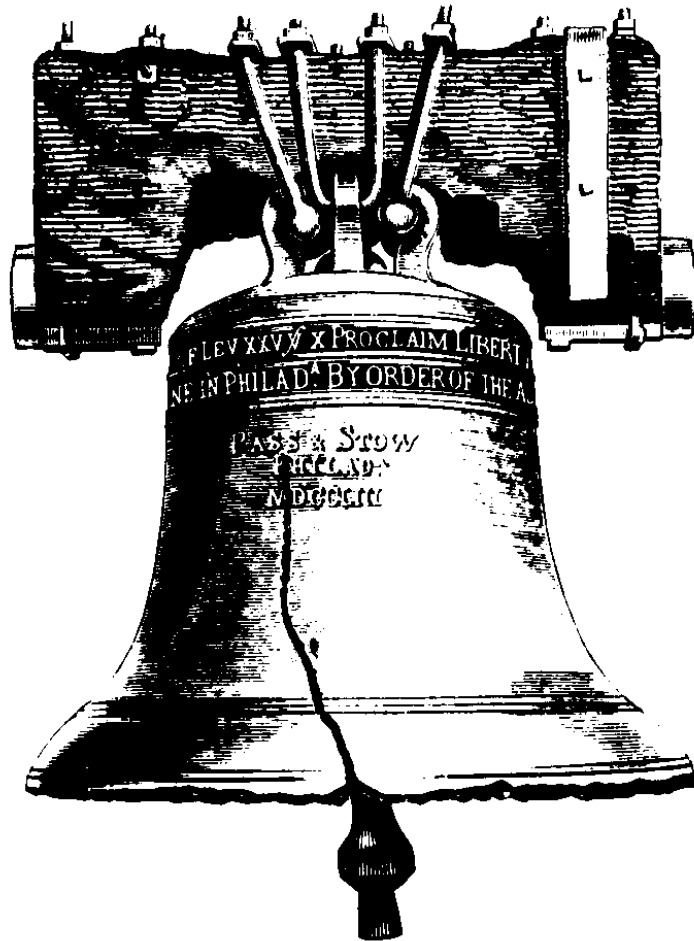


# The Catalysis Club of Philadelphia

## 2015 Spring Symposium



Thursday, May 7, 2015

Double Tree by Hilton® Hotel

4727 Concord Pike, Wilmington, DE

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# Catalysis Club of Philadelphia

## Spring Symposium 2015

### Schedule of Events

- 8:00 AM **Registration/Breakfast**
- 8:40 AM **Opening Remarks**
- 8:45 AM **Wei Fan**, University of Massachusetts, Amherst  
*Development of Hierarchical Zeolite Catalysts for Bulky Molecule Reactions*
- 9:25 AM **Dion G. Vlachos**, University of Delaware  
*Renewable Chemicals and Fuels from Biomass*
- 10:05 AM **Graham Hibbert**, HEL Group  
*Platinum Sponsor Presentation: HEL – Better Chemistry – Faster*
- 10:20 AM **Coffee Break**
- 10:40 AM **Steven L. Suib**, University of Connecticut  
*Novel Porous Metal Oxides and Sulfides and Their Applications in Adsorption, Batteries, and Catalysis*
- 11:20 AM **Marco J. Castaldi**, City College of New York/CUNY  
*The Role of Oxidation State on Regeneration Capacity When Reforming Oxygenated Fuels With Rh Based Catalysts*
- 12:00 PM **Lunch**
- 1:20 PM **Robert Farrauto**, Columbia University  
*A Dual Function Material for Capturing and Catalytically Converting CO<sub>2</sub> to Synthetic Natural Gas Using Renewable H<sub>2</sub>*
- 2:00 PM **Hasan Dindi**, DuPont  
*Design of Bimetallic Catalysts for Use in DuPont IsoTherming® Hydroprocessing Reactors*
- 2:40 PM **Bryan Yonemoto**, University of Delaware  
*Student Poster Winner: Mesoporous Materials for Energy Applications*
- 3:00 PM **Award Announcement**
- 3:15 PM **Coffee Break**
- 3:35 PM **Cathy H-Y. Chin**, University of Toronto  
*Catalytic Conversion of Renewable Feedstocks to Value-Added Products*
- 4:15 PM **Phillip E. Savage**, Penn State  
*Advances and Applications of Hydrothermal Catalysis*
- 4:55 PM **Closing Remarks**
- 5:00 PM **Conference Adjourns**

**More information can be found on our webpage or by email:**

Website: <http://catalysisclubphilly.org/symposium/>

Email: [Torren.R.Carlson@dupont.com](mailto:Torren.R.Carlson@dupont.com)

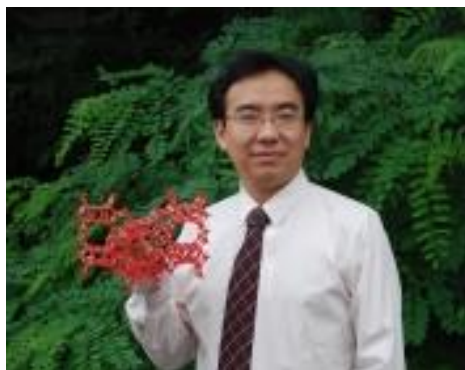
# Development of Hierarchical Zeolite Catalysts for Bulky Molecule Reactions

Wei Fan

*Department of Chemical Engineering, University of Massachusetts, Amherst*

Due to the intrinsic ordered micropore structures and strong acid strength, zeolites are extensively used as heterogeneous acid catalysts in oil refining processes and chemicals synthesis. However, the micropore structures and high intrinsic activities frequently lead these materials to be subject to diffusion limitations that restrict reactant accessibility to the active sites on the interior surfaces of zeolites and inhibit the full utilization of zeolite catalysts. Nanofabrication of hierarchical zeolite catalysts with mesoporosity is a proven strategy for integrating shape selectivity provided by the intrinsic micropore structures and efficient mass transport facilitated by the mesopore structures. Considerable efforts have been devoted to the synthesis of zeolite catalysts with mesoporosity. Among the various approaches, the synthesis of hierarchical zeolites by the confined synthesis in hard templates holds exciting implications in term of creating ordered mesopore structures and controlling mesopore sizes. These advantages provide unique opportunities to design the hierarchical pore structures and quantitatively investigate the effects of mesopore structure on the catalytic performance of zeolite catalysts.

In this talk, I will demonstrate how a wide range of zeolite morphologies can be realized through such a confined growth within 3-dimensionally ordered mesoporous (3DOM) carbon with the pore size smaller than 40 nm. The carbon template was synthesized by replication of colloidal crystals composed of size-tunable silica nanoparticles. Confined crystal growth within the carbon template leads to size-tunable, uniformly shaped zeolite nanocrystals as well as 3DOM-imprinted single-crystal zeolite particles. In addition, novel crystal morphologies, consisting of faceted crystal outgrowths from primary crystalline particles have been discovered, providing new insights into constricted crystal growth mechanisms underlying the confined growth. The approach exhibits versatile abilities for controlling the mesoporosity of hierarchical zeolites from 5 nm to 10 nm. The mass transport in the hierarchical zeolites has been significantly improved, which can mostly be attributed to the shortened diffusion path length in the micropores. The catalytic performance of the hierarchical zeolite catalysts for the reactions of bulky chemicals and biomass conversion will be discussed.



**Wei Fan** is currently an Assistant Professor in the Department of Chemical Engineering at the University of Massachusetts, Amherst. He is also a faculty member at the Center for Energy Innovation, an DOE Energy Frontier Research Center. He received his B.S. in Materials Science and Engineering from the University of Science and Technology of China, Hefei and his M.S. and Ph.D. degrees in Chemical Engineering from the University of Tokyo, Japan. Before joining UMass he was a Postdoctoral Researcher at the University of Minnesota, Twin Cities supervised by Michael Tsapatsis. During his time there he was the technical specialist of X-ray diffraction and scattering. He has received several awards including the Hundred Talents Program of Anhui Province and the 3M Non-Tenured Faculty award. He was also recently nominated for a distinguished teaching award at University of Massachusetts.

# Renewable Chemicals and Fuels from Biomass

Dion G. Vlachos

*Department of Chemical Engineering, Center for Catalytic Science and Technology, and Catalysis Center for Energy Innovation, University of Delaware*

In this talk, an overview of the catalysis center for energy innovation will be given. Modern catalytic-based technologies will be presented that may overcome challenges of traditional methods in converting biomass to renewable fuels and chemicals. Cross-cutting technologies, including hierarchical multiscale materials and models will be introduced. We will then discuss modern technologies that rely on biomass degradation to simple derivatives, such as sugars, followed by a number of reactions, such as Lewis and Brønsted acid catalyst driven isomerization and dehydration to convert sugars to valuable intermediate furans. Diels-Alders and dehydration chemistry will be outlined for the production of renewable aromatics, such as para-xylene. Hydrodeoxygenation of biomass will also be discussed as an effective means to remove oxygen and produce certain platform chemicals. We will discuss how enabling technologies provide insights into novel catalyst selection to facilitate these complex transformations.



**Dion Vlachos** is the Elizabeth Inez Kelley Professor of Chemical Engineering at the University of Delaware and the Director of the Catalysis Center for Energy Innovation (CCEI), an Energy Frontier Research Center (EFRC) funded by the Department of Energy (DOE).

Dr. Vlachos obtained a five years diploma in Chemical Engineering from the National Technical Univ. of Athens, in Greece, in 1987. He obtained his MS and Ph.D. from the University of Minnesota in 1990 and 1992, respectively, and spent a postdoctoral year at the Army High Performance Computing Research Center, MN, after which he joined UMass as an Assistant Professor. He was promoted to an associate professor at UMass in 1998. He joined the Univ. of Delaware in 2000. He was a Visiting Fellow at Princeton University in the spring of 2000, a visiting faculty at Thomas Jefferson Univ. and Hospital in spring of 2007 and the George Pierce Distinguished Prof. of Chemical Engineering and Materials Science at the Univ. of Minnesota in the fall of 2007.

Dr. Vlachos is the recipient of the R. H. Wilhelm Award in Chemical Reaction Engineering from AIChE, an AAAS Fellow, an ONR Young Investigator Award and a NSF Career Award. He is a member of the American Institute of Chemical Engineers, the American Chemical Society, the Combustion Institute, the Catalysis Society, and SIAM.

His main research thrust is multiscale modeling and simulation along with their application to catalysis, crystal growth, portable microchemical devices for power generation, production of renewable fuels and chemicals, catalyst informatics, detailed and reduced kinetic model development, and process intensification.

He is the corresponding author of more than 300 refereed publications and has given nearly 200 plenary lectures, keynote lectures, and other invited talks. He has served as an executive editor of the Chemical Engineering Science journal and has served or serves on the editorial advisory board of several journals (e.g., ACS Catal., Industrial and Engineering Chemistry Research (I&ECR), Applied Catalysis A: General, The Combustion Institute, The Open Energy and Fuels Journal, the Journal of Nano Energy and Power Research, and J. Chem. Eng. & Proc. Tech.).

## **HEL – Better Chemistry – Faster**

Graham Hibbert

*HEL Inc. (Platinum sponsor presentation)*

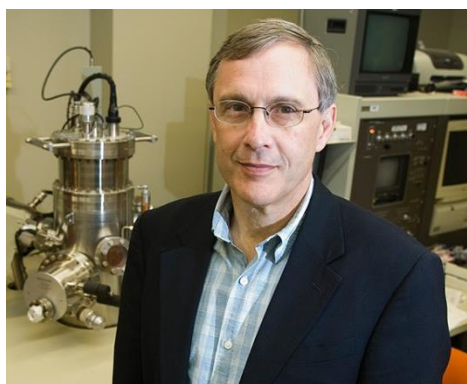
HEL is a leading equipment provider for catalytic processes in chemical, petrochemical and pharmaceutical Industry. Stirred and fixed-bed reactors for catalytic & thermal conversions (hydrogenation reactor, polymerization, hydrocracking, bio-fuel synthesis etc.) are supplied to a range of industries. Often at elevated temperature & pressure, HEL specializes in research scale, multi-reactor and high pressure reactors processing, testing, equipment and systems. Custom designs to client flow sheets are also supplied including pilot scale processes.

# Novel Porous Metal Oxides and Sulfides and Their Applications in Adsorption, Batteries, and Catalysis

Steven Suib

*Department of Chemistry, University of Connecticut*

This presentation will focus on synthesis, characterization, and applications of novel mesoporous materials. Such mesoporous materials have crystalline walls, high thermal stability, and monomodal pore size distributions. These systems can be made for most elements throughout the periodic table. They have unique catalytic reactivity in a number of reactions including selective oxidations, total oxidations, coupling reactions, water splitting, one pot Wittig reactions, dehalogenations, and others. Some other applications include adsorbents for sulfur species, adsorption of oils and hydrophobic materials, and battery materials.



**Steven L. Suib** was born in western New York State where he obtained a B. S. degree in chemistry and geology at the State University College of New York at Fredonia. His graduate work was done at the University of Illinois at Champaign Urbana with Galen D. Stucky. His postdoctoral work was done at Illinois with Larry R. Faulkner. He joined the faculty of the Department of Chemistry at the University of Connecticut in 1980 where he is currently Board of Trustees Distinguished Professor and Director of the Institute of Materials Science.

# The Role of Oxidation State on Regeneration Capacity when Reforming Oxygenated Fuels with Rh Based Catalysts

Marco J. Castaldi

*Department of Chemical Engineering, City College, City University of New York*

Conversion of bio-derived oils and feedstock with high concentrations of oxygen-containing hydrocarbons, into chemicals is a highly desirable objective for environmental and economic sustainability. However no efficient catalyst technologies exist for such a conversion because current chemistries rely on catalysts that have been developed for processing natural gas and petroleum fractions with low oxygenate concentrations. Therefore an understanding of how oxygenates interact with Pt and Rh catalyst formulations needs to be more fully developed. To address this challenge, an oxygenated hydrocarbon, ethanol, was selected to represent derivatives from the main biomass polymers: hemicellulose, cellulose, and lignin. Ethanol was chosen because it enables the study of O-H, C-H, C-C and C-O bond interaction with the catalyst.

Bimetallic Rh/Pt catalyst mixtures were prepared via an incipient wetness impregnation technique on high surface area silica-zirconia supports. Our initial results show for the first time that the oxidation state of catalytic Rh nanoparticles changes with time on stream under reaction conditions with ethanol and that the extent of Rh oxidation appears to control catalyst activity and the rate of deactivation. In addition, regenerating the Rh-containing catalysts in 5% H<sub>2</sub> in He for one hour shows that roughly 70% of the observed deactivation is reversible, though the initial level of hydrogen production was not attained. The Pt-only formulation exhibited no change in product distribution after regeneration thus its activity remained low. The bimetallic formulation was demonstrated to achieve the highest level of H<sub>2</sub> production at a near equilibrium value of 1.490 mole% whereas the Rh-only formulation and Pt-only formulation yielded 1.392 mole% H<sub>2</sub> and 1.084 mole% H<sub>2</sub> respectively. The understanding of such changes and interactions between Rh and oxygenated fuels at the molecular level is critical for optimizing catalytic performance.

To determine the underlying causes of this partial regeneration, *in situ* XAFS measurements were taken to monitor any conformational and oxidation state changes to the precious metals of the catalyst during ethanol reforming. Both Rh- and Pt-edges were examined to determine how the changing nature of each metal contributes to the overall behavior of the system. This presentation will show the details of the experiments done and the results obtained to begin to explain the underlying rationale of the performance.



**Marco Castaldi** was born in New York City and received his B.S. ChE (Magna cum Laude) from Manhattan College. His Ph.D. is in Chemical Engineering from UCLA and he has minors in Advanced Theoretical Physics and Astrophysics. Prior to joining CCNY he was Associate Professor at Columbia University's Earth & Environmental Engineering Department. Professor Castaldi has approximately 60 peer-reviewed research articles, 40 peer-reviewed conference papers, 3 book chapters and 11 patents in the fields of catalysis, combustion and gasification. In addition, he is the Editor of the North American Waste to Energy Conference (NAWTEC) Series, Co-Editor of the Waste to Energy text published by Woodhead Publishing, Editorial Board Member of *Waste and Biomass Valorization* and *Catalysts*. Prior to his academic career in Professor Castaldi worked first as Manager of Fuel Processor Component Development for Precision Combustion Inc. in New Haven, CT overseeing projects totaling \$5 MM. Professor Castaldi is currently Chair of the Materials and Energy Recovery Division of ASME and Chair of the Research and New Technology Council of AIChE and recent Past-Chair of the North American Catalysis Society's New York Metropolitan Section. He is a consultant to several companies including WasteManagement and AECOM. Dr. Castaldi is the Director of the Waste-to-Energy Research and Technology Council (WERT) in the United States, an international organization that supports several students and post doctoral researchers. Dr. Castaldi has established the Earth Engineering Center at City College, City University of New York. The goal of EEC|CCNY is to bring to bear rigorous engineering solutions that enable responsible use of energy and materials for the advancement of society.



## Dual function materials for CO<sub>2</sub> capture and conversion using renewable H<sub>2</sub>

Robert J. Farrauto

*Department of Earth and Environmental Engineering, Columbia University*

The accumulation of CO<sub>2</sub> emissions in the atmosphere due to industrialization is clearly of great concern to all of us. In order to prevent its further accumulation in the atmosphere, CO<sub>2</sub> must be captured for storage or converted to useful products. Current materials and processes for CO<sub>2</sub> capture using amine solutions are energy intensive. We report a new approach using a dual function material (DFM), which captures CO<sub>2</sub> from an emission source at 320°C and at the same temperature converts it to methane (synthetic natural gas) using H<sub>2</sub> generated by electrolysis of water from excess renewable energy sources such as solar and wind. The DFM consists of Ru as methanation catalyst and nano dispersed CaO as CO<sub>2</sub> adsorbent, both supported on a porous  $\gamma$ -Al<sub>2</sub>O<sub>3</sub>. A spillover process drives CO<sub>2</sub> from the solid sorbent to the Ru sites where methanation occurs by reactions with H<sub>2</sub>. The product is dried and lightly compressed for injection into the natural gas pipeline. This approach utilizes flue gas sensible heat and eliminates the current energy intensive and corrosive capture using amine solutions and storage processes without having to transport captured CO<sub>2</sub>.

A reaction mechanism obeying the Eley-Rideal kinetic rate model for the methanation will be also presented.



**Robert Farrauto** is Professor of Practice in the Earth and Environmental Engineering Department at Columbia University in the City of New York. He retired in August 2012 from BASF (formerly Engelhard) Iselin, New Jersey as a Research Vice President after 37 years of research. His major responsibilities in industry included development of advanced automobile emission control catalysts and catalysts for the chemical and alternative energy industries. He has over 120 publications and 60 US patents and is co-author of three textbooks “Catalytic Air Pollution Control: Commercial Technology” (2009) and “Fundamentals of Industrial Catalytic Processes” (2006) and “Introduction to Catalysis and Industrial Catalytic Processes” (September 2015) all with Wiley and Sons.

He is the 2008 recipient of the Ciapetta Lectureship Award sponsored by the North American Catalysis Society and the 2005 Catalysis and Reaction Engineering Practice Award sponsored by the American Institute of Chemical Engineers. His research interests at Columbia are; catalytic upgrading of carbon dioxide to fuels, generation of hydrogen from hydrocarbons by catalytic steam reforming and new catalyst materials for abatement of carbon monoxide, various hydrocarbons and oxides of nitrogen. He teaches graduate classes in environmental and industrial catalysis.

# Bimetallic Catalysts for use in IsoTherming® Hydroprocessing Reactors

Hasan Dindi

*DuPont Sustainable Solutions, Clean Technologies*

DuPont™ IsoTherming® Hydroprocessing technology is emerging as a cost-effective alternative to the traditional trickle-bed reactors in refinery hydroprocessing applications. Performances of many hydrotreating and hydrocracking catalysts have been observed in a pilot plant setting as well as in commercial operation. Most of the catalysts contain nickel, cobalt, molybdenum, and/or tungsten on an alumina support for hydrotreating applications and on a zeolite support for hydrocracking applications.

In the refining industry, highly aromatic light cycle oil (LCO) offers a limited market value due to its low cetane value, high density, and high sulfur content. LCO must undergo hydrotreatment in order to meet diesel product specifications, but the highly reactive nature of the hydrocarbon stream causes complications with regards to supplying the necessary hydrogen and managing the considerable exothermic heat release. There are commercial units using conventional trickle-bed technology to process the LCO with the use of hydrotreating and hydrocracking catalysts to meet product specifications, but often yield of the primary diesel product is sacrificed.

IsoTherming® technology offers a one- and two-stage process to hydrotreat highly aromatic light cycle oil (LCO) using bimetallic hydrotreating and hydrocracking catalysts to meet the desired product specifications while also maximizing product yield. While commercial trickle-bed processes often result in diesel yields of about 50% (Thakkar et al., AM 05-53, NPRA, 2005), a one-stage IsoTherming® process (US 2012/0205285 A1), consisting of both hydrotreating and hydrocracking catalysts, may result in diesel yields of up to 75-90%. The efficacy of the zeolitic cracking catalyst may be further increased and yields greater than 90% achieved in a two-stage IsoTherming® process (US 8,721, 871 B1), which includes an intermediate separation step between the hydrotreating and hydrocracking sections to remove ammonia that has a poisoning effect.

This presentation will discuss pilot plant tests of LCO hydroprocessing in IsoTherming® reactors using bimetallic hydrotreating and hydrocracking catalysts including tests both with and without removal of dissolved ammonia after hydrotreating (as is the case of a two-stage and one-stage process, respectively).



**Hasan Dindi** is currently a Research Fellow in DuPont's Sustainable Solutions business. He received his M.S. and Ph.D. Degrees in 1984 and 1988, respectively, both in Chemical Engineering from the University of Colorado at Boulder. He worked with Klaus Timmerhaus for his M.S. Degree and with Bill Krantz for his Ph.D. Degree. He taught at the University of Colorado in 1988-1991 before joining DuPont.

Dr. Dindi started with Conoco R&D (then part of DuPont) in 1991, conducting research on low emissions fuels and alternative oxygenates until he transferred to DuPont CR&D in 1995. He has been a part of DuPont for the past 24 years, working on Research and Development programs on Process Development, Reaction Engineering, and Catalysis.

For the past eight years, Dr. Dindi has led the R&D Team of scientists and engineers supporting the DuPont™ IsoTherming® Hydroprocessing Technology that has carried out over 200 pilot plant tests using over 30 commercial catalysts to support the design and optimal operation of commercial IsoTherming® hydroprocessing reactors worldwide.

# Mesoporous Materials for Energy Applications

Bryan T. Yonemoto

*Department of Chemical and Biomolecular Engineering, Center for Catalytic Science and Technology, University of Delaware*

In this talk a showcase of recent developments with mesoporous metal sulfide and oxide materials within the Jiao Lab will be presented. To form the mesoporous structures the nanocasting technique is employed, which allows easy access to hierarchical mesostructures when the hard templating is performed within well-ordered silica. These ordered mesostructures are wonderful tools to investigate structural phenomena during application testing. As an example, we recently studied material changes to 3DOM TiO<sub>2</sub> as a battery anode thru collaboration with The Mark Snyder Lab at Lehigh University.<sup>1</sup>

One of the biggest challenges with nanocasting is finding synthetic pathways to make new materials. For example, there are a substantial number of crystal phases available for oxides, but only a limited number of sulfide materials can be made. Recently we proposed and demonstrated a new synthesis strategy, coined “oxide-to-sulfide” conversion, to make the first report of mesoporous FeS<sub>2</sub>, CoS<sub>2</sub> and NiS<sub>2</sub>.<sup>2</sup> The reasoning behind this method, and other updates to mesoporous metal sulfides will be discussed.



**Bryan Yonemoto** is a chemical engineering graduate student at the University of Delaware. A NSF graduate research fellow, his work focuses on the design and testing of novel porous materials for electrochemical energy storage applications. Before Delaware he received an undergraduate degree at Tulane University in New Orleans, LA.

1. **Yonemoto, B.T.**, Guo, Q., Hutchings, G. S., Yoo, W. C., Snyder, M. A., & Jiao, F. *Chem. Commun.* 50, 8997-8999 (2014)
2. **Yonemoto, B. T.**, Hutchings, G. S., & Jiao, F. *J. Am. Chem. Soc.* 136, 8895-8898 (2014)

# Catalytic Pathways and Requirements for the Removal of Oxygen Functional Groups in Light Carboxylic Acid and Aldehyde

Ya-Huei (Cathy) Chin

*Department of Chemical Engineering and Applied Chemistry, University of Toronto*

Light oxygenates derived from pyrolysis of lignocellulosic biomass remove their oxygenate functions via deoxygenation on solid Brønsted acid sites and hydrogenation on transition metal clusters. I will describe the catalytic pathways, their kinetic requirements, and reactivity trends for small carboxylic acids and aldehydes, as they undergo reduction on Group VIII metal clusters and deoxygenation on zeolites (H-FAU, H-MFI) and polyoxometalate clusters ( $H_{4-x}Na_xSiW_{12}O_{40}$ ,  $H_{3-x}Na_xPW_{12}O_{40}$ ), respectively. I will focus on the connection of thermodynamic properties of the reactants, active sites, and their interactions to the rates and selectivities. Reduction of carboxylic acid on Group VIII metal clusters (Ni, Co, Fe, Ru, Pt, Pd) proceeds via kinetically relevant C-O bond activation followed by hydrogen insertion into the C=O bond to evolve ethanol. This step competes with the C-C bond cleavage that forms methane. I will report the periodic reactivity trend and the connection of carbon binding strengths to the turnover rates for acetic acid conversion and interpret the trend in terms of a Born Haber thermochemical cycle constructed between adsorbed acetic acid and surface acetyl species, the reactant and product of the kinetically relevant step, and relate the heat of reaction of this step to its barrier. In the separate case, the deoxygenation of aldehyde on Brønsted acid catalysts promotes C=C bond formation, chain growth, and then ring closure as an attractive route to increase its molecular size via the formation of new carbon-carbon linkages between molecules followed by a ring closure step. The focus here is the pathways for condensation and chain growth and their dependence on local site confinement. This fundamental catalytic knowledge provides the foundation for tuning the catalytic fates of these light oxygenates, retaining their carbon in the liquid fraction of bio-oil, thus increasing the overall yield during bio-oil refining.



**Ya-Huei (Cathy) Chin** is an assistant professor of Chemical Engineering and Applied Chemistry at the University of Toronto. She is a recipient of Ontario's Early Researcher Award (2014) and Imperial Oil's University Research Award (2014). She obtained her PhD degree in Chemical Engineering from University of California, Berkeley (2011). She was a senior research scientist at the Pacific Northwest National Laboratory (PNNL), one of the ten United States National Research Laboratories, where she held a joint appointment at the William R. Wiley Environmental Molecular Sciences Laboratory, a U.S. Department of Energy's national scientific user facility (2000-2005). Cathy's research addresses the technological challenges in catalytic processing of hydrocarbons and oxygenates, emission control, microchemical reactor development, and on-anode natural gas reforming in solid oxide fuel cell. Her recent work focuses on elucidating the molecular events during catalytic conversions of alkanes, alkenes, and oxygenates to liquid fuels and value-added chemicals. Specifically, she applies isotopic, kinetic, and

density functional theory methods to investigate the dynamics of catalyst surfaces and their kinetic consequences. She has authored 35 peer-reviewed publications and is the joint inventor of 18 patents.

# Advances and Applications in Hydrothermal Catalysis

Phillip E. Savage

*Department of Chemical Engineering, Pennsylvania State University*

Driven by applications in petroleum processing, petrochemical manufacturing, and automotive emission control, catalytic science and technology has developed to deal primarily with chemical reactions in the vapor phase or in condensed organic phases. By comparison, the catalytic science and technology undergirding reactions in a condensed aqueous phase is much less developed. Appreciation for the significance of hydrothermal heterogeneous catalysis has increased in recent years, however, as interest in green chemistry (using water as a more environmentally friendly reaction medium) and in processing biomass and bio-oils has grown. Both biomass and bio-oils produced by its fast pyrolysis or hydrothermal liquefaction contain appreciable amounts of water. Moreover, there are engineering considerations in biomass conversion, particularly for aquatic biomass, that argue for aqueous-phase processing of such material.

This presentation will discuss examples of research from our lab that have advanced the science or technology of hydrothermal catalysis. Examples will include catalyzed oxidation of organic compounds in supercritical water, catalytic hydrothermal gasification to produce fuel gases, catalytic upgrading of crude bio-oils, and hydrothermal catalytic cracking and deoxygenation of bio-crude model compounds (e.g., fatty acids, phenolics, pyridine) to make renewable hydrocarbon fuels and chemicals. In all cases, we focus on the reaction pathways and kinetics as we seek to discover materials that are active and stable catalysts in these less conventional hydrothermal environments.



**Phillip E. Savage** is the Head of the Chemical Engineering Department at Penn State and the Walter L. Robb Family Chair. Phil is also Arthur F. Thurnau Professor Emeritus at the University of Michigan. Phil is a Fellow of both the AIChE and ACS and Editor-in-Chief of *I&EC Research*. He is past-chair of the Industrial & Engineering Chemistry Division of ACS and a past-chair of the AIChE Catalysis and Reaction Engineering Division. Phil's professional service also includes membership on NRC committees dealing with treatment of stockpile munitions and chemical agents and being an expert reviewer for the U.S. EPA Report to Congress entitled "Biofuels and the Environment: First Triennial Report to Congress".

Phil has published nearly 200 research articles in archival journals and given 85 invited lectures at other universities and international symposia. He holds three U.S. patents, two of which have been licensed and put into practice commercially, and he has two additional patent applications pending. Phil's research deals broadly with reaction kinetics, pathways, and mechanisms and his recent work focuses on hydrothermal conversion of biomass to fuels. He is widely recognized as a leader in applying catalysis to reactions in near- and supercritical water. Phil has mentored 41 PhD students, nine of whom have been NSF and/or EPA STAR graduate fellows. He received the 2014 Research Excellence Award from the AIChE Sustainable Engineering Forum, the Inaugural (2009) Michigan Governor's Award for Green Chemistry, and the 2001 National Catalyst Award from the American Chemistry Council in recognition of his outstanding teaching and contributions to chemical education. In August, he will receive the inaugural *Energy & Fuels* Excellence in Publication Award at the ACS National Meeting in Boston.

# Notes