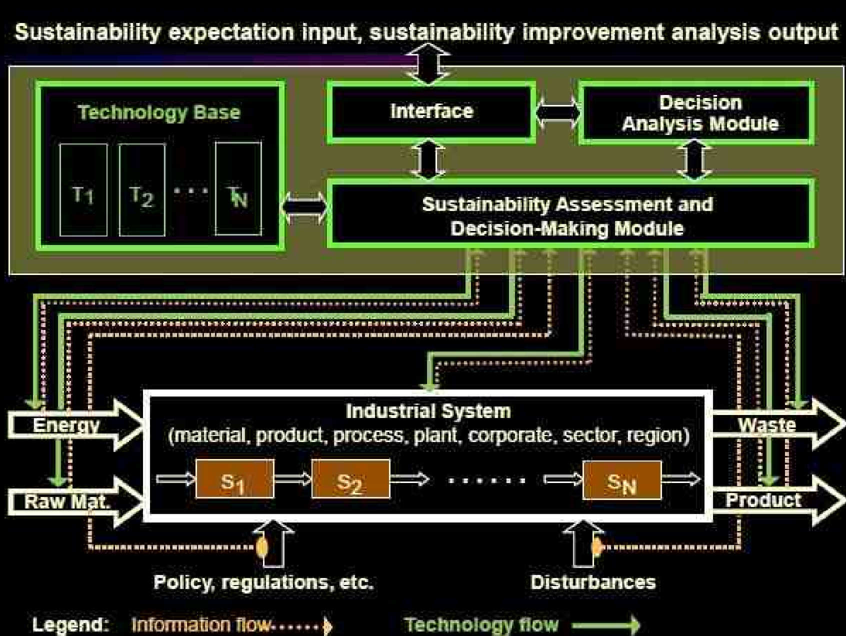

1st P3 Technology Demonstration Workshop
Novel Source Wastewater
Reduction in Electroplating Plants
Fresh Water
WWTF
Sponsored by: Michigan Dept. of Environ. Quality,
Reilly Plating Company, and Wayne State University
Location: Reilly Plating Company
Date: August 14, 2002
Reilly Plating Application
• 27% wastewater reduction
• Profit vs. total annualized cost: ~20:1


2nd P3 Technology Demonstration Workshop
A Chemical-Metal Zero-Discharge Technology for
Profitable Pollution Prevention in
Electroplating Processes
15
14 13 12 11 10 9 8 7 6 5 4 3 2 1
0
Fresh Water
WWTF
Sponsored by: Michigan Dept. of Environ. Quality
KC Jones Plating Company, and Wayne State University
Warren, Michigan, Aug. 17, 2007
K.C. Jones Plating Application
• Chemical and waste reduction
✓ SCAN: 8%~100% chemical reduction, 40% water reduction, 70% wastewater treatment cost reduction
✓ RESORS: 20%~45% chemical reduction, 36% wastewater treatment cost reduction
• Profit vs. total annualized cost: ~17:1

Multiscale Sustainability Study: A New Effort

- Material / product sustainability (nano-macroscale)
- Process sustainability (meso-macroscale)
- Business sustainability (macroscale)
- Industrial regional sustainability (macroscale)

Sustainable Technology Integration



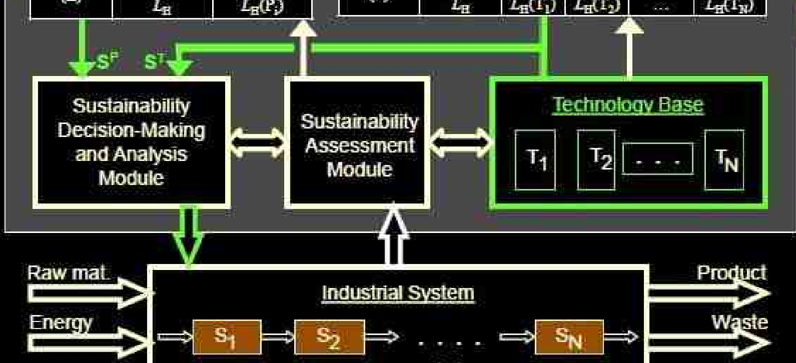
Sustainability Aspects of Technologies

- Frequently asked questions in technology adoption
  - What are the true benefits?
  - What is the investment?
  - How long can this technology survive?
  - Should this technology be used with other technologies?
  - etc.
- Fact
  - Most technologies are not functionally "networked"
  - Sustainability assessment of technologies is basically not available

Technology Integrated Sustainability Enhancement

Category	Indicator Symbol	Process (P_j)
Econ. (E)	E_1	$E_1(P_j)$
	...	...
	E_F	$E_F(P_j)$
Environ. (V)	V_1	$V_1(P_j)$
	...	...
	V_G	$V_G(P_j)$
Soc. (L)	L_1	$L_1(P_j)$
	...	...
	L_H	$L_H(P_j)$

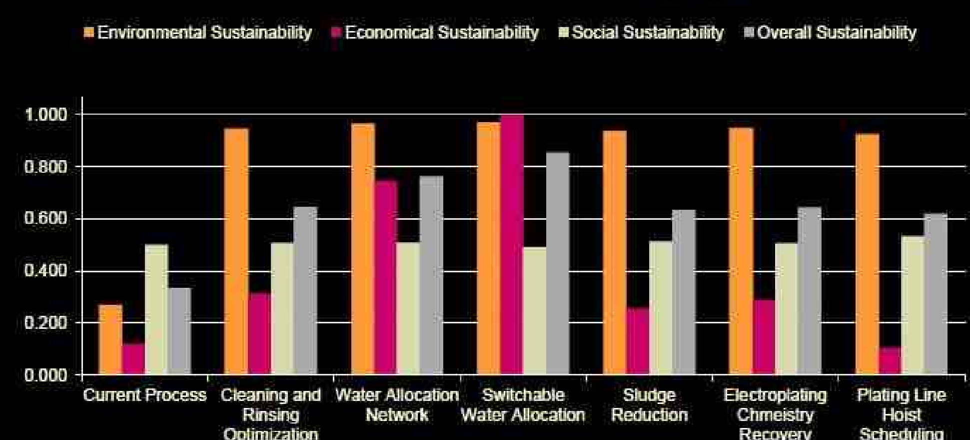
Category	Indicator Symbol	Technology			
		T_1	T_2	...	T_N
Econ. (E)	E_1	$E_1(T_1)$	$E_1(T_2)$	...	$E_1(T_N)$
	...	...	...	...	...
	E_F	$E_F(T_1)$	$E_F(T_2)$	...	$E_F(T_N)$
Environ. (V)	V_1	$V_1(T_1)$	$V_1(T_2)$	...	$V_1(T_N)$
	...	...	...	...	...
	V_G	$V_G(T_1)$	$V_G(T_2)$	...	$V_G(T_N)$
Soc. (L)	L_1	$L_1(T_1)$	$L_1(T_2)$	...	$L_1(T_N)$
	...	...	...	...	...
	L_H	$L_H(T_1)$	$L_H(T_2)$	...	$L_H(T_N)$

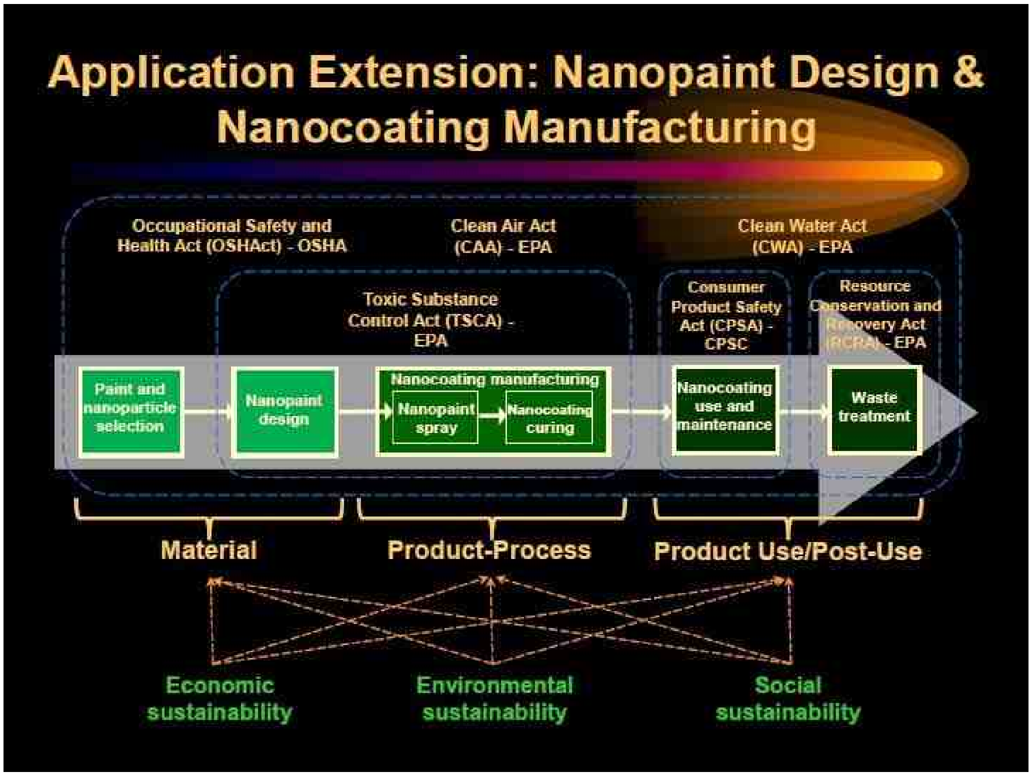


Sustainability Assessment of Technologies

Sustainability Indicators	Indicator Symbol	Technological Applications T_1	T_2	…	T_N	Combined Benefits per Sustainability Indicator	Combined Benefits per Sustainability Single Bottom Line	Combined Benefits of Sustainability After Using (T_N) Technologies
Economic (E)	E_1	p_{11}	p_{12}	…	p_{1N}	$E_1 = \sum_{i=1}^{N} f(p_{1,i})$	$E = \sum_{j=1}^{M}\sum_{i=1}^{N} f(p_{j,i})$	$S^{Whole} = E + V + L$
	E_2	p_{21}	p_{22}	…	p_{2N}	$E_2 = \sum_{i=1}^{N} f(p_{2,i})$		
	⋮	⋮	⋮	⋮	⋮	⋮		
	E_M	p_{M1}	p_{M2}	…	p_{MN}	$E_M = \sum_{i=1}^{N} f(p_{M,i})$		
Environmental (V)	V_1	q_{11}	q_{12}	…	q_{1N}	$V_1 = \sum_{i=1}^{N} f(q_{1,i})$	$V = \sum_{j=1}^{M}\sum_{i=1}^{N} f(q_{j,i})$	
	V_2	q_{21}	q_{22}	…	q_{2N}	$V_2 = \sum_{i=1}^{N} f(q_{2,i})$		
	⋮	⋮	⋮	⋮	⋮	⋮		
	V_M	q_{M1}	q_{M2}	…	q_{MN}	$V_M = \sum_{i=1}^{N} f(q_{M,i})$		
Social (L)	L_1	r_{11}	r_{12}	…	r_{1N}	$L_1 = \sum_{i=1}^{N} f(r_{1,i})$	$L = \sum_{j=1}^{M}\sum_{i=1}^{N} f(r_{j,i})$	
	L_2	r_{21}	r_{22}	…	r_{2N}	$L_2 = \sum_{i=1}^{N} f(r_{2,i})$		
	⋮	⋮	⋮	⋮	⋮	⋮		
	L_M	r_{M1}	r_{M2}	…	r_{MN}	$L_M = \sum_{i=1}^{N} f(r_{M,i})$		
Combined Benefits of Sustainability per Technology		S_1	S_2	…	S_N	$S_{T_i} = \sum_{i=1}^{N} f(S_i)$		$S_{T_i} = S^{Whole}$

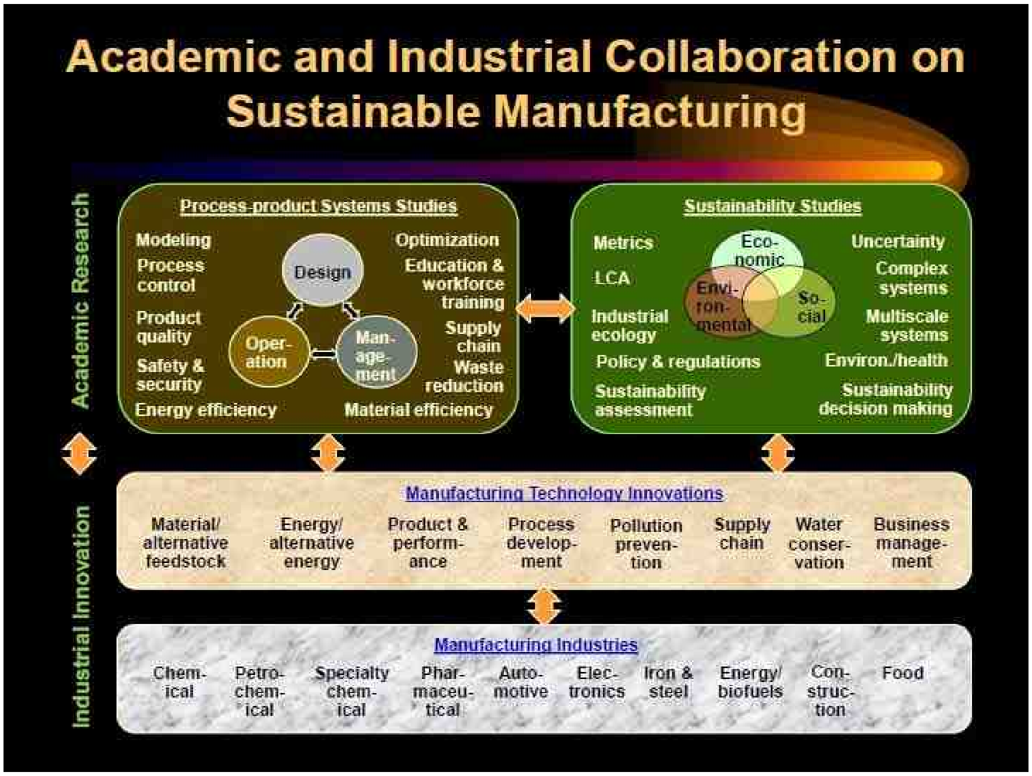
Evaluation of Plating Process and Improvement after Implementing Profitable Pollution Prevention (P3) Technologies





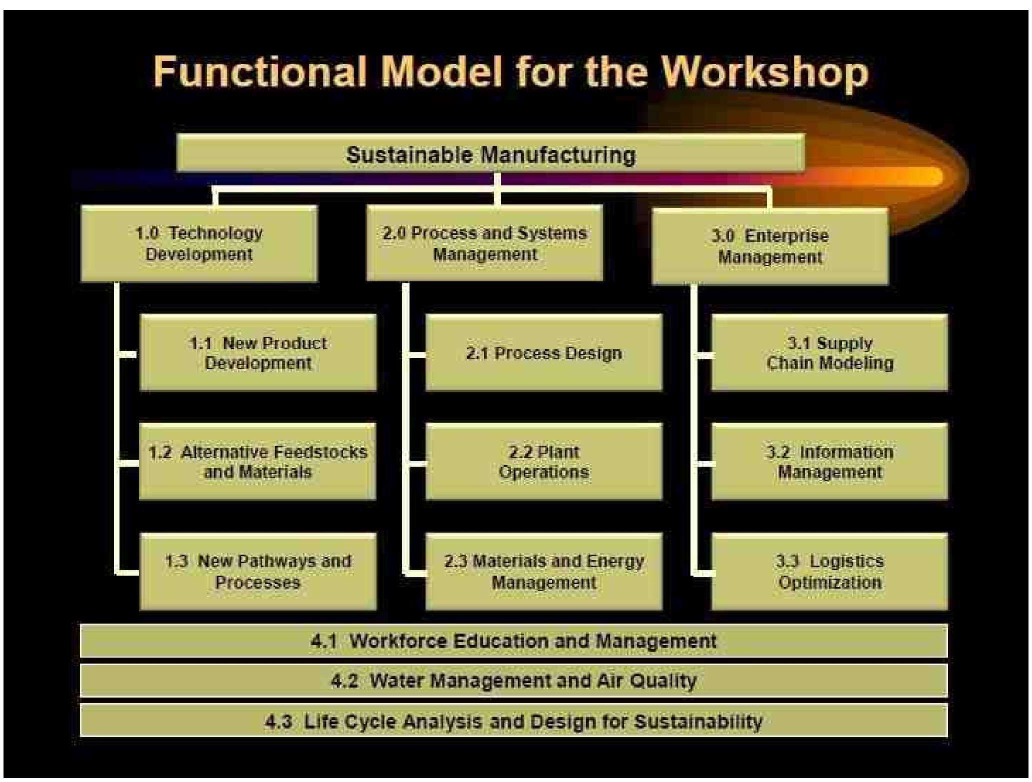
Application Extension: Nanopaint Design & Nanocoating Manufacturing
Occupational Safety and Health Act (OSHAct) - OSHA
Clean Air Act (CAA) - EPA
Clean Water Act (CWA) - EPA
Toxic Substance Control Act (TSCA) - EPA
Consumer Product Safety Act (CPSA) - CPSC
Resource Conservation and Recovery Act (RCRA) - EPA
Paint and nanoparticle selection
Nanopaint design
Nanocoating manufacturing
Nanopaint spray
Nanocoating curing
Nanocoating use and maintenance
Waste treatment
Material
Product-Process
Product Use/Post-Use
Economic sustainability
Environmental sustainability
Social sustainability

Sustainable Manufacturing Network: An International Effort
• Sustainable Manufacturing Advances in Research and Technology Collaboration Network (SMART CN) - an NSF-funded academic and industrial collaboration network (PI/PD: Y. Huang, WSU)
• Objectives
• To bridge the gap between the academic knowledge discovery and industrial technology innovation for sustainable manufacturing.
• To foster interactions that create new research directions or advance manufacturing sustainability.

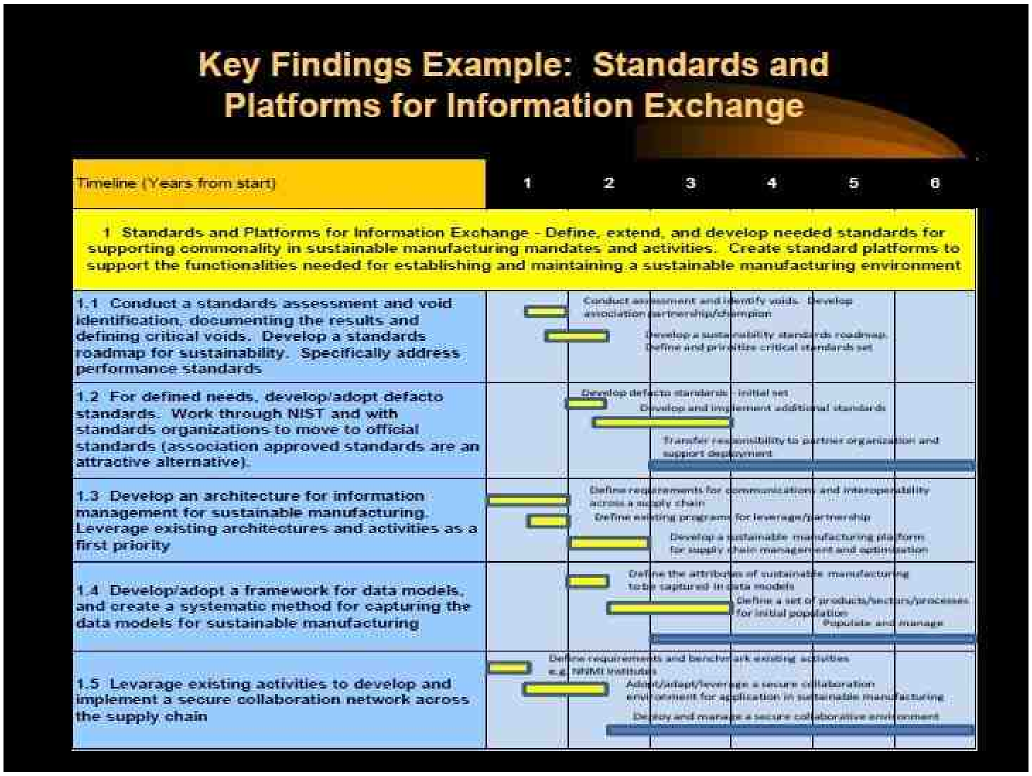

Academic and Industrial Collaboration on Sustainable Manufacturing
Academic Research
Industrial Innovation
Process-product Systems Studies
Modeling
Process control
Product quality
Safety & security
Energy efficiency
Design
Oper-ation
Man-age-ment
Optimization
Education & workforce training
Supply chain
Waste reduction
Material efficiency
Sustainability Studies
Metrics
LCA
Industrial ecology
Policy & regulations
Sustainability assessment
Eco-nomic
Envi-ron-mental
So-cial
Uncertainty
Complex systems
Multiscale systems
Environ./health
Sustainability decision making
Manufacturing Technology Innovations
Material/ alternative feedstock
Energy/ alternative energy
Product & perform-ance
Process develop-ment
Pollution preven-tion
Supply chain
Water conser-vation
Business manage-ment
Manufacturing Industries
Chem-ical
Petro-chem-ical
Specialty chem-ical
Phar-maceu-tical
Auto-motive
Elec-tronics
Iron & steel
Energy/ biofuels
Con-struc-tion
Food


Sustainability and Process/Product Systems Research and Education Coordination
Core Areas
I – Fundamental study on manufacturing sustainability (Y. Huang, Wayne State U.)
II – Sustainable design and integration (M. El-Halwaki, TAMU)
III – Sustainable operation and system management (T. Edgar, U Texas – Austin)
IV – Energy and alternative energy (M. Eden, Auburn U.)
V – Sustainability Education (C. Davidson, Syracuse U.)

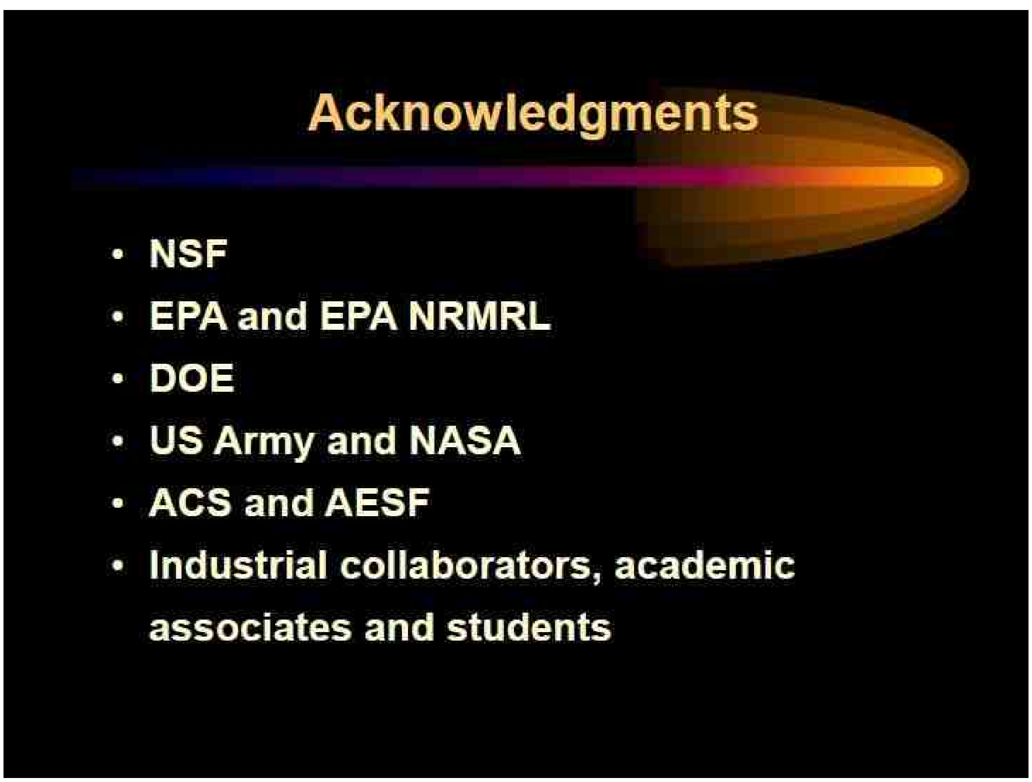

Sustainable Manufacturing Roadmap Development Workshop
Cincinnati, OH, Aug. 15-16, 2013
• Workshop Goal
• To explore the topics of sustainable manufacturing
• To capture the key needs and solutions that point to an R&D agenda
• To flesh out some key ideas into project slates
• To facilitate a meaningful dialogue
• To develop a roadmap
• Participants (53)
• Academic (25)
• Industrial, National Labs, and Government (28)


Functional Model for the Workshop
Sustainable Manufacturing
1.0 Technology Development
2.0 Process and Systems Management
3.0 Enterprise Management
1.1 New Product Development
2.1 Process Design
3.1 Supply Chain Modeling
1.2 Alternative Feedstocks and Materials
2.2 Plant Operations
3.2 Information Management
1.3 New Pathways and Processes
2.3 Materials and Energy Management
3.3 Logistics Optimization
4.1 Workforce Education and Management
4.2 Water Management and Air Quality
4.3 Life Cycle Analysis and Design for Sustainability


10 Key Themes
1) Comprehensive Characterization and Quantification of Manufacturing Processes
2) Data and Model Access for Sustainability
3) Model-Based Assessment and Control for Sustainability
4) Optimized Design for Sustainability
5) Comprehensive Life-Cycle Assessment
6) Standards and Platforms for Information Exchange
7) Clear Definition and Semantic Understanding
8) Pervasive Adoption of Sustainability Practices
9) Systematic Sustainability Achievement
10) Sustainable Manufacturing Education
- Huang, Y., T. Edgar, M. El-Halwagi, C. Davidson, and M. Eden,
Report on Sustainable Manufacturing Roadmap Development Workshop, 2013
(http://www.research.che.utexas.edu/susman/documents/workshop/
SMART%20CN_SM%20Roadmap%20Workshop_Final%20Report%20_041514.pdf)


Key Findings Example: Standards and Platforms for Information Exchange
Timeline (Years from start)
1
2
3
4
5
6
1 Standards and Platforms for Information Exchange - Define, extend, and develop needed standards for supporting commonality in sustainable manufacturing mandates and activities. Create standard platforms to support the functionalities needed for establishing and maintaining a sustainable manufacturing environment
1.1 Conduct a standards assessment and void identification, documenting the results and defining critical voids. Develop a standards roadmap for sustainability. Specifically address performance standards
Conduct assessment and identify voids. Develop association partnership/champion
Develop a sustainability standards roadmap. Define and prioritize critical standards set
1.2 For defined needs, develop/adopt defacto standards. Work through NIST and with standards organizations to move to official standards (association approved standards are an attractive alternative).
Develop defacto standards - initial set
Develop and implement additional standards
Transfer responsibility to partner organization and support deployment
1.3 Develop an architecture for information management for sustainable manufacturing. Leverage existing architectures and activities as a first priority
Define requirements for communications and interoperability across a supply chain
Define existing programs for leverage/partnership
Develop a sustainable manufacturing platform for supply chain management and optimization
1.4 Develop/adopt a framework for data models, and create a systematic method for capturing the data models for sustainable manufacturing
Define the attributes of sustainable manufacturing to be captured in data models
Define a set of products/sectors/processes for initial population
Populate and manage
1.5 Levarage existing activities to develop and implement a secure collaboration network across the supply chain
Define requirements and benchmark existing activities e.g. NNMI Institutes
Adopt/adapt/leverage a secure collaboration environment for application in sustainable manufacturing
Deploy and manage a secure collaborative environment


Concluding Remarks
• The future of surface finishing – a need for sustainable development roadmap.
• Sustainability metrics system development: a critical need as the first step.
• Technology innovation and sustainability assessment: key for sustainable manufacturing.
• Sustainable surface finishing forum: a good approach for exploring development opportunities.
• Sustainable future: joint effort among the industry, academia, and government.


Acknowledgments
• NSF
• EPA and EPA NRMRL
• DOE
• US Army and NASA
• ACS and AESF
• Industrial collaborators, academic associates and students

About the author

The NASF Scientific Achievement Award is the Association's most prestigious award. Its purpose is to recognize those whose outstanding scientific contributions have advanced the theory and practice of electroplating, metal finishing and allied arts; have raised the quality of products and processes; or have advanced the dignity and status of the profession.

Dr. Yinlun Huang is a Professor at Wayne State University (Detroit, Michigan) in the Department of Chemical Engineering and Materials Science. He is Director of the Laboratory for Multiscale Complex Systems Science and Engineering, the Chemical Engineering and Materials Science Graduate Programs and the Sustainable Engineering Graduate Certificate Program, in the College of Engineering. He has ably mentored many students, both Graduate and Undergraduate, during his work at Wayne State.

He holds a Bachelor of Science degree (1982) from Zhejiang University (Hangzhou, Zhejiang Province, China), and M.S. (1988) and Ph.D. (1992) degrees from Kansas State University (Manhattan, Kansas). He then joined the faculty of Wayne State University as Assistant Professor, eventually becoming Full Professor from 2002 to the present. He has authored or co-authored over 220 publications since 1988, a number of which have been the recipient of awards over the years.

His research interests include:

- Multiscale complex systems
- Sustainability science
- Integrated material, product and process design and manufacturing
- Computational multifunctional nano-material development and manufacturing
- Multiscale information processing and computational methods

In his work as Director of the Laboratory for Multiscale Complex Systems Science and Engineering, sustainability is the operative world. These efforts focus on both the theoretical study on multiscale science and complexity and the applied research ranging from sustainable (nano)material design to industrial system restructuring, including the surface finishing industry, for sustainable development.

He has served in many editorial capacities on various journals, as Guest Editor, Associate Editor or member of the Editorial Board, including the *Chinese Journal of Chemical Engineering,* the *Journal of Clean Technologies and Environmental Policy,* the *Journal of Nano Energy and power Research.* In particular, he was a member of the Editorial Board of the AESF-published *Journal of Applied Surface Finishing* during the years of its publication (2006-2008).

He has served the AESF and NASF in many capacities, including the AESF Board of Directors during the transition period from the AESF to the NASF. He served as Board of Directors liaison to the AESF Research Board, and was a member of the AESF Research and Publications Boards, as well as the Pollution Prevention Committee. With the NASF, he served as a member of the Board of Trustees of the AESF Foundation, the education-technical arm of the NASF. He has also been active in the American Chemical Society (ACS) and the American Institute of Chemical Engineers (AIChE).

Beside the NASF Scientific Achievement Award, he has been the recipient of many other honors. He has been the keynote lecturer or plenary speaker on Sustainability Engineering and related topics at many venues, including most recently at NASF SUR/FIN 2017 in Atlanta, Georgia. He was elected AIChE Fellow in 2016 and NASF Fellow in 2017. He was a Fulbright Scholar in 1988 and has been a Visiting Professor at many institutions, including the Technical University of Berlin and Tsinghua University in China. His many awards include the AIChE Sustainable Engineering Education Award (2016), several awards for teaching and graduate mentoring from Wayne State University, and Wayne State University's Charles H. Gershenson Distinguished Faculty Fellow Award. These and many other accomplishments show that Dr. Huang is most deserving of the NASF Scientific Achievement Award for 2013.