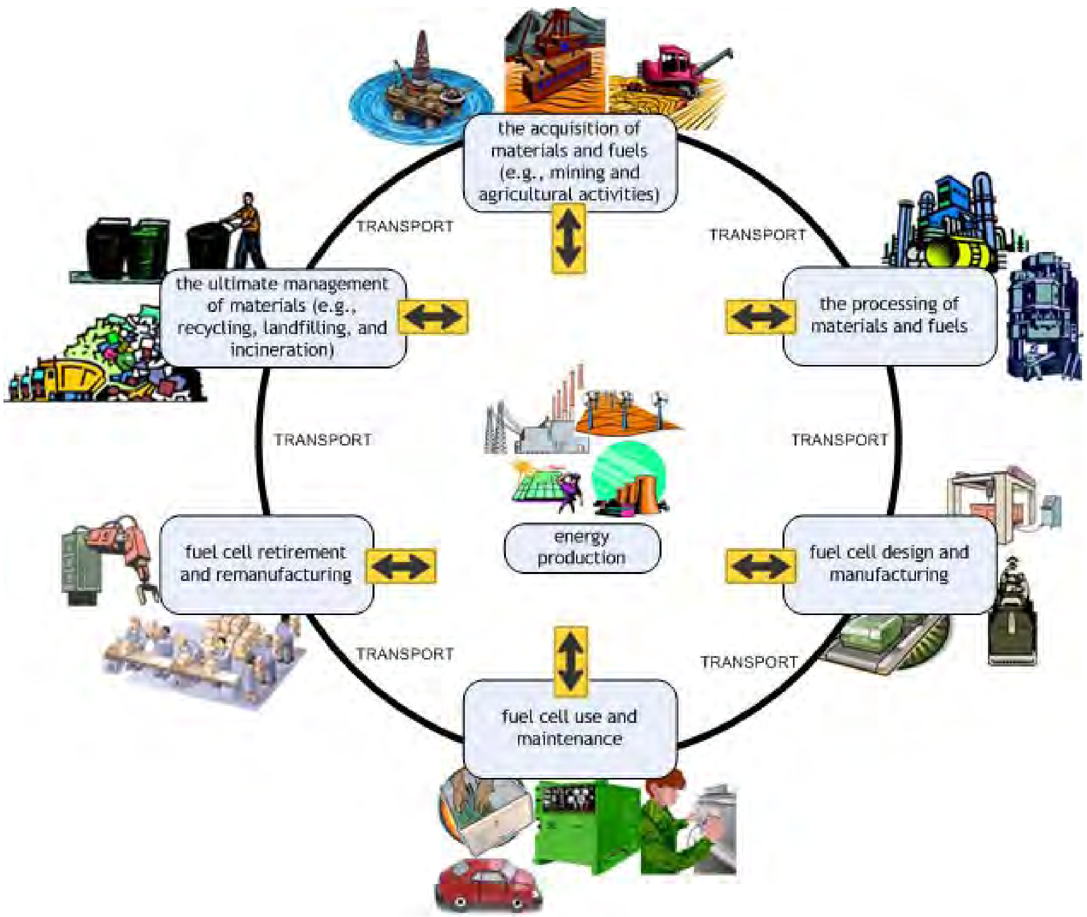
Energy Related Research Expertise

Mechanical Engineering Department
U. of Washington



Life Cycle Assessment of BioFuels and Energy Technologies (Joyce Cooper)

Multiphase Fluid Dynamics: liquid fuel injection and mixing with a gaseous oxidizer, emission of solid pollutants from combustion, bubbles in the cooling system (Alberto Aliseda)

Nov 28th 2011

OVERVIEW OF INCLUDED FACULTY PROFILES

- **Joyce Cooper:** life cycle assessment, design for environment, industrial ecology.
- **Brian Polyage:** marine renewable energy, tidal hydrokinetics, environmental effects.
- **Y. (Steve) Shen:** vibration, dynamics, sensing, and actuation; spindle and rotor dynamics.
- **Minoru Taya:** thermoelectric devices, energy harvesting, solar heat-gain control using electrochromic windows.
- **Brian C. Fabien:** development of energy storage devices, dynamic system modeling, nonlinear optimal control.
- **Jiangyu Li:** multifunctional materials design and synthesis for energy systems, ferroelectrics, ferromagnetic materials, multiferroics, thermoelectrics, and electro-active polymers.
- **Alberto Aliseda:** applications of multiphase fluid flows in energy conversion, liquid fuel injection and mixing with a gaseous oxidizer, solid pollutants emitting from a combustion process, bubbles in the cooling system in nuclear plants.
- **Amy Shen:** nanotechnology, bioenergy, and novel materials; microbial fuel-cell studies and micro-bioreactors, biofuel conversion.
- **John Kramlich:** combustion, turbulent reacting flows in combustion, solid oxide fuel cells, algal biofuels, biofuel handling/degradation, alternative fuel combustion flameout characteristics, combustor fuel interchangability.
- **Phil Malte:** director of the UW Northwest National Marine Renewable Energy Center (NNMREC).

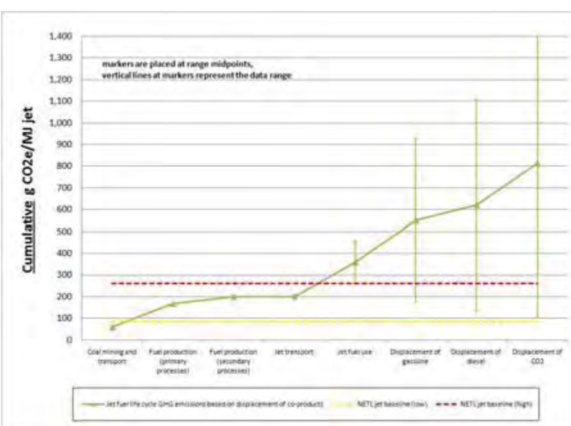
Joyce Cooper

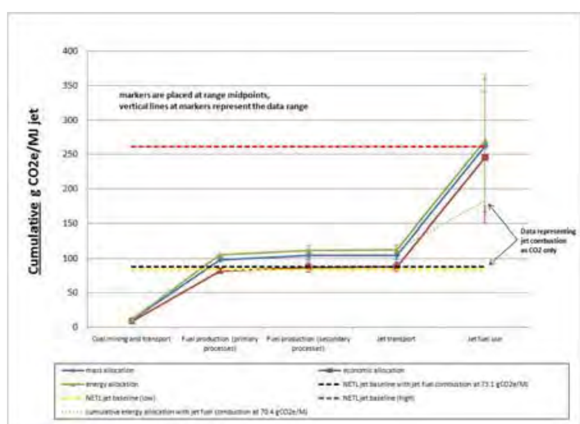
Joyce Cooper's research program concerns the characterization and optimization of the life cycle of emerging energy technology systems through the use of Life Cycle Assessment (LCA) and within the contexts of technology design and infrastructure development. Whether the system of interest is energy conversion equipment or an alternative/synthetic fuel, resource conservation and pollution prevention opportunities are identified from materials acquisition (e.g., mining, agriculture) through materials processing, energy conversion, and equipment decommissioning/ materials recovery. Research in Cooper's laboratory leverages interdisciplinary expertise at the University of Washington and beyond to incorporate considerations of both environmental implications (e.g., use of rare materials, uses of water, and the contribution to climate change) and socio-economic implications (e.g., job creation and changes in resource markets) in all assessments. Research in Cooper's lab has been funded by the National Science Foundation, the US Air Force, the US Department of Agriculture, and the US Department of Energy as well as by Ford, Boeing, and Plug Power. Some research projects are described as follows.

Alternative and Synthetic Fuel Research

Evaluation of the Life Cycle Greenhouse Gas (GHG) Emissions from Alternative and Synthetic Fuel for Procurement under the US Energy Independence and Security Act (funded by the US Air Force)

Cooper's laboratory contributed to the development of a protocol[1] for the estimation of the life cycle GHG emissions associated with the production and combustion of alternative or synthetic jet fuels. Subsequently, the Lab developed three case studies applying the protocol to coal-derived jet fuel produced through the Fischer-Tropsch process and soy and algae oil-derived hydrotreated renewable jet fuels with the objectives of identifying implementation issues and making recommendations for protocol changes. Case study results include the development of an understanding of uncertainty associated with life cycle process data and co-product management assumptions.





Co-product displacement and allocated LCA results: Coal-Fischer-Tropsch jet fuel

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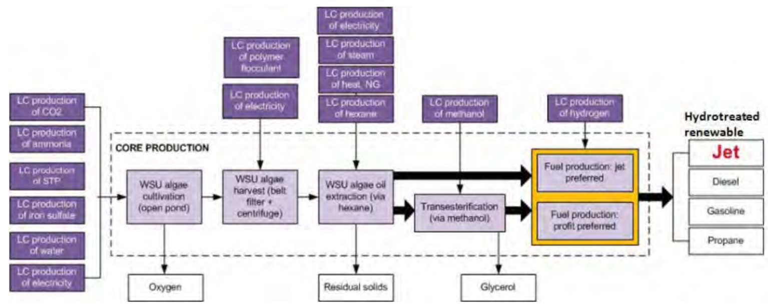
[1] See *Framework and Guidance for Estimating Greenhouse Gas Footprints of Aviation Fuels* available at http://www.netl.doe.gov/energy-analyses/pubs/EstGHGFtprntsAvFuels2009.pdf

Consequential LCA of Algae Oil-Derived Hydrotreated Renewable Jet Production (funded by the Boeing Company and in partnership with researchers at Washington State University (WSU))

Although several studies have evaluated the average life cycle impacts of algae oil-derived hydrotreated renewable jet, researchers in Cooper's laboratory were the first to integrate considerations of potential market consequences. The implications of changes in water and land use were identified as the critical to understanding life cycle environmental impact and highlighted opportunities to design systems leveraging regional agricultural, industrial, and natural resources.



Algae Oil-Derived Hydrotreated Renewable Jet Production

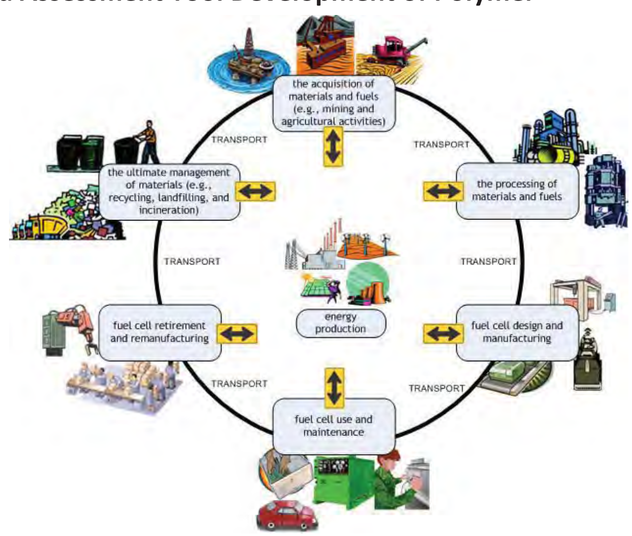
Development of a Database for Assessing the Life Cycles of US Agricultural Systems (funded by the US Department of Agriculture's National Agricultural Library)

Although agricultural product data for use in LCA are available, those for US production are both incorrect and incomplete. Researchers in Cooper's laboratory are working closely with USDA researchers to geographically and statistically relevant data for current and prospective crops, forest products, and livestock for the development of LCAs of bioenergy, food, and biochemical systems.

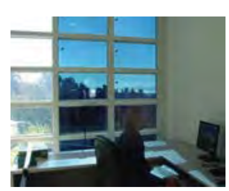
Energy Equipment Research

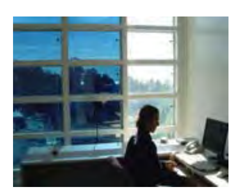
Manufacturing and Environmental Assessments and Assessment Tool Development of Polymer Electrolyte Membrane Fuel Cells (PEMFCs) and Solid Oxide Fuel Cells (SOFCs) (funded by Ford Motor Company, Plug Power, and the National Energy Technology Laboratory)

Researchers in Cooper's laboratory developed frequently cited reviews of materials and manufacturing options for both PEMFCs and SOFCs. These reviews were developed to facilitate the development of LCAs characterizing the performance of design and manufacturing variants and were used in the development of an Excel-based tool for fuel cell LCAs.



Life Cycle Impacts of Emerging Zero-Energy Building Technologies (funded through the National Science Foundation's Emerging Frontiers in Research and Innovation (EFRI) program)





LCA is supporting research and development in energy-harvesting electrochromic windows to ensure optimal dissemination of this new building technology.

Brian Polagye

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Dr. Polagye is a research assistant professor in the Department of Mechanical Engineering at the University of Washington. He is also a member of the Northwest National Marine Renewable Energy Center, a DOE-funded partnership between Oregon State University and the University of Washington. He holds a BSME (2000) from Princeton University and MSME (2005) and PhD (2009) from the University of Washington.

His research focuses on two aspects of tidal hydrokinetic power generation: resource characterization and evaluation of environmental effects. Tidal hydrokinetics is a branch of marine renewable energy which utilizes the kinetic energy in fast-moving tidal currents to generate electricity.

Tidal Hydrokinetic Resource Characterization

While the vertical motion of ocean tides is well-understood, the high speed tidal currents required for hydrokinetic power generation are not.

Currents regularly exceeding 2 m/s (4 knots) occur only in relative constrictions where local bathymetry and topography exert a strong influence. This may lead to large and operationally important asymmetries in power generation between ebb and flood tides or intense, turbulent eddies. On a site-specific basis, research focuses on the interpretation of current measurements using standardized metrics to support appropriate device selection and optimal siting decisions. On a national level, a major challenge is quantifying the practically recoverable tidal resource. This is not a measurable flow quantity but rather a balance between the theoretical resource (which can be modeled), the technically recoverable resource (which can be evaluated using engineering rules), and the practically recoverable resource (which requires cost-benefit analyses to evaluate environmental impacts).

OpenHydro tidal turbine (courtesy of Open Hydro)

Environmental Effects of Tidal Energy Development

The environmental effects of tidal energy development encompass a number of research sub-topics. Much of this research is collaborative with Dr. Jim Thomson of the Applied Physics Lab. The common theme is the investigation of environmental effects through monitoring in order to design for mitigation. This requires characterizing the pre-device installation environment, estimating post-device installation effects, and monitoring for high-priority effects post-device installation.

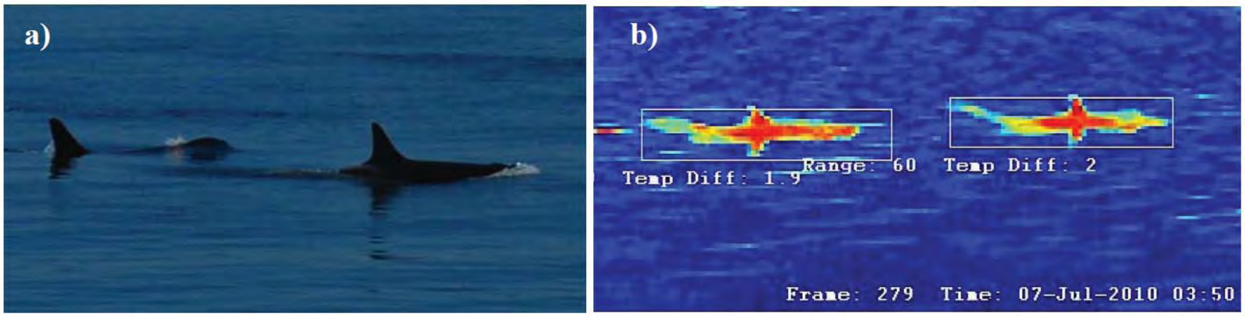
Pre-installation studies are carried out by instrumentation deployed on the seabed (Sea Spiders), from surface vessels, or from shore. Focus studies investigated to date include:

- Velocity measurements using acoustic Doppler profilers;
- Ambient noise measurements using hydrophones;
- Marine mammal presence/absence using a combination of specialized hydrophones and infrared cameras; and
- Shipping traffic using Automatic Identification System (AIS) receivers to characterize existing anthropogenic activity at potential turbine deployment sites.

UW-APL Sea Spider instrumentation package

Information gained from these measurements can be used to estimate post-installation environmental effects. Without an understanding of post-installation effects, regulatory risk is too great to permit project installation and operation. For example, site-specific information about how noise propagates from existing anthropogenic sources (e.g., shipping) can be combined with estimates of acoustic source levels for tidal turbines to determine the post-installation acoustic footprint and potential for marine mammal behavioral disturbances.

Both pre- and post-installation monitoring efforts require that advanced instrumentation be deployed in harsh marine environments for extended durations. In order to enable long, autonomous deployments, harnessing power from tidal currents on a micropower scale is attractive. This concept is currently being developed to power instruments on the Sea Spider platforms and could be extended to other oceanographic moorings.

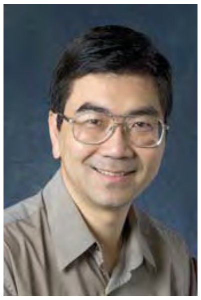


Imaging of Southern Resident Killer Whales by (*a*) optical camera and (*b*) infrared camera

Collaborative Opportunities

Collaboration is welcomed in all areas of environmental effects research, including testing of novel instrumentation, approaches to monitoring high-priority turbine-biota interactions, and mitigation measures which could be incorporated into turbine designs. Modeling approaches to complement field and laboratory studies are also of interest.

Research Profile of Professor I. Y. (Steve) Shen



Professor Shen's research expertise includes vibration, dynamics, sensing, and actuation. Currently, his research focuses on the following two subjects: (a) Piezoelectric thin-film devices and (b) spindle and rotor dynamics.

Piezoelectric Thin-Film Devices. This research is to develop lead-zirconium-titanium oxide (PZT) thin-film sensors and actuators. Being a piezoelectric material, PZT generates charge as it deforms, thus making it an ideal sensor. PZT also deforms when it is subjected to an electric field, making it an ideal actuator. For tiny sensors and actuators, PZT must appear in the form of thin films to maintain proper aspect ratios of the devices. Current research topics include (a) micro-actuators for hybrid cochlear implants and (b) micro-sensors for totally implantable cochlear prostheses.

Our micro-actuator takes the form of a probe with 1 mm wide, 10 mm long, and 0.4 mm thick; see Fig. 1. At the tip of the probe, there is a piezoelectric diaphragm serving as an acoustic actuator; see Fig. 2. When a voltage is applied, the piezoelectric diaphragm deforms to generate acoustic stimuli serving as an actuator. The designed diaphragm has a size of 0.8 mm by 0.8 mm, and is able to deflect at least 200 nm. The same platform can also be used as a micro-sensor. Figure 3 shows an SEM photo of our prototype, and Fig. 4 shows a measured response.

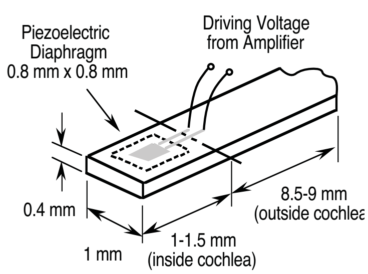


Fig. 1 PZT sensor & actuator probe

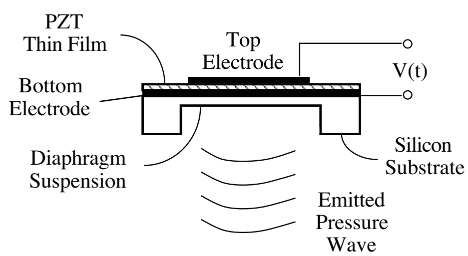


Fig. 2 Principle of operation

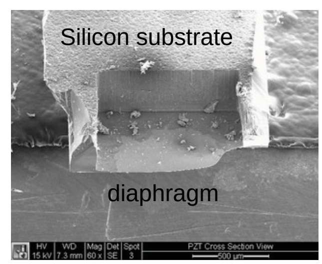


Fig. 3 SEM of prototypes

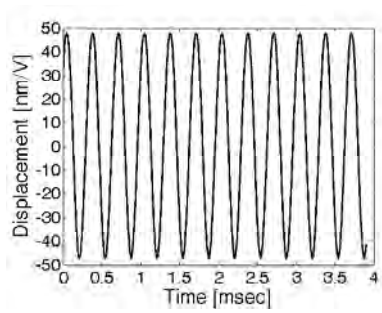


Fig. 4 Measured response

Aside from fabrication and instrumentation, we also aim to overcome fundamental challenges encountered in the design of these devices. For example, we perform finite element analysis to design top electrodes that maximize actuator displacement. We develop feasible ways to alleviate residual stresses to improve actuator sensitivity. We developed accurate and yet cost-effective methods to measure piezoelectric coefficient of PZT thin films. We are experimenting with nano-technology-based electrodes and PZT composites to enhance performance.

Opportunities for Collaboration: PZT is a material widely used for sensors and actuators. It has large piezoelectric coefficients (i.e., very sensitive), high bandwidth, large energy density and large actuation force. Miniaturization of PZT in the form of thin films will find various new killer applications in sensors (e.g., microphones, gyroscopes, shock/force/pressure sensing, accelerometers, and viscosimeter) and actuators (e.g., hearing aids, scanners, mixers, pumps, resonators, and nano-positioners).

Spindle and Rotor Dynamics. In this area, Professor Shen is developing computational algorithms to predict vibration and understand the physics of complex rotating machines, such as disk drives and turbines. Specific research topics include (a) vibration of spinning cyclic symmetric rotors (e.g., wind turbines), (b) interaction of spinning rotors with bearings and housing, (c) vibration of spinning mistuned rotors, and (d) health monitoring, damage detection and machine diagnostics.

Traditional rotor dynamics analyses focus on individual components (e.g., blade-disks or rotor shaft) using a *rotor-based* formulation. As a result, they do not completely describe interactions among all components in a rotating machine (e.g., wind turbine blades interacting with their tower). Nor do traditional analyses lead to a *ground-base* formulation, which can be more feasible for monitoring health of the rotary machines.

The approach we used is called component-mode synthesis (CMS). The idea is to analyze each component using finite element models to accommodate arbitrary and complex geometry of each component. After the finite element analyses, vibration characteristics of each component are distilled into a small number of "modes." Then the modes from all components are synthesized to give ground-based response of the entire rotary machine at the system level.

We have successfully used CMS to analyze vibration encountered in hard disk drives (HDD). We have been the world leader in HDD vibration research since 1995. In particular, we identify the cause and mechanism of rocking vibration in HDD spindle motors that often cause read-write errors in HDD. We establish experimental techniques to measure spindle motor vibration accurately. We have also developed simulation software to predict HDD spindle response. Our current effort in HDD research is to extract fluid-dynamic bearing coefficients of spindle motors from experimental data.

We have also applied CMS to spinning cyclic symmetric rotors, such as propellers and wind turbines. We find that cyclic symmetric rotors present both primary and secondary resonances for a ground-based observer. The former is often observed in rotor-base coordinates, but the latter is not. The presence of secondary resonances provides a brand new avenue to monitor the health of a spinning cyclic symmetric rotor. We have also found that a cyclic symmetric rotor will selectively interact with its housing through bearings. Some rotor vibration modes will couple their vibration with the housing, but others will not. These coupling modes can be predicted accurately via our mathematical formulations.

Opportunities for Collaboration: The method of CMS has more applications than spinning rotors. It can be used to predict vibration of complex structures subjected to prescribed motion. One example is deformation of flapping wings of insect flight. The method can predict wing deformations under Coriolis forces for biologists to understand sensori-motor coordination of movement in insects. It can also bear importance in future design of micro-aerial vehicles.

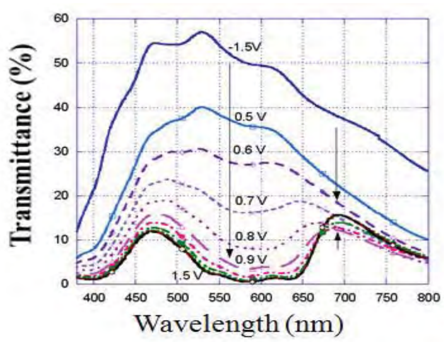
Minoru Taya

Dr. Minoru Taya has been a Professor of Mechanical Engineering, and Adjunct Professor of Materials Science and Engineering at the University of Washington since 1986. He received a Bachelor of Engineering in 1968 from the University of Tokyo, Japan; Master of Science in Civil Engineering in 1973 and Doctor of Philosophy in Theoretical Applied Mechanics in 1977, both from Northwestern University. He taught at the University of Delaware as an Assistant and Associate Professor from 1978-1985. He has had visiting appointments at the University of Oxford, U.K., Ris・National Laboratory, Denmark, University of Tokyo, and Institute of Space and Aeronautical Science, Japan. During 1989-1991 he was Professor of Materials Systems, Department of Materials Processing, Tohoku University, Japan, where he supervised a number of research projects on processing composites.

Dr. Taya is currently running a Center for Intelligent Materials and Systems (CIMS) as Director, where he is involved in supervising a number of projects related to intelligent materials and systems. The intelligent materials that he has been studying are shape memory alloys(SMA), ferromagnetic SMA(FSMA), piezo-composites, electro- and photo-active polymers. The electroactive polymers (EAPs) that Dr. Taya's group has been studying include hydrogels such as Nafion and Flemion, and electrochromic polymers . In addition, Dr. Taya has been working on design, processing of Thermal Interface Materials(TIMs) that have high thermal conductivity, thus for use an interface material between heat dissipating chips and pumped diodes and heat sink/spreader. Dr. Taya's group is also involved in designing a temperature sensor with high special resolution. The details of CIMS activities are given at http://depts.washington.edu/cims/

Toward Zero-energy Buildings Based on Electrochromic Windows(ECW) and Energy-harvesting ECW The objective of this EFRI-SEED project is to develop a set of new switchable dyes and polymers as the basis for electrochromic windows (ECWs) and energy-harvesting (EH) ECWs which substantially reduce cooling/heating loads and increase human comfort. An secondary objective is to develop a partner methodology for moving towards the design of zero-energy buildings that transfers this new technology into educational programs for both the academic and building design communities. The project will develop EH-ECW technology by combining the merits of electrochromic window and dye-sensitized solar cell technologies for dimming control and to generate power to operate not only the ECWs but also other electrical systems. The researchers will study the fundamentals of sensor/controller systems for optimal use of the EH-ECWs in a given room, and the consideration of environmental life cycle impact into EH-ECW technology development and dissemination. The integration of EH-ECW systems into an autonomous building system is the basis for a new concept called "locally harvesting and locally used." The material systems studied promise substantial improvements over existing systems and will parallel component development with the use of Life Cycle Assessment (LCA). The LCA will form an overall framework to bring together the research and expertise of an interdisciplinary team including technology development and educational integration. The researchers will develop models to forecast environmental impacts for scaled fabrication sequences, performance for a variety of building types with the proposed ECW/EH-ECW systems and locations, and demolition systems.

The research will investigate the use of EH-ECWs to generate a substantial portion of the energy used by buildings, thus reducing the impacts of central energy generation, and to increase visual comfort and building envelope performance resulting in healthier, more productive indoor environments, as well as to smooth the transfer of the above integrated technology to residential and commercial building design and the construction industry, targeting the $20B window market. This team plans to interact with the existing NSF centers, the Pacific Northwest National Laboratory, UW laboratories, a local architectural group and window company, the Seattle Science Center, and the University of Ulster (UU) as a foreign collaborator.



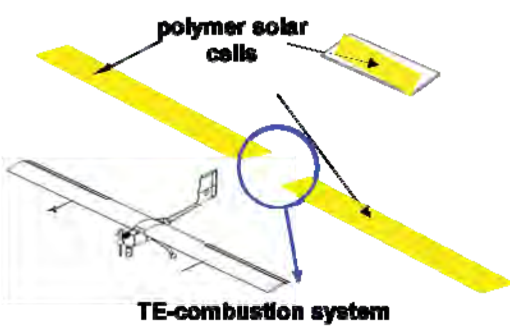
CIMS Electrochromic window of 12 x 20 inch size

Airborne Energy-Harvesting based on TE modules(AFOSR - MURI)

Goals:To develop thermoelectric device and its integration for energy harvest/storage system in “self-powered” load-bearing structures of UAV.

Benefits:

1) Provide a new propulsion power for a UAV/MAV
2) No moving part which has advantage for ‘load-bearing’ structure system
3) Environmental-friendly and **light weight and low-cost materials** based on Mg-Si, MnSi, etc. .



Material	Density [g/cm^3]	Specific figure of merit (ZT/Weight)		Average Clarke number (%)	Cost [$/g]
		At 300K	At 800K		
Mg_2Si	1.95	0.051 /g	0.359 /g	14.83	0.005
SiGe	2.93	n/a	0.171 /g	12.9	0.586
Bi_2Te_3	7.86	0.095 /g	0.038 /g	2.03e-5	0.091
$AgPb_{18}SbTe_{20}$	8.08	0.05 /g	0.259 /g	6.8e-3	0.061
$CoSb_{3-x}Te_x$	7.62	0.026 /g	0.098 /g	2.08e-3	0.034

Mg_2Si : High figure of merit(ZT) for low to intermediate temperature, Light Weight, Cost-effective and Non-toxic

Professor Brian C. Fabien joined the mechanical engineering department at the University of Washington in 1993. He received his BEME from the City College, CUNY; his MS, MPhil. and Ph.D. from Columbia University in New York. His major research interests include: (i) multi-discipline dynamic system modeling, (ii) nonlinear optimal control, and (iii) the development of energy storage devices.

Flywheel Energy Storage Systems

Energy storage systems are critical for increasing the reliability of intermittent renewable sources such as solar, wind and tidal energy. Here we provide an overview of some research activities related to the development of a high energy density flywheel energy storage (FES) device.

A schematic of a FES device developed at the University of Washington is shown in Figure 1. The flywheel is supported in the housing via the permanent magnet pairs at the top (**T, T'**) and bottom (**B, B'**) of the system.

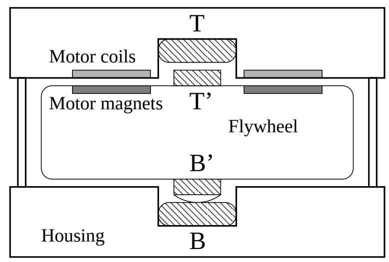


Figure 1: A prototype FES system

These magnets are arranged such that the magnet **T** is attracted to magnet **T'**, and magnet **B** is attracted to magnet **B'**. A unique feature of this hybrid magnetic bearing arrangement is that it is able to provide stable/low friction support of the flywheel without the need for any external power.

In addition to the passive bearing shown here, we have develop active and semi-active for use in these devices.

Stacked-ply composite flywheels

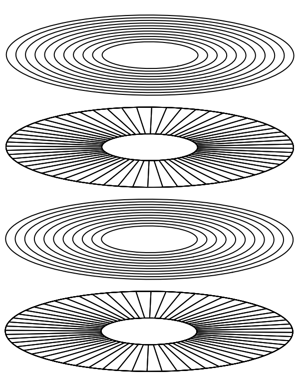


Figure 2: Stacked-ply flywheel

As part of an NSF sponsored research we have developed novel techniques for the design and construction of *thin* stacked-ply composite flywheels. This research answered the following questions; (i) Is it possible to improve the energy density of a stacked-ply composite disk by varying the orientation of the fibers in the radial plys? (ii) How can such a disk be constructed?

Using the the stacked-ply arrangement shown in Fig. 2 we are able to design and construct thin composite flywheels with energy densities in excess of 500 KWh/kg. This composite disk design consists of alternating layers of radial and tangential plys. The orientation of the fibers in the radial layer is optimized so as to maximize the energy density of the disk. Current research activity centers around the development of composite flywheels with energy densities approaching 1000 KWh/kg.

Motor/generator design

As part of this research effort we have developed very efficient motor/generator systems. We have found that for FES systems it is advantageous to have an axial flux orientation for the motor/generator. This axial magnetic flux arrangement is often referred to as a pancake motor design. An example of such an arrangement is shown in Fig. 1. The magnetic flux is generated by magnets that are embedded into the top of the flywheel. The conductors for the motor are embedded at the top of the housing.

This magnet-coil arrangement serves three purposes: (i) a torque actuator (i.e., a motor); (ii) a voltage/current source (i.e., a generator); and (iii) a radial force actuator. This third feature is a unique outcome of our research.

Radial force: We have demonstrated that this axial-flux magnet-coil arrangement can be used to produce radial forces that act on the flywheel. This novel application of the magnet-coil arrangement lead to the development of a control system that attenuates the vibrations of the flywheel due to external disturbances.

Our motor/generator designs achieve efficiencies of 95%. Moreover, these systems produce very large torques which allow for rapid charge/discharge of the FES device. Hence our energy storage systems are suitable for use in pulsed power applications.

Control

The successful integration of FES devices into the existing energy generation/transmission infrastructure requires robust controls to manage the transfer of energy from one system to the next. Some of our research activity centers around the development these control technologies. The techniques we employ include: (i) learning control, (ii) model predictive control and (iii) adaptive control. Using these strategies we are able to provide effective power balancing in the presences of intermittent generation and fluctuating loads.

Jiangyu Li

Director, Multifunctional Materials Laboratory

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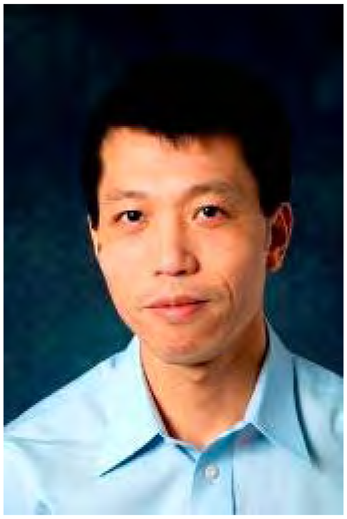


The Multifunctional Materials Laboratory at University of Washington is devoted to investigating the mechanics and physics of multifunctional materials, using tightly combined theoretical, numerical, and experimental investigations. We are interested in understanding the formation and evolution of microstructure in materials, clarifying their structure-property relationship, and optimizing microstructures and processing conditions for superior functional properties. We have been working on ferroelectrics, ferromagnetic materials, multiferroics, thermoelectrics, and electro-active polymers and composites, and we are currently focusing on global energy need through multifunctional materials design and synthesis. Some of our current activities are summarized below:

Nanocrystalline thermoelectric oxide for high efficiency energy harvesting

Currently, about 34% of world primary energy needs are supplied by petroleum, and a large portion of them are consumed by cars and airplanes for transportation. For a vehicle powered by a typical gasoline-fueled internal combustion engine, vast majority of the fuel energy is lost as waste heat - only 25% of the fuel energy is used for vehicle mobility and accessory power. This points to an urgent need for alternative energy technology to recover the waste heat in an efficient, economical, and environment friendly manner, and high efficiency thermoelectric materials that convert waste heat directly into electricity are promising to fulfill this need. We are developing nanocrystalline thermoelectric oxides with grain size as small as 10nm to drastically reduce their thermal conductivity, and thus substantially enhance their conversion efficiency. We are also developing advanced scanning probe microscopy techniques to characterize the thermoelectric effect at nanoscale, and developing multi-scaling modeling and simulation techniques to guide our material development efforts.

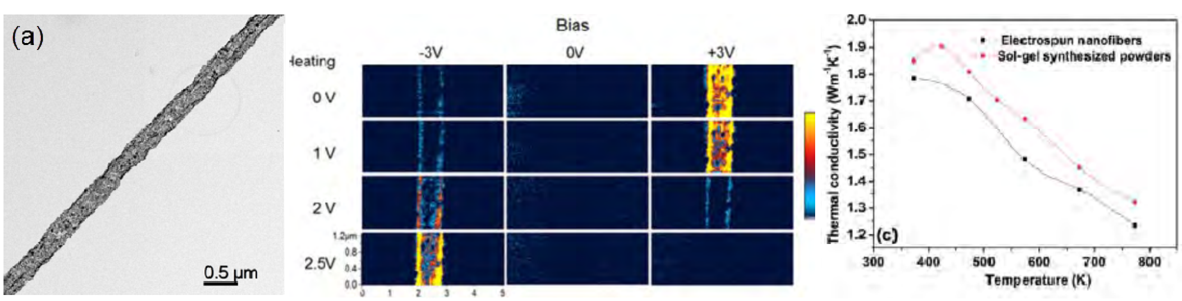


Fig. 1 (a) Nanocrystalline thermoelectric nanofiber synthesized by electrospinning; (b) thermoelectric effect of nanofiber confirmed by advanced scanning probe microscopy; (c) reduced thermal conductivity of nanofiber-sintered thermoelectric ceramics.

Hierarchical porous nanostructures for dye-sensitized solar cells

Sunlight is arguably the ultimate solution to the global energy problem, supplying earth approximately 3×10^{24}J/year, 10^4 times more than what mankind consumes today. While photovoltaic solar cells based on single crystalline Si and semiconducting films have relatively high conversion efficiency and the largest market share today, they are expensive to process and not environment friendly, and the next generation dye-sensitized solar cells (DSCs) offer an attractive low cost alternative with easy processability and viable conversion efficiency over 10%. We are developing hierarchical porous nanostructures for DSCs to facilitate effective light harvesting, electron injection, and electron collection, with the objective to substantially enhance their conversion efficiency.

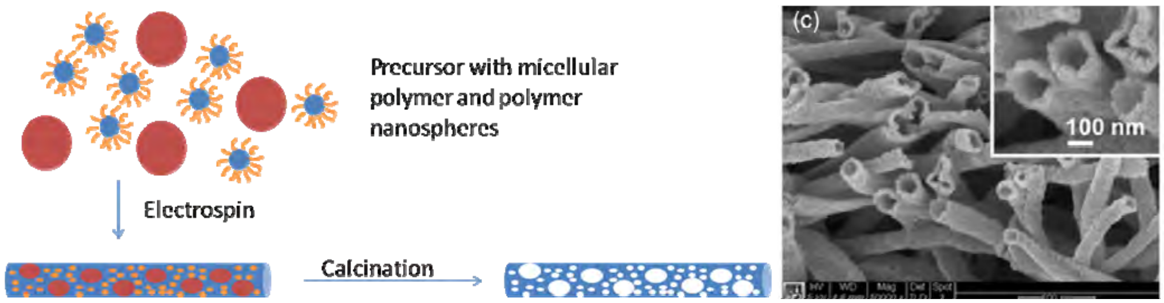


Fig. 2 (a) Strategy for synthesis hierarchical porous nanostructures for DSCs; (b) porous nanotube we synthesized.

Hierarchical oxide nanostructures for Li-ion batteries

We are living in a highly mobile society that demands constant motion and uninterrupted connection, and batteries with both high specific power density and specific energy density are essential in delivering electricity on demand, anywhere, anytime, to a wide range of portable electronic devices such as smart phones and laptops. Even more importantly, as we gradually move away from traditional gasoline-fueled internal combustion engines toward environment friendly electric vehicles, there would be tremendous demand for high performance batteries with high energy density and rapid charging rate. Among all the electrical energy storage devices, lithium-ion battery has the highest energy density and excellent cycling stability, and is likely to play a dominant role in the next generation portable power market. We are developing hierarchical oxide nanostructures for Li-ion batteries to substantially enhance their energy storage density and cycling stability. We are also developing advance scanning probe microscopy techniques and multi-scale modeling and simulations to understand electrochemistry and its coupling with mechanical deformation at nanoscale.

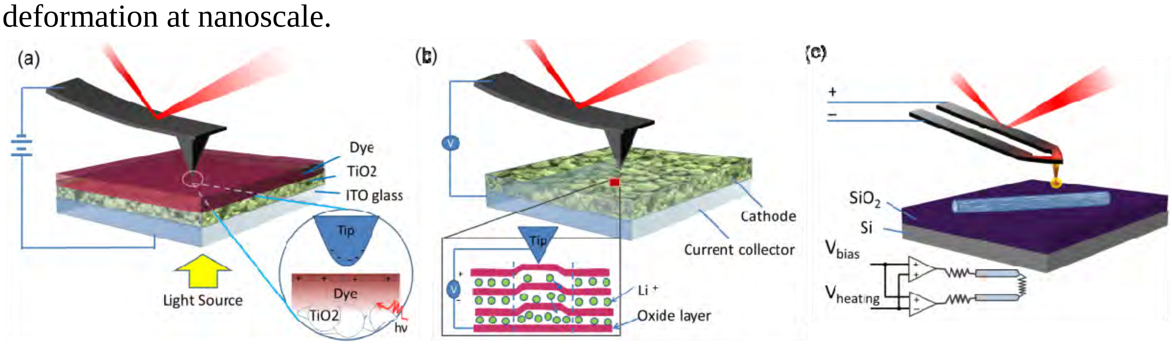


Fig. 3 Advanced scanning probe microscopy for DSCs, Li-ion batteries, and thermoelectrics.

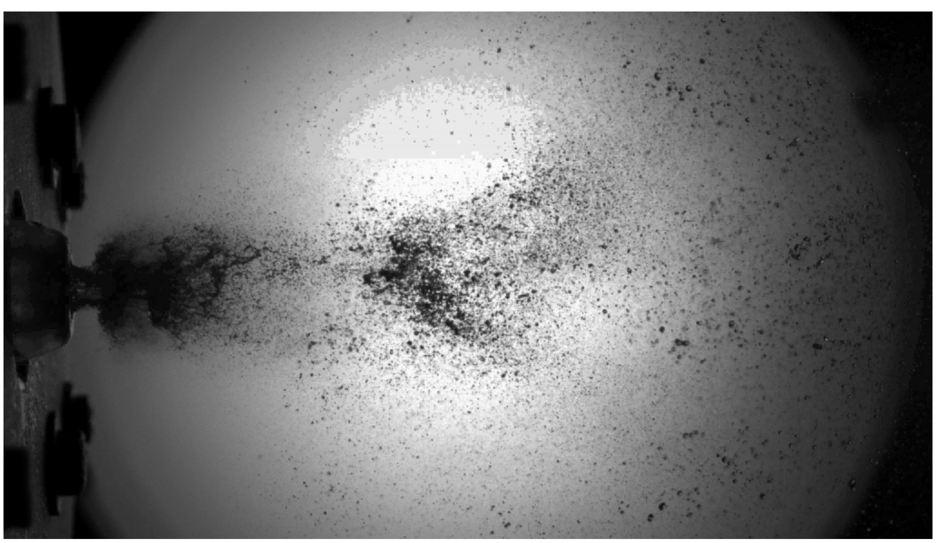
Research Profile of Alberto Aliseda:

Multiphase Fluid Mechanics applied to Energy Conversion

Alberto Aliseda's research interests span a wide number of areas where multiphase flows and energy conversion intersect. The driving principle of my lab is to study problems that contain some new or incompletely understood physical mechanism and present exciting new applications to energy conversion. There are multiple subfields in which fluid systems that contain two or more phases are present in energy conversion devices. Liquid fuel injection and mixing with a gaseous oxidizer, solid pollutants emitting from a combustion process, bubbles in the cooling system in nuclear plants, are just some examples that we have studied in the past. We use a combination of experimental techniques to investigate the dynamics of particles, drops and bubbles in turbulent flows. Phase Doppler Particle Analyzer, Particle Image Velocimetry and High Speed Quantitative Visualization are among the many tools we use in our research. We complement these with a suite of theoretical and numerical methods that we use to help with the analysis of our data.

Current Research Thrusts:

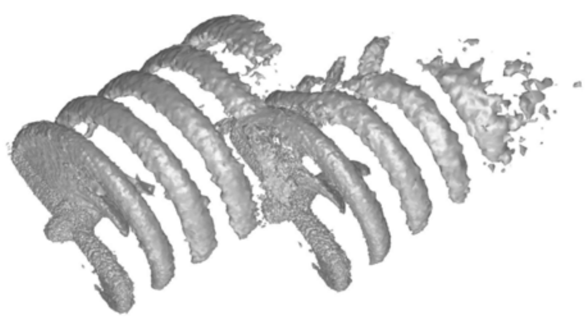
- Flow Instability in Complex Fluid Atomizers: the fundamental physical processes involved in the break up of a liquid jet is still poorly understood, despite being the most usual fuel injection strategy in engines and stationary power generation devices. We are working to develop models of the droplets size, velocity and spatial concentration in the spray. In particular, we are interested in complex rheology fluids where liquid viscosity plays an important role. This is a key new development as new fuels come into market, such as pulverized coal suspensions and biofuels, that do not share the physical properties of traditional hydrocarbons. We are currently collaborating with General Electric on the understanding of injection instabilities and optimization of atomizers for coal gasifiers.



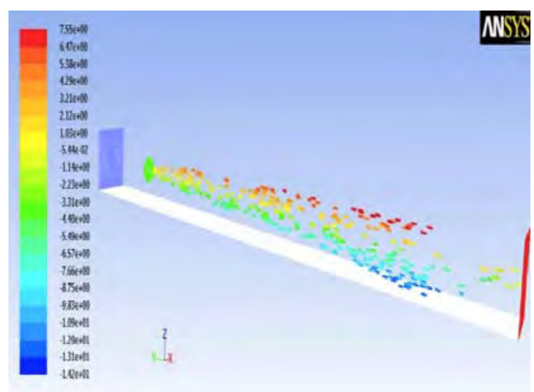
High Speed Visualization of a coaxial two-fluid atomizer

- Droplet Impact of Solid Surfaces: the dynamics of droplets impacting a solid surface are dominating by a complicated balance of inertia, surface tension, viscosity and gravitational forces. We are interested in understanding the spreading of complex-rheology fluids when they impact solid surfaces of varying wettability at high speeds. This problem is related to the atomization of novel fuels and the fate of the droplets produced by the atomization in the combustion chamber. It is important in many energy applications in which liquid fuels or coolants are atomized onto hot solid surfaces.

- Tidal Energy: as part of the National Northwest Marine Renewable Energy Center, funded by the US Department of Energy at the University of Washington, Aliseda's lab is investigating the dynamics of wakes in Marine Hydrokinetic (MHK) Turbines. These are underwater turbines that are placed in regions of very fast currents and produce electricity in much the same way wind turbines extract energy from the kinetic energy in the wind to generate electricity. There are multiple important scientific issues that need to be well understood before this technology can be widely deployed. We are interested in the influence of wakes on turbine performance and the environmental effects that these turbines can have through modifications on the flow. We use a variety of numerical techniques to simulate the hydrodynamics of flow around MHK turbines and experiments to validate the simulations and explore other phenomena that are not accurately modeled.



Turbine-Wake interactions: visualization of the vorticity field in two closely packed MHK turbines.



Visualization of heavy particles sedimenting in the wake of a tidal turbine.

Research Description of Amy Shen

Soft Matter and Microfluidics Lab

Amy Shen's research program concerns complex fluids and microfluidics to create morphologies and structures of new devices and materials that can find application in the nanotechnology, bioenergy, and novel materials. The ability to mimic the in vivo environment for cellular studies in vitro is a major engineering and biological challenge. Microfluidics provides a tool to recreate an in vivo-like environment with small reagent volumes, short reaction times, and the possibility of parallel operation. Furthermore, unique phenomena at reduced length scales, such as enhanced surface effects, fluid rheological variations, and faster diffusive equilibration, can be exploited in novel device designs. Listed below I highlight some examples of using microreactors for bioenergy applications.

Microbial fuel-cell studies and micro-bioreactors

Methanogens belong to the form of life known as Archaea. Discovered in the 1970s, Archaea inhabit environments with harsh conditions, such as petroleum deposits and the digestive tracts of cows. Methanogens can exist on earth, other planets, and moons; they can also generate methane from carbon dioxide and water. Previous studies have generally been conducted in larger media bottles or reactors ranging anywhere from several milliliters to several liters in size. These reactors serve to provide a hospitable environment for the methanogens to grow and survive. However, because they cannot be placed on a microscope stage, they do not allow for any type of direct observation of methanogen behavior, growth or ability to attach to a substrate. My group studied the methanogens attachment behavior in-situ by utilizing an *anaerobic*

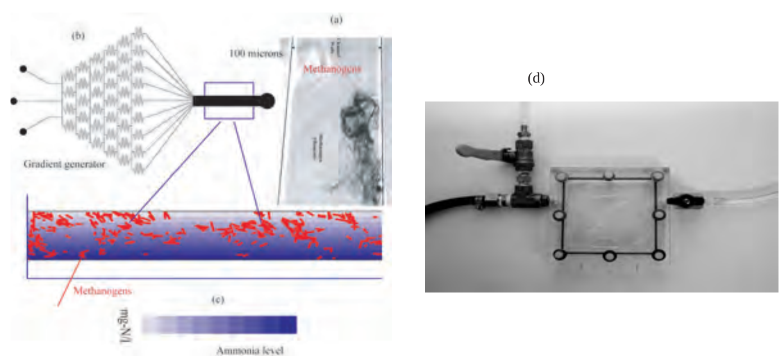


Figure 1: Chemical gradient presentation in vitro using microfluidic devices. (a) Dense methoanogen filaments grown inside microchannels after 3 months. (b) Microfluidic gradient generator. (c) Overlay of filament density with ammonia gradient. (d) Anaerobic box containing the microdevice.

micro-bioreactor. The anaerobic micro-bioreactor is a portable, airtight chamber, filled with N_2/CO_2 gas, which houses a micro-fluidic chip used to culture the anaerobes (see fig. 1). The microfluidic chips contain tiny fluid channel of width ranging from a few microns to approximately one millimeter and have a total system volume of 5 μL. The waste-water anaerobe methanothrix concilli was cultured for a period of 3 months inside the micro-bioreactor in a fluid network with varying channel widths to study the effects of shear-rate. A manuscript based on above results has appeared in the *Journal of Applied Environmental Microbiology* in 2007. Current and future directions include modifying our current micro-bioreactor design for use in **microbial fuel-cell studies.**

Novel microreactor for biomass to biofuel conversion

The high crude oil price and fuel shortage have led to global economic and social impacts. As a clean and renewable energy source, biomass plays an important role in the future energy market. **Traditional technology:** Conversion of biomass to biofuels consists of two major steps: biomass gasification and Fischer-Tropsch Synthesis (FTS). *Biomass gasification* converts carbonaceous biomass into carbon monoxide and hydrogen (syngas: $CO+H_2$) by treating the raw material at high temperature with controlled amount of oxygen or steam (see Fig.3). This process is important for carbon neutral economy.

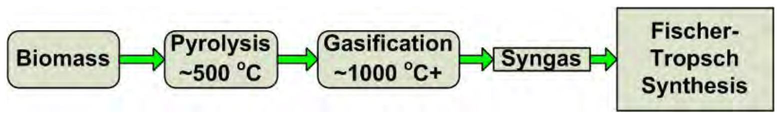


Figure 2: A simplified flow chart of biomass to biofuel conversion.

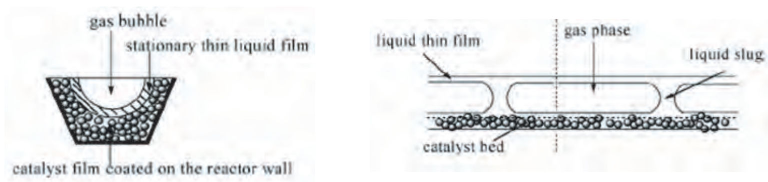


Figure 3: Microreactor for gas-liquid reaction with catalyst.

Current commercially available FTS reactors have been mainly designed for coal to fuel conversions. The reactor types include fixed bed reactors, multi-tubular fixed bed reactors, and slurry phase reactors. Among them, the Sasol slurry reactor is the largest FTS reactor in the world, with an outer diameter of 10 m and 60 m in height. For biomass to biofuel conversion, the same FTS reactors for coal conversion are currently being used with the following disadvantages: (A) It is expensive to build the traditional FTS reactors. (B) FTS reactors have to be operated under high temperature (150°C-300°C) and pressure (10-40 atm), causing higher maintenance and operation fees. Due to high temperature, hot spots and wax accumulation are abundant inside the reactor, causing low heat transfer efficiency. (C) Biomass resources are usually distributed in remote rural areas with low biomass density. A concentrated, large-scale, high capital, complex operation FTS reactor is not appropriate for biomass FTS process. (D) It is difficult to control residence time and product distribution inside the large scale reactor.

Motivated by the limitations of the traditional FTS reactors, we are developing a microreactor for biomass FTS reaction with high mobility and efficiency. The advantages of microreactors are: (a) The operation is small scale, easy scale-up. (b) High gas/liquid surface to volume ratio renders more efficient mass transfer. (c) Higher mobility and easy parallel design are good for remote distributed bio-fuel system.

Targeted technology

With the rapid development of microfluidics and MEMS technology, achieving gas-liquid reaction at small length scales has become possible (Figure 3). We aim to pioneer the microreactor technology for biomass to biofuel conversion, with higher efficiency, mobility, and lower cost. Our research goal is to utilize our expertise in microfluidics and hydrodynamics (Shen) and catalyst (Cao) to identify the optimal design parameters to obtain the desired fuel distribution curve inside a simple microreactor. Further, we hope to expand our study for portable biomass conversion system by using parallel design. In addition, we will integrate our design and performance analysis of FTS microreactor with Cooper group's supercritical gasification research to maximize the overall biomass to biofuel conversion efficiency.

John Kramlich

Prof. Kramlich's principal technical interests involve systems that convert raw energy resources (sun, wind, fuels) into useful energy (electricity and mechanical power). The main focus areas are:

- Combustion, with an emphasis on pollutant formation and control.
- The numerical and theoretical analysis of turbulent reacting flows involving combustion.
- Solid oxide fuel cell design and performance analysis.

After completing his Ph.D. in 1980 he spent twelve years with Energy and Environmental Research Corporation (EER) of Irvine, California. During that time he was involved in basic contract research directed at the development of pollution reduction techniques for large fossil fuel-fired energy systems. He also worked on a number of consulting projects involving energy systems at power plants, oil refineries, and biomass conversion plants. He joined the University at the start of 1992 (EER was subsequently purchased by General Electric, principally to obtain one of the pollution control technologies developed by in-house research). Examples of current research projects are described below.

Algal Biofuels (Boeing):

Problem: Fuel molecule chain length critical to meeting jet fuel specification requirements. Long chain lengths lead to fuel solidification in wing tanks.

Approach: Oil extraction from algal biomass can be done as a stagewise process. We took algae samples grown under carefully controlled conditions (i.e., attempting to start with the same samples for each experiment), and subjected them to a new stagewise oil extraction process. We then analyzed the oil from each stage for variations in composition. The results indicated that a mild fractionization did occur.

Biofuel Handling/Degradation (USAF):

Problem: Normal jet fuel contains components that interact with sealing rings in fuel systems, causing the rings to swell and provide a good seal. Pure biofuels lack these components, which can lead to poor fuel system integrity. Aromatic additives can be used with the pure biofuels to provide the correct fuel seal swell, but there is a concern that these fuels will undergo thermal degradation in heated fuel systems, leading to deposits.

Approach: In experiments at Wright-Patterson Air Force Research Center, we performed laboratory experiments on thermal degradation and deposit formation. We identified formulations that met fuel seal requirements without generating deposits on heated fuel surfaces.

Alternative Fuel Combustion Flameout Characteristics (USAF):

Problem: Blowout or flameout from highly mixed combustors is a critical parameter limiting the maximum amount of fuel that can be processed through a given combustor. This ultimately sets the upper limit on power output. While the blowout characteristics of standard jet fuel are well known, the behavior of alternative fuels is not. A major barrier is that these tests require significant quantities of fuel, and only a few laboratories are capable of supplying enough to perform these tests.

Approach: We conducted experiments at Wright-Patterson Air Force Research Center in which the blowout characteristics of various alternative fuels were compared with jet fuel in a torrodial stirred reactor. The Wright-Patterson lab is one of the few that has the capability to generate a sufficient variety of alternative fuels to enable testing. The fuels tested included Fischer-Tropsch fuels synthesized from coal gas and natural gas, and biofuels generated by hydroprocessing of biofuel feedstocks. We were able to correlate the blowout temperature and stoichiometry with the aromatic content of the fuel.

Combustor Fuel Interchangeability Criteria (California Energy Commission):

Problem: Existing combustors are often tightly designed around a specific fuel composition to avoid problems such as flashback and blowout. There is an increasing desire to use these combustors in a fuel-flexible way. Fuels of interest include landfill gas, sewage treatment offgas, the new shale-based natural gases, liquefied petroleum gas, refinery off gas, and gasification products from coal or biomass. Given the wide variety of fuel compositions, there is a need for a methodology to guide the use of a new fuel in an existing combustor.

Approach: This project is a team effort involving UC-Irvine and Georgia Tech. Our work involves using a premixed, intensely backmixed combustor (i.e., a laboratory prototype of a lean, premixed gas turbine combustor) to (1) investigate blowout, flame structure, and NO_x/CO/ hydrocarbon emissions for the various fuels, and (2) use modeling to develop a means of predicting the combustion key parameters for a new fuel based on its composition.

Phil Malte

Professor Malte is the director of the UW Northwest National Marine Renewable Energy Center (NNMREC).

Hydrokinetic tidal power is emerging as an exciting new source of renewable energy for the Puget Sound region. With no carbon emissions or visual expression, tidal turbines have the potential to turn the predictable power of tidal currents into green electricity. Tidal turbines extract power from moving water much in the same way as wind turbines do from moving air, and many tidal device concepts bear more than a passing resemblance to wind energy converters. The Northwest National Marine Renewable Energy Center (NNMREC) at the University of Washington is supporting the responsible development of this renewable resource in the United States.

NNMREC's tidal energy research brings together faculty and students from several academic units, including Mechanical Engineering, Oceanography, and the Applied Physics Laboratory. In addition to academic collaborators, the UW center involves a number of public and private partners: Snohomish Public Utility District, BioSonics, Sound and Sea Techno logy, Pacific Northwest National Lab (PNNL), and the National Renew able Energy Lab.

For over a year, the UW center has collected data to characterize the physical and biological environment in Admiralty Inlet, where Snohomish PUD proposes to deploy two OpenHydro turbines in 2012. The methods developed to study this particular site are being generalized for tidal energy sites throughout the United States. "The emphasis here is on learning," said Jim Thomson, a PI from the UW Applied Physics Lab (APL). Data are being collected from aboard the APL research vessel Jack Robert son, on the seabed using an instrumentation tripod, and from the shore. Recently, ME graduate researcher Chris Bassett combined background noise recordings from the seabed tripod with ship traffic information to estimate how the noise from operating tidal turbines would propagate in Admiralty Inlet. Jeff Epler (ME graduate researcher) has developed a technique to combine shipboard and tripod measurements of velocity to map the intense tidal currents in the area. This summer, researchers will expand their monitoring activities under a new award from the US Department of Energy as part of a project team that includes Snohomish PUD, Sea Mammal Research Unit, Ltd., and PNNL.

Numerical modeling is also an important component of the UW center's activities. Researchers are using a set of validated models to investigate the potential effects that turbine wakes could have on marine life through changes to downstream sedimentation and mixing. Teymour Javaherchi (ME graduate researcher), presented preliminary results of this work at the annual AGU Ocean Sciences Meeting in Portland. Kristen Thyng (ME graduate researcher) is investigating dynamic flow behavior due to the rough underwater topography in Admiralty Inlet. Simplified numerical models are being employed to investigate stratification and the interactions between the shallow sills at the northern and southern ends of the inlet. These flow dynamics have potentially important implications for tidal turbine siting and operation.

The UW center also recently hosted Environmental Effects of Tidal Energy: A scientific workshop that brought together more than seventy experts with diverse technical backgrounds. Workshop participants, from the US, Canada, and Europe, helped to identify approaches to close gaps in knowledge, monitor for effects, and mitigate stresses for areas of high priority environmental concern. Initial response was highly positive, with more than 90% reporting that they will use the information learned at the workshop for projects related to tidal energy. For more information about NNMREC, including recent presentations in other areas of tidal energy research and videos from instrumentation deployments in Admiralty Inlet, please visit the UW center's website at http://depts.washington.edu/nnmrec .

(L to R) Sam Gooch and Chris Bassett (MEgraduate researchers) and Dave Sutherland (Oceanography post doc) prepare the instrumentation tripod for deployment in Admiralty Inlet.

(L to R) Mitsuhiro Kawase (Oceanography faculty), Alberto Aliseda (ME faculty), Kristen Thyng (ME graduate researcher), Jim Thomson (APL/CEE faculty), Phil Malte (ME faculty), and Brian Polagye (ME faculty) aboard the Applied Physics Lab research vessel Jack Robertson. Not shown: Jim Riley (ME faculty), Brian Fabien (ME faculty), and Mark Tuttle (ME faculty).