A density difference plot showing the highly delocalized nature of the highest occupied molecular orbital in a CO2 reduction catalyst.

Annealed reactive dynamics on a 3 nm sized gold nanoparticle shows its predicted surface reconstructing.
Swanson School of Engineering, Summary of Faculty Research 2018

On behalf of the Swanson School of Engineering and U.S. Steel Dean of Engineering Gerald Holder, we are proud to present the newest edition of the Swanson School of Engineering Summary of Faculty Research. Within are highlights and descriptions of the research conducted in individual faculty research laboratories as well as some of the Swanson School-based centers and institutes. Research capabilities and expertise from faculty within each of the School’s six departments are represented. These summaries are written for the “scientific lay person,” and much more information on any specific faculty member or center/institute can be found on the Swanson School website at engineering.pitt.edu. Contact information is provided to encourage collaboration, and we invite you to reach out to any faculty of potential interest to discuss possibilities.

Sincerely,

David A. Vorp, PhD
Associate Dean for Research
Swanson School of Engineering
Table of Contents

Bioengineering
Steven Abramowitch, PhD ............................................. 8
Aaron Batista, PhD .................................................. 9
Kurt E. Beschorner, PhD ........................................... 10
Harvey Borovetz, PhD ............................................... 11
Bryan N. Brown, PhD ............................................... 12
Rakié Cham, PhD .................................................... 13
April Chambers, PhD .............................................. 14
Tracy Cui, PhD ....................................................... 15
Moni Kanchan Datta, PhD ......................................... 16
Lance A. Davidson, PhD ........................................... 17
Richard E. Debski, PhD ............................................ 18
William Federspiel, PhD ........................................... 19
Neeraj J. Gandhi, PhD ............................................. 20
Alan D. Hirschman, PhD .......................................... 21
Tamer S. Ibrahim, PhD ............................................. 22
Takashi “TK” Kozai, PhD .......................................... 23
Prashant N. Kumta, PhD ........................................... 24
Patrick J. Loughlin, PhD ........................................... 25
Spandan Maiti, PhD ................................................. 26
Partha Roy, PhD ..................................................... 27
Warren C. Ruder, PhD .............................................. 28
Joseph Thomas Samosky, PhD ................................. 29
Sanjeev G. Shroff, PhD ............................................ 30
George Stetten, MD, PhD ......................................... 31
Gelsy Torres-Oviedo, PhD ......................................... 32
Jonathan Vande Geest, PhD ...................................... 33
David A. Vorp, PhD ................................................ 34
Doug Weber, PhD ................................................... 35
Justin S. Weinbaum, PhD ......................................... 36
Savio L-Y. Woo, PhD, D.Sc., D.Eng. ......................... 37

Chemical and Petroleum Engineering
Ipsita Banerjee, PhD ................................................ 39
Eric J. Beckman, PhD ............................................. 40
Robert M. Enick, PhD ............................................. 41
Susan Fullerton, PhD ............................................. 42
J. Karl Johnson, PhD .............................................. 43
John A. Keith, PhD ................................................. 44
George E. Klinzing, PhD ......................................... 45
Lei Li, PhD .......................................................... 46
Steve R. Little, PhD ................................................ 47
James R. McKone, PhD .......................................... 48
Badie Morsi, PhD ................................................... 49
Giannis Mpournmpakis, PhD ................................... 50
Tagbo Niepa, PhD .................................................. 51
Robert S. Parker, PhD ............................................. 52
Jason E. Shoemaker, PhD ....................................... 53
Sachin Velankar, PhD ............................................. 54
Götz Veser, PhD ..................................................... 55
Christopher E. Wilmer, PhD .................................. 56
Judith C. Yang, PhD ............................................... 57

Civil and Environmental Engineering
Melissa Bilec, PhD .................................................. 59
Andrew P. Bunger, PhD .......................................... 60
Leanne M. Gilbertson, PhD ....................................... 61
Kent A. Harries, PhD, FACI, P.Eng .......................... 62
Anthony Iannacchione, PhD, P.E. ......................... 63
Xu Liang, PhD ........................................................ 64
Jeen-Shang Lin, PhD, P.E. ....................................... 65
Mark Magalotti, PhD ............................................. 66
Carla Ng, PhD ...................................................... 67
Piervincenzo Rizzo, PhD ........................................ 68
Luis E. Vallejo, PhD ................................................. 69
Radisav Vidic, PhD ................................................ 70
Qiang Yu, PhD ....................................................... 71
### Electrical and Computer Engineering

<table>
<thead>
<tr>
<th>Name</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alan D. George, PhD, FIEEE</td>
<td>73</td>
</tr>
<tr>
<td>Brandon M. Grainger, PhD</td>
<td>74</td>
</tr>
<tr>
<td>Jingtong Hu, PhD</td>
<td>75</td>
</tr>
<tr>
<td>Alex K. Jones, PhD</td>
<td>76</td>
</tr>
<tr>
<td>Hong Koo Kim, PhD</td>
<td>77</td>
</tr>
<tr>
<td>Alexis Kwasinski, PhD</td>
<td>78</td>
</tr>
<tr>
<td>Guangyong Li, PhD</td>
<td>79</td>
</tr>
<tr>
<td>Zhi-Hong Mao, PhD</td>
<td>80</td>
</tr>
<tr>
<td>Gregory F. Reed, PhD</td>
<td>81</td>
</tr>
<tr>
<td>Ervin Sejdić, PhD</td>
<td>82</td>
</tr>
<tr>
<td>William E. Stanchina, PhD</td>
<td>83</td>
</tr>
<tr>
<td>Feng Xiong, PhD</td>
<td>84</td>
</tr>
<tr>
<td>Jun Yang, PhD</td>
<td>85</td>
</tr>
<tr>
<td>Minhee Yun, PhD</td>
<td>86</td>
</tr>
</tbody>
</table>

### Industrial Engineering

<table>
<thead>
<tr>
<th>Name</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mostafa Bedewy, PhD</td>
<td>88</td>
</tr>
<tr>
<td>Karen M. Bursic, PhD</td>
<td>89</td>
</tr>
<tr>
<td>Youngjae Chun, PhD</td>
<td>90</td>
</tr>
<tr>
<td>Renee M. Clark, PhD</td>
<td>91</td>
</tr>
<tr>
<td>Joel M. Haight, PhD, P.E., CIH, CSP</td>
<td>92</td>
</tr>
<tr>
<td>Daniel R. Jiang, PhD</td>
<td>93</td>
</tr>
<tr>
<td>Jeffrey P. Kharoufeh, PhD</td>
<td>94</td>
</tr>
<tr>
<td>Paul W. Leu, PhD</td>
<td>95</td>
</tr>
<tr>
<td>K. Louis Luangkesorn, PhD</td>
<td>96</td>
</tr>
<tr>
<td>Lisa M. Maillart, PhD</td>
<td>97</td>
</tr>
<tr>
<td>Jayant Rajgopal, PhD</td>
<td>98</td>
</tr>
<tr>
<td>M. Ravi Shankar, PhD</td>
<td>99</td>
</tr>
<tr>
<td>David T. Sturrock</td>
<td>100</td>
</tr>
</tbody>
</table>

### Mechanical Engineering and Materials Science

<table>
<thead>
<tr>
<th>Name</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heng Ban, PhD, PE</td>
<td>102</td>
</tr>
<tr>
<td>Markus Chmielus, PhD</td>
<td>103</td>
</tr>
<tr>
<td>William W. Clark, PhD</td>
<td>104</td>
</tr>
<tr>
<td>Daniel G. Cole, PhD, PE</td>
<td>105</td>
</tr>
<tr>
<td>Tevis D. B. Jacobs, PhD</td>
<td>106</td>
</tr>
<tr>
<td>Jung-Kun Lee, PhD</td>
<td>107</td>
</tr>
<tr>
<td>Scott X. Mao, PhD</td>
<td>108</td>
</tr>
<tr>
<td>Ian Nettleship, PhD</td>
<td>109</td>
</tr>
<tr>
<td>David Schmidt, PhD</td>
<td>110</td>
</tr>
<tr>
<td>Inanc Senocak, PhD</td>
<td>111</td>
</tr>
<tr>
<td>Nitin Sharma, PhD</td>
<td>112</td>
</tr>
<tr>
<td>Patrick Smolinski, PhD</td>
<td>113</td>
</tr>
<tr>
<td>Albert C. To, PhD</td>
<td>114</td>
</tr>
<tr>
<td>Jeffrey Vipperman, PhD</td>
<td>115</td>
</tr>
<tr>
<td>Guofeng Wang, PhD</td>
<td>116</td>
</tr>
<tr>
<td>Jörg M.K. Wiezorek, PhD</td>
<td>117</td>
</tr>
</tbody>
</table>

### Research Laboratories

<table>
<thead>
<tr>
<th>Name</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center for Energy</td>
<td>119</td>
</tr>
<tr>
<td>Center for Faculty Excellence</td>
<td>120</td>
</tr>
<tr>
<td>Center for Medical Innovation</td>
<td>121</td>
</tr>
<tr>
<td>Coulter Translational Research Partners II Program</td>
<td>122</td>
</tr>
<tr>
<td>Electric Power Systems Laboratory</td>
<td>123</td>
</tr>
<tr>
<td>Engineering Education Research Center</td>
<td>124</td>
</tr>
<tr>
<td>Human Factors Engineering Laboratory</td>
<td>125</td>
</tr>
<tr>
<td>Human Movement and Balance Laboratory</td>
<td>126</td>
</tr>
<tr>
<td>Mascaro Center for Sustainable Innovation</td>
<td>127</td>
</tr>
<tr>
<td>Materials Micro-Characterization Laboratory (MMCL)</td>
<td>128</td>
</tr>
<tr>
<td>McGowan Institute for Regenerative Medicine</td>
<td>129</td>
</tr>
<tr>
<td>Musculoskeletal Research Center</td>
<td>130</td>
</tr>
<tr>
<td>NSF Center for Space, High-performance, and Resilient Computing (SHREC)</td>
<td>131</td>
</tr>
<tr>
<td>National Science Foundation (NSF) Engineering Research Center (ERC) on Revolutionizing Metallic Biomaterials (RMB)</td>
<td>132</td>
</tr>
<tr>
<td>Orthopaedic Robotics Laboratory</td>
<td>133</td>
</tr>
<tr>
<td>Gertrude E. and John M. Petersen Institute of NanoScience and Engineering (PINSE) Nanoscale Fabrication and Characterization Facility (NFCF)</td>
<td>134</td>
</tr>
<tr>
<td>RFID Center of Excellence</td>
<td>135</td>
</tr>
<tr>
<td>Watkins Haggart Structural Engineering Laboratory</td>
<td>136</td>
</tr>
</tbody>
</table>
Tissue Mechanics Laboratory

Dr. Steven Abramowitch is the Director of the Tissue Mechanics Laboratory (TML), which is located in the Musculoskeletal Research Center (MSRC) where he serves as Associate Director. Dr. Abramowitch’s expertise is in the areas of female pelvic floor biomechanics and orthopedic biomechanics, and more specifically, the structural and functional mechanics of soft tissues in these systems.

Currently, the research focus of the TML is on the impact of pregnancy, delivery, and other life changing events (aging, menopause, etc.) on the structural integrity of the pelvic floor, in women. In addition, the lab aims to understand how changes in the structural integrity of the pelvic floor contributes to the pathogenesis of pelvic organ prolapse (POP), and if current clinical treatments and diagnostic measures for this disorder are effectively addressing the underlying pelvic floor abnormalities. Thus, the ultimate goals of these research efforts are to develop preventative treatment options for POP, and more effective, patient specific treatments.

The TML is equipped with experimental testing systems that measure the structural and mechanical properties of soft tissues and biomaterials in response to both quasi-static and dynamic loading conditions, including uniaxial and multi-axial tension, compression and shear. Computational mechanical analyses in the TML are based on custom codes for 3D image segmentation, reconstruction, and analysis of patient specific geometries obtained via various medical imaging modalities (MRI, CT, ultrasound, etc.). These data along with those from mechanical testing serve as inputs for finite element analyses (FEA).

These techniques are used to 1) rigorously characterize normal, healing, and diseased soft connective tissues, 2) to develop robust models that describe tissue function, and 3) to teach students and clinical fellows to conduct proper mechanical testing experiments and analysis.

Selected Referenced Journal Articles


Sensory-Motor Integration Laboratory and Engineering

Dr. Aaron Batista’s research group examines the neural control of visually-guided action. We seek to understand basic principles that underlie the function of the cerebral cortex, and to use those discoveries to improve the function of clinical brain-computer interface (BCI) systems as a treatment for paralysis. Here we describe two of the research endeavors taking place within the laboratory.

**Neural constraints on learning**

Why are some new skills learned relatively quickly, while others take far longer? What changes in the brain when we learn, so that pre-existing abilities are retained even as we learn new skills? We are examining the neural underpinnings of learning using a novel paradigm, brain-computer interface control, which allows us to study the neural basis of learning more directly than is possible with arm movements. We can directly request of our animals that they generate specific patterns of neural activity across a population of 100 or so neurons. We can then observe whether the animals are capable of generating the patterns we requested. Mathematical tools drawn from machine learning enable us to predict which new neural activity patterns (and, corresponding skills) are relatively easy to learn (a day or so), and which will be more difficult (a week or two), just by examining the pre-existing patterns of neural activity prior to learning.

This work is pursued along with colleagues Byron Yu and Steve Chase of Carnegie Mellon University. It is currently supported by an NIH R01 grant from the National Institute of Child Health and Human Development.

**Multisensory Integration in Action**

Our actions are shaped by our perceptual experience. Consider the fine adjustments a violinist makes to play the correct pitch. Sensory experience is often multimodal: we see, hear, and feel the thing with which we are interacting, and our movements are adjusted on-the-fly to achieve our objectives. We seek to understand how the brain uses sensory information to guide action, we train animals to perform challenging balancing tasks in a virtual environment. We record from motor and sensory areas, in the hope of discovering how the areas communicate to send detailed sensory information to sculpt the activity of motor neurons.

This work is pursued along with my Pitt Bioengineering colleague Pat Loughlin. It is supported by an NIH R01 grant from the National Institute of Child Health and Human Development.
**Research Mission:** Dr. Beschorner’s research focuses on the development of ergonomic solutions for preventing falling accidents through the utilization of core competencies in biomechanics and tribology. Dr. Beschorner’s current research topics include 1) developing and applying innovative methods to model and assess the tribological interaction between shoe and floor surfaces in order to prevent slips and falls; 2) identify the personal and environmental factors that contribute to falls from ladders and develop strategies to reduce these falls; and 3) assessing the negative effects of multifocal lens glasses (bifocals/progressive lens glasses) on walking balance and identifying solutions that improve balance in this population. Dr. Beschorner’s research has been funded by the National Institute of Occupational Safety and Health, Department of Labor and the National Institutes of Health.

**Background:** Dr. Beschorner received his BS in Mechanical Engineering from University of Illinois Urbana-Champaign and his PhD in Bioengineering from University of Pittsburgh. He also spent four years as an Assistant Professor of Industrial Engineering at the University of Wisconsin-Milwaukee where he founded and directed the Gait Analysis & Biodynamics Lab and the Human Tribology Lab.

**Tribology of Slip and Fall Accidents**

Slip and fall accidents are among the leading causes of injuries in the workplace and for older adults. The slipperiness of the shoe-floor interface is a major modifiable contributor to slip events. Dr. Beschorner’s research focuses on the development of new experimental (right, top figure) and modeling techniques that guide interventions and improve our understanding about the tribological causes of slipping accidents. This research has led to the development of an under-shoe fluid pressure paradigm for mapping the fluid-drainage capability across shoe tread (right, bottom figure) and finite element modeling approaches that predict friction based on material properties and surface properties. Dr. Beschorner currently works with industry partners to enhance workplace safety through training, footwear programs, and workplace design.

**Biomechanics of Fall Accidents**

The biomechanical response to balance perturbations is dependent on a complex interaction between personal and environmental factors. Dr. Beschorner’s research aims to characterize this complex interaction by measuring the biomechanical response to high fall risk scenarios in a safe, controlled laboratory environment. This approach is being applied to examine the impacts of ladder design and climbing style on fall risk (left figure) and to understand the personal and environmental factors that influence the fall risk and functional balance of wearers of bifocals and progressive lens glasses.
The PediaFlow® Pediatric Ventricular Assist Device (VAD)

PediaFlow R&D

With the support of two NHLBI contract awards, our consortium has developed mixed-flow turbodynamic (continuous flow) pediatric ventricular assist devices (VAD) utilizing a magnetically levitated impeller capable of producing 0.3-1.5 liters per minute (LPM) of blood flow for supporting infants and small children weighing 3-15 kg for up to six months duration. A particular focus of our work has been on achieving exceptional biocompatibility of our prototypes through state-of-the-art CFD design of the blood flow path. The goal of our program is to operate our pediatric VAD clinically with minimal anticoagulation requirement and optimal biocompatibility.

Over 20 design variations were initially considered, with three pump topologies selected for further design refinement and evaluation. The three designs, two centrifugal and one mixed-flow pumps, were judged based on a multi-component objective function which factored several criteria including anatomic fit, estimated biocompatibility, heat generation and transfer, magnetically levitated suspension robustness, and manufacturability. This evaluation led to selection of the mixed-flow configuration.

The design was improved using computational fluid dynamics to minimize flow-induced blood damage via modification of the geometry of the predicted blood flow path.

The housing was modified to improve surgical fixation. A transparent replica of the blood flow path was built to perform validation of the computer predictions by flow visualization analyses.

Other ongoing efforts were focused on controller development, materials selection, biocompatible coating application, nanotechnology based infection control, cannula design, and overall assessment of hemodynamic performance and cellular biocompatibility.

Pre-clinical testing of the current PediaFlow prototype ventricular assist device (the smallest mag lev blood pump to date, the size of an AA cell battery) was performed in vitro and in vivo. Our most recent 60-day implant demonstrated very low levels of both hemolysis and platelet activation. No thrombi were noted on explant, further validating the excellent biocompatibility of the PediaFlow pediatric VAD in anticipation of eventual clinical trial testing.
Brown Laboratory

The Brown Laboratory is an interdisciplinary team housed within the McGowan Institute for Regenerative Medicine. The overarching mission of the Brown Laboratory is to couple a mechanistic understanding of the host inflammatory response in injury and disease with the development of context-dependent biomaterial-based strategies for tissue engineering and regenerative medicine. The focus of our current research is upon clinical applications where few effective solutions currently exist, with increasing emphasis upon unmet clinical needs in women’s health.

Our laboratory is highly collaborative within the University of Pittsburgh, the University of Pittsburgh Medical Center, the McGowan Institute for Regenerative Medicine as well as a number of outside collaborations spanning basic science, engineering, medical and veterinary disciplines. Most of the ongoing projects within the Brown Laboratory combine basic science and immunology with engineering concepts towards the design, evaluation, and implementation of biomaterials in tissue engineering and regenerative medicine applications.

Under the direction of Dr. Bryan Brown consists of approximately eight undergraduate students, six graduate students, two postdoctoral associates, a laboratory technician, and administrative staff. In addition, it is common to have one or more clinician-surgeons or veterinarian involved with each ongoing project. The capabilities of the Brown Laboratory span a full spectrum of bench-top science and pre-clinical models and we can support first-in-human and clinical studies through collaborations with the University of Pittsburgh Medical Center.

Major Research Interests

- Macrophage Phenotype and Polarization
- Host Response to Biomaterials
- Extracellular Matrix Biomaterials
- Injectable Hydrogels
- Biomaterials Development
- Tissue Engineering
- Regenerative Medicine
- Stem Cells
- Preclinical Disease Models
- Women’s Health
- Veterinary Medicine
- Clinical/Commercial Translation

Active Research Projects

- Assessment of the host response following mesh placement in pelvic organ prolapse
- Investigation of macrophage phenotype in pathogenesis of endometriosis
- Macrophage polarization and aging in the context of regenerative medicine
- A regenerative medicine approach to TMJ meniscus restoration
- Development of tissue specific hydrogels for peripheral nerve reconstruction
- Exploratory study of the application of regenerative medicine to the equine airway
Background and Research Overview

Dr. Cham holds a B.Sc. degree and an M.Sc. degree in Physics from McGill University. Her doctoral training is in Bioengineering from the University of Pittsburgh. Dr. Cham’s interests are focused on understanding (1) underlying biomechanical mechanisms of falls, e.g. postural strategies generated in response to slips and trips, and (2) human (e.g. sensory deficits, central nervous impairments) and environmental (e.g. lighting) factors contributing to balance and gait impairments. Her populations of interest include young and older healthy adults, as well as clinical populations such as individuals with autism, neurological conditions and vision-related conditions, e.g. glaucoma, age-related macular degeneration. Dr. Cham’s research is supported by the National Institutes of Health (NIH), the National Institute of Occupational Safety and Health (NIOSH), industry and various foundations. Her collaborations with scientists from a very wide range of disciplines at the University of Pittsburgh and across other academic institutions are a key component of her research.

Examples of Ongoing Research Projects

Anthropometry

Body segment parameters (e.g. segment mass, center of mass location) are needed in many applications, including ergonomics and occupational biomechanics. They are also needed in biomechanical models to study joint loading during various tasks, gait and more. In this project, imaging methods are used (1) to assess the impact of body shape, specifically being obese or overweight, on body segment parameters in men and women, and (2) to develop regression models that accurately predict these variables.

Autism

The goal of this project is to determine the reasons for balance and gait impairments in Autism Spectrum Disorders (ASD). We focus on the relationship between these impairments and attention. Experiments involve adults with autism and control subjects standing and walking in challenging environments (dimmed lighting and/or walking on a soft carpet) while performing a secondary task (pushing a button when hearing an auditory stimulus). Findings will enhance our understanding of gross motor impairments and balance difficulties in ASD, both of which may contribute to the development of novel and more effective therapeutic approaches.

Vision Impairments

Visual field losses are a common type of vision impairment found in age-related ocular pathologies such as glaucoma and age-related macular degeneration. Falls are a serious public health concern in adults who have such conditions. One of Dr. Cham’s project is to determine the impact of visual field losses on balance and gait. Findings will improve our understanding of the etiology of falls in older adults who have vision problems. Another related project of Dr. Cham and her collaborators is to develop standard methods that evaluate the efficacy and quality of emerging technologies and therapies on patients’ lives with vision-related conditions.
Dr. April J. Chambers is a Research Assistant Professor of Bioengineering at the University of Pittsburgh. She received her PhD in Bioengineering from the University of Pittsburgh in 2011. Dr. Chambers is a bioengineer with research expertise in the fields of gait biomechanics and fall prevention. Dr. Chambers serves as the Laboratory Director of the Human Movement and Balance Laboratory. The overall goal of her research is musculoskeletal injury prevention and improving quality of life. Dr. Chambers’ research interests include occupational biomechanics and injury prevention in healthy and special populations, as well as medical device design and translational research.

Dr. Chambers’ Background and Research Interests

Dr. Chambers is currently working on projects that examine musculoskeletal injury risk during long term standing. The goal of her research is to investigate the impact of prolonged standing on in vivo changes in articular cartilage deformation within the knee joint and lower extremity muscle characteristics. A second objective is to investigate the impact of human and environmental factors on these effects. Dr. Chambers uses novel and innovative methodologies to assess the effect of prolonged standing on measures of joint and muscle injury risk. Dr. Chambers’ research and advanced training uniquely position her to conduct research incorporating new methods, not traditionally used in ergonomics, of evaluating injury risk and developing more effective interventions to reduce musculoskeletal injuries in the workplace.

Dr. Chambers enjoys collaborating with a multidisciplinary group of researchers including biomechanical engineers, physicians, physical/occupational therapists, and exercise scientist to achieve her research goals. Additional research projects include a wide range of experimental studies examining fall prevention following external disturbances such as slipping or tripping, ergonomics and human factors, medical device design, and special populations including amputees, obese adults and the elderly. Dr. Chambers collects her data at the Human Movement and Balance Laboratories. These are state of the art facilities designed and equipped to analyze the dynamics of human motion and human factors during standing, walking, balance perturbations, activities of daily living and occupational tasks.
Research Description

Research projects are being conducted in the following areas: (1) Neural Electrode Device / Tissue Interface – Implantable neural electrode arrays elicit inflammatory tissue responses that lead to performance failure. We study the interaction between implanted material and neural tissue and develop multifunctional smart biomaterial to improve the electrode/host tissue interface. Approaches include biomimetic coating, controlled release of soluble drug and growth factors and stem cell seeding. (2) Control of Embryonic and Neural Stem Cell Growth and Differentiation via Surface Characteristics and Electrical Stimulation - Majority of the stem cell studies focus on the effect of soluble factors on stem cell behavior. We are interested in whether surface cues and electrical stimulation can guide the growth and differentiation of stem cells. The findings will provide design ideas for tissue engineering and regenerative medicine on how to direct the stem cell fate for functional integration into the host nervous system. (3) Cultured Neuronal Networks – An in vitro multi-electrode array system is established in the lab to answer neuroscience questions on how neuronal networks communicate or mature. Furthermore, we can build in vitro disease or injury models and use the model to screen therapeutic agents. (4) Neural Chemical Delivery and Sensing. Instead of establishing an electrical interface with host neurons, we are developing micro and nanotechnologies to chemically interface with them via delivery of neurotransmitters and modulators as well as detecting endogenous neurochemicals. These will be great tools for neuroscience research and can potentially be used as neuroprostheses alone or in conjunction with electrical neural interfacing devices.

By surface immobilization of biomolecules on the implant we seek to control the cellular interaction and promote intimate integration of the implant and neural tissue with the ultimate goal of reliable and stable long term neural recording or stimulation.

Expertise and Facilities

The NTE Lab has team with a multidisciplinary expertise ranging from polymer chemistry, electrochemistry, biomaterial and biocompatibility, microfabrication, molecular and cellular neurobiology to neural recording, stimulation and biological imaging. Our facility is equipped with wet lab material synthesis, electrochemical set up, in vitro cell culture, basic histological tissue processing and staining, small animal stereotaxic surgery, optical and fluorescent microscopy as well as electrophysiology.
Research Interests

Dr. Datta’s current research is focused on two broad areas of biodegradable biomaterials, and energy harvesting and storage. He has a strong solid background in Metallurgical Engineering (PhD), Materials Engineering (MS), as well as Nanotechnology along with a thorough understanding of Physical chemistry and various electrochemistry aspects of solid-state materials. His group mainly conducts fundamental, transformative and innovative biomaterials and energy related research in collaboration with Dr. Kumta, Dr. Roy, Dr. Jampani and Dr. Velikokhatnyi directed at fostering clean energy, regenerative therapies, national security and human welfare. The main focus of Dr. Datta’s research in all of these areas is to develop (a) rapid experimental synthesis and processing tools; quantitative analytical and characterization tools; accelerated testing and rapid prototyping; techniques to validate and advance materials theory and (b) computational tools for predictive modeling, exploration, simulation and design.

Biodegradable Biomaterials Related Research

In the area of biomaterials, Dr. Datta’s group’s goal is to create implantable devices and regenerative therapies by merging advances in biology, engineering, and materials sciences. Particularly, he aims to develop materials that will not only be compatible with patients, but can also direct the cellular responses of the patient in a desired manner. In this direction, his research is directed in identifying a novel class of suitable load bearing, non-toxic biocompatible and biodegradable metal alloys aided by density functional theory (DFT) calculations as a hard tissue substitute for orthopedic and craniofacial applications. Processing of near-net shape biocompatible and biodegradable porous 3D scaffolds exhibiting controlled corrosion and mechanical properties mimicking normal bone without eliciting any toxicity while regenerating new bone is under research and development by powder metallurgy (PM) and additive manufacturing (AM) processing techniques. In addition, Dr. Datta’s research has directed towards development and optimization of stable organic and inorganic bioactive coatings on implants to decrease the alloys’ corrosion rate and hydrogen evolution as well as increase the alloys’ surface bioactivity, thus increasing the clinical relevance of biodegradable alloys. Surface functionalized micro- and meso-porous bio-composites is also under study for tunable delivery of biologics and drugs from the regenerative bone scaffolds.

Energy Harvesting and Storage Related Research

The ultimate vision of energy related research is the development of a coherent computational model and concomitant advanced experimental tools enabling rapid screening, development and manufacturing of advanced energy related materials with significant cost benefits. His group focuses on identification of ultra-low noble metal/non-noble metal electrocatalysts for water electrolysis, fuel cell and air battery, and carbon capture through CO₂ conversion to fuel. In the field of electrical energy storage technologies based on rechargeable batteries (Li-ion, Na- ion, Mg- ion batteries), supercapacitor and flow batteries, his research is directed at fulfilling the vision for meeting the EV(electric vehicle) everywhere grand challenge and Renewable Energy Storage goal of DOE. In this direction, his research is focused on rapid synthesis and advanced characterization of next-generation energy related materials in 1D nanotube, nanowire, 2D nono-film, nano-sheet or 3D hierarchical structures consisting of nanoparticles or nanocomposite.

Research and development of electricity as electric vehicle fuel
Mechanics of Morphogenesis

Our group has two long-term objectives: (1) to understand the mechanical processes that control morphogenesis, and (2) to apply principles of morphogenesis as a technology to advance cell and tissue engineering.

Morphogenesis is the central process of tissue self-assembly that couples physical processes that move cells and tissues with the biological processes that give cells their identity, establish tissue architecture and physiological function. By necessity our research lies at the interface between cell biology, mathematics, physics, and engineering. Projects typically involve overlapping expertise that combine cell biological, biophysical, and bioengineering methods.

The Biomechanics of Tissue Elongation

The elongation of the vertebrate body, from head to tail, during early development and the elongation of structures such as long bones during growth are driven by collective cell rearrangement of mesenchymal cells. Our research has uncovered hidden mechanical phenotypes where losses in force production can be compensated by reduced mechanical resistance. Genetic and cell signaling control actomyosin complexes responsible for the mechanics of early embryonic tissues but their spatial organization is regulated by cell geometry and architectural features of the embryo. Our studies in this area require development of microscale mechanical testing, high resolution confocal imaging, and theoretical and computational modeling. Discoveries from this project have provided novel insights into integration of genetic and mechanical programs of development and how these systems are robust against the variation in their environment.

Cardiac Progenitors Sense Mechanical Cues as they Assemble the Heart

The heart is assembled from cells that migrate halfway across the early embryo. As these cells migrate they take instruction from their surroundings, either through chemical signaling or through mechanical cues. These cues drive cells to transition from one type to another. Recently, we have found a fundamental transition, that converts cells from a loose mass to a structured sheet, requires cells sense their mechanical environment. An altered environment, leading to delayed or precocious transitions during these early stages, produce commonly seen structural defects analogous to those seen in human congenital heart defects.

Advancing Cell and Tissue Engineering

In these projects we seek to actuate morphogenetic programs within engineered microenvironments to achieve specific end-points. For instance, using 3D microfabricated structures to direct either single cell or collective migration within tissues. We utilize additive and subtractive manufacturing and scaffold-free engineering to enhance ‘organs-in-a-dish’ and ‘organs-on-a-dish’ applications. We develop microfluidic tools in order to control the local biochemical microenvironment enabling high spatial and temporal resolution actuation to be combined with rapid non-invasive interrogation by live-cell reporters.
Dr. Debski’s Background and Research Interests

Richard E. Debski, PhD received both his B.S. (1991) and PhD (1997) in Mechanical Engineering from the University of Pittsburgh. Dr. Debski’s research interests focus on orthopaedic biomechanics and are aimed at elucidating the contribution of ligaments, tendons, muscles, and bone to joint stability throughout the musculoskeletal system. Specifically, experimental and computational analyses are performed to examine the properties of the ligaments and joint capsules; determine ligament forces and joint kinematics; and evaluate the effect of injuries and repair procedures on joint motion. Novel experimental techniques such as a robotic testing system and Dynamic Shoulder Testing Apparatus rev.4 are utilized to answer research questions. Recent major projects have focused on improvement of diagnoses and repair procedures for injuries to the ligaments, capsules, and bony structures at the shoulder; improvement of rehabilitation for rotator cuff injuries; quantification of knee stability during the pivot shift test; and robotic technology for biomechanical testing.

Orthopaedic Robotics Laboratory

The mission of the Orthopaedic Robotics Laboratory is the prevention of degenerative joint disease by improving diagnostic, repair, and rehabilitation procedures for musculoskeletal injuries using state-of-the-art robotic technology. Thus, diarthrodial joint function will be elucidated and the roles of the bony and soft tissues assessed. The technology in the laboratory includes novel robotic systems and the lab serves as a multi-disciplinary CORE facility with collaboration promoted between investigators. The Orthopaedic Robotics Laboratory is a collaboration between the Department of Orthopaedic Surgery and Department of Bioengineering.
Under the direction of Dr. William Federspiel, the Medical Devices Laboratory is developing highly translatable medical devices by utilizing bio and chemical engineering principles such as biotransport, mass transfer, and fluid mechanics. Advanced respiratory assist devices for patients with acute and chronic lung injuries are being designed and investigated, in addition to particle-based adsorption technologies for the removal of targeted solutes from whole blood for the treatment of pathogenic reactions. Biotransport modeling, computational fluid dynamics, and in vitro and in vivo testing are employed in the development of these medical devices. The highly collaborative research efforts of the Medical Devices Laboratory combine the expertise and strengths of academic researchers, clinicians, and industrial partners. Translation of research into formal product development and clinical trials is a primary focus of the laboratory so that the technological advancements can benefit those in need.

**Respiratory Assist Devices**

Each year nearly 350,000 Americans die of some form of lung disease. To address the limitations of existing methods of respiratory support, such as mechanical ventilation (MV) and extracorporeal membrane oxygenation (ECMO), the Medical Devices Lab is developing respiratory assist devices that could provide improved treatment. The Modular Extracorporeal Lung (ModEL) integrates a blood pump and highly efficient gas exchanging unit into a wearable device intended to replace ECMO and MV as a bridge to transplant or recovery during lung failure. The modular design enables configuration of the device with different gas-exchanging units depending on the type of support needed, resulting in a respiratory assist platform technology able to treat a variety of adult, and even pediatric, patients. Prior work in this area within the Medical Devices Lab led to the commercialization and market approval of the Hemolung Respiratory Assist System, a product of ALung Technologies. Development of novel bioactive coatings to improve device efficiency and hemocompatibility is also a focus of the Medical Devices Lab. Current efforts focus on the use of zwitterionic copolymers to reduce intra-device thrombus formation and carbonic anhydrase to enhance CO₂ removal efficiency.

**Blood Conditioning Devices**

Sepsis, a systemic inflammatory response due to an infection, is a major health problem that kills nearly 250,000 Americans each year and costs upwards of $20 billion annually. The Medical Devices Lab is designing novel extracorporeal blood purification devices to reduce organ damage in sepsis. These devices alter leukocyte response by selectively removing excess cytokines from circulation or ‘reprogramming’ immune cell behavior through cell-cell interactions. These treatments are hypothesized to both improve clearance of infection and reduce injury to remote organs. A device which removes blood antibodies to generate universal donor plasma is also under development. After treatment, the universal plasma can be safely transfused to all patients, regardless of blood type.
The nervous system continuously monitors the environment and produces overt or covert orienting behavior in response to relevant sensory stimulation. Research in the Cognition and Sensorimotor Integration (CSI) lab investigates neural mechanisms involved in the multiple facets of sensory-to-motor transformations, including cognitive processes. We employ a combination of experimental (extracellular recording, microstimulation, chemical microinjections, transient blink perturbation) and computational tools. An understanding of the cognitive and motoric processes that produce integrated orienting behavior has implications for neural prostheses as well as diagnostic value for deficits resulting from neuropsychiatric disorders (e.g., ADHD, schizophrenia) and ocular dysmotility (e.g., strabismus).

Neural Coding through Population Dynamics

The instantaneous firing rate of individual neurons has traditionally been assumed to be the primary neural correlate of sensory, cognitive, and motor processes. Although this so-called rate code can explain a number of perceptual and behavioral phenomena, it falls short in other instances. One of the research directions in the CSI lab involves considering alternatives to standard rate-based coding. This requires zooming out to the systems level and studying the dynamics of activity in a network or population of neurons. Using pooled single-unit recordings, we have found that the temporal structure of population activity fluctuates in the visual burst but remains stable in the motor burst of visuomovement neurons, specifying a code to distinguish between incoming sensory output and premotor output. We plan to further explore the role of the population temporal code in sensorimotor integration using multi-electrode techniques as well as testing the robustness of the code using computational modelling.

Interception of Moving Stimulus

While navigating through their local environment, primates combine rapid (saccadic) and slow (pursuit) voluntary eye movements in an effort to gather visual information from stationary and moving objects. Throughout much of the twentieth century, these eye movements were mostly studied in isolation; however, recent experiments in several laboratories have shown that their neural substrates may overlap significantly. Future experiments in our laboratory will combine behavioral, neurophysiological, and computational techniques to compare the role(s) of the cortex, superior colliculus and oculomotor brainstem in the planning and execution of saccades to both static and moving stimuli. Basic knowledge gathered from these experiments will allow us to test specific hypotheses concerning the role of these structures in the maintenance of saccade accuracy and precision to both static and moving targets as well as the selection of targets in more complex environments.
Research Interests

Dr. Hirschman's primary interest is in the application of technology to translational medicine and medical product innovation. He has been instrumental in the development of a Professional Master of Science in Bioengineering oriented toward Medical Product Engineering. This work also recently resulted in the Provost's approval of a Professional Certificate in Medical Product Innovation offered through the Swanson School of Engineering. He has developed several courses (Medical Product Ideation, Medical Product Development) to help train future product developers, managers, entrepreneurs, and investors in the medical product domain.

As Executive Director of the Center for Medical Innovation at the Swanson School of Engineering since 2011, Dr. Hirschman is responsible for tactical and strategic direction. His work is focused on matching physicians with engineers and students in SSOE to create funded project teams focused on the advancement of technologies into clinical practice. Also, as a former executive at Bayer (MEDRAD® division), Dr. Hirschman is interested in bringing best industry practices to the new innovation and entrepreneurship efforts underway at the University of Pittsburgh.

Biographical Highlights

Dr. Hirschman came to the University of Pittsburgh in 2010 as a visiting professor in the Department of Bioengineering. In 2013 he received a full appointment as Professor of Bioengineering. Most of his career (30+ years) was in the medical device industry as an inventor, biomedical product development engineer, business development professional and corporate executive. Earlier in his career he worked as a research physicist and electrical/computer engineer. Dr. Hirschman earned his PhD in Electrical Engineering from Carnegie Mellon University and a Bachelor’s in Physics from New York University. He is a Fellow of AIMBE and a Life Member of the IEEE.
Ultrahigh Field Neuro and Extremity MRI at the Highest Resolutions

Ultrahigh (≥ 7) Tesla (T) field magnetic resonance imaging (MRI) have been growing at considerable rate over the last decade. More than 60 7T and higher human scanners are currently or expected to be operational. Images obtained using 7T MRI systems have shown tremendous research potential including the ability to visualize microvasculatures at super high resolutions. Using Pitt’s state of the art 7T human MRI system which equipped with parallel transmit system, Dr. Ibrahim’s RF Research Facility has recently developed an RF coil system that consists of 20-Ch transmit array with 32-Ch receive insert 7T Neuro Studies (see above) The coil system addresses electromagnetic inhomogeneity and heating issues associated with 7T MRI. The coil system is subject-insensitive and does not require tuning or matching for different patients. The coil system is capable of producing 0.2mmx0.2mmx1.5mm as well as isotropic (0.45mm)3 in-vivo human images in a reasonable scan time with excellent contrast and SNR. Due to its design, the coil system operates one specific 3D shimmed homogenous mode without the need to adjust for different patients. In addition, we also performs wide variety of very high resolution 7T extremity imaging using custom-made RF Coil systems designed and constructed in our lab. The 3D field homogeneity of RF coil system in human brain/cerebellum represents one of the most homogenous performances for 7T imaging and is currently being utilized in studies and patients population such as Alzheimer’s, Mild Cognitive Impairment, Dementia, Sickle Cell, Schizophrenia and arm-transplanted patients.

Electromagnetic Interactions with Biological tissues

Using in-house developed proprietary electromagnetic simulation software, the RF Research Facility studies the interaction of electromagnetic fields and biological tissues in many applications including brain machine interface and MRI.

Anatomically Detailed Electromagnetic Human Head Model & 3D-printed and compartmented equivalent prototype
Bio-Integrating Optoelectric Neural Interface & Cybernetics Lab

Our lab employs a highly transdisciplinary approach to understand interactions at micro-scale neural interfaces and to develop next-generation Neural Technologies that attenuate or reverse negative tissue interactions. Specifically, we focus on elucidating biological structures and biochemical pathways that control physiological function and bidirectional communication between the nervous system and neural interface technology. We then apply these newly discovered constraints and possibilities into designing novel technologies.

In order to elucidate real-time long-term cellular and molecular tissue interactions to chronically implanted medical devices, we employ in vivo functional electrophysiology, two-photon microscopy, electrochemistry, and electrical and optical stimulation techniques. In addition, we leverage principles in molecular and cellular neurobiology, electrical engineering, mechanical engineering, computer science, physics, biochemistry, material science, optics, and biomaterials. The availability of new optical methods to image brain function and new genetically engineered mice and rat models present a leading-edge opportunity to understand normal and pathological brain function in new ways with exquisite dynamic details.

These technologies allow us to advance our understanding of the brain and brain interfaces, as well as create new avenues for diagnosis and treatment of brain pathologies.

Current Research Projects

1. **Blood-brain barrier (BBB) dysfunction** plays an important role in cellular damage in neurological diseases and brain injuries. This project quantifies structural, cellular, and molecular level tissue response to chronic implants in the brain in real-time through combining multiphoton imaging technology and neural engineering technology.

2. **Microthread probes** are new classes of ultrasmall neural interfaces that uses leading-edge biocompatible polymers to develop innovative ‘microthread neural probes’ that are ultra-small and flexible, with bioactive surfaces and nanostructured electrode sites for enhanced signal transduction. We create these microthread probes using advanced carbon nanotube (CNT) and bioactive polymer coating technologies for chronic recording, chronic electrical stimulation, chronic wireless stimulation, chronic chemical sensing, and chronic wireless drug delivery.

3. **In vivo evoked two-photon imaging and electrophysiology.** Past studies characterizing the CNS response to implants have used postmortem histology at discrete time points. This approach suffers from a large degree of variability and fails to capture the dynamic molecular, cellular and vascular changes of the host. To address this issue, we have developed an experimental set-up to directly image the electrode-tissue interface in live animals using 2-photon microscopy in conjunction with evoked electrical recording (Visual and Somatosensory Cortex). We employ this experimental setup to rigorously characterize dynamic tissue changes that occur around neural camouflage coated devices and a variety of pharmaceutical and genetic intervention strategies.
Brief Biography of Dr. Prashant Kumta

Professor Kumta’s research interests cover two broad areas: energy storage, generation, conversion and biomaterials. He earned his Bachelor of Technology with Honors in metallurgical engineering from the Indian Institute of Technology, Bombay, India in 1984. He then earned his MS and PhD in Materials Science and Engineering from the University of Arizona in 1987 and 1990, respectively. After graduation, Professor Kumta joined the Department of Materials Science and Engineering at Carnegie Mellon University, where he was promoted to Full Professor with tenure in 1999. He joined the University of Pittsburgh in 2007, where he now manages a large group of researchers, research faculty (Dr. Datta, Dr. Roy, Dr. Velikokhatnyi and Dr. Jampani) and students. Professor Kumta is the author or co-author of more than 270 refereed journal publications and has given more than 460 conference presentations. He is currently the Editor-in-Chief of “Materials Science and Engineering: B, Advanced Functional Solid-State Materials,” an International Journal by Elsevier Publications.

Research in Biomaterials

In the biomaterials area, Professor Kumta’s group focuses on the creation of clinically relevant novel biomaterials for next-generation therapies in regenerative medicine. His group is also currently developing novel materials for craniofacial and orthopedic applications comprising new biodegradable metals and injectable calcium phosphate (CaP)-based resorbable bone cements and polymers for mineralized tissue regeneration and stem cell viability. Additive manufacturing techniques are also employed to generate user specific scaffolds using biocompatible and biodegradable metals and ceramics. Research is also on-going to understand the effects of morphology, and surface structures of CaP based nanoparticles for targeted and surface mediated non-viral gene delivery. Biodegradable stents and drug eluting coatings are also under development to prevent coronary and pediatric pulmonary arterial sclerosis, repair intracranial aneurysms, and fill atrial septal defects. Another area of biocompatible materials under development is the understanding of cell-surface interaction between organic and inorganic materials as well as generation of chemical and biosensors for detection of biomarkers for cardiovascular and traumatic brain injury related conditions.

His laboratories house a wide range of state-of-the-art equipment for materials synthesis and characterization, cell and tissue culture, and 3D printing of advanced materials and structures.

Research in Energy Storage

Professor Kumta’s research group is involved in the study of novel reversible lithium-ion, sodium-ion, and magnesium-ion batteries. These energy storage systems utilize myriad nanostructured configurations and architectures that can be synthesized at low-temperatures using innovative vapor, solid and liquid phase methods. Research is also being conducted to develop improved supercapacitors, photoelectrocatalysts for water splitting and hydrogen generation as well as electro-catalysts for low-temperature proton exchange membrane (PEM) based fuel cells. These technologies rely on nanostructured heterostructures and systems synthesized using indigenous low-temperature sol-gel and economic template approaches. His research also explores reduced noble metal containing electronically conductive and electrochemically stable catalysts for efficient hydrogen generation via acid based water electrolysis using density functional theory (DFT) based techniques.
BioSignal and Systems Analysis Laboratory

Many biological and biomedical signals and systems change over time (e.g., speech, hearing, vision, balance), and tracking these changes is important for disease monitoring and understanding the underlying physiological processes. The BioSignal and Systems Analysis Laboratory conducts research into multisensory integration and motor control, nonstationary signal processing, and the quantitative analysis and modeling of biomedical signals and systems. Specific activities include human postural control (Fig. 1); frequency tracking and instantaneous frequency estimation of biomedical signals such as gait and heart rate (Fig. 2); and developing sensory substitution modalities (e.g., vibrotactile feedback) to improve impaired sensorimotor function or for brain-machine interfaces (Fig. 3).

Fig. 1: Time-frequency analysis of human balance uncovers sensory adaptation [Peterka 2004, Mahboobin 2005].

Fig. 2: Frequency tracking of a noisy quasi-periodic signal.

Fig. 3: Subject performance in a control task with vibrotactile feedback [Quick 2014].

Selected Publications

- Quick et al., Assessing vibrotactile feedback strategies by controlling a cursor with unstable dynamics, IEEE EMBC, 2014.
- O’Connor et al., Postural adaptations to repeated optic flow stimulation in older adults, Gait & posture, 2008
- Mahboobin et al., A model-based approach to attention and sensory integration in postural control of older adults, Neuroscience letters, 2007
- Mahboobin et al., Sensory re-weighting in human postural control during moving-scene perturbations, Exp. Brain Research, 2005
- Peterka et al., Dynamic regulation of sensorimotor integration in human postural control, J. Neurophys., 2004
- Loughlin, Spectrographic measurement of instantaneous frequency and the time-dependent weighted average instantaneous frequency, J. Acoust. Soc. Amer., 1999

Principial Investigator Brief Biography

Patrick Loughlin earned a PhD in electrical engineering from the University of Washington, an MS in bioengineering from the University of Utah, and a BS in biomedical engineering from Boston University. He has been a faculty member at Pitt since 1993. Dr. Loughlin is a Member of the Editorial Board for the IEEE Transactions on Biomedical Engineering, and a Fellow of AIMBE, ASA and IEEE.
Primary research interest of our group lies in the predictive modeling and simulation of constitutive and failure response of complex materials. We study the evolution of these systems in a multi-physics environment at multiple spatial and temporal scales. A general objective of our research is to provide quantitative descriptions of the relationship between the measurable features of the microstructures of materials and their emergent macroscopic behavior. We employ a full suite of experimentally validated theoretical and numerical tools to achieve this feat. Our effort involves development of advanced theoretical techniques and numerical algorithms for materials modeling, and computational frameworks to conduct large-scale simulations in a massively parallel environment. While we develop new numerical techniques whenever necessary, the emphasis of our research is on investigating and predicting the physical aspects of complex materials behavior.

Currently our research activities span two application areas: A) Biomechanical behavior of soft tissues and B) electrochemical-mechanical response of advanced energy storage materials. Of special interest are the microstructural features and events that lead to loss of mechanical integrity of these materials systems. We envisage that our research effort will unlock fundamental mechanisms responsible for damage, tear, and ultimate failure of these complex materials subjected to not only normal, but also altered operating environment.

Mechanical Failure of Native Tissues

Clinical interventions resulting from biomechanical failure of soft fibrous tissues are common in occurrence. Yet, the microstructural mechanisms, associated biomechanical principles, and structure-property relationships mediating onset and propagation of tears in tissues remain elusive. Our research group focuses on two particular instances: dissection of aortic wall (left), and tear of rotator cuff tendon. Our computational modeling approach is based on characterization of microstructural features by appropriate computer representation of experimental images obtained from different microscopic modalities and integration of this microstructural information in computational models using fracture mechanics based numerical techniques, and large scale patient-specific simulations to predict progression of disease mediated by onset and progression of tear in relevant soft tissues. Our research is expected to yield mechanism-based information of early disease progression resulting in timely clinical intervention.

Mechanical Reliability of Energy Storage Materials

Alkali ion based rechargeable batteries (AIB) are currently at the forefront of electrical energy storage technologies. However, advanced electrode materials for AIBs (right) often suffer from mechanical reliability issues over repeated electrochemical charge and discharge cycles, hindering their commercial potential. Thus there is a critical need to tightly couple mechanical failure response of these materials with its electrochemical performance. Our research goal is to develop coupled multiphysics models for electrode materials linking atomistic scales to continuum, simulate their mechanical integrity under operating electrochemical conditions, and discover optimized material and morphology to meet specific performance goals. We develop a host of experimentally informed predictive modeling and simulation tools spanning multiple length and time scales to achieve this goal.
Actin Cytoskeleton in Health and Disease

Directed cell migration plays an important role in embryonic development, wound healing, angiogenesis, immune response, cancer invasion and metastasis. Dynamic reorganization of actin cytoskeleton, a key aspect of cell migration, is regulated by the concerted actions of various classes of actin-binding proteins (ABPs). Our overall research focus is studying the role of actin-cytoskeleton binding proteins in cell migration and other actin-dependent processes in physiology and pathology at the molecular levels. Specifically, we are aiming to 1) understand the role of cytoskeletal proteins in the regulation of tumor growth, invasion and dissemination, metastatic colonization, and chemotherapy response of cancer cells, 2) identify novel drugs that have potential to block specific steps of tumor metastasis using high-throughput/high-content screening strategies, 3) identify novel anti-angiogenic compounds, and 4) understand molecular regulation of key controllers of cell migration. Most of our current efforts are centered on profilin-1, a ubiquitously expressed actin-binding protein that is essential for embryonic development and a key molecular regulator for actin dynamics in cells.

Major techniques: protein biochemistry (immunoprecipitation, 2D gel electrophoresis), gene cloning, immunocyto/histochemistry, time-lapse imaging of cell migration and invasion, FRET, high-throughput high-content screening, mouse models of tumor progression (tumor xenograft, GEM), angiogenesis assays (in vitro, ex vivo and in vivo).

Selected Representative Publications:


Engineered Living Systems and Synthetic Biology Lab

The Engineered Living Systems and Synthetic Biology Lab focuses on applying synthetic biology constructs, methods, and paradigms to solve a range of medical, industrial, and environmental problems. Our mission includes both understanding the fundamental biology of natural bioprocessing systems as well as re-engineering these systems with synthetic control circuits. We have expertise in multiple fields including gene circuit engineering, cell physiology and biomechanics, microfluidics, MEMS, and biomaterials. The research team currently develops new approaches in synthetic biology and links these technologies with biomimetic systems that mimic cell, tissue, and organism physiology. Active research areas include: (1) creating synthetic control modules for 2nd-messenger signaling in neurons, (2) a living, bacterial microbiome for a biomimetic, robotic host, (3) artificial and engineered living microbiome constituents that deliver nutrients within organ-on-a-chip systems, (4) synthetically engineered cells that control material assembly, and (5) a biomimetic biofilm that combines microfluidics with synthetic biology to enable the discovery and monitoring of spatially segregated phenotypes within cell populations. These systems hold significant promise for both elucidating fundamental principles of physiology while also serving as new technologies for biomechanical engineering.

Biographical Highlights

Dr. Warren Ruder moved his research group to the University of Pittsburgh’s Bioengineering department in January of 2017. Previously, he spent four and half years as an assistant professor in Virginia Tech’s Biological Systems Engineering department, where he led the Engineered Living Systems Laboratory. His expertise is in synthetic biology, cellular and molecular biomechanics, and lab-on-a-chip systems. Dr. Ruder received his PhD in Biomedical Engineering and his M.S. in Mechanical Engineering from Carnegie Mellon University, and his B.S. in Civil and Environmental Engineering from MIT. From 2003-2005, he was a Health Science Specialist at the Veterans Affairs Boston Healthcare System and Harvard Medical School. From 2005-2009, Dr. Ruder was an inaugural NIH trainee in the Pitt-CMU Biomechanics in Regenerative Medicine program and a Dowd graduate fellow in the groups of Phil LeDuc and Jim Antaki. From 2010-2012, he was a postdoctoral research associate in the group of Jim Collins at Boston University (now at MIT), and Harvard University’s Wyss Institute for Biologically Inspired Engineering.
Simulation and Medical Technology Laboratory

The Sim|Med|Tech Lab is a multidisciplinary research, development and innovation center directed by Dr. Joseph Samosky. Our mission is to integrate design, engineering and clinical medicine to invent next-generation enabling technologies for simulation-based healthcare training and new “smart” medical devices. Our ultimate goals are improving patient care and enhancing patient safety. Simulation-based training in healthcare offers hands-on, experiential learning with objective feedback while not exposing real patients to risk during training. Just as flight simulation revolutionized crew training and dramatically improved safety in aviation, simulation-based experiences can promote learning and enable medical students, physicians, nurses and first responders to practice skills and receive quantitative feedback on their performance before treating actual patients. Our research centers on the development of both fundamental new enabling technologies and practical systems for healthcare simulation, the user-centric design of real-time interactions, sensors, advanced information displays, learner-adaptive feedback, and autonomous operation.

BodyExplorer Augmented Reality Simulator

BodyExplorer is a next-generation medical simulator designed to enhance the ability of healthcare trainees to learn anatomy, physiology and clinical procedures through naturalistic interaction with an augmented reality enhanced full-body simulated patient. BodyExplorer is designed to enable 24/7 on-demand training and self-learning for students by providing an intuitive interface, immediate feedback and automated instruction using a highly sensorized physical body, projected augmented reality (AR), and an integrated virtual instructor. AR enables “x-ray vision” views inside the body, enabling trainees to see the internal effects and consequences of their actions. We have developed novel sensor systems for common clinical procedures such as identifying injected drugs and sensing the depth of insertion of an endotracheal tube. Injection of cardioactive drug simulants, for example, results in automatic changes to heart rate, audible heart sounds and displayed ECG waveforms.

Laboratory Director Dr. Joseph Samosky

Dr. Samosky received his PhD in Medical Engineering from the Massachusetts Institute of Technology and the Harvard-MIT Division of Health Sciences and Technology. He received his MS in Electrical Engineering and Computer Science from MIT, and his BS in Behavioral Neuroscience and BSE in Electrical Engineering from the University of Pittsburgh. His work has been recognized with the first-place award for technology innovation at the International Meeting on Simulation in Healthcare, a Coulter Translational Research Award, and exhibition at the ACCELERATE Creativity and Innovation Festival at the Smithsonian Institution. Dr. Samosky is an enthusiastic advocate of experiential learning, design thinking and project-based, hands-on engineering education. He has mentored over 150 bioengineering students in senior design projects and also teaches in the Department of Bioengineering’s Medical Product Innovation graduate program.
Cardiovascular Systems Laboratory

Our research interests are focused on three areas: (1) Relationships between left ventricular mechano-energetic function and underlying cellular processes, with a special emphasis on contractile and regulatory proteins and post-translational regulation of cardiac contraction (e.g., via phosphorylation or acetylation). Whole heart, isolated muscle (intact and detergent-skinned), and single cell experiments are performed using various animal models, including transgenic mice. (2) The role of pulsatile arterial load (vascular stiffness in particular) in cardiovascular function and potential therapeutic applications of vascular stiffness-modifying drugs and/or hormones (e.g., relaxin). Novel noninvasive measurement techniques are used to conduct longitudinal human studies, which are complemented by in vivo and in vitro vascular and cardiac studies with animal models. (3) The role of regional contraction dyssynchrony in global ventricular mechanics and energetics. In addition to basic research, we work on developing novel mathematical models of biological systems for scientific inquiry, education, and engineering design. Two ongoing research projects are described below.

Post-translational Regulation of Cardiac Muscle Contraction

Phosphorylation-mediated regulation of cardiac muscle contraction has been studied extensively. Our group has been focusing on cardiac Troponin I (cTnI), especially the effects of PKA- vs. PKC-mediated cTnI phosphorylation on cardiac contraction under normal and pathological conditions. In collaboration with the Gupta laboratory (University of Chicago), we discovered a completely new post-translational modification, myofilament protein acetylation, that can regulate cardiac muscle contraction as potently as phosphorylation (acetylation → myofilament calcium sensitivity for force generation). Experiments are currently underway to determine the biophysical mechanisms responsible for this novel contractile regulation and to examine its physiological significance under in vivo conditions. This basic science information regarding the post-translational regulation of contraction is being used to develop novel inotropic therapies.

Role of Relaxin in the Cardiovascular System

Our group has been working on examining the role of relaxin, traditionally considered to be a pregnancy-associated hormone, in the cardiovascular system. We have shown that exogenous relaxin administration produces significant vasodilation (systemic vascular resistance) and vasorelaxation (global arterial compliance) in both male and female animals. Furthermore, relaxin-1 and its receptor mRNA are expressed in vascular tissues obtained from various mammals of both sexes, leading us to propose that the relaxin ligand-receptor system acts locally to regulate arterial function and the loss of one or both of these components may form the molecular basis of vascular aging. We and others have shown that relaxin is a potent anti-fibrotic agent. In collaboration with the Salama laboratory (University of Pittsburgh), we recently showed that relaxin administration completely suppressed induced atrial fibrillation in aged spontaneously hypertensive rats and both the reversal of myocardial fibrosis and an increase in myocyte sodium current contributed to this suppression. Current studies are aimed at further examining the therapeutic potential of relaxin in fibrosis-associated cardiovascular diseases (e.g., diastolic heart failure, atrial fibrillation).

Primary Research Areas

The Visualization and Image Analysis (VIA) Laboratory, directed by George Stetten, MD, PhD, is developing new methods of displaying and analyzing images, primarily for medical applications. We have introduced a new device called the Sonic Flashlight™ for guiding invasive medical procedures by placing ultrasound images directly within the patient (see top figure below), so that the clinician can see the internal anatomy in-situ, visually fused with the external anatomy and the surgical tool. After extensive development and successful testing in patients for the placement of catheters in the deep veins of the arm, we are currently looking for partners to commercialize the technology based on issued US and foreign patents to the University of Pittsburgh. With more than a decade of continuous funding from the NIH, we have extended the approach to holography-based displays and are currently developing a similar in-situ image guidance system to display optical coherence tomography under the surgical microscope to guide eye surgery. We are also developing a system called ProbeSight, using video cameras mounted on the ultrasound transducer to incorporate visual information from the surface of the patient with the ultrasound data for better anatomical localization.

Most recently, we are developing a new type of surgical tool, the Hand-Held Force Magnifier, which provides a magnified sense of force at the tip of the tool for microsurgery (lower figure), by actively pushing or pulling on the handle of the tool relative to a brace attached to the back of the hand. Other projects include FingerSight™ to allow visually impaired individuals to sense the visual world with their fingertip, as well as automated image analysis systems for 2D and 3D medical images.

Further Research and Background

George Stetten earned an A.B. in Engineering and Applied Physics from Harvard in 1976, an M.S. in Biology from NYU in 1986, an MD from the SUNY Syracuse in 1991, and a PhD in Biomedical Engineering from UNC, Chapel Hill in 1999. Dr. Stetten wrote the software for the first computer system onboard Deep Submersible Alvin at the Woods Hole Oceanographic Institute and designed a telemetric egg to study incubation of endangered birds at the Bronx Zoo that was nominated for the 1992 Discover Magazine Award for Technological Innovation. He conducted the first full-scale classroom in which laptop computers were networked wirelessly in 1994, helped develop the first Real-Time 3D ultrasound scanner, and was a founding contributor to the National Library of Medicine Insight Toolkit for image analysis (ITK). He received the 2004 Chancellor’s Distinguished Research Award in the Junior Scholar category from the University of Pittsburgh and is a fellow of the American Institute for Medical and Biological Engineering. Dr. Stetten is currently Professor in Bioengineering at the University of Pittsburgh and a Research Professor at the Robotics Institute at CMU, with courtesy appointments in Radiology at the University of Pittsburgh and Biomedical Engineering at CMU. He served as Co-Director of the CMU/Pitt Medical Scientist Training Program from 2007-2011. He is the founding director of the new Music Engineering Laboratory (MEL) in the School of Engineering.
We investigate the ability of the human motor system to adapt walking patterns and learn new movements upon sustained changes in the environment. I am interested in improving the gait of patients with unilateral cortical lesions, such as stroke. To this end, I also study how to stimulate learning mechanisms in post-stroke survivors via locomotor adaptation paradigms. I particularly focus on investigating 1) the adaptability of muscle coordination in patients and healthy subjects when they experience novel walking conditions, 2) the functional consequences (i.e., biomechanical changes) of the adapted muscle activity, and 3) the generalization of adaptation effects from treadmill walking to over ground locomotor movements. To attain these goals, I am an expert in quantifying human motor behavior through kinematic, kinetic and muscle activity recordings. I also understand how to design adequate psychophysical experiments to observe the adaptation of locomotion in human subjects with and without neurological disorders. Three ongoing research projects are described below.

**Development of Personalized Gait Rehabilitation Post-stroke**

A major challenge in physical rehabilitation is developing treatments that are both effective and efficient. Most physical treatments follow a general protocol for all patients, but often do not achieve similar positive results. It is well accepted that personalized treatments would improve clinical outcomes. However, current standard measures are frequently insensitive to detect individual variations across patients. Thus, sensitive measures to patient-specific impairments are needed to customize treatments accordingly. In this project we have two main goals: 1) to examine patient-specific deficits leading to step asymmetry during gait in individuals with stroke, and 2) to develop strategies to specifically target these deficits. To this end, we developed an analytical model and an innovative experimental approach to evaluate what patient-specific deficits underlie step asymmetry post-stroke. Based on this information we target asymmetries specific to each patient. These are key steps towards developing personalized gait rehabilitation after stroke.

**Understanding Generalization of Locomotor Learning**

A primary issue in rehabilitation robotics is the fact that devices like exoskeletons and treadmills correct patients’ movements while using the device but not without them. Several clinical trials have reported limited efficacy of robotic aid in gait rehabilitation -possibly because patients cannot improve their mobility during ‘real-life’ situations off of the training devices. To address this challenge our objective is to identify key factors that regulate the generalization of locomotor learning after stroke. Our rationale is that once factors mediating the generalization of learning are identified, they could be harnessed to develop interventions that would improve the mobility of stroke survivors beyond the clinical setting. In these projects we use a computational framework and experimental approaches that analyze step-to-step changes when subjects transition between treadmill and overground walking. Our results allow us to generate predictions on how to train patients to maximize the positive effects of treadmill-assisted learning to real-life situations.
**Soft Tissue Biomechanics Laboratory**

The primary goal of the Soft Tissue Biomechanics Laboratory (STBL) is to develop and utilize novel experimental and computational bioengineering approaches to study the structure function relationships of soft tissues in human growth, remodeling, and disease. These relationships are then used to develop and fabricate the next generation of novel endovascular medical devices and bioactive drug therapies.

The STBL achieves this goal by seamlessly bringing together state-of-the-art techniques in tissue characterization, device fabrication, nonlinear optical microscopy, finite element modeling, and cell mechanobiology. This multifaceted approach allows members of the STBL and its interdisciplinary collaborators to expedite the mechanistic understanding and therapeutic treatment of human disease.

**Current Active Projects**

- Assessing the role of the extracellular matrix and cell mechanobiology in primary open angle glaucoma
- Development of a functional biopolymer-based compliance matched tissue engineered vascular graft using human tropoelastin and blood derived endothelial cells
- Assessing the role of aortic compliance in the onset of idiopathic vocal fold paralysis
- Experimental and computational optimization of patient specific endovascular medical devices
- Experimental, analytical, and computational modeling of the multiphasic and chemo-mechanically driven growth and remodeling of soft tissues
- Extracellular matrix remodeling of murine aneurysm
Vascular Bioengineering Laboratory Mission

Pathologies of the vascular system are tightly linked to biomechanical alteration of the vessel wall during disease. By applying our strengths in computational and experimental biomechanics, image analysis, cellular and molecular biology, and tissue engineering, our research mission is to develop regenerative treatments for vascular diseases such as aortic aneurysm and coronary heart disease. In addition to our research mission, we aim to train the researchers of tomorrow using the most cutting-edge technology available. Ongoing projects in the lab include:

- Assessing the mechanopathobiology of thoracic and abdominal aortic aneurysm
- Creating a novel regenerative therapy for abdominal aortic aneurysm
- Developing a human stem cell-based tissue engineered vascular graft
- Characterizing the biomechanics of cerebral aneurysms, including changes that occur with coil embolism therapy
- Using a novel ex-vivo perfusion system to simulate the biomechanical milieu of vascular diseases
- Extending our biomechanical analysis to other tubular structures such as the urinary tract, intestine, and esophagus

Our best assets for collaboration pertain to the thrusts of vascular biomechanics and vascular tissue engineering.

Vascular Biomechanics: Our group performs both experimental and computational biomechanics studies on tubular tissues; recent studies have focused on aneurysms of the aorta (thoracic and abdominal) and cerebral arteries but we also have experience with the ureter, esophagus, and intestine. On the experimental end, we perform extensive mechanical testing of tissues including tensile and compression tests, indentation tests, perfusion tests, and dynamic mechanical tests. Using mechanical properties determined from experimental testing we build strain energy function models of these tissues and computationally analyze the progression of degenerative disease. We also work with imaging collaborators at the School of Medicine to obtain structural information on human blood vessels; the geometries of these tissues have allowed us to computationally model stress distributions and develop rupture potential indices.

Vascular Tissue Engineering: Our group is developing an autologous tissue engineered vascular graft (TEVG) utilizing adipose-derived mesenchymal stem cells (AD-MSCs) seeded into tubular porous synthetic scaffolds. Utilizing our novel cell seeding device which applies rotation and vacuum to a lumenally infused cell suspension, we are able to seed our vascular grafts rapidly, evenly, and efficiently. Our TEVG has remained patent during rodent implantation, remodeling extensively in vivo towards a blood vessel-like architecture. A unique slant to our investigation in recent years has been testing AD-MSC from patients at high cardiovascular risk, such as diabetics and the elderly; determining if these patient populations will be suitable for autologous therapy will be critical in designing the next generation of vascular grafts.
Research in the Rehab Neural Engineering Lab

The Rehab Neural Engineering Lab is committed to advancing rehabilitation science and practice through scientific discovery and the development of new technologies for assisting and restoring sensory, motor, and autonomic functions after nervous system injury and limb loss. Central to this mission is the development of new strategies for interfacing directly with large population of motor and sensory neurons. In our lab, penetrating and non-penetrating arrays of microelectrodes are used to record or stimulate neuronal activity in the peripheral nerves and brain.

Research in the Rehab Neural Engineering Lab spans the continuum from basic science (neurophysiology studies of the somatosensory and motor systems) to highly applied (neural engineering projects with an eye towards clinical translation). Our goals are to:

- Understand how body-state information is encoded by sensory neurons (e.g. muscle length, bladder pressure)
- Understand the roles of somatosensory feedback in motor planning, control, and learning
- Develop new approaches to restoring function to paralyzed muscles via electrical stimulation of motor and sensory pathways
- Develop somatosensory neural prostheses to restore touch and proprioception

Current Projects in the Rehab Neural Engineering Lab

Reliable spinal nerve interfaces for sensorimotor neuroprostheses

The goals of this project are to develop scientific and technological solutions that will enable a high-performance, clinically viable system for interfacing directly with motor and sensory fiber tracts in the spinal nerves. The specific aims of this project are to 1) obtain reliable recordings of motor signals from ventral root nerves, 2) decode volitional command signals from the ventral root recordings, and 3) deliver sensory feedback through patterned microstimulation of sensory neurons in the dorsal root ganglia.

Multichannel microstimulation of primary afferent neurons to restore proprioception

The goal of this project is to develop a technique for providing proprioceptive sensations to users of prosthetic limbs via patterned electrical stimulation of sensory neurons in the dorsal root ganglia. This approach is similar, in principle, to that of the cochlear implant which uses patterned electrical stimulation of auditory nerves to restore hearing in people with profound deafness. The goals of the study are to 1) develop stimulation paradigms that can effectively deliver proprioceptive information to the brain, and 2) provide proprioceptive feedback that is useful for maintaining balance during postural perturbations.
Vascular ECM Dynamics Laboratory

Our laboratory uses a multidisciplinary approach. At the fundamental biological level, we are dedicated to understanding how the native extracellular matrix orchestrates tissue regeneration. As bioengineers, we use this information to innovate strategies to combat vascular disease. Our most recent work has focused on fabricating small-diameter vascular grafts and slowing the progression of abdominal aortic aneurysms.

Our primary areas of expertise are in extracellular matrix biology (particularly with respect to components of the elastic fiber and matricellular proteins), cell-matrix interactions, matrix modulation of growth-factor signaling, non-invasive reporters of matrix turnover, three-dimensional biological scaffolds, and vascular engineering.

Multiple opportunities for collaboration are available for future lines of research. Potential topics of interest include:

1) Designing novel degradable scaffolds functionalized with matricellular protein domains to guide the behavior of host cells (adhesion, migration, differentiation)

2) Using cellular “reporter” technologies to optimize ECM remodeling in the context of a dynamic chemical/mechanical environment (e.g. varying growth factors, stretching regimes)

3) Improving decellularization techniques to preserve an ECM rich in matricellular proteins; thereby enhancing downstream remodeling and recellularization

4) Establishing three-dimensional models for studying vascular physiology and pathology

5) Modulating growth factor activity in the context of wound healing to reduce scar formation

Selected Publications


Knee Joint Biomechanics & Robotics Laboratory
Tissue Mechanics Laboratory
Mechanobiology Laboratory

Dr. Savio L-Y. Woo is a Distinguished University Professor of Bioengineering and the Founding Director of the Musculoskeletal Research Center (MSRC), a diverse multidisciplinary research and educational center. Dr. Woo is a pioneer in bioengineering and is renowned for his 40+ years of translational research in healing and repair of tissues. Together with hundreds of students, resident, fellows and junior faculty member, the teams have published 320 original research papers in refereed journals as well as 146 book chapters and review articles. The outcome of their work has directly impacted the management of ligament and tendon injuries including clinical paradigm shifts that has led to significant improvement in patient outcome.

Currently, Dr. Woo’s research focuses on: 1) accurate measurement of the biomechanical properties of ligaments and tendons and in-vitro and in-vivo joint mechanics and function, and 2) using functional tissue engineering (FTE) strategies to biologically accelerate the healing and regeneration of ligaments and tendons. Dr. Woo is the inventor of the robotic/UFS testing system, or “Smart” Robot, to determine joint kinematics under unrestricted, multiple degrees-of-freedom (DOF) motion and in-situ forces of soft tissues and their replacements in a non-contact way. The system collects data of ligaments and their replacement grafts from the same specimen; thus eliminates interspecimen variations and increases statistical power (repeated measures ANOVA). This powerful apparatus has now been adopted by more than 30 other laboratories.

Dr. Woo has worked in collaboration at the Steadman Philippon Research Institute on using a bi-planar fluoroscopy system that can capture bone motions to within 0.2mm/0.2° accuracy. Thus, this new system can obtain in-vivo kinematic data to help characterize the function of the anterior cruciate ligament (ACL) and understand mechanisms of ACL injury that could lead to better ways for injury prevention.

More recently, Dr. Woo and his team are designing biodegradable and bioresorbable magnesium (Mg) devices. These devices can aid soft tissue (e.g. ACL) healing and then be programmed to degrade so that the healing tissue would take over the loads so that it could become better and stronger. The devices can also be used together with extracellular matrix scaffolds and hydrogels to further accelerate the healing process.

Selected Referenced Journal Articles


Our research group is organized around design and development of engineering strategies for next-generation therapy. On one hand we design engineering tools for stem cell based regenerative therapy. In parallel we develop systems level mechanistic models of cell signaling pathways for various disease models as well as to understand self-renewal and differentiation of pluripotent stem cells.

**Systems Analysis of Cell Signaling Pathways**

Cells sense and respond to their surrounding environment via cell signaling pathways, which is critical for their normal function. Deregulation of these pathways results in pathogenic conditions. Our goal is to develop experimentally verified mathematical models of the cell signaling pathways critical for the normal function of the cells, and identify specific deregulations resulting in pathogenic conditions. In particular we have developed mechanistic model of the PI3K/ AKT pathway driving self-renewal of human pluripotent stem cells and TGFβ pathway driving their endoderm specific differentiation. These two pathways have strong interactions between them, which we resolve using Boolean models and Dynamic Bayesian Networks.

During the process of differentiation the cell cycle behavior of stem cells also undergo a rapid dynamic transition. We use stochastic population models to track this dynamics of cell cycle transition from population level experimental data. This approach allows us to quantify the heterogeneity in the cell population, and the evolution of heterogeneity with differentiation.

**Engineering of Regenerative Organs**

Functional organs typically rely on the coordinated function of multiple organ specific cell populations. Supporting vasculature and mesenchyme are also known to be key contributors to proper organ function. Our goal is to engineer human pancreatic islets by reconstructing the islet’s native microenvironment. We are designing multi-component ‘organoid’ systems composed of stem cell derived pancreatic cell populations, engineered microvasculature, and supporting mesenchyme. The organoid spontaneously self-organizes on a designed hydrogel to synergize vascularization with islet maturation.

This platform allows us to closely capturing the intricate cooperative relationship between islet cell populations. We also design composite natural hydrogels to facilitate three dimensional culture and differentiation of stem cells. These scaffolds, derived from alginate, chitosan, fibrin, and native decellularized pancreas ECM provide physical cues to the encapsulated cells, along with enhancing the effect of soluble chemical cues. Cell-cell interactions established by the 3-D scaffolds along with cell-extracellular matrix interactions synergize towards enhanced functionality of the differentiated phenotype.
We are interested in molecular design and engineering, both for the creation of more sustainable chemical products and for applications that will improve health care outcomes. In the case of the former, we endeavor to employ life cycle impact analysis to examine current solutions to identify key environmental bottlenecks, hence allowing creation of more sustainable alternatives. Our ultimate goal is to fulfill the desired outcomes of the users of chemical technologies while reducing life cycle impacts across the board and thus avoiding the need to employ value judgments in a less-than-adequate way to deal with trade-offs.

In collaboration with Robert Enick’s group, we are designing molecules that allow replacement of water by liquid $\text{CO}_2$ in oil and gas production. Finally, we also employ molecular design to try to create products that improve healthcare outcomes. For example, tissue engineering work on lysine-based polyurethanes in our lab led directly to the creation of TissuGlu® surgical adhesive for use in eliminating the need for drains following flap surgery, as well as Sylys® surgical sealant for use in reducing anastomotic leakage following bowel surgery.

Life Cycle Analysis and Polymer Design

Bisphenol A has been identified as a possible endocrine disruptor, rendering the use of Bisphenol A polycarbonate (BAPC) in a number of human-contact applications suspect. At the same time, BAPC’s combination of transparency, high impact strength, and robustness at higher temperatures present high hurdles for competing materials. Eastman recently introduced a BPA-free copolyester designed to compete with BAPC, and we looked at its life cycle impacts.

Upon comparing the LCIA of the BAPC process tree (shown above) and that of the Tritan copolyester (partial life cycle shown to the left), we found a number of interesting facets. First, although the phosgene used to make BAPC has received most of the attention in previous green re-design schemes, it is the phenol that dominates the overall life cycle impacts. Further, the life cycle impacts of the Tritan copolymesters are generally lower than the analogous scores for BAPC. However, if one compares bottles manufactured from each of the materials, we found that 30% more polymer is used to create the Tritan containers, wiping out any environmental gains presented by the material itself.
High Pressure Phase Behavior and Viscosity Related to Enhanced Oil Recovery, Carbon Capture and Supercritical Fluid Technology

Our research lab focuses on the thermodynamic and transport properties of high pressure systems. For example, we are equipped with a high pressure (10,000 psi), low-high temperature (-4 to 356°F), windowed, agitated, invertible, variable-volume cell that allows direct observation of the phase behavior of gases, liquids and solids. This enables us to determine the optimal conditions for high pressure processes. For example, we can determine the pressure required for a solvent such as CO\textsubscript{2} or propane to become miscible with a crude oil, or what types of polymeric liquids are best suited for selectively capturing CO\textsubscript{2} from a high pressure that also contains water vapor and hydrogen, or the best temperature-pressure conditions needed to remove a contaminant from a commercial motor oil product using supercritical CO\textsubscript{2}.

Our lab is also equipped with the world’s highest temperature-pressure (500°F - 40000 psi) rolling ball viscometer, which is mounted on tilting tables. This apparatus allows us to precisely measure the viscosity of hydrocarbons (e.g. hexane, decane) at extreme conditions that are representative of those found in the deepest petroleum-producing formations in the world.

We also have a unique windowed, high pressure reactor equipped with a high speed (6000 rpm) emulsification mixer for particle/fluid processing studies.

Design of CO\textsubscript{2}-soluble and CO\textsubscript{2}-philic Compounds for Chemical and Petroleum Engineering Applications

Dr. Enick and Dr. Beckman have teamed together to design, synthesize, purify, characterize and evaluate novel compounds that have been engineered to improve the performance of high pressure CO\textsubscript{2}. For example, supercritical CO\textsubscript{2} (T > 88°F) is used extensively to recover crude oil from underground layers of porous sandstone or carbonate rock in the United States. Although CO\textsubscript{2} is a good solvent for oil recovery, its viscosity is so low that it tends to “fingerprint” from the injection well through the rock towards the producing wells, rather than uniformly sweeping the porous volume of the rock layer. Therefore Enick and Beckman are designing high molecular weight polymers and small associating molecules that can not only dissolve in dense CO\textsubscript{2}, but also (at very dilute concentrations of ~0.1wt%) increase the CO\textsubscript{2} viscosity to a value that is comparable to the oil viscosity.

Our lab has also identified and designed liquid polymeric solvents that can be used to selectively remove CO\textsubscript{2} (but not water vapor or hydrogen) from a high temperature, high pressure stream in an IGCC power plant (a novel high efficiency power plant). These polymers (e.g. silicone oil) interact favorably with CO\textsubscript{2}, but have little or no affinity for water or hydrogen.
Next-generation Electronics

The interplay between ions and electrons governs the performance of devices as ubiquitous as batteries, and processes as common as the biochemistry essential for life. The Fullerton lab uses the interplay between ions and electrons for the development of low-power logic and memory devices, and polymer electrolytes for energy storage.

Using Ions for More than Just Batteries

Transistors are the building blocks of all electronics. Since its first demonstration in the 1940s, the transistor has benefited from aggressive scaling down to 1000x its original size; however, this scaling is now reaching a fundamental limit. The semiconductor industry is seeking alternative materials and device concepts to push electronics to smaller geometries that are less power hungry. We are using new materials and completely new approaches to address this scaling challenge. For example, we combine two-dimensional (2D) semiconductors that are a single molecule thick with ions to replace three-dimensional silicon and its associated gate dielectric. Beyond scaling, ions can access regimes of transport in 2D materials that cannot be explored by conventional approaches. While many groups use ions as a tool to uncover new properties of 2D semiconductors, we ions as an active device component to impart completely new device functionalities. For example, we have invented a monolayer ion-conductor that introduces bi-stability for application as a flash memory (Xu, ACS Nano 2017). We’ve engineered the ion-conductor for application in tamper-resistant electronics (Kinder, ACS AMI 2017). Together with our collaborators, we are exploring the fundamental limits of speed (Li, J. Phys. Chem. C 2017) to make ultra-fast devices for neuromorphic computing.

For more information visit the Fullerton lab website at www.fullertonlab.pitt.edu and check out our 2017 publications:

- Subramaniana, et al., Carbon, 2017, 125, 551.

Outreach: Polymer Crystallization on Your iphone

The Fullerton group enjoys teaching budding scientists about materials. We developed a demonstration where a smartphone can be turned into a microscope to observe polymer crystallization in real time!
Molecular Modeling: A Tool for Development of New Materials

The Johnson research group uses computer simulation tools to discover, characterize, and optimize new materials from the bottom-up, starting at the levels of electrons, atoms, and molecules. Application areas studied by the Johnson group include designing new membrane materials for desalination of seawater, as shown in Figure 1, design of nanoporous materials for gas separation, CO₂ capture, and conversion of CO₂ to useful products, as illustrated in Figure 2, and elucidation of reaction mechanisms on surfaces and in condensed phases.

Molecular modeling can be used to screen a range of materials for a given application, thereby saving time and money by identifying a relatively small collection of promising candidate materials that can be investigated experimentally. For example, we have employed this strategy for screening of complex metal hydrides for hydrogen storage using a set of criteria including gravimetric, volumetric, and thermodynamic metrics. We were able to screen millions of compositions and conditions in order to identify a small subset of a few promising candidate materials that had not previously been identified. Several of these materials were investigated experimentally and some were found to outperform existing complex hydrides in many respects. This basic approach can also be applied to designing tailored sorbent and membrane materials based on metal organic framework or similar materials. We also use the techniques of molecular modeling to study complex systems involving chemical reactions on surfaces and in condensed phases. For large-scale systems this demands a hybrid approach employing both quantum mechanical modeling, to account for bond breaking and bond forming events, and classical modeling to capture long-range interactions and physical collective phenomena that are difficult to describe from a purely quantum mechanical approach.

Figure 1. Molecular simulation (left) and experimental realization of a functionalized carbon nanotube membrane for desalination of seawater. Simulations first predicted that zwitterion functionalized nanotubes could be effective for desalination by imparting gatekeeper functionality to the nanotubes. The experiments verified the predictions, showing that a polyamide/carbon nanotube mixed matrix membrane has both higher flux and higher selectivity compared with plain polyamide membranes.

Figure 2. Porous metal organic framework, UiO-66, functionalized with a Lewis pair catalytic site for chemical reduction of CO₂ to formic acid. This functional group was designed from first-principles simulations.
Renewable Solar Fuels Research in Catalysis

Societies in the Information Age are becoming more cognizant of the future energy demands of growing populations and economies worldwide. Indeed, the early 21st century is witnessing unprecedented impetus to develop new technologies that mitigate humanity’s demand for fossil fuels and petrochemicals. The chemical processes that societies rely upon for liquid fuels or industrial chemicals usually consume finite supplies of natural resources and/or release carbon dioxide (CO₂) into the atmosphere. Neither consequence is sustainable. Thus, economically viable technologies utilizing renewable resources with a minimal anthropogenic footprint must be developed.

Hydrocarbon fuel combustion ultimately leads to CO₂ and water as bi-products. It is possible though, that both would become feedstocks for recycling processes that regenerate fuels. Doing so would undoubtedly require harnessing substantial amounts of energy, but in principle, the requisite energy could be tapped from the sun. What remains is unraveling how to carry out refined conversions of energy and matter. This is the essence of catalysis.

The Keith Laboratory at Pitt focuses on modeling fundamental aspects of catalysis in order to uncover and understand feasible routes to CO₂–neutral renewable energy. We do so by developing and applying computational simulation methods that provide characteristically deep insights into material and molecular phenomena under different environments.

First-Principles-Based Multiscale Modeling of Materials and Molecules

Our computational methods are rooted in first-principles quantum chemistry theories that permit us to study and predict various phenomena (e.g. molecular acidities, electrochemical reduction potentials, adsorption energies, bond-dissociation energies, mechanical properties, and material band gaps). Notably, our studies are 1) entirely carried out in silico (on a computer) and 2) almost entirely free from artificial biases that would result when using inputs from experiment. Whether doing so alone or in collaboration with experimentalists, our group provides a unique perspective on the atomic-scale of catalytic environments to help rationalize or improve catalytic processes.

Our ‘ground-up’ multiscale modeling approach involves quantum chemistry on systems requiring highest accuracy (on systems of up to ca. 200 atoms). These data allow the development of analytic reactive forcefields, which are robust enough to model atomistic dynamics of bond-breaking and bond-forming processes on systems of up to ca. 106 atoms. Forcefield data in turn can be used to generate rate constant libraries for kinetic Monte Carlo (kMC) simulations to model larger time-scale and length-scale phenomena such as nanoparticle/material growth and ripening.

Figures: a) Annealing reactive dynamics on a 3 nm-sized gold nanoparticle shows its predicted surface after reconstructing. b) A density difference plot showing the highly delocalized nature of the highest occupied molecular orbital in a CO₂ reduction catalyst.
Professor Klinzing holds degrees in Chemical Engineering from the University of Pittsburgh and Carnegie Mellon University culminating in the Ph.D. degree from the latter. He recently was given a Honorary Doctor of Engineering Degree from the University of Newcastle in Australia. Before joining the University of Pittsburgh as a professor on its USAID Ecuador project. On the Ecuador project at Universidad Central in Quito, Ecuador he helped develop laboratories, libraries and curriculum in chemical engineering as well as teaching a number of courses. Professor Klinzing returned to the main campus of the University of Pittsburgh after three years and began his teaching and research career that has span 50 years with summer employment in the energy industries. Through his research and teaching he helped to produce 54 M.S. theses and 25 Ph.D. dissertations in the areas of mass transfer and particle technology. His research in particle technology spans a wide spectrum of topics mostly in the experimental field addressing challenging problems in from pressure behaviors to measurements and electrostatic influences. He has written two books in the area of pneumatic conveying one being in its third edition and published by Springer. In 1987 he joined the administrative team of the Swanson School of Engineering as the Associate Dean for Research followed by a seventeen year stint as the Vice Provost for Research for the University. During this time he helped grow the research enterprise of the University quadrupling the size to $800 M annually. He helped to establish university-wide interdisciplinary centers; the Center for Energy, the Petersen Institute for NanoScience and Engineering, the Center for National Preparedness and the Center for Simulation and Modeling. He began several multi-disciplinary initiatives on such topics as Suffering, Geriatrics and Ambulatory and Cognitive Capacity, Wisdom and Aging, Cybersecurity and Immunology, Business of Humanity, Nano Particle Safety, Synthetic Biology. Professor Klinzing has been invited to give keynote and plenary lectures in several International Meeting of Particle Technology. He is a fellow of the American Institute of Chemical Engineering and the American Association for the Advancement of Science. He was a Fulbright lecturer at the Universidad del Norte in Bucaramanga, Colombia. As an A.I.Ch.E. lecturer, he has offered short courses for 12 years on pneumatic conveying theory and practice. In addition he has given short courses and seminars on pneumatic conveying throughout the world. He holds the Life Time Achievement Award from the Particle Technology Forum of the A.I.Ch.E. as well as the Gary Leach Award and the McAfee Award. He serves on the editorial board of Particulate Science and Technology and Powder and Bulk Engineering. At the Swanson School of Engineering he holds a Whitford Professorship. He has produced over 250 research publications and holds three U .S. patents and 6 U.S. copyrights. His research work has been funded by the National Science Foundation and the Department of Energy of the U.S. government.

Some recent research topics are:
- Dense Phase Conveying of Solids
- Development of a Flow Economizer for Long Distance Conveying
- Unstable Flow Behaviors in Pneumatic Conveying
- Control of Pneumatic Conveying Operations Using AI and Fuzzy Logic
- Transport of Coal in Bends and Pipelines
Li Lab: Surface, Interface and 2D Materials

Our research focuses on surface, interface and 2D materials. We are interested in the molecular-level structure and dynamics at the interfaces and how they impact many important properties such as wetting and friction.

Nanometer Lubricants for Hard Disk Drives (HDD)

On magnetic media, there is a nanometer-thick lubricant that provides low friction, anti-wear and anti-corrosion functions. The next-generation HDD technologies require the lubricant to be more thermally stable and cost-effective. We are developing novel materials to address the challenges. (Wang Y.; Sun J. and Li L. Langmuir; 2012, 28, 6151; Wang Y.; Williams K. and Li L. Macromol. Chem. Physic. 2011, 212, 2685)

Ionic Liquid (IL) Nanofilms

Ionic liquids have attracted extensive attention in the past decades due their “green” nature and excellent physiochemical properties. The interface between ionic liquids and various solids are critical for applications in energy storage, electrochemistry, nanofluids and lubrication. We are uncovering the static and dynamic properties of ionic liquids confined to solid surfaces. (Gong, X.; Frankert, S.; Wang, Y. and Li, L. Chem. Commun. 2013, 49(71), 7804)

Surface Properties of Graphene and 2D Materials

Graphene is an atomically thin carbon atom lattice that has high thermal conductivity, high mechanical strength, and unique electrical properties. It is essential to understand the surface property for its future applications. In close collaboration with Prof. Haitao Liu’s research group in the Chemistry Department at Pitt., we are exploring the intrinsic wettability of CVD graphene and relating it to the adhesion, tribology and other properties. We aims to develop reliable coatings based on graphene and understand how to improve the reliability of Graphene-based device. (Li, Z. et. al. Nature Mater. 2013, 12, 925.; Kozbial, A. et.al. Carbon, 2014, 74, 218; Kozbial, A. et.al. Langmuir, 2014, 30(28), 8598)

Simultaneous Oleophobicity/Hydrophilicity

Simultaneous oleophobic/hydrophilic coatings are critical for applications in anti-fogging, self-cleaning and oil-water separation. However, the underlying mechanisms remain clear. We are investigating the governing mechanisms and exploring the approaches in real-life applications. (Li L.; Wang Y.; Gallaschun C.; Risch T. and Sun J. J. Mater. Chem., 2012, 22(33), 16719)

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Researchers in Dr. Little’s Lab focus upon therapies that are biomimetic in that they replicate the biological function and interactions of living entities using synthetic systems. The areas of study include bioengineering, chemistry, chemical engineering, ophthalmology, and immunology. The health issues addressed include autoimmune disease, battlefield wounds, cancer, HIV, ocular diseases, and transplantation. Some of the ongoing research projects in the lab include: Mimicking Biological Structure and Behavior Using Polymeric Release Systems and Carbon Nanotubes, Treatments for Periodontitis that Restore Immunological Homeostasis, Sequential Delivery of Growth Factors for Regeneration of Tissues, and Thermo-gelling Eye Drops for the Delivery of Ophthalmic Therapies. The majority of the projects in the Little Lab utilize some aspect of controlled release for drugs, proteins, or other molecules. While such techniques are not uncommon in the field of drug delivery, our lab is unique in its ability to design such systems in silico, thereby avoiding unnecessary expenditure of time and resources on heuristic testing of controlled release formulations. Our expertise in fabricating and characterizing such systems in vitro and in vivo is augmented by our modeling capabilities.

Rational Design of Controlled Release Systems
At the University of Pittsburgh, our laboratory has developed a unique technology that allows for the specific dosing and delivery needs of a particular therapy (e.g. therapeutic concentrations of chemokine over one month or longer) to be used as “input” to generate a unique and customized formulation “recipe”. This model-aided methodology can dramatically reduce (or even completely eliminate) the need for traditional trial and error based optimization of controlled release behavior. Importantly, this can be accomplished using well-established, biodegradable polymers that are biocompatible, biodegradable and have an extraordinary track record of safety and translatability with the United States Food and Drug Administration. This unique methodology is also not only is capable of saving months to years in development time, but also able to uniquely predict a final formulation’s sensitivity to future changes in critical processing parameters, allowing designs to be optimized for consistent performance through scale-up for preclinical and clinical studies. Through projects funded on a number of NIH, NSF, DoD, State, and Private Institute-funded grants, we have developed not only the tools needed to experimentally design, build, and validate a wide variety of controlled release vehicles but also the expertise needed to troubleshoot common road-blocks in this formulation development process.
Translational Research in Electrochemistry for Sustainable Energy

Our laboratory combines fundamental and applied research in electrochemistry to invent new technologies for energy and environmental sustainability. We combine research capabilities in analytical electrochemistry, solid-state chemistry and materials synthesis (including a range of low-dimensional and nanostructured materials), and electrochemical device design. Current research targets include improved flexibility for all forms of renewable electricity, efficient synthesis of carbon-neutral fuels, and electrochemical approaches for water cleanup.

Electrochemistry for a Solar-Powered Future

Sunlight is by far the most abundant source of renewable energy, but our ability to make use of sunlight for electricity is limited by the fact that solar energy is intermittent—the natural intensity variations of sunlight do not match well with energy usage patterns. Addressing this challenge requires a means of economically storing solar power. Electrochemistry provides a variety of technological opportunities in this area, including advanced batteries and efficient synthesis/utilization of fuels. The key difficulty lies in making solar energy conversion/storage technologies efficient, robust, and scalable.

Dr. McKone has extensive experience in experimental research on potentially transformational electrochemical energy conversion and storage technologies, such as:

- artificial photosynthesis, which involves direct conversion of solar energy into chemical bonds in storable fuels like hydrogen or hydrocarbons, and
- redox flow batteries, which are promising for large-scale energy storage and can be readily combined with photovoltaic installations.

Our work at Pitt is expanding on these themes and exploring new avenues that combine traditional engineering approaches for catalysis and process design with cutting-edge materials synthesis and electrochemical characterization.

Dr. James R. McKone joined the faculty in the Department of Chemical and Petroleum Engineering in the Fall of 2016. He received a BA in chemistry and music from Saint Olaf College in 2008 and a PhD in chemistry from the California Institute of Technology in 2013. From 2013 to 2016 he was a postdoctoral researcher at Cornell University. Dr. McKone’s research interests include experimental electrochemistry and materials synthesis/processing with an emphasis on energy applications.
Professor Badie I. Morsi joined the Chemical and Petroleum Engineering Department, University of Pittsburgh in 1982 and currently is Director of the Petroleum Engineering Program. He received his B.S. in Petroleum Engineering from Cairo University, Cairo, Egypt, in 1972; and M.S., Ph.D and ScD in Chemical Engineering from Ecole Nationale Supérieure des Industries Chimiques (ENSIC), Institut National Polytechnique de Lorraine (INPL) Nancy, France, in 1977, 1997, and 1982, respectively.

Professor Morsi's research activities involve different aspects of Chemical, Environmental, and Petroleum Engineering. His recent research work focuses on: design and scaleup of multiphase reactors, and modeling and optimization of industrial processes with focus on the Fischer Tropsch Synthesis. \(\text{CO}_2\) sequestration in deep coal seams; \(\text{CO}_2\) capture from fuel gas streams using chemical and physical solvents; and \(\text{EOR}\) using \(\text{CO}_2\) and alcohols. Professor Morsi is serving as the Executive Director for the Annual International Pittsburgh Coal Conference (PCC) and has been serving as a consultant to major corporations and organizations in the US and worldwide, in addition of being a reviewer for numerous scientific journals, conferences and agencies. Professor Morsi is the Editor, Proceedings of the International PCC; Associate Editor-in-Chief, International Journal of Clean Coal and Energy; Editorial Board, International Journal of Chemical Engineering; and Editorial Board, Journal of Materials Science and Chemical Engineering. Among his various honors are the Beitle-Veltri School of Engineering's Outstanding Teaching Award (1999); CNG Faculty Fellow (1991-1995); The Richard A. Glenn Award, ACS National Meetings (1995&2002); Mentor of the Year Award, 2002-2003 Minority Engineering Mentoring Program; and George M. and Eva M. Bevier professorship (2001-2005). He is also a member of SPE, AIChE, ACS, and AFS.

### Multi-Phase Reactor Design and Scaleup

The design, scaleup, modeling, and optimization of industrial processes require, among others, precise knowledge of the hydrodynamic, kinetics and heat as well as mass transfer parameters of the pertinent gas-liquid-solid systems under actual process conditions. The focus of our ongoing research is on characterization of the hydrodynamic and gas-liquid mass transfer parameters in several important industrial processes, including Fischer-Tropsch synthesis, propylene polymerization, cyclohexane oxidation, benzoic acid oxidation, toluene oxidation, hydrocracking of heavy oil residue, \(\text{CO}_2\) capture from fuel gas streams using chemical/physical solvents, and \(\text{SO}_2\) and well as \(\text{NO}_x\) removal from flue gas using dry sorbents.

### Novel Solvents for \(\text{CO}_2\) Capture from Hot Fuel Gas Streams

Carbon dioxide is the main contributor to global warming and therefore needs to be removed from fuel gas streams. Conventional processes for acid gas removal (AGR), including \(\text{CO}_2\) in power generation facilities are either chemical, using methyl-diethanolamine (MDEA); or physical process, using chilled methanol (Rectisol) or mixtures of dimethylethers of polyetheleneglycol (Selexol). The issue with using Selexol is that it is hydrophilic and the process is not energy efficient as it requires cooling the fuel gas and then heating it after \(\text{CO}_2\) absorption. Therefore, finding other solvents with more favorable properties is necessary to remove \(\text{CO}_2\) more efficiently.

### Process Modelling and Optimization

Development of robust reactor and process models is of vital importance and interest to all branches of the chemical and petroleum, and biological process industries. Our ongoing modeling activities include process modeling and optimization of the Fischer-Tropsch (F-T) Synthesis by incorporating different tail gas recycling options, in addition to 1-D and 2-D empirical modeling of Slurry Bubble Column Reactors (SBCRs) and 1-D empirical modeling of Microchannel reactors (MCRs) using the axial dispersion model. Moreover, multiphase Computational Fluid Dynamics (CFD) modeling with emphasis on F-T SBCRs through the developing of mathematical 3-D multi-Eulerian and/or Eulerian-Lagrangian CFD model for investigating key spatio-temporal complexities and local hydrodynamics, and CFD modeling with emphasis on F-T MCRs to evaluate process intensification capabilities.
Research in CANELE

In the Computer-Aided Nano and Energy Lab (CANELE), we use theory and computation to investigate the physicochemical properties of nanomaterials with potential applications in diverse nanotechnological areas, ranging from energy generation and storage to materials engineering and catalysis. Our laboratory core expertise lies on "ab-initio" electronic-structure theoretical calculations. We develop structure-activity relationships and apply multiscale tools to elucidate complex chemical processes that take place on nanomaterials. Ultimately, we design novel nanostructures with increased, molecular-level precision and tailored multifunctionality.

Research Thrusts

**Nanocatalysis**: Catalysis becomes extremely complex at nanoscale. The goal of this work is to understand the catalytic behavior of metal-oxide supported nanoparticles under realistic experimental conditions. We elucidate the bonding characteristics of adsorbates on nanoparticles and develop relationships predicting their binding energy versus the nanoparticle structural characteristics. Additionally, we investigate the catalytic mechanisms on both metals and metal oxide supports by taking into account complex physical phenomena (support effects and reconstruction) occurring on the catalyst. Finally, we propose novel nanocatalysts with optimal catalytic activity under experimental conditions.

**Biomass Conversion**: Dehydration reactions are the most important reactions for converting biomass to fuels and chemicals. A fundamental understanding of the dehydration mechanisms can help us elucidate and eventually control the selective dehydration of complicated biomass molecules, such as polyols, to value-added chemicals. In this work, we investigate the dehydration of simple alcohols on various metaoxides in the presence of water. We develop dehydration relationships as a function of the metal-oxide acidity and the alcohols properties, aiming to predict the dehydration behavior of polyols on different oxides.

**Nanoparticle Growth**: The nanoparticle properties are directly related to their structural characteristics. Even though nanoparticles of different sizes and morphologies can be synthesized in the lab, their growth mechanisms are completely unknown. Here, we investigate the colloidal nanoparticle growth in the presence of solvents and capping agents. We provide insights into the nanoparticle growth mechanisms and propose design guidelines to control nanoparticle characteristics (size, shape, dispersity) during synthesis.

Dr. Niepa is an Assistant Professor of Chemical and Petroleum Engineering with an expertise in microbial interactions with biointerfaces. He received a PhD in Chemical Engineering with honors from Syracuse University, focusing on electrochemical treatment of surface-attached and drug-resistant bacteria. Upon graduating, he joined the University of Pennsylvania as a Postdoctoral Fellow for Academic Diversity. At UPenn, he worked with Professors Kathleen Stebe and Daeyeon Lee in Chemical and Biomolecular Engineering, in collaboration with Professor Mark Goulian in Biology to develop new methods to study microbial dynamics in artificial microniches. He deciphered the interfacial properties of bacterial films at oil-water interfaces. This expertise provides a platform for him to make unique contributions to diverse fields ranging from microbial-based methods of oil recovery to the development of technologies having applications for personalized therapeutics, or in high-throughput screening of currently unculturable microbial communities relevant to biotechnology and drug discovery. His efforts in bioelectrochemistry led to the design of patent winning technologies for controlling of microbial pathophysiology with bioelectrical systems. Also, Dr. Niepa is a co-founder of Helios Innovative Technologies Inc. (now PurpleSun Inc.), a medical device company that develops automated sterilization systems to fight bacterial cross-contamination and hospital acquired-infections.

Research Interests

Our mission is to decipher how the interfacial properties of materials affect the physiological response of microorganisms and thereby develop new strategies to minimize the deleterious and optimize the beneficial activities of cells. The physicochemical mechanisms that regulate microbial growth in various settings remain poorly understood for reasons linked not only to the versatility of the microorganisms but also to the challenge of designing new platforms to study or control them. Our translational research program elucidates these mechanisms by developing sustainable control strategies for microbes relevant to health, industry and the environment. We are pursuing three interrelated research thrusts to: (1) Eliminate pathogenic microbial communities (biofilms) associated with implantable devices using conductive-substrate interfaces; (2) Model pathogenic and beneficial microbial communities (microbiomes) in artificial microniches made of soft biomaterial; and (3) Control beneficial interfacial biofilms using surface active compounds.

Building upon the understanding of the electrophysiology of highly drug-tolerant bacteria to cure chronic infections, we target the design of alternative ways to control microbial persistence and pathogenicity with conductive-substrates incorporated in medical devices. In our second thrust, we develop porous, semi-permeable or polyelectrolyte membranes (soft nanomaterials) for biotechnological applications. We direct their metabolic activity towards desired ends, e.g., the creation of new materials and bioproducts. Finally, our third thrust addresses interfacial phenomena influencing the metabolic activity of bacteria at fluid interfaces. By characterizing the interfacial and metabolic properties of bacterial films, we aim to elaborate new surface-active molecules to prevent the biodeterioration of economically relevant food and pharmaceutical products, while promoting crude oil remediation.
Systems Engineering at the Medical Interface

Advanced computation and analysis tools are sorely needed to help clinicians visualize, assimilate, and analyze the complex interplay of the measurements and data available to them. These tools provide a complement to the outstanding linear intuition of clinicians, as multiple variables of interest (actuations and/or measurements) are common and nonlinearities (such as saturation phenomena) are ubiquitous in biological systems.

We take a model-based approach to characterizing medical disease and treatment problems, working to understand the dynamics and mechanism of disease progression as well as treatment. We closely collaborate with clinical practitioners to formulate and solve clinically-relevant problems for societal benefit. The overall goal is to improve the efficacy and efficiency of health care delivery and policy by developing patient-tailored treatment approaches in such problem areas as:

- **Cystic Fibrosis:** Working with UPMC clinicians and scientists, we are characterizing the system (body) and cellular response to osmotic challenges and therapies. By focusing on easily accessible cells (nasal epithelia), as a personalized model for bronchial epithelia, we target a patient-tailored understanding of disease dynamics in the individual and targeted treatment approaches and interventions.

- **Glucose Control in Critical Care:** Intensive care unit patients often manifest stress-induced hyperglycemia even though they are not diabetic. In collaboration with Critical Care Medicine, we are developing artificial pancreas-like control systems and a clinician-friendly interface and alarm layer to improve patient outcomes in intensive care.

- **Inflammation and Sepsis:** Pathogenic invasion excites the human inflammatory response system, and the role of these inflammatory mediator dynamics in survival is not well understood. We are working to model the dynamics of system response in order to characterize patient groups that are aided by existing or novel therapeutic interventions.

- **Solid Tumor Cancer Chemotherapy:** see below.

Patient-Tailored Cancer Treatment

Most cancer patients receive chemotherapy during their course of treatment. These agents impede cellular growth, thereby limiting the development and spread of cancerous tumors, but they are often toxic and lead to side-effects that ultimately limit the efficacy of chemotherapy treatment.

We follow the anecdotal evidence that “more is better” — patients receiving more cycles of therapy typically demonstrate better overall survival. Our focus, however, is on limiting the toxicities that lead to withholding or reduction of chemotherapy doses for patients.

In a model-based approach (top figure), we construct mathematical representations of drug concentration versus time profiles in the body (PK) and the impact of these drug administrations in efficacy (PDeff) and toxicity (PDtox). By understanding the mechanisms of toxicity and the potential for rescue by administered agents (bottom figure), we can tailor our models to individuals using clinical measurements of toxicity, response, and resistance. Ultimately, this systems medicine problem is solved via an engineering algorithm to provide the dose magnitude and schedule that provide controlled toxicity during treatment while also eliminating cancer cells.
Systems Immunology

We all fear disease but the unfortunate truth is that our bodies are often responsible for the damage wrought during disease progression. Our bodies have evolved several internalized sentinel programs that compromise our immune response. When functioning effectively, our immune response rapidly detects threatening pathogens and activates processes that assess and respond appropriately. But, occasionally, such as during certain viral and bacterial infections, our body responds too aggressively to the pathogen. These overly aggressive responses by our immune system results in major tissue inflammation and can greatly complicate patient recovery. We seek to develop immuno-modulatory therapies that work with the immune response to improve patient health.

Big Data-Driven Modeling of Lung Inflammation

Inflammation is a complex, multicellular process that is generally a protective response to a pathogen, but inflammation often becomes dysregulated, resulting in greater and occasionally fatal damage. New experimental techniques allow us to quantify changes across the genome in response to a pathogen, but the cellularly diverse environment makes it difficult to determine which genetic events are associated with inflammation and what specific immune cell populations may play a role in the response. We are developing approaches that combine individual gene expression profiles, dynamic clustering, and time-course gene expression to unravel the key genetic events associated with severe inflammation. Our early tools can be found at www.influenza-x.org/~jshoemaker/cten/.

How Does Herpes Avoid Immune Detection?

Herpes simplex virus (HSV) and HIV are DNA viruses and both are very competent at avoiding our immune response. We are now working with our collaborators at UPMC to better understand how our cells detect DNA viruses and by what mechanisms might the virus be able to either avoid detection (Fig.1). We are developing mathematical models of the molecular interactions responsible for DNA virus detection and immune activation. Uniquely, these models can exploit immune response dynamics to identify hidden, disease-associated signaling mechanisms. Then combined with machine learning and protein similarity data, these models can provide deep insight into viral escape.
Principal Research Interests

The Soft Materials and Rheology group conducts experimental research on a variety of topics including **polymers, multiphase flow, colloids, interfacial phenomena, block copolymers, and rheology**. Broadly, we conduct fundamental research to support the materials science of soft materials. Some highlights of past research include:

- In blends of immiscible polymers, tiny amounts of interfacially-active diblock copolymers (here called compatibilizers) enormously affect the rheological properties: raise the viscosity over two-fold, increase shear-thinning, and viscoelastic behavior. These changes can be interpreted as an immobilization of the interface by the compatibilizer.

- Compatibilizers generated by interfacial reaction of multifunctional reactive polymer chains crosslink the interface and cause even larger changes in structure and rheology.

- Interfacially-active particles can modify the structure of polymer blends by interfacial jamming and drop bridging (pictured top right), and the corresponding fluids may show profoundly non-Newtonian rheology (graph right). All these effects are heavily influenced by the wettability of the particles.

- Polymer foams can be stabilized by interfacially-active particles (picture right): the particles endow the foam bubbles with a robust shell that protects against bubble coalescence. Thus stable foams can be realized even from polymers that are usually regarded as unfoamable.

Other Research

- We are keenly interested in thin film buckling phenomena, e.g. the coupling between elastic mechanics of thin films and viscous flow, swelling-induced buckle delamination of films, buckling in block copolymers, and realizing reversibly-texturing surfaces by harnessing thin film buckling.

- Our lab regularly assists researchers with rheological characterization of hydrogels. These include hydrogels prepared from Extracellular Matrix proteins (in collaboration with the Badylak lab at Pitt), or synthetic hydrogels used in medical or sensor applications.

- We have assisted the Asher lab in Chemistry in developing new ways to fabricate two-dimensional colloidal crystals (right).

- We are interested in using microfluidic devices for material synthesis. For example, we developed a microfluidic device that can handle molten polymers so as to make polymer microparticles.
Götz Veser obtained a Diploma in chemical engineering at the University of Karlsruhe (now Karlsruhe Institute of Technology) and a PhD in physical chemistry at the Fritz Haber Institute, Berlin (with R. Imbihl and G. Ertl). Following two years as Feodor-Lynen Postdoctoral Fellow with Lanny Schmidt at the University of Minnesota, he returned to Germany as research associate at the University of Stuttgart and research group leader at the Max-Planck-Institute for Coal Research (Mülheim an der Ruhr). In 2002, he joined the University of Pittsburgh.

Dr. Veser’s research interests are in catalytic reaction engineering with a focus on natural gas conversion and related energy technologies. Among his recent honors and awards are the Career Award of the National Science Foundation (2005), the R.A. Glenn Award of the Fuel Chemistry Division of the American Chemical Society (2007), and invited plenaries at the 6th World Congress on Oxidation Catalysis (Lille, France; 2009) and the 10th Natural Gas Conversion Symposium (Doha, Qatar; 2013). Dr. Veser is also RUA faculty at the U.S. Department of Energy’s National Energy Technology Laboratory, and currently serves on the editorial boards of multiple journals in the area of reaction engineering.

Process Intensification

“Process Intensification” (PI) is a conceptual approach to reaction engineering with the aim to radically reduce the physical and/or energy footprint of existing processes. The Veser group is developing intensified process schemes for natural gas conversion, focused on multifunctional reactor concepts via dynamic reactor operation. These include heat-integrated reactors via reverse-flow operation and so-called “chemical looping”, a reactor concept originally proposed for clean combustion but with broad applicability in fuel processing.

Nanomaterials for Catalysis

Tailoring of materials structure and composition on the nano- and sub-nanometer scale has enabled the “engineering” of functional materials with unprecedented precision. Nanomaterials are hence becoming key enablers for a wide range of emerging technologies. The Veser lab is developing new approaches to endow nanomaterials with the stability and robustness required to withstand the often extremely demanding conditions of industrial catalytic processes.

Nanotoxicity

Despite increasing evidence that nanomaterials can show significantly elevated toxicity, they are finding increasingly widespread application in consumer products ranging from cosmetics over clothing to consumer electronics. There is hence urgency to establish appropriate toxicity tests for this emerging class of materials.

In collaboration with colleagues at UPMC, the Veser group is developing zebrafish assays as a fast screening tool for nanotoxicity. To-date, they have demonstrated that nanstructuring can have profound impact on the fate and toxicity of these materials, and can serve as an effective means to counter their toxicity.
The Hypothetical Materials Lab

What is the best possible material for hydrogen storage? For longer lasting batteries? For carbon capture? As experimental chemists and materials scientists approach the ability to synthesize any material, the question becomes which material should we be making? The Wilmer Lab tackles this question head on by using supercomputers to simulate the properties of millions of hypothetical materials and find the most promising ones for experimental groups to synthesize. Our research group is particularly interested in using this strategy to solve energy and environmental problems, and so we search for materials that can enable better carbon capture technologies and improve fuel cell technologies, for example.

![Image of hypothetical materials]

We also investigate materials that can improve the energy efficiency of industrial processes, such as the production of pure xenon gas. Xenon and krypton gas are usually found mixed together, and they are very difficult to separate. By screening thousands of hypothetical filter geometries (pictured on left), we are able to find ones that can potentially trap the krypton while allowing the xenon gas to pass through.

Can an Electronic Nose Beat a Dog’s Nose?

Although we now have cameras that can see better than human eyes, we still lack an electronic device that can replicate the sensitivity and accuracy of the mammalian nose. A biological nose uses hundreds of distinct olfactory receptors to distinguish different odors. An electronic nose needs, correspondingly, hundreds of materials that each respond in a unique way to different odors. This is a classic “big data” problem, and our lab is exploring thousands of materials to find the combination that will out-smell a dog.

What porous material would let you make the most energy efficient carbon capture technology? By computationally simulating CO2 capture in each of over a hundred thousand porous materials (pictured above), we are able to ignore ineffective candidates (grey) and focus on promising ones (colored).
Dynamic Surface Reactions: Bridging the Gaps

The rational design of new and improved materials, such as for corrosion-resistance or catalysis, requires an understanding of the relationship between their processing, structure, and performance and the underlying reaction mechanisms. The spatial and temporal scales of these processes span orders of magnitude, and no one technique covers them all. Another gap lies in the disconnect between the simple, idealized materials used for computation and the ill-defined “messy” materials of experiment. Our research focuses on bridging these gaps by coupling computational modeling with a host of experimental techniques. Of particular importance for this task is the environmental transmission electron microscope (ETEM), which enables the direct observation of the structure, chemistry, and composition of these materials at the meso- to atomic-scale in real time and under reaction conditions. Some of our current projects include:

**Metal and Metal Alloy Oxidation**

Understanding metal of metal oxidation is critical to corrosion control, catalysis, and advanced materials engineering. Classical oxidation theories assume a uniform oxide film growth; however, *in situ* TEM studies reveal this is far from the case. It is a complex set of (often coupled) processes involving physical and chemical changes at multiple scales. A great knowledge gap exists between the oxygen-induced surface reconstructions of the early stages and the formation of the subsequent oxide structure. We are using ETEM in concert with DFT calculations to study early-stage oxidation to determine the structure of these reconstructed surfaces and how they depend on the metal surface faceting and environmental conditions (O₂ pressure, temperature), such as the Cu(110) “sawtooth” reconstruction under O₂ (Fig. 1).

**Heterogeneous Catalysts and Nanomaterials**

Bimetallic nanoparticle catalysts can exhibit enhanced activity and selectivity over their single-metal constituents, since each part can be tailored for a specific function. However, adding a second metal greatly increases the complexity of the bimetallic system, especially under environmental conditions; variation in the elements’ mixing patterns and reconfiguration (e.g., NiCo nanoparticles, Fig. 2) can affect the reaction mechanisms and thus catalytic performance. Our design cycle iterates between theory (DFT, MM), synthesis, characterization (TEM, X-ray), and testing to discover and optimize new catalysts. This mutually supportive approach yields insights that could not be achieved separately.
CIVIL & ENVIRONMENTAL ENGINEERING
Dr. Bilec is an associate professor in the Swanson School of Engineering’s Department of Civil and Environmental Engineering. Dr. Bilec’s research program focuses on sustainable healthcare, the built environment, and life cycle assessment. She is interested in improving the overall environmental performance of buildings while connecting the occupants in a more thoughtful manner.

She is the Principal Investigator in a multi-disciplinary and multi-institutional research project, NSF EFRI-Barriers, Understanding, Integration – Life cycle Development (BUILD). She has worked in the sustainable engineering arena since 2004. As the assistant director of education outreach in the Mascaro Center for Sustainable Innovation, Pitt’s center for green design, she translates research to community outreach programs and develops sustainable engineering programs for K-12 education.

The Built Environment and Life Cycle Assessment

Buildings are recognized as a technological sector where large improvements in sustainability-related categories are achievable. The question of what is environmentally sustainable is best addressed through the use of life cycle assessment (LCA).

Indoor Environmental Quality – Most LCAs do not include the building’s direct impacts on its occupants, though these impacts also occur primarily during the use phase and can be significant. For commercial buildings, some of the impacts on occupants may decrease their productivity, leading to lower revenue or otherwise reducing the owner’s financial return on investment.

Dynamic LCA – The long service life of buildings also introduces a need to examine the possibility of changes over time. However, the current state of the practice in LCA is to assume a static, unchanging set of values for the duration of the use phase, due to the additional data requirements for modeling system dynamics and generating multiple scenarios. Recent development in sensing and building automation technologies indicates that the additional data requirements of dynamic life cycle modeling may be within reach. Real-time measurements of building requirements such as energy usage and indoor air quality are already implemented in some automation and control systems. The needs of a sensor network used for life cycle modeling may not extend significantly beyond those for a building system diagnostic and control network. Such a network provides the dynamic building operations portion of the LCA database; when coupled with time-dependent information on external industrial and environmental systems, it could give true life cycle updates in real time.

Sustainable Healthcare

As environmental sustainability increases, the healthcare industry, with its relative size, costs, waste generation, and expected growth, is under pressure to improve its economic, social, and environmental sustainability. With these challenges and growing concerns about the US healthcare industry and the general health of the public, hospitals are called upon to be designed more sustainably and to improve the environmental sustainability of their processes and procedures. In order to implement more environmentally sustainable hospital building design and medical practices, healthcare decision-makers need proper tools and information about the industry’s current environmental footprint, which aspects of hospital design and function contribute most significantly to environmental and human health impacts.
Improving Effectiveness and Sustainability of Hydraulic Fracturing

Hydraulic fracturing has been the most important method for stimulating production of oil and gas for more than 60 years. With its critical role in the growth of shale gas/oil, hydraulic fracturing has now come to the forefront of conversations about energy and the environment as well as intensified research efforts aimed at ensuring it is done in a manner that is both effective for its purpose and sustainable for communities and the environment.

The effectiveness and sustainability of hydraulic fracturing operations go hand in hand. When the methods of hydraulic fracturing are optimal, the surface impacts and environmental risks are minimized. Similarly, poor practice that fails to minimize environmental and community impacts jeopardizes the benefits that can be achieved from responsible production of gas and oil emerging sources such as shale reservoirs.

Dr. Bunger’s research aims at achieving optimality of hydraulic fracturing processes by predicting and controlling the types of growth patterns that will be generated when high pressure fluid injection is used to break reservoir rocks. Dr. Bunger uses analytical, numerical, and experimental methods to understand fundamental physical processes with an emphasis on contrasting network versus localized growth, growth that is contained to the reservoir versus growth out of zone, and practices that minimize versus exacerbate risk to well integrity and hence to groundwater resources due to the potential for contaminant migration along poorly completed or damaged wells. Dr. Bunger’s additional and complimentary research interests include the mechanics of hydraulic fractures, coupled fluid-shale interaction, and the emplacement dynamics of magma-driven dykes and sills.

Experience and Facilities

Dr. Bunger has 15 years of experience in experimental, analytical, and computational investigation of hydraulic fracturing, rock mechanics, and site testing including in situ stress measurement. The University of Pittsburgh Hydraulic Fracturing Laboratory supports research into hydraulic fracture propagation. It includes: 1) a true-triaxial cell, including hydraulic pump and pressure control, capable of applying up to 20 MPa of stress independently in each of 3 direction to specimens measuring up to 300 mm on a side, 2) multi-axis video monitoring that is enabled by viewing ports in the loading platens of the triaxial cell, backlight sources built into the loading platens, and digital video cameras 3) a syringe pump used for injecting fluid for hydraulic fracturing, 4) sensors for monitoring injection fluid pressure and temperature.

Sustainable Design of Emerging Materials

Development of new materials and discovery of novel nano-scale properties has immense potential to significantly improve the functional performance of current and future technologies. Sustainability by design is a framework that aims to ensure that these emerging materials are able to meet (or even exceed!) desired performance metrics while also being safe to humans and the environment. The framework is established on the premise that material structure and physicochemical properties serve as a design handle to manipulate and tailor the desirable and undesirable outcomes in a way that precludes potential unintended consequences. Structure-property-function (SPF) and structure-property-hazard (SPH) relationships are determined by establishing robust relationships between specific material structure-property parameters and the desired function (SPF) and inherent hazard (SPH).

Select Publications Related to this Research Thrust


Select Publications Related to this Research Thrust


Evaluation of Life Cycle Tradeoffs to Inform Emerging Product Design

The unique properties achieved through engineering materials at the nano-scale have inspired innovative applications with the potential to positively influence society and the environment. Biological and chemical sensors, energy capture and storage, and advanced water treatment technologies are just a few examples. Yet, the benefits realized through nano-enabling products are not without impacts that manifest across the life cycle. Example upstream impacts include resource intensive processes for acquisition of raw materials and synthesis of nanomaterials while downstream environmental and human exposure to nanomaterials upon release from the products is a concern. Our research applies a systems approach to quantifying the impact and benefit tradeoffs while also advancing current tools for enhanced applicability to emerging product design.

Select Publications Related to this Research Thrust


Infrastructure Renewal

The state of the Nation’s and the world’s civil infrastructure is poor and deteriorating rapidly. Innovative, cost-effective and sustainable means of repairing, retrofitting and rehabilitating our built environment are of critical importance. Dr. Harries’ expertise lies in developing and demonstrating these means. Harries is a structural engineer; his specialization in large- and full-scale structural testing, coupled with a background in applied mechanics places him in a unique position among university researchers.

Harries’ infrastructure-related research focuses in the following areas:

- methods of repair and retrofit of concrete and steel structures with a focus on prestressed concrete bridge systems;
- innovative structural systems for high-rise structures;
- fiber-reinforced polymer (FRP) structural systems (bridge decks);
- applications of large- and full-scale structural testing methods with a focus on full-scale structural component fatigue testing;
- natural-hazards mitigation with a focus on seismic design and retrofit; and,
- forensic study and analysis of structural failures.

Non-traditional Materials in Civil Infrastructure

Focusing on infrastructure repair, Harries’ research has a strong focus on the use of fiber-reinforced polymer (FRP) materials in civil infrastructure. This includes applications of:

- CFRP (carbon) for concrete and steel structural repair;
- GFRP (glass) for concrete and timber structural repair; and,
- spray applied materials for concrete repair with a focus on underground infrastructure applications.

In most cases, bond to the substrate material is a key limit state for repair material performance; Harries is a recognized international leader in the field of FRP bond behavior, particularly durability of bond under fatigue loading conditions.

Non-conventional Materials in Civil Infrastructure

Focusing on engineering and natural-hazards mitigation applications in the developing world, Harries has built a research expertise in the structural application of full-culm bamboo and the development of standard test methods for quantifying the behavior of bamboo for structural applications. While a nascent field, this work has resulted in collaborations in Brazil, China, India, Nepal, France and the UK. This focus has also provided a large number of research opportunities for undergraduate students both at Pitt and abroad.
Determine the Factors Influencing Barriers Design to Prevent Discharges from Underground Coal Mines

The Appalachian Research Initiative for Environmental Sciences (ARIES) is a consortium of major research universities formed to address the environmental impacts of the discovery, development, production, and use of energy resources in Appalachia. ARIES is under the direction of the Virginia Center for Coal and Energy Research at Virginia Tech. The University of Pittsburgh is a sub-contractor to Virginia Tech with the goal of developing the next-generation eco-friendly mining. Several projects have been funded since 2011 for a total of approximately $180,000. The current project is part of the ARIES Water Impacts to Underground Coal Mining and is a task entitled “Barrier Pillar and Water Management.” This project is examining the factors influencing the design of barriers and the control of mine-pool discharge from coal mines. The project goals include:

- investigate the factors affecting water transmission characteristics of barriers, both coal (as in down-dip) and strata (as in sedimentary rock layers between the mine-pool and a nearby surface stream),
- where possible, characterize the extent and quality of mine-pools,
- summarize case-study reports in a series of formal presentations and publications, and
- produce guidelines for use in the design of hydraulic barriers to control mine-pool discharges.

Assessing the Impacts of Underground Coal Mine Subsidence on Surface Structures and Water Supplies

The Bituminous Mine Subsidence and Land Conservation Act of 1966 and its subsequent 1994 amendment, commonly called Act 54, require the Pennsylvania Department of Environmental Protection, or PA DEP, to produce an assessment of the surface impacts of underground bituminous coal mining in Pennsylvania every five years. The University of Pittsburgh was asked by the PA DEP to assess underground bituminous coal mining surface impacts in two separate contracts valuing over $900,000 over a four year time frame. The mining engineering program has a major role in these research projects shared with the Biology and Geology Departments at Pitt. The first contract was completed in 2010 and published in 2011. The second contract is on-going. The mining engineering program has focused on recording mining trends and evaluating subsidence impacts, including effects on structures, water supplies, and land.
Liang’s primary research interests are to discover and reveal fundamental laws that govern water and energy cycles, and to investigate how the water and energy cycles affect the health of our environment and ecological systems, and how they influence the transport and cycling of nutrients and pollutants at different spatial scales, such as at local, regional, continental, and global scales. Liang’s research work includes (1) land surface hydrology and modeling, (2) advanced hydroinformatics, and (3) environmental monitoring via wireless sensors and sensor network (WSN).

**Advanced Informatics**

Due to significant advancements in information and communication technologies, hydroinformatics, an emerging cross-disciplinary field, could change the way of hydrological and environmental research profoundly. Liang and her team have been developing new methodology to conduct data fusion and data assimilation by making good and effective use of various heterogeneous data sources. They have also been investigating decades-long difficult problems on improving prediction accuracies for ungauged basins by combining machine learning approaches with physical modeling approaches.

**Land Surface Hydrology and Modeling**

The fields of surface water hydrology and atmospheric sciences were developed as two independent fields in the past. With the evolvement of the new inter-disciplines, the atmosphere, land surface, and soil zone below the land surface are now viewed as one integrated system. Such new view provides great opportunities to understand the nature which have never been possible before, such as, how to connect climate change of global warming at different scales in order to conduct impact studies on flooding, drought, agricultural yields, water resources, human welfare, etc. One of the outstanding and difficult problems in resolving these connections is to effectively deal with different spatial scales associated with the climate-model predictions of various physical variables, such as rainfall, snowfall, soil moisture, etc. from large spatial domains in atmospheric models to much smaller spatial domains associated with hydrological models. Liang and her team are developing a new modeling strategy to address some of the emerging challenges in the field of land surface modeling.

**Environmental Monitoring via WSN**

Wireless sensor networks (WSNs) enable the continuous monitoring of various hydrological phenomena at unprecedented high spatial densities and long time durations and hence, open new exciting opportunities for numerous scientific endeavors. It is of paramount importance to deploy large scale monitoring WSNs for environmental monitoring. Because sensor nodes are battery-powered, one of the most critical challenges in WSNs is to minimize the use of power for data gathering. Liang and her team have worked on building their own sensors to significantly reduce the cost for making a large number of field deployment possible. In addition, collaborating with computer scientists, they have been investigating the energy characteristics of different types of sensors in environmental wireless sensor networks, and developing an innovative framework to significantly improve energy efficiency for large scale environmental monitoring using WSNs.
Mechanics of Rock Cutting and Modeling

Rock cutting is a fundamental problem facing engineers, as any structure that is placed on or in rocks would involve some degree of rock cutting. Yet it is a challenging problem from a modeling perspective. This challenge appears as a sequence of difficult problems: A contact problem first arises as a cutter advances and interacts with the target rock material. This is followed by the problem of determining when and whether or not the rock would fail. Subsequently, the problem of how to initiate the fragmentation process after the material failure has to be resolved. This cycle of problems then repeats starting with a new contact problem after new surfaces are generated because of fracture. We have successfully applied both the discrete element and the finite element methods in capturing the various fracture phases of the fragmentation during rock cutting. We have also demonstrated the feasibility of modeling a drilling operation using computation mechanics. Other focus of our study included the modeling of failure mode transition from ductile to brittle as the depth of cut increases. In fact, we have shown that rock cutting also follows a size law if the depth of cut is used as the measure of size.

Continuum-Discrete Analysis

Many problems of importance involve interaction of continuum with discontinuum. For instance, bones may be viewed as discrete objects and tissues and muscles the continuum; dams the continuum and the fracture rocks foundation the discrete objects. A continuum may also rupture into several discrete objects. This class of problems requires a dedicated, efficient computational approach. We have worked on continuum damage mechanics together with element erosion in FEM to model fracture. We have also developed algorithms in a mesh based partition of unity method, also known as the numerical manifold method, to address interaction across discontinuities.

Constitutive Modeling of Hydrate-Bearing Soils

Methane hydrates have been touted as an important potential future source of energy. Production of gas hydrates faces significant challenges, such as the geomechanical changes brought about by hydrate dissociation. Specifically, the dissociation of gas hydrates could affect the structural integrity of unconsolidated hydrate-bearing sediments. In this connection, a good grasp of the geomechanics of hydrate-bearing sediments is also crucial in addressing potential geohazards resulting from global warming. We have been funded by NETL and successfully developed a new constitutive law for methane hydrate-bearing soils. We are currently focusing on implementation of this new law, and on coupling geomechanics code with multiphase flow code.
Advanced Traffic Control Systems

Ramp Management can be used as a method to help reduce congestion on freeways, without the high costs of capacity improvements. Congested freeways that are eligible for ramp metering or ramp closures are likely to see not only a decrease in mainline congestion, but also a decrease in emissions and crash rates. A basic, high level planning tool was developed by Dr. Magalotti based upon readily available volume and geometry information from DOT and the local Metropolitan Planning Agencies to determine appropriate locations for this advanced traffic control system. In addition, this analysis set the framework for discussion with local municipalities about how the ramp management project may impact the local roadway network and plan for these impacts. The research also created an integrated operations system that responds to both changes to the freeway and local roadway network conditions. Operation of local traffic signal systems in conjunction with the ramp meters or closures is critical to the success of a ramp management system because of the changes in both daily travel patterns and incident induced patterns. A benefit/cost methodology was developed to test the relative benefits of such coordinated installations. The methodology developed was testing on I-376 in Pittsburgh Pennsylvania to reduce congestion at the Squirrel Hill Tunnel.

Multi-Modal Transportation Planning

Current methods of highway and bridge project development only evaluate multi-modal design features relative to their function as accessory uses, subservient to the primary function of a highway or bridge project. These methods rely on user input, which does not have a validation system behind it; the process is largely qualitative. This evaluation process has resulted in projects that were devoid of, or inadequately provided with, adjacent transit, pedestrian and bicycle facilities. No quantitative methodology is available to make, validate, or assist in this determination.

Dr. Magalotti has developed a more quantitative means of assessing the need for bicycle, pedestrian, and transit facilities early in the planning and design process. This new process has determined an appropriate project scope, based on land use and demand for various transportation modes; the extent to which various modes of transportation should be accommodated and the value of such accommodations in a multi-modal transportation system.
Chemical Fate in the Anthropocene

Human influence on the environment has reached geologic scales, prompting a call to label our current epoch the “Anthropocene.”

Our group studies how human activity interacts with physiological and ecological systems to determine the fate of hazardous chemicals in organisms and the environment.

We use a variety of complimentary approaches, including multimedia environmental fate models, physiologically based toxicokinetic (PFTK) models for organisms, and in vitro assays to understand and predict the distribution of emerging organic chemicals. Chemicals of particular interest include per- and polyfluorinated alkyl substances (PFAS), current-use pesticides, and chemicals that find their way into food by accumulation from the environment or via food production, processing or packaging.

We also use and develop quantitative structure-activity relationships (QSARs) to predict environmental hazards of new chemicals and screen existing chemicals for substances of concern.

The Global Industrial Food Web as a Chemical Transport Network

Food is a basic human need and also part of a complex system with social, environmental, and economic implications. One critical dimension of this system is chemical contamination. Food is a major pathway of human exposure to chemicals, and food production causes substantial contamination to surrounding environments. We use an integrated modeling strategy, combining substance flow analysis, regional bioaccumulation and global chemical fate models to investigate how site-specific emissions intersect with global trade patterns to influence human exposure to hazardous chemicals.

What Makes a Chemical Bioaccumulative?

Perfluorinated alkyl acids like PFOA and PFOS redefined our understanding of bioaccumulative chemicals. Unlike legacy persistent organic pollutants, they accumulate to high concentrations in blood and liver, where they are bound to proteins like serum albumin and liver fatty acid binding protein, rather than partitioning to storage lipids.

In order to understand emerging chemicals like these, we are developing novel PBTK models that explicitly include protein binding as a mechanism of accumulation. We parameterize these models using a combination of molecular modeling and in vitro assays to determine uptake, distribution, elimination and protein interactions in different tissues.
Prof. Rizzo has nearly 15 years’ experience in nondestructive evaluation (NDE), structural health monitoring (SHM), and signal processing. To date, Dr. Rizzo has published nearly 70 peer-reviewed papers, over 120 conference proceedings, and he holds 2 patents. His research portfolio spans from the application of guided waves for the NDE of rails, pipes, and cable structures, to the use of infrared technology in NDE and sustainability. His research has been supported by the National Science Foundation, the Federal Railroad Administration, the American Society for Nondestructive Testing and the Pennsylvania Department of Transportation. Recently, he is applying some NDE techniques for biomedical applications.

HNSWs for the Prevention of Rail Thermal Buckling

One of the major structural problems in the railroads made of continuous welded rails is buckling in hot weather and breakage or pulling apart in cold weather. The prevention of buckling is related to the determination of the temperature, called rail neutral temperature, at which the net longitudinal force in the rail is zero. Our group is investigating the capability of a novel sensing system to indirectly measure applied stress in rails. This system consists of a simple and cost-effective transducer, recently developed at Pitt. The transducer enables the generation and detection of highly nonlinear solitary waves (HNSWs), which are compact non-dispersive stress waves that can form and travel in nonlinear systems such as granular materials.

EMI for the Assessment of Dental Implants

Missing teeth is a problem that involves people of any country and race. Dental implants are increasingly used to replace missing teeth, but the proper success of the therapy is related to the ability to assess the occurrence of full osseointegration, when a stable implant-bone interface is reached. We propose a new biomedical device to assess such stability. The device exploits the electro-mechanical impedance (EMI) of a piezo-transducer glued to the abutment screwed to an implant. We hypothesize that the electrical impedance of this disposable transducer glued to the abutment inserted, during periodic visits, to the implant, can diagnose the progress of the implant therapy.

Guided Ultrasonic Waves (GUWs) for SHM Applications

The demand for robust and cost-effective SHM systems is on the rise. Among the several methods proposed to monitor waveguide-like structures, ultrasonic-based and impedance-based methods are gaining increasing attention in the research community. Dr. Rizzo’s group has positioned itself in the area of GUWs-based SHM. We developed a general paradigm that combines guided waves with discrete wavelet transform to extract a set of damage sensitive features that are fed to a supervised (artificial neural network) or an unsupervised learning (outlier analysis) algorithm. The paradigm aims at identifying and/or classifying damage.
Mechanical Properties of Binary Granular Mixtures

Natural soil deposits are often made of a binary mixture of gravel and sands or clays. Glacial till is an example of this abundant type of natural binary mixture. Fig. 1 shows an example of a soil deposit made of a mixture of rock particles and clay and forms part of a failed natural slope. Very little is known about the mechanical properties of this abundant natural mixture. A knowledge of the mechanical properties of this type of mixture is needed for the safe design of foundations for buildings or the stability aspects of a highway cut in deposits made of this binary mixture. A research that involves laboratory, numerical and theoretical analyses is being conducted in order to understand the behavior of the binary granular mixtures when subjected to static loads or seepage. Mechanical properties that are being investigated are: (a) the consolidation characteristics of gravel-clay, (b) the hydraulic conductivity of sand or clay mixed with gravel, (c) the shear strength of mixtures of gravel and sand or clay (Fig. 2). The numerical analysis makes use of the Discrete Element Method (DEM). The theoretical analysis makes use of mixture theory.

The Piping Failure of Earth Dams and Natural Slopes

Clays forming part of homogeneous earth dams and natural slopes contain isolated (unconnected) fissures or cracks in their structures. It is generally assumed that these isolated cracks do not have an influence on the hydraulic conductivity. Also, it is unknown whether the seepage force associated with hydraulic conductivity causes the growth and interaction of the cracks. Crack growth and interaction will cause the piping failure of the clays. Thus, an evaluation of these two issues is required. The objectives of the proposed research are: (1) to study whether seepage forces have an effect on the growth and interaction of isolated fissures in clay samples; (2) to study whether fissure parameters such as number, length, orientation, mode of arrangement, separation and overlap have an influence on the seepage force values needed for the possible growth and propagation of the isolated fissures; and (3) to conduct a finite element analysis of the Darcy flow equations in order to evaluate whether seepage forces induced during hydraulic conductivity tests cause the propagation and interaction of isolated cracks (piping) in clay samples (Fig. 3).

Other Areas of Research in Geotechnical Engineering

(1) The application of fractals to solve geotechnical engineering problems; (2) The mechanics of crushing of granular materials; (3) Use of network theory to analyze force chains in granular materials; and (4) The sustainability and stability of the retaining walls at Machu Picchu.
Prof. Vidic has 25 years of experience in environmental engineering focused on physical/chemical/biological processes for water, wastewater and air treatment with main focus on advancing the applications of surface science by providing fundamental understanding of molecular-level interactions at interfaces. He published over 120 journal articles and over 150 conference proceedings and reports that were cited over 6,000 times in the scientific literature.

**Municipal and Industrial Wastewater Reuse**

Reuse of municipal and industrial wastewaters is often hindered by scaling, biofouling and corrosion issues that need to be addressed effectively and economically. Based on the fundamental understanding of these phenomena, we are developing solutions that include both wastewater treatment (i.e., chemical and non-chemical) and chemical addition (i.e., antiscalants, biocides and corrosion inhibitors) to provide optimal control strategies for specific situations. Pilot-scale validation of the proposed solutions using real wastewater is conducted to validate research results under relevant process conditions.

**Water Management for Unconventional Gas Industry**

Development of sustainable water management strategies for produced water generated by the unconventional gas industry is of critical importance for the development of this natural resource. Advancing the wastewater reuse through treatment and blending is the key strategy for accomplishing that goal. We are focused on fundamental understanding of physical and chemical processes governing the reuse practice and developing models that can be used to predict kinetics and equilibrium of chemical reactions (e.g., softening, sulfate precipitation) that govern effluent water quality. These insights into the chemistry of high salinity solutions is relevant for a number of shale plays in the U.S. We are developing treatment technologies that would be suitable for water recovery from high-salinity wastewater (e.g., membrane distillation, crystallization) when the reuse is no longer feasible in mature well fields. The origin and fate of Naturally Occurring Radioactive Materials (NORM) in the shale gas wastewater under a variety of water management scenarios (e.g., treatment, storage, reuse) is elucidate by both laboratory and field studies.

**Control of Water Quality in Institutional Water Distribution Systems**

Current regulations do not address best management practices to protect water quality in institutional distribution systems that may include miles of pipes, storage reservoirs, heating tanks and other features. Technical solutions offered by numerous vendors require validation under relevant process conditions based on scientifically sound understanding of key process parameters and their impact on long-term chemical and biological water quality. We have extensive experience with testing and development of technical solutions that offer public health protection and are compatible with design and operation of water distribution systems.
Yu's research interests are directed to the mechanical performance of quasi-brittle materials, composite materials and bio-inspired materials with the aim of improving structural safety, reliability and sustainability by novel analysis and design methodologies. Yu’s research work includes (1) theoretical formulation of micromechanical inclusion problem; (2) micro-characterization and simulation of cementitious materials; and (3) coupled chemomechanical laws for time-dependent performance of structures.

Micro-characterization and Simulation
Cementitious materials are the most widely used building materials in civil construction. As a product of chemical hydration, cementitious materials display complex microstructures of pores spanning many size scales. Characterizing this porous microstructure of cementitious materials is critical for understanding the essential physical laws governing the micro- and macro-performance of cementitious materials. Furthermore, atomistic simulation based on the micro-characterization will provide qualitative and quantitative information for novel design and optimal application. By utilizing advanced experimental and numerical techniques, Yu and his team have conducted comprehensive investigation on the concrete microstructure and its correlations with the mechanisms associated with concrete durability.

Inclusion Problem
Inclusion-induced disturbance is one of the essential yet challenging problems in contemporary composite mechanics and micromechanics. Its theoretical formulation is of significant importance for innovating advanced composite materials for aerospace, marine, automotive, civil, energy, biomedicine and many other conventional/unconventional engineering applications. For these advanced engineering materials, their mechanical, electronic and optical properties strongly depend on the size and spatial distribution of the inclusions embedded in their unique RVEs. For this critical problem, Yu’s group is focused on the theoretical formulation using advanced mathematical framework.

Time-dependent Performance of Structures
With the increasing demands for sustainability, a lifespan of 100 years is now generally expected in design for critical civil infrastructures such as super-tall buildings, large-span bridges and nuclear containments. A notorious threat to this goal is the structural aging and deterioration induced by the coupled chemo-mechanical attacks during service. To mitigate this deleterious impact, a deeper understanding of the physical rules describing the damage accumulation and material fracture at different size scales is needed for structures subject to concurrent chemical and mechanical attacks. Formulation and characterization of the kinetics laws of damage growth in the microstructure as well as its coalescence to cracks in macrostructure will enable a multiscale predictive framework in structural design and analysis. Yu and his team have worked on investigating the damage growth laws by using novel instrumentation and advanced modeling.
DEPARTMENT OF

ELECTRICAL & COMPUTER ENGINEERING
Dr. George joined Pitt in January 2017 as Department Chair, R&H Mickle Endowed Chair, and Professor of Electrical and Computer Engineering. He is Founder and Director of the new NSF Center of Space, High-performance Reconfigurable Computing (SHREC), a national research center and consortium founded in September 2017 and headquartered at Pitt. SHREC features 30 academic, industry, and government partners working on collaborative research in mission-critical computing. In this field, Dr. George’s research expertise and activities are in high-performance computer architectures, apps, networks, services, systems, and missions, featuring reconfigurable, parallel, distributed, and dependable computing, from satellites to supercomputers.

Dr. George is Fellow of the IEEE for contributions in reconfigurable and high-performance computing. He was lead recipient of the 2012 Alexander Schwarzkopf Prize for Technology Innovation by an NSF Industry/University Cooperative Research Center (I/UCRC) for leading the development of Novo-G, the most powerful reconfigurable supercomputer in the world at that time. Dr. George has won a variety of faculty awards, including college scholar and teacher of the year, university teacher of the year, college doctoral advisor of the year, college faculty mentor of the year, university service award, and university productivity award. He has served as principal investigator on research contracts and grants totaling well over $20M and, with his students, authored over 200 refereed journal and conference papers. During his 20 years on the faculty at the University of Florida, he established and led to prominence the computer engineering half of the ECE Department, and he led the university committee that founded the first supercomputer center in school history that has grown to become one of the largest campus facilities in the U.S.

One of the hallmarks of Dr. George’s research is demonstrable impact from close collaboration with industry and government partners. His group works closely with NASA, AFRL, NSA, ONR, and other federal agencies, as well as Lockheed Martin, BAE Systems, Harris, Intel, and many other companies on research in mission-critical computing. One recent example is a novel form of hybrid and reconfigurable space computer (called CSP), invented by his group and then adopted by many of these partners. Computing in space is of critical need, since future spacecraft must achieve high performance and reliability in computing to fulfill mission parameters for autonomous sensor processing, guidance, and control. However, computing in space is a daunting challenge, due to the limited resources (power, size, weight) and the hazardous environment (radiation, temperature, vacuum, vibration) of spaceflight. In March 2017, a pair of these CSP space computers with high-resolution camera on the DOD STP-H5 mission became operational on the International Space Station (ISS) and will serve as a research testbed for several years under Pitt control. A second research experiment for Pitt on the ISS, featuring a cluster of CSP space computers and dual high-resolution cameras on the DOD STP-H6 mission, is scheduled for launch in early 2019. Moreover, a series of CSP-based satellites for Earth orbit and lunar flyby are slated for launch in the next few years.
Dr. Brandon Grainger holds a PhD in electrical engineering concentrating in megawatt scale power electronics and controls, microgrids, and medium voltage DC systems. Dr. Grainger has a master’s degree in electrical engineering with a concentration in electric power engineering and bachelor’s degree in mechanical engineering. He was also one of the first endowed R.K. Mellon graduate student fellows through the Center for Energy at the University of Pittsburgh.

Dr. Grainger’s research concentrations and interests are in medium to high voltage power electronics (380V and higher).

**Power Electronic R&D Efforts in Modern Grid Architectures**

The high-level technical challenges associated with microgrids include operation modes and transitions that comply with IEEE1547 (Standard for Interconnecting Distributed Resources with Electric Power Systems), control architecture and system communication. Key research and development needs are centered upon operational inverter improvements (harsh environment design, robust operation during fault conditions, improved overload, volume and weight reduction) and improved system yields (micro and mini converters). Focus is currently on (1) an integrated storage inverter, (2) high power density, medium voltage inverter design and (3) DC microgrid subsystems for shipboard applications. These areas are extremely important but protection is also one of the most vital challenges facing the deployment of microgrids.

Dr. Grainger takes a bottom-up approach to solving global electric power issues. With colleagues and graduate students, he is envisioning / designing power electronic system solutions that, when integrated, help to resolve system level problems.

**Power Electronic Circuit Reliability**

The tradeoff of grid voltage support (grid resiliency enhanced by advanced inverter capability) and the reliability of the power semiconductors (handling added stress) is under study.

**Shipboard Power Conversion**

Modular approaches are being designed to integrate energy storage on ships, reduce ship weight, equipment footprint, and improve system resiliency.

**Direct Current System Design**

Novel methods for determining faulted segments of DC architectures and microgrids are patent pending. DC circuit interruption using power electronics is a key enabler for DC grids being studied.

Power semiconductor evaluation (SiC and GaN), DC/DC converter and inverter topology design, advanced controller design, high power density design, military power systems, DC system design and protection, HVDC/FACTS, and other genres. He is a member of the IEEE Power and Energy Society, Power Electronics Society, and Industrial Electronics Society and is an annual reviewer of various power electronic conference and journal articles. He is also the chair of the award winning IEEE Pittsburgh PELS chapter.

“Presently 30% of all electric power generated uses power electronics technologies somewhere between the point of generation and end-use. By 2030, 80% of all electric power will flow through power electronics.” –Dept. of Energy
Self-powered computing devices that can run for decades with little maintenance are especially attractive to many sensor applications for which it is challenging to employ traditional battery or cable power since it is inconvenient, costly or even dangerous to replace or service them. Examples of such applications include implantable sensor, wearable health monitor, water pipeline or building HVAC status monitor, soil or water pollution monitor, etc. Energy harvesting techniques, which generate electric energy from their ambient environment using direct energy conversion techniques, provide a promising way to realize this goal. Energy harvesting can eliminate the need for batteries or wires and enable long-term running of these systems.

However, to achieve this goal, there are still several challenges. One of the intrinsic challenges is that the harvested energy sources are intermittent. Under frequently interrupted power, system running will be interrupted. Therefore, large tasks can never finish under such circumstances. To take advantage of unlimited free energy supply, a new computing paradigm which can make progress even under intermittent power supply is needed.

Non-Volatile Processor on Energy Harvesting Powered Embedded Systems

This project focuses on enabling correct and efficient software execution on non-volatile processors (NVP) for energy harvesting powered embedded systems. NVPs work with unstable harvested energy sources vital for applications such as wearable devices and the Internet of Things (IoT). Software specifically optimized for NVPs is important in that it allows an NVP to function correctly and is key for realizing embedded systems that are energy efficient, user-friendly, and environmentally-friendly. Compared with current devices that need regular maintenance, this project will enable a new class of maintenance free NVP-based embedded devices which are more practical across a wide range of applications, including healthcare, and military innovation and technology.

Non-Volatile FPGA Based System

This project aims to fine-tune various procedures on the FPGA synthesis flow based on NVM characteristics, so as to exploit their advantages and mitigate their shortcomings. First, considering the needs of self-adaptive applications, this project fine-tunes various steps on the FPGA synthesis flow. Novel techniques are proposed to optimize task scheduling, data allocation, logic mapping, placement, and routing to improve reconfiguration speed, energy efficiency, reliability, and endurance of NVM FPGAs. Second, this project explores the rich NVM design space and sets different optimization goals for look-up tables, flip-flops, and on-chip memories. The success of this project will lead to a long-lasting, rapid-adaptive, reliable, and energy-efficient platform better suited to the needs of a wide range of applications with self-adaptivity requirement, including healthcare, wellness, industry, and even military applications, all of which are critical for the United States to drive its new strategies of innovation and technology.
The parallelism and heterogeneity of new computing systems have led to a myriad of new opportunities in the design of computer architectures and systems. My research focuses on methods to allow compilers, operating systems, and computer architectures to work together in enabling higher levels of performance, improving energy efficiency, and increasing reliability and robustness of next-generation computer systems. This form of cross-layer research enables optimizations that can achieve orders of magnitude of improvement over techniques that address each layer individually. I am also active in computing for sustainability. As a member of the Pitt's Mascaro Center for Sustainable Innovation (MCSI), my work has investigated lightweight grid computing, computing/sensing hubs to support life-cycle assessment of larger systems such as buildings, emerging non-volatile memory research to support ultra-low energy computing, and balancing environmental impacts from the manufacturing and use-phases of integrated circuits. Further, I am active in interdisciplinary electrical, computer, and biological research related to development of medical instruments. My research is funded both by the National Science Foundation (NSF) and industry partners. Moreover, I collaboratively developed and direct a new NSF I/UCRC center called Nexys, which brings together industry, government, and multi-university collaborations to form multidisciplinary teams to address collectively identified key research challenges in computing.

Cross-layer Computer System Design

A key limiting factor of modern computer systems is data access latency, motivating the employment of every increasing cache size. My research shows that data access locality can often be discovered through software-layer or compiler analysis and communicated to the architecture through the operating system in a cross-layer fashion. This information can be used to improve the efficiency of architectural components such as caches and on-chip networks between processors in multi-core environments. Further, improved methods to access memory in a comprehensive fashion are possible compared with examining each system level or component in isolation. As such, cross-layer optimization often leads to dramatic improvements in performance and energy.

My research is based on the premise that system layers should be designed cooperatively to improve data access latency. Thus, application information extracted from higher system levels such as from the compiler can be used throughout the system layers to optimize the whole system. An example contribution of my work would be classification of data for parallel applications, which can be used to keep data local to the core that uses it in a chip multiprocessor (CMP). Further, the shared memory concept and non-uniform cache architectures (NUCA) that ease the programmer’s burden for leveraging parallelism in CMPs can also obscure the implied data partitioning and communication of the underlying parallel algorithm. My research also detects and recovers this information at various levels and uses it to guide data placement in distributed caches and optimize the interconnect to reduce communication delays. Further, my research leverages application data access characteristics to enable integration of new and traditional non-volatile memory technologies (e.g., flash, STT-RAM) by mitigating their asymmetric access properties.

Interdisciplinary Computing Research

I work closely with other disciplines to employ optimized computing in innovative ways. One example is the development of a lightweight grid and sensor hub called Ocelot and Lynx, respectively (Figure), which supports dynamic life-cycle assessment research crossing the borders of civil and mechanical engineering. I am also involved in developing lightweight, massively parallel sensor hubs for low-cost patient testing and monitoring.

Through my research and service I am a leader of community-wide efforts to improve the scientific method of computer science research and develop a new vision for next generation design technology and automation of computing in light of new technologies and levels of scale.
Nano-optics and nano-electronics: materials and devices; hierarchical integration of nanoscale structures into systems for multifunctional operations. Study of plasmonic phenomena as a possible gateway to merging optics with electronics and overcoming their limits. Use of nanoscale void (air) channel as a medium for low-voltage, ultrafast transport of electrons. Nano-plasmonics as an enabling technology for implementing nanosystems-on-a-chip that offer multifunctionality across heterogeneous domains including optical, electrical, chemical, and biological domains.

Nanoelectronics, Nanophotonics, and Plasmonics

Professor Kim’s research in nano-electronics area deals with developing a new class of devices that offer femtosecond transit time operating at a single-electron level at room temperature. The operating principle involves ballistic transport of electrons in localized nanochannels. This study aims at developing a fundamental understanding of the charge transport process and its application to ultrafast, low power device operation.

His research in nano-optics area focuses on: elucidation of the mechanisms of the interactions of light and metal at nanoscale; visualization of surface plasmon dynamics and interplays between polarization charges, electromagnetic fields, and energy flow on nanostructured surfaces of metal and dielectrics; utilization of these interactions in a controlled manner to enable novel functions of beam shaping and spectral filtering that can go beyond the conventional diffractive/refractive optics limits.

In nanosystems-on-a-chip research his group investigates multiscale integration of nanostructures into hierarchical systems involving various functional materials such as wide bandgap semiconductors, ferroelectric films, and plasmonic nanostructured materials. Single-domain ordered nanochannel arrays with controlled symmetry have been developed on macroscale area of wafer surface using a directed self-organization method, and have been investigated as an interaction medium.

Surface-plasmon phenomena occurring in nano-optic structures are of particular interest, since many novel properties can be derived from those and can be incorporated into an on-chip configuration for interaction with other functional materials. His group investigates plasmonics as an enabling technology for implementing nanosystems-on-a-chip that offer multifunctionality across heterogeneous domains.

He has authored five patents in nanotechnology area: self-organized nanostructured wafers; metal nanolenses; chip-scale optical spectrum analyzers and multispectral imaging devices; nano-optics-enabled photovoltaic devices; single-electron-level ballistic devices.

Relevant Publications

Alexis Kwasinski, PhD
Associate Professor
R. K. Mellon Faculty Fellow in Energy

Prof. Kwasinski’s research is in the broad areas of sustainable and resilient power and energy systems, with a focus on microgrids, power electronics, controls, availability modeling, interdependencies characterization, smart grids, integration of energy storage devices and of renewable and alternative power sources, and advanced power distribution architectures. Prof. Kwasinski joined the University of Pittsburgh from The University of Texas at Austin where he reached the rank of Associate Professor with tenure. Early in his career he worked for almost 10 years in telecommunications power and outside plant industry. This combination of academic and industry experience provided Dr. Kwasinski with a practical research perspective based on real world applications supported by thorough theoretical analyses and strong experimental validation. In his research vision, system analysis is supported and integrated with component level studies. At Pitt, Dr. Kwasinski founded the Laboratory for the Exploration of Advanced Energy Resilience Solutions (e-LEAdERS).

Resilient Power and Communications Infrastructures

Prof. Kwasinski has been studying characterization of power and communications infrastructures resilience and searching for solutions for improved performance to extreme events, such as the use of microgrids and integration of energy storage devices. He has also been developing availability models that include the effect of renewable energy sources and of lifeline infrastructures. Such models also consider the dynamic effect that local energy storage has to reduce or even prevent failure propagation from power grids into other dependent infrastructures. Resilience planning and design studies have a quantitative approach that measures degree of dependency and resilience using availability metrics and that consider power and communications infrastructures as human-cyber-physical system-of-systems. In these studies Prof. Kwasinski has conducted damage assessments in areas affected by natural disasters including hurricanes Katrina, Dolly (2008), Gustav, Ike, Isaac (2012) and Sandy, and earthquakes in Chile in 2010, New Zealand in 2011, Japan in 2011 and Napa, California, in 2014.

Power Electronic Systems

Power electronics have been enabling technologies for electric power generation, distribution and utilization, such as microgrids, that have been revolutionizing the electric power industry by challenging decades-old paradigms. These paradigm shifts also influence novel views in power electronic research integrating system and component-level studies. Prof. Kwasinski’s research is a leader in this field with studies that include advanced ac and dc power distribution architectures with active power distribution nodes, control and stabilization of constant-power loads, integration of energy storage and power generation units with multiple-input converters, and stability analysis and decentralized controls for microgrids. Prof. Kwasinski is applying this research in an NSF CyberSEES project in order to achieve more resilient and energy-sustainable wireless communication networks by integrating base station traffic, power generation and energy storage management.
Dr. Guangyong Li is an Associate Professor in the Department of Electrical and Computer Engineering. Li’s major research interests include micro/nano robotics; nanoscale characterization; thin film solar cells; biocellular mechanics. Particularly, Li is interested in developing nanorobotic systems to manipulate materials at nanoscale; developing nanoscale metrological instruments and technologies to study fundamental physics of nanodevices and to characterize biomaterials at cellular and molecular levels; studying fundamental physics of organic/inorganic thin film solar cells through multiscale modeling and simulation as well as nanoscale characterization.

**Multiscale Modeling, Simulation and Optimization for Designing Organic Solar Cells**

Organic solar cells hold the potential of being a low-cost, highly flexible renewable energy harvesting technology. But organic solar cells have not yet proven to be a viable alternative to silicon-based ones due to the limited understanding of charge transport behaviors across length scales of organic solar cells, yet such transport is crucial for device efficiency.

The objective of this research is thus to develop a multiscale simulation and optimization methodology for organic solar cells that directly links the basic materials properties (electronic and optical), nanoscale morphology and their dependency on processing conditions (e.g. temperature and time), bulk material properties (e.g. bulk mobility), and device designs, to device efficiency. We aim to merge simulation tools across multiple time and length scales using successive integration steps. The resulting tools would enable a holistic design approach where the design space will be systematically explored to dramatically improve the performance of organic solar cell devices.

**Development of Kelvin Probe Force Microscopy for In Situ Characterization of Thin Film Solar Cells**

Kelvin probe force microscopy is able to differentiate work function of surfaces at nanoscale. It has evolved into an effective tool to study electrical properties of materials such as semiconductors, organic materials, biomolecules, and nanoscale materials. For example, it can directly observe the charge transfer at interface between two materials. The right figure shows the direct observation of hole transfer between a carbon nanotube and organic semiconductor polymer revealed by Kelvin probe force microscopy. Our objectives in this research area include (1) the fundamental study on Kelvin probe force microscopy with aim to improve the resolution and accuracy; (2) investigation of charge transfer among interfaces by Kevin probe force microscopy with aim to reveal the fundamental physics of organic/inorganic thin film solar cells; (3) Characterization of junctions in organic/inorganic thin film solar cells with aim to locate any barriers that deteriorate the performance of the cells.
Human-in-the-Loop Control Systems

This direction of research is aimed to understand the capabilities of human operators in human-machine interaction (HMI) and apply this understanding to the design of efficient and robust human-in-the-loop control systems. The complexity of HMI grows rapidly in modern control systems. Highly automated systems often rely heavily on human intervention, supervision, and maintenance. Therefore, it is important and critical to understand the human capabilities and to apply this understanding to control systems design. My current work tries to evaluate quantitatively the capabilities of the human neural system in manual control. We take a comprehensive approach that synergistically combines control theory, information theory, computational neuroscience, non-invasive human experiments, and computer simulations in the study of human-in-the-loop control systems.

Adaptive Control of Networked and Large-Scale Dynamical Systems

This direction of research is to develop an adaptive, learning architecture for control of networked and large-scale dynamical systems such as the power grid. The human brain is the most intelligent controller in nature. It is an ideal source for an enlightening study of advanced control for complex engineering systems. Our research goal is to understand the control and learning principles of the human brain and to bring ideas inspired by neural principles to the control of complex engineering systems. Our current work consists of two tasks. The first task is to develop a brain-inspired adaptive control and learning architecture that takes advantages of the brain’s organizational and operational principles. The second task is to apply the brain-inspired control architecture for high-voltage direct-current (HVDC) power system. This work creates interdisciplinary schemes for biologically inspired engineering design. The brain-like circuits and algorithms can be developed and embedded in the controllers of power systems, robots, and other automatic systems that will have capabilities of self-observation, self-healing, and self-improvement.
Electric Power Engineering and Technology Development

The Electric Power program at Pitt has been developed in close collaboration with industry, government, and other constituents to provide innovative education and collaborative research programs in the areas of electric power and energy engineering. Working together with our partners, Pitt is contributing to solutions that address the aging workforce issues in the electric power and energy sector through progressive modernized educational programs, as well as to advances in technology development through basic and applied research. The program also has a strong outreach component, including contributions to K-12 STEM programs.

In the area of electric power engineering education, concentrations have been developed at both the undergraduate (B.S.) and graduate (M.S. and Ph.D.) levels, including a synchronous distance-learning based post-baccalaureate/graduate certificate program in power. The curriculum consists of a strong set of courses addressing the core principals in electric power, while being augmented with new offerings in emerging technology areas. The program’s research work spans the electric power grid chain from generation to transmission and distribution to utilization. Specific expertise is based on emerging technology development needs for microgrid and bulk power grid-level power electronics technologies and supporting systems and components of both AC and DC system infrastructures, as well as aspects of renewable energy integration and smart grid applications – including advanced power electronics converter designs, semiconductor developments, transmission & distribution system control technologies, energy storage systems, and energy management concepts. The ability to conduct both micro-grid and large-scale systems integration research for modeling, simulation, and analysis is based on the application of key industry standard tools. Research is supported through industry partnerships and government grants.

Electric Power Systems and GRID Laboratories

The Electric Power Systems Laboratory at Pitt, sponsored in-kind by Eaton Corp., is a multi-use facility for both research and educational activities. The lab is located in Benedum Engineering Hall, and has a top-end power capacity of 480-V, 200 A, 75 kW. In addition, a new high-power/high-capacity lab is currently being constructed as part of the GRID Institute at the Energy Innovation Center near downtown Pittsburgh, and will have capabilities up to 15-kV, 5-MVA AC and 1.5-kV, 1-MVA DC, with advanced networking, controls, and real-time operating and testing facilities. These facilities provide opportunities for faculty and graduate students to perform advanced work in the areas of AC and DC micro-grid developments, smart grid technologies, power electronics devices and systems, renewable energy systems and integration, controls and communications, automation and relaying, distribution engineering, power quality, energy management, energy storage, and other emerging technology areas.
Innovative Medical Engineering Developments

The iMED (Innovative Medical Engineering Developments) lab was founded in 2011 through the generous support of the Swanson School of Engineering and the University of Pittsburgh. The vision of this lab is to become an international leader in dynamical biomarkers indicative of age- and disease-related changes and their contributions to functional decline under normal and pathological conditions. In particular, the mission of the lab is to develop clinically relevant solutions by fostering innovation in computational approaches and instrumentation that can be translated to bedside care.

Given the vision and mission behind the lab, our motto is: “Output and outcome.” These two simple words fully describe the essence of the lab. “Output” describes the first goal of the iMED lab: to conduct rigorous scientific investigations whose results will be published in respected high impact journals. In order to achieve this goal, we strive to conduct cutting-edge research projects which produce results with an immediate impact. “Outcome” describes the second goal of the iMED lab: to conduct research projects that matter to patients and the public. In other words, our research must make a difference in people’s lives. The research conducted in the iMED lab must lead to important and real-life relevant advances in biomedical computational approaches and instrumentation.

The iMED lab serves as a unique, clinically oriented training ground for undergraduate students, graduate students and post-doctoral fellows interested in computational tools and instrumentation. We work very closely alongside numerous health and allied health professionals and scientists, including physicians, occupational therapists, physical therapists, speech language pathologists, throughout all stages of research, from problem formulation to grant application, from data collection to journal publication.

Our Core Expertise

Our core expertise is in signal processing, instrumentation and physiological monitoring.

Sample Project Areas

Compressive Sampling

Time-Frequency Analysis

Medical Image Processing

Transcranial Doppler Sonography

Human Walking Assessment

Functional Brain Networks

Signal Processing

Electroencephalography

Pattern Recognition

Brain-Computer Interfaces
Recent Research

Wide Bandgap Power Transistors: Research has focused on the characterization and equivalent circuit modeling of GaN and SiC power switching transistors for application to efficient electric power conversion. Device models have utilized Synopsis SaberRD for analysis of larger power conversion circuits and subsystems. We’ve also derived compact models to enable us to understand the causes of unwanted characteristics such as “false turn on.” In still other modeling efforts we’ve transformed compact models into frequency domain for incorporation of control algorithms for new concepts of Maximum Power Point Tracking in photovoltaic systems.

Rapid Point-of-Care Diagnostic Instrument: We have been developing a rapid point-of-care diagnostic instrument that can be applied to a variety of human pathogens and provide an indication of infection within 20 minutes. This represents an alternative to more costly and time-consuming techniques such as PCR. Our patent pending approach utilizes an isothermal DNA amplification technique and automated optoelectronic detection of emitted fluorescence for UV irradiated dyed samples. Data is transmitted to a hand-held mobile phone and displayed graphically for interpretation by a medical professional.

Growth and nanofabrication of β-Ga$_2$O$_3$ nanowires for devices: We are investigating vapor-liquid-solid growth techniques for single crystal β-Ga$_2$O$_3$ nanowires and subsequent arrangement of these nanowires into organized parallel arrays by mechanical combing. Beta-phase gallium oxide (β-Ga$_2$O$_3$) is gaining attention as a potentially superior wide bandgap semiconductor (WBGS) for application in power switching transistors for efficient power electronic converters or potentially for high dynamic-range mixed signal circuits at the nanoscale.
Biography

Dr. Feng Xiong is an Assistant Professor in the Electrical and Computer Engineering (ECE) Department at University of Pittsburgh (Pitt) since 2016. He received his PhD (2014) and M.S. (2010) in ECE from the University of Illinois at Urbana-Champaign (UIUC) and his B. Eng. in ECE (2008) from the National University of Singapore (NUS). Prior to joining Pitt, Xiong was at Stanford University as a postdoc fellow. His research interests are in energy-efficient electronics, next-generation memory devices, novel 1D and 2D materials, flexible electronics, nanoscale thermal transport and renewable energy harvesting. He received several awards including the Nano- and Quantum Science and Engineering Postdoctoral Fellowship, MRS Graduate Student Gold award, and TSMC Outstanding Student Research Gold Award. He is a member of IEEE and MRS.

Tunable Two-Dimensional (2D) Electronics

2D Transition metal dichalcogenides (TMDs) are widely considered to be promising candidates for beyond-Si computing due to their two-dimensional nature with no dangling bonds and unique material properties. They are studied for a range of applications such as transistors, optoelectronics, sensors, and electro-catalysis, which often have different material properties requirements. While researchers are actively looking for methods such as doping, strain, and nano-structuring to engineer the material properties of 2D films and optimize their performances for various applications, there has yet to be an effective way to manipulate their properties. We adopt a novel approach using electrochemical intercalation to engineer electrical, optical, and thermal properties in 2D materials and achieve “materials by design” for tunable electronics.

Low-Power Emerging Memories

In today’s big-data era, trillions of sensors will connect every aspect of our lives to the Internet, constantly producing an overwhelming amount of data. Traditional memory technologies such as DRAM and flash are approaching their fundamental limit and cannot satisfy the required throughput and energy efficiency. The Xiong group is working on alternative memory technologies such as phase change memory PCM and resistive memory (RRAM), which are highly scalable, energy-efficient with high-speed switching and excellent endurance.

Research Interests

- Energy-efficient electronics
- Device physics
- Flexible, wearable electronics
- Novel 1D/2D materials
- Electrochemical intercalation
- Tunable electronics
- Next-generation memory devices (PCM and RRAM)
- Neuromorphic computing
- Electro-thermal transport
- Thermoelectric energy harvesting
Emerging Non-volatile Memory Technologies

Data centers in the U.S. consume well over 100 billion kilowatt hours of energy yearly, according to U.S. Department of Energy. One of the most power hungry parts of data centers has traditionally been the processor. With technology scaling and applications’ growing demand for more memory, the majority of power consumption of data centers is shifting from the processor to main memory. Today’s memory technology cannot keep pace with this change and is reaching its limit in power consumption and density at data-center scales. This project aims to solve the energy problem posed by memory. Rather than relying solely on DRAM, our approach integrates emerging non-volatile memories, e.g. Phase Change Memory, Spin-Torque-Transfer Magnetic RAM, to construct a high-capacity and energy-efficient memory system. The research is ambitious with fundamental and applied contributions in the design and development of energy-efficient computer servers. The fundamental research includes: a new integrated memory architecture that manages hybrid memory resources; novel techniques for energy, performance, endurance and fault tolerant management; and a new hybrid main memory controller. The applied contributions are our tools that we develop including simulation and analytic models and actual software/emulated hardware system.

Nanophotonic Interconnection Network

Electrical on-chip networks are hitting great challenges in power, latency and bandwidth density with technology scaling. Such challenges are especially pronounced in the era of multi-core computing where high bandwidth, low power, and low-latency global transmission are required. For those reasons, and recent breakthroughs in nanophotonic devices, optical interconnection is again considered as a potential on-chip network for future many-core microprocessors. However, there are still fundamental limitations in nanophotonic networks that hinder their success in competing with their electrical counterpart. This project aims at future optical Networks-on-Chip, and target the bandwidth, performance, power/energy, and reliability, all being fundamental problem of on-chip optics. We use complementary solutions, joining device-level innovations, architectural novelties and operating system originalities into a systematic framework. The objective is to make on-chip nanophotonics a more practical and applicable technology for future many-core microprocessors.

Power and Thermal Management for Future Microprocessors

Many mobile embedded systems are designed to be small and compact to favor portability. As the user demand expands for more powerful, versatile, and integrated solutions, the designers endeavor to pack more and more devices into the small embedded form factors thanks to the technology advancement. In parallel with this trend, the microprocessor technology has evolved into an era of integrating multiple cores in one die, a.k.a. chip multiprocessor or CMP, to support concurrent execution of multiple applications. The recent promotion of the 3D stacking technology (stack multiple die vertically) further enables smaller chip footprints and packaging at a higher transistor density. As can be foreseen, the marriage of the future embedded systems and future microprocessors brings forth concerns in increased power density which renders the thermal management a key challenge for embedded processors. This project recognizes the incessant power and thermal challenges and the limitations of the current approaches, and promotes a new suite of solutions at a higher level that address the drawbacks of existing solutions. It is important to raise the power and thermal awareness to a high level, such as the embedded operating system, where application thermal behavior are more explicit. The proposed techniques leverage the natural discrepancies in the power and thermal behavior among different application threads, and allocate, migrate, or schedule them among different cores. The goal is to minimize power consumption and thermal violations through proactive thread management at a high level.
Highly Sensitive and Selective Biosensor Development

In this research, we have developed polyaniline (PANI)-based biosensors (top figures) for detecting four cardiac biomarkers in serum and human bloods, including Myo, cTnI, CK-MB, or BNP. The PANI was directly fabricated via both electrochemical deposition and chemical synthesis methods between pre-patterned Au electrodes. Hence our polymer growth is a mass producible and reproducible method. For the functionalization of the fabricated PANI (1-D and 2-D structures), the mAbs of cardiac markers were covalently attached to PANI by a surface immobilization method. After the PANI functionalization, the biosensing of cardiac biomarkers was carried out by measuring the conductance change of the biosensor. The conductance of PANI was monitored in the various conditions of the functionalized PANI, injecting phosphate buffer saline (PBS), bovine serum albumin (BSA), and target biomarkers. The conductance of nanowire can be modulated by the major carrier accumulation or depletion. The binding between immobilized mAbs and target biomarkers changes the net surface charge of the PANI and induces the carrier accumulation or depletion depending on the values of net surface charge and types of PANI. In addition, the developed biosensor shows non-response of conductance change to BSA or non-target proteins due to the mAbs specificity.

Graphene-Engineered Devices

We are investigating graphene-based materials for various device applications. In particular, our current focus is infrared sensor development based on graphene and graphene-oxide materials. The goal of this research is to investigate thermoelectric graphene and thermal graphene oxide (G0x) infrared radiation (IR) sensors that will operate at uncooled temperatures. The specific aims of this research are; (1) understanding of critical parameters for IR detectors, (2) development of thermoelectric IR sensor based on graphene, and (3) development of thermal IR sensor (bolometer) based on G0x. The primary scientific focuses of this research are (i) to identify responsible parameter for producing the wideband IR and backgrounds so that the proposed work will improve the understanding of graphene and G0x properties for IR sensor applications, (ii) to determine the key advantages of the graphene/G0x based IR detector approach that offers inherent broad frequencies and enhanced sensitivities without the need for bulky filters, and (iii) to conduct wide range IR surveys of the thermal emissions from hot objects at room temperature.

Current Results:

To realize a proof of concept graphene-based IR sensor, we have fabricated thermopile devices using multilayer graphene (MLG) on the top of a free-standing SiNx membrane and established a substantial temperature gradient on the device as shown in the figure (bottom). To demonstrate the IR sensor operation, graphene channels were placed such that long and narrow MLG channels are positioned on free-standing SiNx membrane (hot zone), whereas a wide graphene heat sink is located on the top of Si substrate (cold zone).
Research interests

- Science and technology of nanomanufacturing
- Materials characterization and nanoscale metrology
- Synthesis and self-organization of nanofilaments
- Self-assembly of nanoparticles, block copolymers and proteins
- Precision design and manufacturing of machines/components
- Design and analysis of surgical tools and medical devices

Nanomechanical Interactions

Owing to the mismatch of growth rates among neighboring CNTs, tension-compression competition ensues. We model mechanochemical and proximity effects.

Carbon Nanotube (CNT) Forests

In Situ characterization via transmission electron microscopy and synchrotron X-ray scattering uniquely enables understanding the collective mechanism of CNT population growth.

Biography

Prior to joining Pitt in 2016, Dr. Mostafa Bedewy worked as a Postdoctoral Associate at MIT (2013-2016), after completing his PhD at the University of Michigan in Ann Arbor (2013). Dr. Bedewy recently received the Robert A. Meyer Award from the American Carbon Society in 2016, the Towner Prize for Distinguished Academic Achievement from the University of Michigan in 2014, and the Silver Award from the Materials Research Society (MRS) in 2013.
Bio
Karen Bursic is an Associate Professor and the Undergraduate Program Director for Industrial Engineering. She received her B.S., M.S., and PhD degrees in Industrial Engineering from the University of Pittsburgh. Prior to joining the department she worked as a Senior Consultant for Ernst and Young and as an Industrial Engineer for General Motors Corporation. She teaches undergraduate courses in engineering economics, engineering management, and probability and statistics in Industrial Engineering as well as engineering computing in the freshman engineering program. She is a senior member of the Institute of Industrial Engineers, American Society for Engineering Education and a registered Professional Engineer in the state of Pennsylvania.

Research Interests
Dr. Bursic’s research focus is on improving Engineering Education and she has over 20 years’ experience and numerous publications in this area. She has expertise in researching the effectiveness of state of the art teaching pedagogies including: Active Learning (instructional methods to increase student engagement in the learning process); Model-Eliciting Activities (complex, realistic, open-ended client-driven problems based on six specific principles that include model construction, reality, self-assessment, model documentation, generalizability, and an effective prototype); Student Response Devices (hand-held electronic devices that allows students to anonymously respond to a question posed by the instructor and then compare their response to the rest of the class, also known as “Clickers”); and Flipping (video lectures viewed by students outside of class and homework and problem solving done in class). She has also done research and published work in the areas of Engineering and Project Management with a particular focus on the use of teams in manufacturing organizations. She is a well-known and active member of the engineering economy teaching community via the Engineering Economy division of the American Society for Engineering Education.
Some of the most challenging studies for medical devices today are in the interdisciplinary research on advanced material processing, biology/chemistry of interfaces, physics for design/manufacturing (i.e., microfabrication), in-vitro/in-vivo tests, and clinical trials. Our group’s primary research focus is on designing, manufacturing, and testing of medical devices to treat vascular diseases (e.g., cerebral and aortic aneurysms, peripheral arterial disease, coronary artery diseases and heart valves disease, etc.) using smart artificial materials through minimally invasive surgery. Our research lab is collaborating with a wide range of researchers focused on developing a device for important or sustainment of human life. Besides a fundamental knowledge and technology in design/manufacturing, we have a profound interest in biology, chemistry, and medicine because these complex interrelated topics represent the key challenges facing most medical devices used in the vascular system. In addition, we are expanding our research to implantable microsystems (e.g., sensors and actuators) for diagnose and treatment of vascular diseases, as well as more on circulatory diseases (i.e., cardiac, pulmonary, or renal) in the human body. Our goal of this research is to diagnose and help in the treatment of specific circulatory diseases concurrently using micro-scale devices implanted in the conduit of body. Our ultimate goal is to provide innovative minimally invasive surgical solutions based on new developments in science and engineering.

A Microstent for Cerebral Aneurysm Occlusion
The current gold standard to treat cerebral aneurysms is endovascular therapy using platinum coils to fill the aneurysm sac. While coils are beneficial, they are only useful for aneurysms with “necks” narrow enough to hold coils in place. To address this issue, we developed a novel approach, namely “Thin Film Nitinol Covered Microstent,” to occlude the neck of the cerebral aneurysm using a micro-patterned hyper-elastic ultra-thin film nitinol (i.e., thickness <6μm). This work includes developing thin film nitinol materials with specific properties, designing hyper-elastic (i.e., >700% strain without mechanical failure) micro patterns using finite element modeling, developing innovative microfabrication techniques (i.e., a novel lift-off method) to create robust micro features, and conducting in-vitro/in-vivo testings.

During this work, we had to become knowledgeable on several fields including physics for device mechanism, chemistry for blood and device interaction, and biology for thrombogenic behavior. In one example, we successfully mounted a device we developed into a 3Fr (i.e., inner diameter = 0.69mm) micro delivery catheter, deployed in 3–5mm diameter arteries in vivo swine models overcoming many engineering challenges. More importantly, results showed 4 week patency in the arteries without thrombogenic complications and undesirable excessive neointimal hyperplasia, something that was previously not thought possible in small diameter vessels. In addition, we have found that one of the dominant concerns of thin film nitinol material (or for that matter any vascular device) is thrombosis when a device is used in small vessels (e.g., <4mm diameter).

For many artificial materials thrombosis is directly related to hydrophilic and negatively charged surfaces on the materials. We have successfully demonstrated a new surface that is superhydrophilic and negatively charged, a feature that prevents thrombosis from occurring in small diameter vessels.

Smart Prosthesis using Nitinol and Other Metallic Biomaterials
In addition to vascular devices and associated studies, our group focuses on prosthesis. One novel material for prosthetic devices is Nitinol. This material is a biocompatible, equiatomic alloy exhibiting shape memory properties. It has many desirable attributes ideal for body replacement. The thermally induced phase transformation from martensite to austenite allows it to be deployed using the natural heat generated by the body, exhibiting superelastic behavior. The unique properties of nitinol material such as superelasticity, thermally induced mechanical property control, and lightweight enables the prosthesis to be simple, light, and easy to control. Another novel material is Magnesium, which is a metallic biodegradable material that is ideally able to compromise its mechanical integrity and degradation during the tissue or bone remodeling period. Several magnesium alloys showed a prolonged degradation time during implantation as well as enhanced ductility for medical devices. The unique advantages of biodegradable magnesium provide a promising candidate material for prosthetic devices that are possibly totally resorbed in the healing process. Our group is also studying on other metallic biomaterials and manufacturing processes.
In the Engineering Education Research Center (EERC), there is a focus on active learning instruction, both in the professional development offered as well as in the research conducted. This research consists of both externally and internally-funded projects, many with faculty from the Swanson School who are interested in enhancing and assessing instructional practices in their classrooms and programs. Dr. Renee Clark from the EERC collaboratively works with faculty to implement and assess their instructional practices and ultimately publish their outcomes in conference proceedings and education journals. Renee conducts research on flipped and blended classrooms and the use of games to drive professional skills and engagement. In addition, she also conducts classroom research on scaffolding of open-ended problem solving and on simple active learning in electrical and computer engineering courses, including the use of simulation for active learning and reflection in the ECE classroom. Another current research area is the application of design thinking to sustainability design challenges in the environmental engineering classroom based on a Pitt Innovation in Education grant.

Classroom Research

Renee has conducted flipped classroom research with multiple faculty at Pitt as well as at the University of South Florida via an NSF grant to compare flipped and blended instruction for numerical methods coursework. Her flipped and blended classroom research has been published in *Advances in Engineering Education* and *The Flipped Classroom: Practice and Practices in Higher Education*. Her research on the use of educational games to drive student engagement and professional skills has been conducted at Pitt and ASU, including under NSF and NRC grants, with students highlighting benefits to the use of games in engineering education and for their future careers.

Promising outcomes have also resulted from scaffolding Pitt bioengineering students in open-ended problem solving in a bio-signals course, including significantly-better project results and an ability to apply the skills once the formal scaffolding is removed. Promising outcomes have also resulted from the use of simple active learning in Pitt ECE classrooms. Simple techniques such as think-pair-share and pair programming were implemented (with little-to-no-preparation) after a faculty development workshop, and the impact has been transformational for the instructor. We found significantly-higher exam scores in the instructor’s active (versus non-active) ECE classrooms, along with overwhelming student acceptance and appreciation of the new interactive techniques. This line of research extends to the use of simulation in the microelectronics classroom for active learning and reflection, with significantly better exam scores in the active classroom and appreciative student perspectives. Dr. Clark has published on these research projects in *IEEE Transactions on Education*.

Assessment and Evaluation

Renee focuses on assessment and evaluation of educational outcomes in her classroom research and administrative duties in the Swanson School. She conducts quantitative, statistical, and qualitative analysis and evaluation. Her career background in data analysis and IT enables her to effectively conduct large-scale data management and analysis for educational projects. Renee received her PhD in Industrial Engineering from the University of Pittsburgh and her MS in Mechanical Engineering from Case Western and has 25 years of experience as an engineer and analyst in industry and academia. She completed her post-doctoral studies in engineering education at the University of Pittsburgh.
Biographical Sketch

Dr. Haight has a master’s and PhD in Industrial and Systems Engineering from Auburn University. He spent 19 years in the oil industry, four years at the Centers for Disease Control and Prevention (CDC) and in addition to his time at Pitt, he spent ten years as an Associate Professor of Energy and Mineral Engineering at Penn State. He has over 40 peer reviewed publications and is editor-in-chief and co-author of two large multi-volume handbooks in the safety engineering field.

Mathematical Modeling of Management Systems in a Safety Engineering Context

With much of his career being spent in industry both as an engineer and a researcher, Dr. Haight’s research takes on an applied nature. Most of his work has been done in the process industries of oil refining and gas processing, specialty chemicals, power generation and distribution and pharmaceuticals. His work centers on prevention of catastrophic loss of containment, general injury prevention and understanding the effectiveness of management systems to manage the risk of these types of incidents. The goal of this research is to develop and improve effective resource allocation decision making tools that allow industry management to determine which, at what quality and how much of their available resources (human and capital) can be committed to intervention activities designed to prevent these incidents. This work is titled intervention effectiveness research and it includes an operations research approach to optimizing performance of human driven systems. Dr. Haight has been exploring a multi-variant approach to analyzing the impact of and interaction between multiple performance variables in an injury/incident and safety-related performance context. Through this research Dr. Haight seeks to develop a robust mathematical model that explains the relationship between the management system intervention activities and the injuries that they are expected to prevent injury and catastrophic incidents or, at least reduce their rates of occurrence in industry.

Human Factors Engineering Research

Since humans contribute significantly to the outcomes and performance of management systems, Dr. Haight’s research also includes gaining a better understanding of human performance and human error contributions to loss events. His work includes and has included human implications on automated control systems, age related capacity loss and experience offsets as well as physiological stresses and information overload for operators in the oil and chemical industries. This has included numerous human factors/ergonomic and biomechanical case studies exploring both ergonomic and cognitive stresses on workers in health care settings, the specialty chemical industry and food packaging and distribution industries.
Research Overview

Daniel Jiang’s research interests are in the area of sequential decision making in the presence of uncertainty, where he has a special interest in handling the theoretical and computational challenges introduced by risk. Previous research has focused on topics in energy, an application area that is not only timely and relevant considering today’s rapidly changing energy landscape, but has also proven itself to be a rich problem domain, due to inherent stochasticity, the often-present curse of dimensionality, and the importance of managing risk in a sequential way.

Research Projects

- Approximate dynamic programming algorithms that exploit structural properties of intractable sequential decision problems.
- Optimal policies for energy arbitrage involving dynamic bidding strategies.
- Data-driven methods for solving risk-averse sequential decision problems.
- Spectrum of risk-averse policies for electric vehicle charging policies.
- Monte Carlo tree search using information relaxation upper bounds applied to ride-sharing.
- Naloxone procurement and distribution amidst the opioid crisis.
- Policies for incentivizing voluntary demand response.

Biographical Sketch

Daniel Jiang joined the Department of Industrial Engineering in September 2016. He received his PhD in May 2016 and MA in May 2013 from Princeton University in the Department of Operations Research and Financial Engineering. He completed his Bachelor’s degrees in Computer Engineering and Mathematics from Purdue University in May 2011. The methodologies developed in his dissertation, titled “Risk-Neutral and Risk-Averse Approximate Dynamic Programming Methods,” are readily applicable to sequential optimization problems related to the electricity market, energy storage, integration of renewables, demand response, and electric vehicles.
Research Summary and Interests

Professor Jeff Kharoufeh’s research interests span the theory and applications of probability and stochastic processes. He has made significant methodological contributions to reliability theory by pioneering a novel modeling paradigm for degradation-based reliability analysis that can be used within optimal, condition-based maintenance strategies for systems that deteriorate stochastically over time. Additionally, he has worked collaboratively with electrical engineering faculty to develop and analyze queueing models of communications systems and large-scale wireless sensor networks. His work has been funded by the National Science Foundation, the Air Force Office of Scientific Research, the National Reconnaissance Office, the Department of Veterans Affairs and other federal agencies.

Professor Kharoufeh’s current research interests revolve around energy applications of probability and operations research. Specifically, he and his graduate students are working towards scientifically-grounded ways to reduce the cost of generating, integrating, distributing and consuming renewable energy. This line of inquiry includes maintenance optimization schemes for land-based and offshore wind turbines and optimal operating policies for localized smart microgrids. This research is funded by the National Science Foundation, the Mascaro Center for Sustainable Innovation, and the University of Pittsburgh Center for Industry Studies.

Additionally, Dr. Kharoufeh’s team is currently investigating novel strategies for enhancing smart microgrids – a smart microgrid is a small-scale version of a centralized electric power grid that generates, distributes and regulates electricity flow to local residential consumers using renewable energy sources and the main power grid. In this way, smart microgrids can facilitate the integration of non-fossil-fuel sources within the main grid. Smart grid technologies (e.g. smart metering, pricing availability, etc.) have the potential to transform the means by which residential consumers purchase, store and consume electricity from the grid.

Biographical Sketch

Jeffrey P. Kharoufeh is a Professor and Co-Director of the Stochastic Modeling, Analysis and Control (SMAC) Laboratory in the Department of Industrial Engineering at the University of Pittsburgh. His areas of expertise include applied probability, stochastic processes and stochastic modeling. Dr. Kharoufeh earned B.S. and M.S. degrees in Industrial and Systems Engineering with a minor in Mathematics from Ohio University and a PhD in Industrial Engineering and Operations Research at the Pennsylvania State University where he was an inaugural Weiss Graduate Fellow and Dissertation Scholar. He currently serves as Area Editor of Operations Research Letters and Associate Editor of Operations Research. He is a Senior Member of the Institute of Industrial Engineers (IIE) and a Professional Member of the Applied Probability Society and INFORMS.
Paul W. Leu is the director of the Laboratory for Advanced Materials at Pittsburgh (LAMP). He received his PhD at Stanford University and was a postdoctoral research fellow at University of California, Berkeley. He has received the 2012 Oak Ridge Powe Junior Faculty, 2016 UPS Minority Advancement Award, and the 2016 NSF CAREER Award. His research has been featured in Industrial Engineering Magazine, Pittsburgh NPR, and Pittsburgh Magazine.

Dr. Paul W. Leu’s research group focuses on combining simulations and experiments to discover and evaluate new advanced materials for optoelectronic devices and antibacterial surfaces. His lab simulates and fabricates various nanomaterials, such as metal nanomeshes, nanosphere coatings, nanostructured hazy glass, nanowires, and nanoholes for applications such as solar cells. His research seeks to understand the various process--structure--property relationships of these nanomaterials to enable functionalities such as nanophotonic light scattering, plasmonic light trapping, antireflection, self-cleaning, and high durability.

Experiments are complimented by simulations, which synergistically explore the optical and electronic properties. This includes electrodynamic simulations of how structures interact with light at sub-wavelength scales and transport simulations to study doping and recombination. These simulations are integrated with optimization and statistical learning algorithms for rapid design and inverse design algorithms to determine processes for fabricating these structures.

More recently, LAMP has worked with various researchers at UPMC to evaluate new nanostructured surfaces for anti-biofouling (preventing adhesion), antibactericidal (killing bacteria), self-cleaning, and durability properties. The lab is determining how various mechanisms such as surface energy, topography, surface chemistry may contribute to these antibacterial properties.
Stochastic Simulation

Louis Luangkesorn focuses on the development of methods for use in stochastic simulation. These include discrete event simulation, agent based simulation and Bayesian Monte Carlo methods. His foci are input modeling to represent uncertainty and optimization and design of simulation experiments.

Input modeling in stochastic simulations focuses on representing sources of uncertainty in a system. While standard maximum likelihood estimates are suitable for many cases, what can make this difficult are a large number of classes represented in the data or a small number of samples. In the cases where a data stream is in fact made up of a number of components, data mining methods can partition of the data into classes for which standard input modeling techniques can be used. When few data samples are available, Bayesian methods provide a framework for thinking about the data generation process, then develop distributions for describing the process.

For simulation optimization, Dr. Luangkesorn focuses in cases where decision makers do not necessarily need a true optimal, but need a set of good alternatives. While a true optimal is satisfying from a mathematical perspective, decision makers who need to use the results of simulation studies often need to balance the performance of alternatives with political or economic considerations. Using methods that efficiently provide a set of good alternatives with provable properties provides the decision makers with a set of alternatives that can be tested on other criteria.

Data Science

Data science is the intersection of mathematical and statistical modeling, computer data processing skills, and subject matter expertise. This allows for a series of analysis such as descriptive models and predictive models similar to that which can be developed through data analysis and statistical methods which use models to analyze historical data, identify relationships, and predictive trends. Results can be combined with operations research models that can evaluate alternative designs that optimize objectives while balancing constraints.
The majority of Dr. Maillart’s work in maintenance optimization aims to optimally time inspections, replacements and/or repairs for one or more degrading components in an adaptive way (vs. an a priori manner) over time as information about the underlying deterioration level of the component(s) is either (i) observed directly or (ii) inferred from some signal that is probabilistically related to the true level of deterioration.

Research in medical decision making involves taking systematic approaches to decision making that will improve the health and clinical care of individuals and assist health policy formation. Dr. Maillart's accomplishments in this area have focused on chronic disease screening (e.g., personalized mammography schedules) and organ transplantation (e.g., optimal transplantation timing).

Dr. Maillart’s work to date on healthcare operations has focused on organ allocation system design; vaccine clinic operations; and donor milk bank operations. More specifically, she has considered the impacts of various health-status updating frequencies imposed by UNOS; dynamically adjusting hours of operation when administering doses from multi-dose vials (which do not last more than a day) to maximize coverage while minimizing open vial waste; and optimally blending milk from multiple donors, batching milk for pasteurization, and dispensing milk to hospital NICUs and outpatients.

Dr. Maillart’s work to date on the maintenance of implanted medical devices has focused on implanted cardiac devices, i.e., pacemakers and defibrillators. This research has investigated optimal generator replacement policies as a function of patient type, age and the remaining battery capacity as well as dynamic extract/abandon policies for failed cardiac leads.

Biographical Sketch

Lisa Maillart is a Professor and Co-Director of the Stochastic Modeling, Analysis and Control (SMAC) Laboratory in the Department of Industrial Engineering at the University of Pittsburgh. Prior to joining the faculty at Pitt, she served on the faculty of the Department of Operations in the Weatherhead School of Management at Case Western Reserve University. She received her M.S. and B.S. in industrial and systems engineering from Virginia Tech, and her PhD in industrial and operations engineering from the University of Michigan. Her primary research interest is in sequential decision making under uncertainty, with applications in medical decision making, health care operations and maintenance optimization. She is a member of INFORMS, SMDM & IIE, and was recently awarded a U.S. Scholar Fulbright Award for study in the Netherlands.
Summary of Research Interests

Prof. Rajgopal’s research interests lie in two broad areas: optimization methods (especially continuous optimization) and the development of analytical and data-driven models to solve problems in operations, logistics, supply chains, and inventory control. Of late, his primary focus has been in the area of healthcare delivery. One specific topic he has worked on extensively is vaccine delivery in low and middle income countries. As part of the HERMES team he has helped develop models to analyze and improve how vaccines work their way through the distribution chain from a central delivery location to hundreds of small clinics, many of which are in remote locations. There are many issues to be considered, including cold storage capacity, transportation, personnel, and vaccine wastage. The models help with evaluating metrics related to these as well as with addressing many “what-if” scenarios, such as changes in resource availability, supply chain structure and vaccine regimens. A related topic is the development of mathematical models to optimize vaccine administration at clinics by minimizing so-called open vial waste, which results when a partially used vial of vaccine must be discarded at the end of a clinic day. Another area he has worked on a lot recently is the improvement of operating procedures in hospitals and clinics. This includes things such as better utilization of operating room suites, improving management of hospital inventory items via better storage and inventory control schemes, and improved scheduling procedures at outpatient clinics; most of these have been at the Veteran’s Administration facilities in Pittsburgh. In the past he has also worked on many similar problems in production and manufacturing environments and continues to have an interest in this area as well.

Vaccine Supply Chain Modeling

- No. of doses wasted
- Open vial loss
- Unmet demand
- Average time in supply chain
- No. of trips
- No. stock-outs
- Avg. inventory
- Capacity utilization
- Inventory loss

Biographical Sketch

Jayant Rajgopal is a Professor in the Department of Industrial Engineering at the University of Pittsburgh. He holds a PhD in Industrial & Management Engineering from the University of Iowa and has been at Pitt since 1986. His current professional interests are in mathematical modeling & optimization, production, operations and supply chain analysis, and applications of operations research to healthcare delivery. He has taught, conducted sponsored research, published or consulted in all of these areas. Dr. Rajgopal is a senior member of IIE and INFORMS, and a licensed professional engineer in the state of Pennsylvania.
The Shankar Research Group performs research in the Department of Industrial Engineering at the University of Pittsburgh under the direction of Prof. M. Ravi Shankar. Our research focuses on understanding the behavior of materials over length-scales ranging from the macro to the nano, as a function of composition, thermomechanical history and microstructural design. Research interests include thermal and mechanical behavior of nanocrystalline metals and amorphous alloys, mechanics and property evolution in nano and micro-manufacturing processes and design of multi-functional materials.

**Multifunctional Nanograin Materials**

We are studying how nano-scale grain structures can demonstrate novel functional properties that accompany their enhanced mechanical properties. We are examining scalable approaches for creating such microstructures at surfaces and in bulk-forms in Al, Mg and Ti alloys and their technological implications for structural and biomedical applications. Ongoing research in our group has also focused on identifying the underlying physical phenomena that leads to the creation of nanograin materials with specific microstructural attributes from severe shear deformation.

**Direct Transduction of Photonic Energy into Mechanical Work**

Azobenzene-functionalized polymers can transduce light directly into mechanical work either via trans-cis isomerization or via the trans-cis-trans reorientation of the azo groups. We are examining approaches centered on design of novel compositions and mechanical designs for enhancing the efficiency of this transduction and maximizing the achievable power densities.

**Hierarchical Nanostructured Surfaces**

Surfaces with hierarchies composed of nano-scale structures on micro-scale features endow novel functionalities in several instructive illustrations from the natural world. A common example is the self-cleaning, superhydrophobicity of the lotus-leaf that is characterized by a fine micro-scale texture that is superimposed with dense fibrillar nanostructures. In the animal world, hierarchical structures lead to low drag in textured, self-cleaning skin of the shark, the antireflective eye of the housefly and manifest the phenomenon of structural color in birds and fishes. We are working on new direct-write approaches for the scalable manufacture of such complex hierarchies in polymeric materials for engineering applications.

**Mechanics of Deformations at the Micro-Scale**

Understanding the implications of the stochasticity, size-effects and constitutive properties of deformation of metals at the micrometer and sub-micrometer length-scales is critical for controlling process and product outcomes in mechanical microforming. We are working on new experimental paradigms for exploring the mechanics of deformation and microstructural consequences in microdeformation configurations using a custom-designed platform that can perform multiaxial manipulation inside an electron microscope.
Discrete Event Simulation and Agent-based Modeling

While Discrete Event Simulation (DES) and Agent Based Modeling (ABM) are well-known and popular, they are still used in only a small percentage of applications where they can be beneficial. One of Sturrock’s primary interests is identifying and removing the barriers to broader adoption and more effective use. Lowering the expertise required to use simulation effectively is one such barrier. This includes aspects of data modeling, representation of complex systems, model validation, output analysis, and much more. Sturrock is also lowering barriers in team collaboration and communication with stakeholders. He is evaluating and researching various teaching materials and techniques to help traditional students, instructors, and commercial practitioners more quickly gain command of the available tools to become effective modelers, at a lower cost, so they can solve real problems faster.

Risk-based Planning and Scheduling (RPS)

Companies have made significant investments in their ERP (Enterprise Resource Planning) systems; however, these systems typically fall short with production scheduling. Although there are a number of Advanced Planning and Scheduling (APS) products designed to integrate detailed production scheduling into the overall ERP solution, these solutions have some widely recognized shortcomings. For the most part the ERP systems and day-to-day production remain disconnected.

A critical problem with the traditional APS approach is that it requires that all the data be deterministic. Hence the resulting APS schedule is optimistic, and is typically very different from what occurs in the real facility. Feasible schedules quickly become infeasible as variation and unplanned events degrade performance. Large discrepancies between predicted schedules and actual performance are common. To protect against delays, schedulers must somewhat blindly pad the schedule with extra time, inventory, or capacity; all adding cost to the system.

Sturrock is working to integrate the latest in DES tools to model even the most complex systems and their data, and use deterministic analysis, advanced heuristics, and optimization to generate effective schedules. Then integrate stochastic analysis to evaluate the schedule robustness, and use a full complement of simulation-based tools to assess the cost and performance of potential alternatives. Net result: better performing and more robust schedules with lower user expertise.
My research is in the broad area of thermal sciences and material performance. The scientific focus is to understand the relationship between material microstructure change and its thermal properties. The work covers experimental and computational material thermophysical properties and measurement science and technology. The research has applications in nuclear fuels and materials, micro-scale measurements, and hot-cell and/or in-pile sensors and instrumentations. My group also conduct integral and separate effect experiments and modeling for fuel performance and safety assessment.

Material Microstructural Change and Thermophysical Property

Irradiation-caused damage to the microstructure of materials has a significant impact on their thermal properties, especially thermal conductivity. For instance, the thermal conductivity of silicon carbide can reduce to 5% of its starting value as its microstructure turns into amorphous under irradiation. My lab has developed methods to measure thermophysical properties of ion or neutron irradiated samples. The experimental capabilities promise significant advances in both fundamental and applied contexts. Our research also focuses on energy transfer at material interfaces such as grain boundaries or gas-solid interfaces, which are important in energy applications.

Measurement Science and Technology

Advanced measurement capabilities are essential for creation of new pathways for discovery and innovation. My lab has been developing new measurement techniques for thermophysical properties. These techniques include nano- and micro-scale thermal characterization methods, bench scale techniques, and in-pile sensors and instrumentations. A key element of these techniques is the thermal wave method that relies on phase delays rather than heat flux or temperature values to determine thermal properties. In my lab, the heating can involve an AFM tip, a thin film or fiber joule heating, or an intensity-modulated laser, and the detection can use a variety of options including optical (reflectance or radiometry), spectroscopic (quantum dot fluorescence), or electrical resistance (AFM, or thin film or fiber). A major focus is optical fiber-based techniques for hot-cell and in-pile applications.

Transient Fuel Performance: Experiment and Modeling

Transient fuel performance plays a key role in safety assessment of design-based accidents for nuclear reactors. Fuel transients involve multiple physical processes, such as fuel fracturing and fragmentation, gap conductance, clad ballooning and rupture, and coolant (water) phase change and transient boiling. We are involved in Idaho National Lab’s transient test reactor (TREAT) program, and in-pile instrumentation effort. We collaborate with multiple universities, national and international labs, and nuclear industry in modeling, separate effect experiments, and reactor experiments.
Advanced Manufacturing and Magnetic Materials

The work of Dr. Chmielus’s research group is focused on the influences and relationship of composition, impurities, manufacturing, and processing parameters on the microstructure and properties of metals in structural and functional materials, thin films, single crystalline and polycrystalline bulk as well as 3D structures produced by additive manufacturing.

In additive manufacturing, we are working on identifying the effects of powder properties and processing parameters on green and further processed (e.g. sintering and aging) samples’ microstructure, porosity, residual stresses, mechanical and fatigue properties. We are powder-bed binder jet printing, direct energy deposition, and selective laser melting/sintering in the ANSYS Advanced Manufacturing Research Laboratory. In addition, we built two custom-made printers for very small print volumes and magnetic materials. We have experience in Ni-based superalloys, Ti-64 and other alloys.

The main focuses of this research group in functional materials is in ferromagnetic shape-memory alloys, high temperature shape memory, and magnetocaloric materials. We are mostly interested in microstructure, phase transformations, mechanical, thermal, magnetic properties. Since composition, impurities, manufacturing and processing parameters have an essential effect on the microstructure and properties of samples, we investigate the relationship between them and how to reach an optimum combination of desired properties. For functional materials, we work with poly- and single-crystalline materials, thin films and 3D structures produced via additive manufacturing. Micro-computed x-ray tomography (left, top) is used to identify and quantify porosity and flaws.

In metal thin films and coatings, we are mostly interested in the effects of impurities and processing parameters on as-deposited films, but also phase-transformations, texture transformations and final properties, including resistivity, magnetization, texture, and mechanical properties. Furthermore, we investigate stresses during deposition and cycling.

All microstructure and stress characterizations can be performed with local resources (e.g. x-ray diffraction, nano-indentation, curvature measurement) or more detailed in collaboration with national labs (synchrotron (left, bottom) and neutron diffraction techniques).
The Clark lab's research focus is in the field of dynamic systems and controls. Current research focuses on mechatronic systems and measurements for specific applications.

**Morphing Materials and Structures**

Throughout the history of design, the materials available to engineers have been predominantly fixed in their properties. The design process has been one of choosing from a list of materials to select the best properties for an application (e.g. elastic modulus, toughness, heat transfer coefficients, etc.), often compromising on performance requirements to find the best match. In collaboration with the Meyer group in the Department of Chemistry, our research group has set out to change this design paradigm by creating a new class of flexible materials whose properties are not fixed, but rather can be tuned electrically to meet changing application requirements. We term these new materials electroplastic elastomer hydrogels (EPEHs) and we have recently reported our success in the translation of a molecular phenomenon across multiple length scales to control elastic modulus at the macro scale. We are continuing to develop these material concepts and their areas of use such as medical, adaptive robotics, automotive, and many other applications.

**Medical Mechatronic Devices**

A growing body of research in the Clark lab has focused on development of medical device that are at their core mechatronic systems. For example, there is an unmet clinical need for nurses and medical staff to be able to accurately and successfully place an IV catheter on a first try in patients with more difficult veins such as diabetics, the elderly and infants.

We are working with medical faculty to develop a system to use sensor-based feedback to quickly, accurately, and easily place an IV, thus maximizing successful placement on the first attempt. Another example of research with medical faculty is the development of a retrievable distal perfusion stent. Hemorrhage of the torso is a leading preventable cause of death to soldiers on the battlefield. We are developing a retrievable stent that enables hemorrhage control while still allowing branch perfusion. The device is to be deployable by field medics and allow for rapid removal, accurate device positioning and measurement of patient vitals.

**Inertial Measurement of Human Motions**

The science of human motions continues to see increasing interest and applications, such as sports, physical therapy, soldier movements and many more. The prevalent data collection methods for lab research involve the use of video camera and/or electromyography, and are carried out in restricted scenarios. Inertial sensors (i.e. accelerometers and rate gyros) can fill a need for low-cost, portable sensors for use in real environments, but the hardware and algorithms for analyzing the data are still under development. Our lab is studying the use of inertial sensors for multi-segment body motion studies for rehabilitation and human motion control applications.
The Cole Group’s focus is instrumentation and controls and the application of dynamic systems, measurement and control theory to modern industrial and energy systems. Current research efforts are investigating Bayesian techniques for system estimation and control, the application of advanced computing tools for control, supervisory control of nuclear and energy systems, and cyber security for industrial control systems.

### Bayesian Techniques for Control

Feedback control is very good at handling uncertainty in systems. As systems become more complex, there is a need to develop advanced approaches for handling uncertainty. Probability theory provides flexible and comprehensive techniques for describing uncertainty, and Bayes’ rule provides an important tool for statistical inference and updating probabilities and estimates with new measurements. This research looks at applying probabilistic tools, like Bayes’ rule, Bayesian networks, and Monte Carlo techniques, to control problems. These tools provide techniques for describing control systems that can be used at different time scales and levels of hierarchy.

### Advanced Computing for Control

Supercomputers have been pushed to incredible speeds and are ever more capable at handling huge computational problems. Oddly, the tools and techniques of high-performance computing (HPC) have found little use in control systems, which often depend upon single processors or highly decentralized controllers. This research is investigating the application of advanced computing tools, like parallel computing, to controls. These advanced tools can be used for controller design, using for example HPC, or for controller implementation, using parallel banks of controllers.

### Supervisory Control of Nuclear Systems

A significant challenge for making viable SMRs (small modular reactors) is the need to reduce demands for labor-intensive surveillance, testing, and inspection. In this research, we are using advanced control techniques to enable automated online, in-situ monitoring of SMR instrumentation and control components. This will allow engineers to rapidly measure system dynamics and loop processes, and tune these loops to optimize conditions for peak performance. A significant advantage is that these tools can be used during reactor operation to monitor components. This effort includes modeling and control of light-water, molten-salt, and advanced high-temperature reactors, the development of supervisory control to manage multi-unit SMR plants, and advanced decision-making techniques to meet economic and safety objectives.

### Cyber Security for Industrial Control Systems

As the industrial internet grows, more industrial systems will be digital, enabling robust and resilient operation of industrial processes, and improved system monitoring, fault tolerance, and data acquisition. To achieve this, I&C systems will include networks that connect systems, and supervisory control will require the transfer of information throughout the control system hierarchy from basic process and safety systems to site command and control to corporate decision making. These interdependencies presents the possibility of cyber incidents compromising plant safety, security, and emergency preparedness. This research is developing cybersecurity approaches for industrial systems that diagnose and inform decision makers about potential attacks and that provide procedures and protocols to react to such attacks. Specifically, this research will address the challenges unique to the nuclear power enterprise. The research will develop methods and approaches that can rigorously evaluate the vulnerabilities of cyber-physical systems, and will propose tools that can mitigate these vulnerabilities.
Nanoscale Contact Phenomena

The focus of the Jacobs Research Group is to reveal the atomic-scale processes governing the mechanical and transport properties of surfaces and interfaces at the nanoscale. Contacting surfaces are of critical importance in advanced nanoscale applications, including micro-/nano-electromechanical systems, manufacturing schemes, and microscopy applications. The function of such applications depends on the ability to precisely predict and control contact parameters such as contact stiffness, contact area, adhesion, and electrical contact resistance. Our group uses novel combinations of scanning probe microscopy, electron microscopy, and mechanical testing techniques to interrogate the mechanical behavior of contacts between nanoscale bodies, and the interdependence between mechanical properties and functional properties of the contact.

Mechanical and Transport Properties of Individual Small-scale Contacts

Scanning probe techniques are used inside of a transmission electron microscope (TEM). By simultaneously achieving Angstrom-scale spatial resolution and nanonewton force resolution, we can interrogate individual nanoscale bodies – including the formation and separation of their contact, and its evolution under load. Using an in situ TEM nanomanipulator with specialty scanning probe microscopy tips, we can simultaneously measure transport properties – such as electrical contact resistance and heat transfer. This enables the quantitative interrogation of the load-dependence of functional properties, and the effects of surface properties, such as roughness or structure/chemistry of surface layers.

Scaling up Insights from Nanocontacts to Describe Behavior of Micro- and Macro-scale Surfaces

Nano-/micro-mechanical testing is performed on rationally designed multi-point contacts – either few-asperity tips, or nominally flat surfaces with nanoscale roughness. Insights from single nanocontacts are used to describe larger-scale behavior. Our goal is to develop quantitative, fundamental, and predictive understanding of nanoscale contact behavior, which will enable tailored properties for advanced technologies across length scales.
Dr. Jung-Kun Lee joined the Department of Mechanical Engineering and Materials Science (MEMS) at the University of Pittsburgh (Pitt) in September 1, 2007, after spending more than 5 years at Los Alamos National Laboratory as a Technical Staff Member as well as a Director’s-funded Postdoctoral Fellow. From this background and in concert with Pitt’s strategic emphasis on energy and nanoscience, he has established the “Advanced Functional Materials Laboratory.”

His primary research interest is to explore the functional properties of nanostructured materials to address an ever-increasing energy demand. This is a very broad and interdisciplinary field. Therefore, he established inter-disciplinary research projects covering materials science, electrochemistry, applied physics, and photovoltaic device fabrication. His passion and commitment to high quality science have led to more than 130 publications in peer-review journals and more than 20 invited presentations. These numbers clearly indicates that his research quantity is far better than his peers at a same stage of the academic career. Quantitative index of his research also proves that the scientific quality of his research is very high and academic communities appreciate his achievements. His papers on functional materials have been cited more than 1500 times and the h-index of his papers is 21, which shows that he has focused on important issues of communities rather than trivial problems.

Solar Energy Harvesting

Dr. Lee has worked on solar-electricity and solar-fuel conversion using surface plasmons and shape-controlled nanomaterials. One of his approaches is to explore new types of plasmonic particles to enhance the light absorption of the solar cells containing such particles. To address the issue of the inefficient light absorption in the hybrid solar cells, he has investigated surface plasmons of the nanoshell to control the passage of photons. While the role of surface plasmons has been extensively explored in several types of the solar cells, there has been limited research to implement the surface plasmons in hybrid solar cells such as dye sensitized solar cells (DSSCs). Therefore, the gain in the efficiency of DSSCs employing existing plasmonic structures has been marginal.

To effectively apply surface plasmons to DSSCs, it is essential to explore the physical interactions among surface plasmons, solar light modulation, and carrier/exciton generation in the nanostructured films. In recent research, Dr. Lee has investigated the influence of dielectric core-metallic nanoshell particles on solar energy conversion in DSSCs. His results demonstrate that the optical resonances and the near electromagnetic field response can be tuned by changing the dimension of the core and shell components. The incorporation of plasmonic particles consisting of metallic nanoshells and dielectric core into TiO2 mesoporous photoelectrodes enlarges the optical cross-section of dye sensitizers coated onto the photoelectrode and increases the energy conversion efficiency of DSSCs. The enhanced photon-electron conversion is attributed to tunable surface plasmons of the nanoshell.

Advanced Material Manufacturing

Dr. Lee’s group has also focused on advanced material manufacturing. This includes powder synthesis, green body processing (printing, pressing, slip casting), sintering and microstructure characterization. His approach is to explore the development of disruptive manufacturing techniques that can solve fundamental problems of materials and change an inherent structure-property relation in materials. His research interest in the area of manufacturing lies in 1) high contrast hydrophobic-hydrophilic patterns by an ink-jet printing of metal and ceramic nanoparticles to change interactions between water and material surface, 2) low temperature processing of bimodal SiC ceramic composites with high mechanical strength and machinability for nuclear fuel cladding, 3) synthesis of anisotropic carbide/nitride nanoparticles showing both metallic and catalytic properties for the counter electrode of photoelectrochemical devices.
Revealing the real-time atomic-scale structural evolution is central to understanding and controlling the mechanical degradation of high-performance engineering and energy materials. However, it has been an outstanding challenge to explore those processes due to technical difficulties. Here, we developed a novel in-situ nanomechanical/electrochemical testing setup inside transmission electron microscope (TEM), which provides an unprecedented in-situ atomistically-resolved approach for discovering the previously unknown mechanisms in nanosized engineering and energy materials.

**Formation of Monatomic Metallic Glasses**

How to make a monatomic metallic glass by vitrification has been a longstanding challenge for materials scientists. Here we find an experimental method to approach the vitrification of monatomic metallic liquids by achieving an ultrahigh quenching rate of 1014 K/s. Using this method, liquid body-centered cubic metals (e.g. pure tantalum and vanadium) are successfully converted into monatomic metallic glasses, offering unique possibilities for studying the structure-property relationships of glasses. We further show the great controllable process of reversible vitrification–crystallization. The ultrahigh cooling rate also makes it possible to explore the fast kinetics and structural behavior of supercooled metallic liquids. (Nature, (2014) 512, 177-180)

**Deformation-Induced Stacking Fault Tetrahedra**

Stacking fault tetrahedral (SFT), the 3D crystalline defects, are often observed in quenched or irradiated face-centred cubic metals and alloys. All of the stacking fault tetrahedra experimentally observed till date are supposed to originate from vacancies. We discovered that surface-nucleated dislocations can strongly interact inside the confined volume of Au nanowires, leading to a new type of dislocation-originated SFT, in distinct to the widely believed vacancy-originated SFT. This discovery sheds new light onto the size effect on the mechanical behavior of small-volume materials and advances our fundamental knowledge of the 3D volume defects. (J.W. Wang, et al. Nature Communications (2013) 4, 2340).

**Twin-Size Dependent Deformation and Failure**

Although nanoscale twinning is an effective mean to enhance the strength of metals, twin-size effect on the deformation and failure of nanotwinned metals remains largely unexplored, especially at the minimum twin size. Here, a new type of size effect in nanotwinned Au nanowires (NWs) is presented. As twin size reaches the angstrom-scale, Au NWs exhibit a remarkable ductile-to-brittle transition that is governed by the heterogeneous-to-homogeneous dislocation nucleation transition. Quantitative measurements show that approaching such a twin size limit gives rise to the ultra-high strength in Au NWs, close to the ideal strength limit of perfect Au. (J.W. Wang, et al. Nature Communications (2013) 4, 1742).

**Atomic-Scale Lithiation Process of Si Anodes**

Understanding the atomic-scale structural evolution during the electrochemical reactions in solid-state electrodes is critically important to the development of high-performance Li-ion batteries. Here, we show the first atomic-scale lithiation process of both crystal-Si (c-Si) and amorphous-Si (a-Si). The lithiation of c-Si is controlled by the atomic-scale ledge mechanism, resulting in the crystallographic orientation dependence of lithiation-induced swelling; while the lithiation of a-Si is mediated by an unexpected two-phase mechanism, in contrast to the widely believed single-phase mechanism. These discoveries elucidate the atomistic origin of morphological change and degradation in lithiated electrodes. (Nature Nanotechnologies (2012) 7, 749-756; Nano Letters (2013) 13, 709-715; Science (2010), 330, 1515-1520).
Research Capabilities and Experience

Ian Nettleship’s research focuses on powder processing of ceramics. He has worked in this area for 30 years. Most of his research has focused on sintering; the high temperature process by which the porosity is removed from ceramics and the internal microstructure and properties evolve to their final state. Over the last 10 years Dr. Nettleship has also worked on the processing of macroporous ceramics for specific applications, including low-cost filters for removing harmful bacteria and parasites from drinking water and also highly porous ceramics used in bioreactor cores for bone marrow stem cell culturing. The Nettleship research laboratory has facilities for powder processing of ceramic materials using pressing and colloidal based techniques such as slip casting. The laboratory also has high temperature furnaces and facilities for preparing hard ceramic materials for microstructure analysis.

Dr Nettleship has recently extended his work into sustainable materials through a research collaboration called Pitt-NOCMAT. The goal of this collaboration is to enhance and broaden the impact of materials research by combining it with service learning on sustainably (typically locally) sourced materials and appropriate technologies that empower underserved communities. Specific examples include clay based materials for low-cost ceramic water filters and bamboo construction materials. In this new approach, Dr Nettleship collaborates closely with NGOs who work in the field to put state-of-the art research in the service of marginalized communities. In return, the real-life experience of these communities informs research at the graduate and the undergraduate level as well as student design projects.

Current Projects and Recent Interests

Recent project reflect the continued interests of the Nettleship group in multidisciplinary research on: (i) sintering of ceramics, (ii) processing of highly porous ceramics and (iii) sustainable materials.

For sintering, the research projects involve additive manufacturing of ceramics. In particular, the dry powder printing methods used in additive manufacturing of metals are being adapted to ceramics through post printing infiltration with ceramic precursors and sintering aids. The objective is to print complex ceramic structures, minimize shrinkage on sintering and improve reproducibility.

The research in highly porous ceramics continues to be focused on filters for water treatment. In particular, the processing of low-cost clay water filters for removing parasites and bacteria from drinking water. This is a Pitt NOCMAT initiative in which the research involves 3D imaging of filter pore structures and surface nanoparticle functionalization to add extra capability to the filters (such as removal of chemical contaminants). The service learning component collaborates with NGOs to provide quantitative information to small, local filter makers concerning the effects of processing variables on the properties of the clay filters.

Finally, research on sustainable materials is a Pitt-NOCMAT collaboration focused on providing engineering standards for bamboo construction materials that can accommodate the variability in natural materials. The service learning projects provides new engineering field tests for NGO practitioners.
David Schmidt received his PhD in 2009 from Carnegie Mellon University in the area of computational mechanics. His dissertation research developed predictive simulation approaches tailored to the soft tissue biomechanics of cardiovascular systems. Prior to his doctoral studies, Dr. Schmidt developed a career in industry focused on the integration of engineering design, manufacturing and computational modeling. His industry experience includes aerospace, defense, automotive, biomedical and manufacturing. The experience based developed in these industrial environments serves as a core component in his approach to research. A central aim of among his research projects is to bridge the gap between traditional engineering techniques and the evolving state simulation-based technologies. His recent research activity has been in the area of middle ear gas exchange mechanisms, multi-scale tissue biomechanics, robotic assisted surgery, biodegradable magnesium alloys and powder metal materials processing.

**Soft Tissue Biomechanics**
Motivated by the study of pathology and tissue engineering, researchers have leveraged computational-based predictive models to gain insight into the complex biomechanical response of soft tissues. Simulation approaches have become an essential component in cardiovascular research. Computational models have been used to advance basic science, develop engineered tissue alternatives and guide medical device development. Dr. Schmidt's research has developed a constitutive model based on the characterization of the collagen microstructure as is morphology governs load-bearing tissue response. A primary objective of this research has been to guide the design of engineered tissue scaffolds associated with aortic heart valve replacement.

**Middle Ear Gas Exchange and Pressure Regulation**
Gas exchange within the middle ear mucosa is a dominant mechanism associated with middle ear pressure regulation. Diseased states associated with middle ear inflammation can be attributed to complex structure-function relationships linking mucosa-scale gas exchange and aggregate pressure regulation. Dr. Schmidt's research has developed a computational model to explore the inter-related roles of constituent tissue mechanisms driving gas conductance. The adopted meso-scale approach has been used to quantify gas exchange as a function of mucosa thickness, capillary morphology, gas media and blood flow characteristics. Physiologically consistent models of capillary microstructure have been derived from multi-photon fluorescence imaging. A primary objective of this research is to establish exchange rate-limiting mechanisms under pathologic conditions associated with middle ear pressure dysregulation, Eustachian tube function and the disease state of otitis media.

**Near Net Shape Materials**
Hot isostatic processing is an industrial metal powder forming process aimed at the manufacturing of high performance mechanical parts. The processing involves the densification of a metal powder preform under elevated pressure and temperature conditions. Central to the process is the ability to achieve final part dimensions or “near-net-shape,” as minimization of traditional machining is a primary objective of the processing strategy. Research has developed a constitutive material tailored to the densification of high performance alloys. The simulation tool provides a foundation to explore the complex relationships linking preform geometry and processing parameters with final part shape. This generalized approach can be leveraged to explore densification behavior of preforms developed using additive manufacturing techniques.
High Performance Simulation Laboratory for Energy and Environment

Our research vision is to contribute toward the creation of a sustainable energy economy by providing innovative computational solutions to engineering problems that arise at the intersection of energy and environment. We work toward this vision by developing high performance computing solutions that transcend traditional disciplines. In our research, we integrate fundamentals of thermal and fluid sciences with computational mathematics and supercomputing. We routinely use parallel rendering and data analysis tools to elucidate the fundamental processes underlying the problem and improve our models.

Grid Integration of Wind Power

We apply the large-eddy simulation technique to simulate air flow through wind farms over complex terrain. We deploy the computing power of multiple graphics processing units to predict and forecast variable power generation for potential applications in power scheduling and energy trading.

Weather-aware Transmission Lines

Congestion in transmission lines is a growing concern and hinders integration of the renewable energy resources into the grid. The common practice of static rating of transmission lines operates on conservative assumptions on local weather conditions to avoid excessive line sag. However, for windy locations, these assumptions create unnecessary bottlenecks limiting transmission capacity. In our research we have developed computational tools to challenge the static rating practice in favor of the dynamic line rating, where we have computed and made use of local wind conditions (i.e., speed and direction) imminent on the transmission lines crossing complex terrain (shown above). We have shown that ampacity can be increased by 40-50% without jeopardizing the structural integrity of transmission lines. By tailoring our computational tools for emerging computing hardware, we enable forecasting of local wind conditions to better schedule transmission availability. Our research also showed that industry standards to operate transmission lines could benefit from adopting modern numerical methods.

Engineering Simulation Software Development

With ever-increasing computing power, engineering simulation software has to evolve along with new computer architectures and programming models. In our research, we apply modern software engineering principles to develop scalable parallel solvers and versatile computational geometry algorithms to tackle a variety of large-scale simulation problems that can easily overwhelm high-end workstations.
Human Motor Control Inspired Control of the Hybrid Neuroprosthesis

A hybrid actuation structure introduces effector redundancy, making its automatic control a challenging task because multiple muscles and additional electric motor need to be coordinated. Inspired by the muscle synergy principle, we designed a low dimensional controller to control multiple effectors: FES of multiple muscles and electric motors. The artificially designed synergies are found through dynamic optimizations of a gait model. An example of these synergies is provided in Fig. 2. In Fig. 3, the hybrid neuroprosthesis is used for experimental demonstration. The device uses four electric motors; one on each hip joint and knee joint, and four stimulation channels; the quadriceps and hamstrings of each leg. The hybrid neuroprosthesis is controlled using two synergy-based controllers that work in tandem to produce gait, one for each leg.

Figure 2: Artificial synergies are designed using dynamic optimizations to coordinate FES and electric motors
Biography

Dr. Smolinski graduated with a PhD in Theoretical and Applied Mechanics from Northwestern University. Prior to coming to the University of Pittsburgh, he was a Senior Research Engineer at the General Motors Research Laboratory. Professor Smolinski is a Fellow of the American Society of Mechanical Engineers (ASME) and a Founding Member of the United States Society Association for Computational Mechanics (USACM). In 2013 he was selected as the Outstanding Mentor, PrePhD Summer Research Experience at the Swanson School of Engineering, University of Pittsburgh. He has directed research projects that have been chosen as a finalist in Achilles Orthopaedic Sports Medicine Research Award from the International Society of Arthroscopy Knee Surgery and Orthopaedic Sports Medicine (2011), was 2nd Place in the John J. Joyce Award, International Society of Arthroscopy Knee Surgery and Orthopaedic Sports Medicine (2009), won the Best Paper Award from Asia Arthroscopy Conference (2008), Arthroscopy Association of North America, Resident/Fellow Scholarship Award 2007 (Basic Science).

Areas of Research

Prof. Smolinski’s research includes both computational simulation and biomechanics. Computational studies involve the development of efficient computational algorithms and the application of computational methods to novel problems. Computational simulations have been applied to device design, the study of manufacturing processes and metal forming, response of structures under extreme loading environments, analysis of surgical methods and the study of human injury mechanisms.

Biomechanical studies has involved the characterization of biological tissue structure, form and function including tissue material properties, anatomical features, morphology and tissue in-situ forces. Studies of surgical techniques include anterior cruciate ligament (ACL) and other ligament reconstruction with experimental evaluation. Computer simulations of ACL surgical repair techniques have been used to assess graft stresses and strains. Computational methods have been used for the optimization of joint replacement components to minimize component wear and the bone remodeling associated with joint replacement.
Biography
Dr. Albert To joined University of Pittsburgh as an assistant professor in 2008 and has been associate professor since 2014. He is also directing the ANSYS Additive Manufacturing Research Laboratory – a 1,200 ft² space that houses several advanced metal 3D printers. He did his undergraduate study at UC Berkeley and master’s study at MIT. He received his PhD from UC Berkeley in 2005 and was a postdoctoral fellow at Northwestern University from 2005-2008. He is an Editorial Board Member of Additive Manufacturing. His research has been supported by NSF, America Makes, NASA, DOE-NETL, Army, ANSYS, etc. He is also a recipient of the NSF BRIGE award in 2009.

Areas of Research
The primary research interests of his research group are in design optimization for additive manufacturing (AM), computational mechanics, and multiscale methods. Currently, his group is actively working on developing the “Lattice Structure Design Optimization” software for generating optimal lightweight and multi-physics design for AM. Ongoing research activities also include process-microstructure-property relationship of AM metals and support structure design optimization for AM.

Design and Optimization for Additive Manufacturing
The goal of this project is to develop robust software for design and optimization of additive manufactured (AM) structural designs based on cellular structures. The key innovation in this technology is the utilization of micromechanics models for capturing the effective behavior of cellular structures in finite element analysis (FEA). This will enable solving topology optimization problems via FEA much more efficiently. The computational tools developed will help cut time in design phase, lower manufacturing cost, and reduce time to market for new AM structural product development.
Modeling and Testing of Systems

My lab group has been conducting intricate computational/numerical studies, with experimental validation, of vibration, of acoustics, controls, and signal processing. Projects include acoustic cloaking, thermoacoustic power sensing, modeling of blood coagulation and precision motion control. Acoustic cloaks can make something acoustically invisible (no reflections or “shadows”). This has major ramifications for devices that either need defy detection, such as submarines, or for quieting noisy devices, such as a piece of machinery in a factory. Our modeling methods have shown that some of our proposed discretization approaches for realizing cloaks are feasible, and can be manufactured with 3D printing. Thermoacoustic power sensors (TAPS) were developed by Westinghouse and Idaho National Lab. They are wireless and are installed inside the core of a nuclear reactor, making nuclear power safer and more economical. Next-generation reactors will have very high temperatures, and be cooled by gases, liquid metals, or molten salt. The sensors don’t need external power and temperature. We are developing measurement methods and signal processing techniques to interpret vibrations that are measured externally.

Another exciting project is developing an advanced model of blood clotting in order to develop a decision support system for emergency medical care. Administering a coagulant or anticoagulant medication at the wrong time can have fatal consequences. Our models are lending insight into the early, rapid detection of blood clotting disorders, coagulopathies, and their interventions. New, point of care blood testing methods will likely result.

Medical Device Development

My lab is equipped with a number of capabilities for developing medical devices, including 3D printing, embedded systems programming, prototype creation, electronics design, and signal measurement and processing. One device, “SoundSentinel” listens to the sound of a cranial drill and alerts the surgeon as he or she nears the dura. Unintentionally drilling into the dura increases morbidity and mortality. Our device measures acoustic and vibration signatures, processes the signals, and then uses a classifier to decipher whether the dura has been reached.

Another device consists of novel ways of doing bipolar RF ablation, which will allow for much better control of the cutting process. The technique could result in safer and more efficient laparoscopic resection and then removal of organs.

A third device is monitors nerve impulses during brain surgeries in an effort to better protect the nerves during tumor extraction and predict the amount of sometimes inevitable nerve damage that has occurred.

The final device provides an articulable column which provides single point retraction in a matter of seconds. In addition to efficiency gains, the device is fast enough to use for trauma units. It can also be used as a laparoscopic tool holder. Both this device and SoundSentinell are in the early stages of commercial development.
Computational Materials Science Laboratory

The Wang laboratory at Pitt focuses on studying the composition-structure-processing-property relation of materials using computational materials science techniques. The primary objective of the research is to develop computer simulation/modeling into a powerful scientific technique that accelerates, achieves, and amplifies scientific discoveries in the field of materials science and engineering. Computer simulation, as important as theory and experiment, is an integral part of contemporary basic and applied material sciences. It provides great opportunities to design, characterize, and optimize materials before the expensive experimental process of synthesis, characterization, assembly, and testing.

Research Activities

The main research activities of the laboratory are to develop and apply multi-scale simulation methods to solve problems related to material design and processing. Particularly, we are interested in the development and application of such atomistic simulation methods as density functional theory (DFT), molecular dynamics (MD), Monte Carlo (MC) and kinetic Monte Carlo (kMC) methods, for revealing the microscopic processes underlying the macroscopic properties of materials.

Current Research Projects

- **Computational Design of Electrocatalysts:** We predict the active sites, reaction energetics, and reaction rate for oxygen reduction reaction on Pt-segregated Pt alloy nanoparticles and pyrolyzed non-precious metal catalysts. The acquired knowledge will advance polymer electrolyte membrane fuel cell technology.

- **Atomistic Simulation of Magnetic Alloy Nanostructures:** We study the influence of surface segregation on the magnetic properties of CoPt and FePt nanostructures. The project is aimed at enhancing the performance of magnetic alloy nanomaterials for their application in high-density magnetic recording media.

- **Mechanical Behavior of High Entropy Alloys:** Using atomistic simulation techniques, we investigate the material physics mechanism underlying the superior mechanical properties of high entropy alloys.

- **Modeling Diffusion in Metal Oxides:** Using the first-principles DFT computation method, we predict the diffusion coefficient of charged ions through the lattice and grain boundaries of $\text{Al}_2\text{O}_3$, $\text{Cr}_2\text{O}_3$ and NiO crystal. Furthermore, we study the formation and growth of these metal oxides on high temperature alloys.
Professor Jörg M. K. Wiezorek's research expertise and interest center on the study of processing-structure-property relationships in advanced materials systems. Transmission electron microscopy (TEM) based imaging, quantitative diffraction and analytical spectroscopic methods, and other modern micro-characterization techniques feature prominently in his research. Combining the principles and practice of physical metallurgy and metal physics with electron microscopy observation and measurements with appropriate computer simulations, the research leads to the discovery of novel materials and materials behaviors, explanations of the mechanical, magnetic and other physical properties of modern materials, with an emphasis on intermetallic and metallic systems. Current research thrusts include: (1) Determination of the electron density of transition metals and intermetallics by quantitative electron diffraction and DFT; (2) Surface modification for enhanced performance of structural materials for harsh environments; (3) Ultrafast (nano-scale spatio-temporal resolution) in-situ TEM of pulsed laser induced transformations (e.g. rapid solidification) in metals and alloys; (4) Innovative manufacturing processes for the sustainable preparation of high performance permanent magnet materials.

Unique New Capabilities – Quantitative TEM
Orientation imaging microscopy (OIM) enables effective quantification of microstructural metrics (e.g. grain size, texture, grain boundary character) for polycrystalline materials and is popularly implemented with SEM instruments. Using precession electron diffraction (PED) patterns obtained with 2nm spatial resolution a new TEM-OIM method facilitates automated phase mapping, grain size and texture determination at length scales not accessible by SEM-OIM, permitting study of many previously inaccessible problems in nano-scaled crystalline materials. Texture and grain scale evolution in pulsed laser processed nano-sale metal and alloy thin films (e.g. Figure top) and the origin of the extraordinary strengthening in severe plastic deformation processed steels were determined successfully by TEM-OIM [McKewon et al. (2014) Acta Mat. 65, p56; Idell et al 2013) Scripta Mat. 68, p667].

Validation of density functional theory (DFT) calculated materials properties is often hampered by lack of suitable experimental data for the material of interest. Comparisons of the electronic charge density distribution obtained from quantitative convergent beam electron diffraction (CBED) can provide a new experimental metric for rapid DFT validation protocols. Our CBED method for simultaneous measurements of Debye-Waller factors and structure factors is broadly applicable to crystalline materials. It has been used to determine the nature of bonding (e.g. metallic ‘bonds’ visualized in magenta between blue-green electron charge depleted atoms in FePd, Figure bottom) in transition metals (e.g. Cr, Fe, Ni, Cu) and intermetallics (e.g. NiAl, TiAl, FePd, Ni2MnGa). Comparison with DFT calculated results indicate need for improved theoretical treatments [Sang et al. (2013) J. Chem. Phys 138, 084504].

Research Themes and Expertise
- Processing-Structure-Properties in Advanced Metals & Alloys
- Physical Metallurgy & metal physics
- X-ray diffraction (phase ID & fractions, texture, stress/strain, crystallite size).
- Property measurements (mechanical, magnetic, thermal/calorimetric).
- Processing of metals and alloys by … e.g. Conventional & Severe Plastic Deformation (e.g. ECAP), Heat treatments (T≤1200°C, in air-, controlled atmosphere, vacuum), Melting & Solidification, Laser Irradiation (surface melting, annealing, shocking, sintering), Physical Vapor Deposition (E-beam evaporation, pulsed-laser deposition, sputtering).
Center for Energy

Mission

• Facilitate campus-wide energy-related research programs and initiatives
• Support educational program development and curriculum across energy disciplines
• Promote energy-related research and education through outreach and coordination of activities
• “Rise to the Challenge” of positioning our region for the future in the energy sector, working collaboratively with industry and community partners

Focus Areas of Energy Research

• Resources and Development
• Delivery and Infrastructure
• Utilization and Efficiency
• Materials and Storage
• Markets and Policy
• Education and Training

Objectives

Established in 2008, the Center is a unifying entity for faculty members to collaborate with each other, with regional energy industry leaders, and with government agencies to address the many challenges and opportunities associated with the generation, transmission, and utilization of energy. The Center is ideally situated to accomplish this mission, given the Pittsburgh region’s abundant natural resources and leadership in the development of clean energy technologies and energy infrastructure, the presence of leading global energy companies, and engaged community and government constituents. As the Center for Energy grows, along with the development of the Pittsburgh region’s energy nexus, it will attract and train high-quality undergraduate and graduate students, postdoctoral researchers, and visiting scientists, all of whom are important elements to evolving and sustaining the Center as an internationally prominent, university-based energy program.

Summary

The Center for Energy (www.energy.pitt.edu) is a University-wide endeavor that leverages the energy-related expertise of approximately 100 faculty members across campus from multiple disciplines and departments across the Swanson School of Engineering, Dietrich School of Arts and Sciences, Law School, Business School and the Graduate School of Public and International Affairs. The Center serves as an easily accessible entry point for industry in identifying energy-related research expertise, forming collaborations, and participating in research at the University.
Mission

The mission of the Center for Faculty Excellence (CFE) is to enhance the ability of the tenure track faculty in the SSoE to navigate the tenure period – not just to manage it, but rather to exit this period with a foundation for continued academic excellence and leadership.

Program LE²AP – Leveraging Excellence in Engineering Assistant Professors

A central activity of the CFE is Program LE²AP. This is an individualized program for tenure track faculty, designed to enhance their ability to work effectively during the tenure track period as they lay the foundation for continued success after tenure review. The central components of Program LE²AP are Senior Mentoring Committees, Professional Consultations, Tenure and Promotion Process Lectures/Discussions, and Junior Faculty Networking Lunches. Of these, the Senior Mentoring Committees are particularly important.

LE²AP Senior Mentoring Committees

Each junior faculty member in LE²AP forms a senior mentoring committee of four to five senior faculty members, at least one of who is outside the department and is potentially at another university. The committee and junior faculty member meet two times per year in a formal meeting. These mentors provide scientific and strategic insights, professional connections, regular performance feedback and advocacy for the junior faculty member. During these senior mentoring meetings, the junior faculty member presents an updated CV including information about their research, teaching and service activities. They then work with their mentors to refine strategic plans.

Summary

As of October 2017, 27 junior faculty are enrolled in LE²AP with a combined 76 faculty mentors drawn from the Swanson School of Engineering (48), departments at Pitt outside of the SSoE (13), UPMC (7) and engineering departments at Carnegie Mellon University (8). To date, 62 mentoring committee meetings have been held. The success of the CFE rests on the commitment of these faculty mentors as well as its close collaboration with offices in the SSoE including the Office of Research, the Office of Diversity and the Engineering Education Research Center (EERC).
The Center for Medical Innovation (CMI) is an interdisciplinary program housed within the Department of Bioengineering. The Center’s purpose is to stimulate, guide, and promote the development and commercialization of technological innovations to improve health care. The CMI provides an organizational structure that links faculty, students, and clinicians across the University of Pittsburgh through collaboration among the Swanson School of Engineering (SSOE), Schools of the Health Sciences, the Katz Business School, the School of Law, the Coulter Translational Research Partnership, and the Innovation Institute. As of 2016 almost 50 early-stage projects have received seed funds totaling more than $800,000 from CMI out of 177 competitive proposals considered since program inception in 2012. At least five of these clinical translation projects have attracted significant external investment for commercialization, and all have resulted in significant intellectual property development. Other projects have successfully competed for large external awards from government and private foundations as a result of the CMI Early Stage Seed Grant Funding Program. A few projects have resulted in new company formation.

CMI’s research mission is to serve as a “matchmaker” between the engineering faculty in the Swanson School and the clinical faculty of the Schools of Health Sciences. CMI catalyzes the development of such partnerships between engineers, clinicians, and students who have interests in translating their applied research into commercial products meeting the needs of healthcare delivery.

CMI’s educational mission to train the next generation of medical product innovators, managers, and developers is met through the Master of Bioengineering/Medical Product Engineering curriculum. The 30-credit MS program, established in 2012, is aimed at providing clinical project experience, introduction to new product methodologies considered state of the art in industry, and networking opportunities with regional players in the medical product development industry. Most of our program graduates go on to careers in medical product development, marketing, regulatory affairs, consulting, and entrepreneurship.

Projects identified and funded by CMI have resulted in partnerships between most of the engineering departments at SSOE and many of the clinical disciplines at the Schools of Health Sciences. Additional outreach efforts have resulted in partnerships with Carnegie Mellon University and the Allegheny Health Network. The CMI has contributed to career development of our graduates by collaborating with industry partners to place students in jobs and internships.

Dr. Alan D. Hirschman, Professor of Bioengineering, serves as CMI’s Executive Director. After a career of more than 30 years in research and industry, Dr. Hirschman joined the faculty of the Department of Bioengineering in 2011. He and his colleague, Dr. Kilichan Gurleyik, Assistant Professor of Bioengineering and CMI’s Associate Director of Education, have primary responsibility for guiding the research and educational missions of CMI. They are assisted by a multidisciplinary team of engineering faculty, clinical faculty, and representatives of the Innovation Institute. An industry Board of Advisors provides input into CMI’s direction.

Dr. Alan D. Hirschman, PhD

Dr. Kilichan Gurleyik, DSc
Coulter Translational Research Partners II Program
http://www.engineering.pitt.edu/coulter/

Vision
To provide the anchor for translating University of Pittsburgh biomedical and engineered technologies to commercialization. The Coulter Translational Research Partners II Program (Coulter TPII) envisions itself playing a key leadership role in translational biomedical research, education, and commercialization, making significant contributions to enhancing healthcare, educating future innovators and entrepreneurs, and promoting economic development in our region.

Mission
- To identify, select, develop, and commercialize promising technologies originating from faculty sponsored biomedical research that address significant unmet clinical needs and promise to improve patient care worldwide.
- To create a culture of innovation and entrepreneurial thinking across the biomedical engineering community by uniting faculty and students from engineering or the physical sciences with clinicians from the Schools of Health Sciences, students from the Joseph M. Katz Graduate School of Business (Katz) and the School of Law, and members of the business community.

Objectives
Translational Research and Commercial Preparedness. Since the Program’s funding by the Wallace H. Coulter Foundation in 2011, along with additional matching funds from the Swanson School of Engineering (ENGR), the Schools of the Health Sciences, and the Innovation Institute, Coulter TPII has accelerated the translation of new technologies to improve healthcare and address challenging unmet clinical needs. Our primary objective is to advance projects toward commercial endpoints by way of a unique risk reducing process comprised of business and stakeholder analysis, mentorship, and project management.

Competitive Grants. The Program also awards competitive grants to deserving research teams that have advanced their technologies to the point where they may be considered for license or new business formation. Coulter TPII aims to further reduce technical and business adoption risk by funding pre-clinical and clinical work that may pave the way for commercial and clinical adoption.

Collaboration. We view ourselves as part of the continuum of innovation from basic research to commercial translation. Housed within the Bioengineering Department of the Swanson School of Engineering, we collaborate closely with the Center for Medical Innovation (CMI) and the Clinical Translational Science Institute (CTSI) that support pilot projects, which often then advance through the Coulter TPII Program. Ultimately, we work with the Innovation Institute to help assure a successful transition to commercial enterprises. Our objective is to continue to strengthen these relationships and partner with other programs across campus.

Education. Our educational objective is to engage faculty and students in the process of innovation and entrepreneurship by way of our rigorous and immersive process. Scientific and clinical PI’s work together with fellows and students to develop regulatory, reimbursement, IP and business strategies. We also recruit graduate students from ENGR, Katz and Law schools to assist project teams during a 14-week “Bench-to-Bedside” course intended to align their technology-based solutions with real world needs.

Summary
Since its inception, the Coulter TPII Program has established a new model to assure that Pitt’s world-class biomedical research ideas become commercial solutions to real-world problems. In its short history, the Coulter TPII Program has:
- Attracted over 157 applications covering medical devices, drug delivery systems, and diagnostics
- Funded 20 projects and 40 principal investigators with an awarded a total of over $2.8 million in direct grant support
- Enabled formation of four companies with $3.2 million in professional funding
- Enabled granting of four license options, of which two are under negotiation toward full licenses
- Generated an additional $10 million in follow-on grant funding to the University
- Directly and indirectly impacted 50 students per year
Electric Power Systems Lab

The Electric Power Systems Lab at the University of Pittsburgh, sponsored in-kind by Eaton, is a multi-use facility for both research and educational activities. The lab is located on the Swanson School of Engineering’s Energy Floor in Benedum Hall, and the design of the facility was inspired by Eaton’s Power System Experience Center in Warrendale, PA. Through innovative research and education the ultimate purpose of the lab is to equip and train up the next generation of electric power engineers.

Objectives

The lab provides opportunities for faculty and graduate students to perform advanced work in the areas of AC and DC micro-grid developments, smart grid technologies, power electronics devices and systems, renewable energy systems and integration, controls and communications, automation and relaying, distribution engineering, power quality, electrical safety, energy management, energy storage, and other emerging electric power technology areas. The educational components integrate new course developments in electric power engineering focused on these same emerging areas, utilizing the equipment and technologies of the laboratory.

Summary

- **Technical Specifications:** Maximum power capacity: 480-V, 200-A, and 75-kVA.
- **Core Equipment:** Main Electrical infrastructure, motor control centers, switchboard, protection, M-G sets, UPS, data-servers, power factor correction, isolation transformers, and other miscellaneous components.
- **External Components (as of 2014):** Solar PV panels, donated by John A. Swanson, PhD ’66 and located on the Benedum Hall roof, are integrated into the lab (including both AC and DC interfaces).
- **Future Enhancements:** Provisions have also been made for incorporating a gas-fired generator and potentially a micro-wind turbine. A sag generator has been integrated into the main infrastructure, and a surge generator is under construction.

The Workbenches: Six custom-designed workbenches are innovative features of the Laboratory. The workbenches were designed, prototyped, and tested by Eaton and Pitt throughout 2013, and are now integrated into the overall laboratory environment, and are compatible with the other power system equipment and components.

Each bench is capable of functioning as a stand-alone entity. The overall objective of the workbench design is to seamlessly combine the configurable load banks and programmable logic controller (PLC) into the workstations, providing a wide array of functionality, while minimizing space within the facility. Each bench includes resistive, inductive, capacitive, and harmonic loads, with auxiliary connections for other lads and the capability to feed an external motor control center (MCC). Advanced metering devices are integrated to communicate readings throughout the entirety of the lab and allow students to clearly view all of the electrical phenomena within the bench.
Engineering Education Research Center
http://www.engineering.pitt.edu/eerc/

Director
Mary Besterfield-Sacre, PhD

Mission
The Center strives to engage faculty in the integration of research-based practices to enhance their teaching, as well as to engage faculty in utilizing research to better understand learning of engineering. The vision of the EERC is to expand engineering education research and produce new approaches to learning that engage students.

The Engineering Education Research Center's (EERC) mission is twofold: 1) enhance the teaching and learning of engineering within the Swanson School of Engineering; and 2) expand engineering education research efforts at the University. The overarching goals of the EERC are to:

1. Nucleate the Swanson School of Engineering’s (SSoE) strong research programs to educational innovations at the graduate, undergraduate, and K12 levels.
2. Conduct high quality engineering education research.
3. Foster opportunities for faculty and future faculty development in teaching excellence.

Center/Program Structure
The EERC consists of a Director, Mary Besterfield-Sacre, as well as the following:

1. Director for Assessment, 2. Assistant Director of Professional Development, Director of Special Projects. In addition, the center has faculty that work part time who are involved in special projects. These individuals help to operationalize certain school-wide initiatives. One person works to help with professional development of future faculty, one person works to help foster innovation and entrepreneurship activities in the engineering school, and one person helps to assess new programs. These individuals are non-tenure stream faculty, who are supported to work beyond their teaching obligations on various STEM educational efforts. We also have two technicians that work for us – one for Flipping and Innovation/Entrepreneurship.

Description of Programming
New faculty and future faculty (grad students and post docs) development.

Innovation and Entrepreneurship activities.

- Flipping the classroom
- Research in engineering education
- Faculty Development and evaluation of a new joint institute with Sichuan University

Impact
We are young, but our activities in the SSoE along with support from our dean have allowed us to be successful along a number of lines. Students and faculty are actively involved and we definitely have positive presence in our school. We believe that our greatest achievement is that recently the Provost, who initially supported our start up, was so impressed with our work, that she is funding the start up and creating a sister center (Discipline-Based Science Education and Research Center) in the School of Arts and Sciences.
Human Factors Engineering Laboratory

The Human Factors Engineering (HFE) Laboratory is a team-based teaching and research laboratory for undergraduate and graduate students. The laboratory focuses on cognitive, ergonomic, and environmental aspects of human factors, and their influence on safety, productivity and quality. The lab has a wide array of hardware and software including the University of Michigan’s 3D SSPP for Static Strength Prediction based ergonomic studies and “Energy” the University of Michigan’s Metabolic Energy Expenditure Prediction Program, Discovery Machine virtual reality software for teaching energy isolation, as well as Minitab, SPSS and NVivo7 for data analysis.
**Human Movement and Balance Laboratory**

*http://engineering.pitt.edu/hmbl/*

**Mission**

The mission of the Human Movement & Balance Laboratory (HMBL) is fall and musculoskeletal injury prevention in healthy and clinical young/elderly adult populations. We achieve these goals by gaining a thorough understanding of the biomechanical and postural control principles that govern human movement, balance during standing/walking, and performance of occupational tasks. A multidisciplinary group of researchers including biomechanical engineers, physicians (geriatricians, neurologists and psychiatrists), and physical/occupational therapists work in close collaboration to achieve our research goals. HMBL is a state of the art space designed and equipped to analyze the dynamics of human motion.

**Objectives**

Current research projects include a wide range of experimental studies examining fall prevention following external disturbances such as slipping or tripping, prosthetics, ergonomic-related research, cognitive research and imaging applications in various population types. In conjunction with experimental studies, biomechanical computer modeling is used to gain a greater understanding of the impact of environmental and human factors on the risk of falls and injury.

**Summary**

Our laboratory is a full gait analysis facility specifically designed to conduct locomotion studies related to postural control but also capable of capturing small finger movements involved in typing. Three dimensional motions and foot forces as well as electro-myographic data can be collected during walking or other daily tasks including activities such as stopping, turning, multitasking, etc. We are also equipped with an electromyography and accelerometer system, a Biodex strength machine, a Biolog heart rate and skin conductance monitor. The motion data is collected and synchronized with ground reaction forces and other biomechanical data. Thus, this system allows the collection of all gait variables required to provide a complete description of whole body biomechanics. Motion capture is possible on our level walkway, uneven walkway, ramp, uneven ramp, or stairs. We are also able elicit perturbations of slips, stumbles, and trips.

The two images above are examples of the biomechanical analysis and computer modeling able to be done to better understand the factors involved in normal gait, slips, trips, and falls.

**Investigators**

April Chambers, PhD  
Rakié Cham, PhD  
Kurt Beschorner, PhD  
Mark Redfern, PhD
Mascaro Center for Sustainable Innovation
http://www.engineering.pitt.edu/MCSI/

Mission
Established in 2003, the Mascaro Center for Sustainable Innovation promotes the incorporation of sustainable engineering concepts and practices through the University of Pittsburgh Swanson School of Engineering. Its mission is to create and nurture innovations that benefit the environment, positively impact the University and community-at-large and improve quality of life. MCSI has a holistic approach to sustainability. Through the integration of curriculum, groundbreaking research and social engagement, the Center engages students, faculty and staff as well as everyday citizens to explore and experience sustainability in practice and performance.

INNOVATE Sustainable Research
An interdisciplinary team of faculty researchers engage with the Center to develop the next generation of sustainable engineering solutions for humanity. These faculty are passionate about the impact their research can have on areas including green building design and construction, infrastructure and materials. Participating faculty and PhD students come from all six engineering departments at the Swanson School as well as from the University’s Joseph M. Katz Graduate School of Business, and the schools of Education, Medicine, Public and International Affairs and Public Health.

EXPLORE Interdisciplinary Education
Believing that sustainability can’t simply be taught from a text book, the Mascaro Center encourages students to explore hands-on research through an undergraduate summer program in sustainable engineering. This competitive program culminates in a sustainability conference where student present their research findings to peers, faculty mentors, and community leaders. MCSI also administers two undergraduate certificates in Sustainability and Engineering for Humanity. Both provide students with a more competitive pedigree upon graduation. MCSI also partners with and mentors student groups including competitively awarded service-oriented projects aimed at implementing solutions that benefit the University and / or the greater community.

ENGAGE Community Impact
Sustainable engineering is most effective and impactful when students and faculty engage directly with communities. The Mascaro Center is committed to help underserved and distressed communities develop sustainable, affordable solutions for everyday life from home energy audits and sustainability landscapes to new hydropower generation technologies for Pennsylvania’s many rivers. MCSI faculty and student also engage one-on-one with middle and high school programs to introduce sustainability concepts and practices and also pique their curiosity and interest in STEM fields.

What’s In a Name
The Mascaro Center was named in honor of John C. “Jack” Mascaro, founder of Mascaro Construction Company, LP, one of the Pittsburgh regions leading sustainable development and construction companies. MCSI is guided by Mr. Mascaro’s philosophy to pursue sustainable outcomes that exist outside the lab and directly impact the community.
Materials Micro-Characterization Laboratory (MMCL)

Mission

The MMCL supports research and innovation at the University of Pittsburgh and beyond by providing access to state-of-the-art experimental tools, effective techniques, and expertise of its personnel for complete materials micro-characterization. This encompasses visualization of the surface and internal structure of materials and associated changes across microscopic to near-atomic length scales. Characterizations can also include locally resolved measurements of materials composition, structure, micro- to nano-mechanical properties, and specialized specimen preparation needs.

Facility Description

The MMCL is located on the 5th floor of Benedum Hall and is part of the Mechanical Engineering and Materials Science Department, but is also coordinated with the PINSE NFCF. The MMCL capabilities can be accessed by use-request via the web-based system FOM at https://fom.nano.pitt.edu/fom/welcome. Current characterization resources of the MMCL include a versatile X-ray diffractometer (XRD), two complementing scanning electron microscopes (SEM), and an analytical high-resolution transmission electron microscope (TEM), a multi-mode scanning probe microscope (SPM), and a nano-mechanical testing system. Additionally, a complete suite of modern sample preparation equipment is accessible in the Fischione Center of Excellence for EM-sample Preparation.

Instrument Descriptions

• The XRD (Empyrean, PANalytical) offers non-destructive characterization of solutions for solids, fluids, thin films and nano-materials with Cu- or Co-K-alpha X-ray beams regarding phase constitution, crystallographic texture, crystal quality, lattice strains and/or nanoparticle size distributions and shape.

• The JEOL JSM 6610-LV is a low-vacuum (Environmental) SEM equipped for surface imaging and elemental composition measurements by energy-dispersive X-ray spectroscopy (EDS) with sub-micron resolution.

• The FEI Apreo Hi-Vac is a field-emission gun (FEG) high-resolution SEM optimized for crystal orientation and phase mapping by back-scatter diffraction (EBSD) orientation imaging microscopy (OIM) and EDS capable of imaging with 1nm (1.3nm) at 15kV (1kV) without beam deceleration and 1nm at 1kV with beam deceleration.

• The FEI Tecnai G² F20 S-Twin is FEG-TEM offering atomic column resolution (0.11nm info-limit) in combination with a specimen tilt range of ≤±35°, and is capable of forming intense electron probes as small as ≈0.5nm in diameter for composition and diffraction analysis. Equipped with a 2kx2k CCD camera, EDS, and precession-electron-diffraction assisted automated crystal orientation mapping (NanoMegas Topspin) it permits analysis of microstructural and micro-chemical changes, crystal defects, as well as mapping of texture, strain and phase fractions at micrometer to sub-nanometer length scales.

• The DI Dimension 3100 SPM offers multi-modal surface morphology and property characterization (AFM/STM/MFM).

• The Hysitron TI900 Triboindenter nano-mechanical test system offers nano-Newton resolution depth-resolved measurements of hardness and elastic modulus. Normal (hardness) and lateral (friction) force loading configurations provide a sub-micron scale testing arena with nanometer resolution in-situ SPM imaging.

• The Fischione Lab uniquely offers access to world-class expertise and a complete suite of state-of-the-art equipment for high-fidelity electron microscopy sample preparation by conventional mechanical, electro-chemical, Argon-ion-beam and plasma-based approaches.

Contact the academic Director of the MMCL, Professor Jörg Wiezorek, e-mail at Wiezorek@pitt.edu, or call 412-624-0122, if you are interested or have questions regarding the MMCL use and offerings.

TEM images of solidification microstructures in Al-Cu alloys after laser melting, and Cu distribution map in Al-19Cu.
**Mission**

The McGowan Institute serves as the focal point for the University's leading engineering, scientific and clinical faculty who are working in the areas of tissue engineering, cellular therapies, and medical devices.

**The Institute’s mission is**

- To provide a national center of expertise in regenerative medicine focused on developing and delivering therapies that reestablish tissue and organ function impaired by disease, trauma or congenital abnormalities;
- To foster the generation of scientific knowledge in regenerative medicine and to share that knowledge with researchers, clinicians and the public through educational activities, training and publications;
- To educate and train scientists and engineers to pursue technologies related to regenerative medicine, and train a generation of clinicians in the implementation of regenerative therapies, and;
- To support the commercialization of technologies in regenerative medicine and thereby accelerate the translation of research discoveries to clinical implementation and patient benefit.

**Objectives**

There are over 230 McGowan affiliated faculty, all of whom are independently recognized for their respective expertise, who have elected to work in multidisciplinary teams for the advancement of the core sciences, the development of innovative devices, procedures and clinical protocols, and the pursuit of rapid commercial transfer of new technologies related to regenerative medicine.

Many McGowan affiliated faculty are clinically active, seeing patients every day. These clinicians work with the collaborating engineers and scientists in the identification of research needs and the pursuit of solutions for such needs. This bidirectional clinical translation helps keep projects “on-target” and expedites the adaptation of new technologies in the clinic.

Also critical to the mission is the education and training of the next generation of scientists, clinicians and engineers who will be carrying the field forward toward the ultimate goal of improving the quality of life and the reduction in health care costs. Graduates who are mentored by McGowan faculty are eagerly recruited by commercial, academic and governmental entitites. Training includes opportunities in the laboratory as well as in clinical settings, a combination that is not available at many other institutions.

Technologies developed by McGowan affiliated faculty has resulted in the formation of 25 companies. These start-ups now employ over 430 people and have raised over $436 million in external funding. These companies are an essential component of the McGowan Institute commitment of rapidly moving technologies from the lab bench to the bedside.

**Summary**

The McGowan Institute eagerly seeks opportunities for collaboration with academic, governmental and commercial partners. The Institute Director is William R. Wagner, PhD, who is a professor in the Department of Surgery at the University of Pittsburgh, with joint appointments in the Departments of Bioengineering and Chemical Engineering. For more information, please see www.mcgowan.pitt.edu.
Musculoskeletal Research Center

www.pitt.edu/~msrc

Mission

The Musculoskeletal Research Center (MSRC) was established in 1990 for the purpose of orthopaedic education and research. Since then, the MSRC has been a flourishing enterprise where engineers, biologists, physicians and surgeons work together to teach and mentor highly qualified students, research fellows, and residents. Our multidisciplinary integrative research programs expose all to state-of-the-art translational research in orthopaedic medicine. Our laboratories are designed to allow researchers to collaborate seamlessly and perform research projects at the molecular, cellular, tissue, and joint levels.

Objectives

Research. Our current research is focused in two areas: 1) measurement of the properties of ligaments and tendons and joint mechanics and 2) functional tissue engineering (FTE) and regeneration of ligaments and tendons. Our Mechanobiology, Tissue Mechanics, and Knee Kinematics and Joint Robotics Laboratories are organized to investigate the cellular and molecular responses to mechanical stimuli to improve the outcome of ligament and tendon healing. With the innovative use of robotic technology (developed in our research center for over two decades) in combination with numerical methods for modeling, we examine the contribution of individual ligaments and tendons to joint function. Currently, we are also exploring the use of biodegradable magnesium (Mg) and Mg alloys for ligament regeneration.

The research team at the MSRC is also in close collaborations with Dr. Giuliano Cerulli, Catholic University of Rome in Italy, Drs. Richard Steadman, and Marc Philippon, The Steadman Philippon Research Institute in Vail, Colorado and Dr. Pamela Moalli, Magee-Womens Hospital of UPMC.

Education. The MSRC offers a wide variety of opportunities for motivated undergraduate and graduate students to learn and conduct orthopaedic research. Each year, we offer the Summer Undergraduate Research Program, which serves to expose students to sound scientific research. Those students who have displayed high aptitude and academic excellence are invited to continue their projects throughout the academic year. We also welcome international research fellows from diverse backgrounds to study with us. Our students and fellows also learn how to present their research findings and many have won awards at national and international conferences and symposia, such as the International Symposium on Ligaments & Tendons (ISL&T), the World Association for Chinese Biomedical Engineers (WACBE), the Orthopedic Research Society (ORS) and the Biomedical Engineering Society (BMES). They also have the opportunity to participate in the organization of conferences hosted by the MSRC.

Service. The MSRC also strives to serve the scientific community, particularly the fields of orthopaedic sports medicine and biomechanics, such as the ISL&T, WACBE, ORS, BMES, American Society of Mechanical Engineers (ASME), and so on. Our center has also hosted members of the general public ranging from aspiring middle school students (and their parents), medical and graduate students, visitors from other academic institutions and industry for tours and outreach programs.

Summary

Together, the MSRC has earned a national and international reputation of excellence in basic and translational research. More than two thousand visitors have toured our facilities and many have interacted with our research teams. The MSRC has educated over 465 trainees, including over 100 research fellows from 14 different countries, as well as over 75 graduate students.
With the complementary nature of expertise at each Site, the NSF SHREC Center will address research challenges facing the three domains of mission-critical computing, by exploiting a variety of existing and emerging computing technologies, including digital signal processors, field-programmable gate arrays (FPGAs), graphical processing units (GPUs), hybrid processors, advanced memories, and high-speed interconnects. For space computing, a specialty at the Pitt and BYU Sites, the Center will develop, evaluate, and deploy novel forms of space architectures, apps, computers, networks, services, and systems, while leveraging commercial and radiation-hardened or -tolerant technologies. For high-performance computing, a specialty at the Pitt, VT, and UF Sites, the Center will explore the application and productive use of heterogeneous computing technologies and architectures in support of high-speed, mission-critical computing. For resilient computing, a specialty at the Pitt and BYU Sites, the Center will exploit its expertise in fault injection and mitigation as well as radiation testing to demonstrate unique reliability concepts and solutions, including adaptive hardware redundancy, fault masking, and software fault tolerance.
Mission

The vision of our ERC, led by Pitt PI William Wagner, PhD, is to transform current medical and surgical treatments by creating “smart” implants to improve treatments for orthopedic, craniofacial, neural and cardiovascular ailments, coupled with the development of a vibrant, diverse workforce well-prepared for the multidisciplinary and global challenges and opportunities of the new millennium. The major goal is to revolutionize metallic biomaterials (RMB) and smart coatings with built-in responsive biosensory capabilities which can adapt to biological changes, to create novel bio-functional Engineered Systems. The ERC lead institution is North Carolina A&T State University (NCAT) [a historically black college/university] with core partner institutions, the University of Pittsburgh (Pitt) and the University of Cincinnati (UC), global research partner Hannover Medical School (MHH) and other global and national partners that include industrial partners, innovators, and state and local government entrepreneurial networks.

Intellectual Merit

Through the intertwining of carefully-planned, cutting edge research on a global level among partner institutions the ERC-RMB is creating engineered systems (ESs) related to: 1) ES1-Craniofacial and Orthopedic Applications, 2) ES2- Cardiovascular and Thoracic Devices and 3) ES3- Responsive Biosensors and Neural Applications. The three (3) ESs (ES1, ES2, ES3) are driven by three (3) overarching research thrust areas (color coded in our strategic plan) comprised of enabling technologies and fundamental knowledge: Thrust #1: New materials development (Red Team); Thrust #2: Materials processing/characterization and modeling (chemical, physical, mechanical, modeling) (Blue Team) and Thrust #3: Biocompatibility testing (Green Team). These three thrust areas (Red, Blue and Green Teams) work harmoniously to generate revolutionary breakthroughs in multiple areas of patient care leading to the development of medical systems R&D - devices and applications (Grey Team) in ES1, ES 2, and ES3.

Broader Impact

The strategic plan for education and outreach guides all aspects of education and outreach initiatives. Activities are designed for effective teaming within and across the ERC partner campuses, leveraging the key competencies and constituencies of the ERC’s staff and students, and are assessed formatively and summatively. Dissemination is effectively achieved through relevant conferences and workshops. The human resources pipeline development to recruit outstanding students into the University education component is achieved through broad-based outreach programs targeted at K-12 school students, community college students and teachers, counselors, parents and administrators. Diversity is being promoted through strategic partnerships with community colleges, minority serving institutions and key NSF HRD programs. Graduate courses on topics relevant to ERC-RMB are being successfully offered in a trans-ERC distance learning format. Our highly effective seminar series continued for both ERC and Bioengineering students on converging technologies, translational research and education and the innovation ecosystem.
Mission

The mission of the Orthopaedic Robotics Laboratory is the prevention of degenerative joint disease by improving diagnostic, repair, and rehabilitation procedures for musculoskeletal injuries using state-of-the-art robotic technology. Thus, diarthrodial joint function will be elucidated and the roles of the bony and soft tissues assessed. The technology in the laboratory includes novel robotic systems and the lab serves as a multi-disciplinary CORE facility with collaboration promoted between investigators. The Orthopaedic Robotics Laboratory occupies 1800 sq ft in the Center for Bioengineering (CNBIO) and is a collaboration between the Department of Orthopaedic Surgery and Department of Bioengineering.

Robotic Technology

The MJT Model FRS2010 is a six-axis test robot with a compact workspace and high stiffness. The hybrid control system that uses position and force feedback is quite robust and allows a wide range of applications. Operators can modify every control parameter for their desired purpose. Thus, the MJT can be customized easily. Other advantages of the MJT Model FRS2010 are portability, low maintenance costs, universal programming language, and realistic loading conditions. This robotic technology can also be used to examine the function of multiple joints such as the knee, glenohumeral joint, acromioclavicular joint, spine, elbow, hip and ankle.

These capabilities are enhanced by supporting equipment that can measure joint contact pressures; tissue deformations and forces during joint loading; and tissue properties. State-of-the-art fluoroscopy, ultrasound, and arthroscopy systems are available. In addition, the laboratory includes the Shoulder Testing Apparatus r4 (STAR4) that allows simulation of muscle forces at the glenohumeral joint and measures resulting motion and joint contact forces. Recently, this device has been upgraded to include the capability to test knees.
Gertrude E. and John M. Petersen Institute of NanoScience and Engineering (PINSE)
Nanoscale Fabrication and Characterization Facility (NFCF)
www.nano.pitt.edu

**Mission**

Founded in 2002 on the University of Pittsburgh's Oakland campus, the Gertrude E. and John M. Petersen Institute of NanoScience and Engineering (PINSE) fosters collaboration and innovation for members of the University community, as well as researchers throughout the region. To support the mission, PINSE established the Nanoscale Fabrication and Characterization Facility (NFCF) in 2006 through an endowment by alumnus Gertrude E. and John M. Petersen. The NFCF mission is to provide state-of-the-art characterization and fabrication services and scientific expertise for University of Pittsburgh researchers, as well as others in academics, government, and industry.

**Objectives**

The primary objective of the NFCF facility is to provide the infrastructure, equipment, and staff support that enables faculty, as well as academic and corporate partners, to undertake competitive research and development in the growing number of fields that rely on nanofabrication and materials characterization. NFCF is a University shared-user facility located in Benedum Hall. This 4,000 square foot facility serves the nanofabrication and characterization needs of internal and external users by providing state-of-the-art equipment that is core to nanoscience and nanotechnology research. NFCF is designed to support fabrication and characterization of nanoscale materials and structures, and integration of devices at all length scales. The NFCF Characterization facility houses state-of-the-art electron microscopy and spectroscopy equipment: X-ray diffractometer (XRD), two electron microscopes (JEOL JSM 6510LV and Zeiss FEG-SEM Sigma500V) that are equipped with Oxford EDAX detectors for elemental composition, two transmission electron microscopes (JEOL 2100F STEM and Environmental Hitachi TEM H9500) that are equipped with EDAX detectors for elemental composition; the JEOL 2100F has a field-emission electron source tool with EELS capabilities. In addition, the facility provides an electron probe micro analyzer (JEOL JXA-8530F EPMA), scanning probe microscopy, ellipsometer, FTIR microscopy, and Raman microscopy tools. The NFCF fabrication facility houses advanced equipment with core nano-level (20 nm) capabilities for fabrication, including electron-beam lithography system (Raith e-line 30KV), dual-beam system (FEI Scios FIB/SEM DB), plasma etching, thin film deposition (e-beam evaporation, sputtering, chemical vapor deposition, and pulsed laser deposition), soft lithography (Suss MJB3 and Quintel 4000 mask aligners), and more.

*SEM image of Pt nano-particles on Au prisms (Jill Millstone group).*  
*Optical image of free standing IR detector (Minhee Yun group).*
Mission

Our mission at the RFID Center of Excellence is to be a unique workforce, rooted in a research and learning environment that is strongly connected with industry. As the landscape of engineering design evolves, we will continue to address critical challenges within that landscape by meeting the needs of the regional manufacturing industry. The RFID Center of Excellence was formed in 2005 and is comprised of a team of knowledgeable professionals with extensive expertise in engineering. Products and technologies developed by the RFID Center have been translated into seven companies, with over 135 invention disclosures, 15 innovation awards, 31 U.S. and five foreign patents with more than 25 named student inventors on U.S. Patents, 10 licenses and 15 options, and two international awards. The Center also worked to establish the basis of the 915MHz RFID standards for the U.S. Department of Defense. Currently, the RFID Center focuses on a wide range of translational and theoretical research with topics from civil engineering to biomedical engineering.

Objectives

Research efforts at the RFID Center involve a wide range of industrial, civil and medical collaborations generally involving the applications of wireless technology. The RFID Center has collaborated with the Pennsylvania Department of Transportation to develop a system to monitor the depth of scour, or the erosion of riverbed material, at bridges throughout the state. A real-time location system (RTLS) was developed for tracking of assets inside a building where GPS cannot be accurately implemented. The RTLS system works over the existing wireless networks in the building to communicate the assets location to a host server. The RFID Center developed a Product Emitting Numbering Identification (PENI) tag. The PENI Tag was Pitt’s contribution towards drastically reducing both the cost and size of RFID tags and making RFID more commercially viable technology compared with bar codes.

Several past and current projects have focused on wireless powering and communication with implantable medical devices. Past biomedical research projects include wireless powering designs for deep brain stimulation, vagus nerve stimulation, and muscle stimulation. Current projects include a wirelessly powered implantable Doppler flow meter, the wireless identification of orthopedic implants, and transcutaneous communication with implantable biosensors. These projects involve device engineering along with investigations into electromagnetic propagation through tissue and electromagnetic interference with pacemakers. Additional medical related projects at the RFID Center include a remote monitoring system for medication tracking through a wireless pill dispenser, and wireless programming of implantable cardiac devices and wireless communication between pulse oximeters.

Summary

The RFID Center of Excellence is a state of the art research group dedicated to solving cutting edge technical problems across a range of industries, such as civil, biomedical, and electrical engineering. A world leader in RFID and wireless technology applications, the Center is devoted to translational research, working closely with governmental agencies, private industry, and the entrepreneurial community.
Facility Description

The Watkins-Haggart Structural Engineering Laboratory is the facility at the heart of the experimental structural engineering research efforts at the University of Pittsburgh. This unique facility is located in the sub-basement of Benedum Hall on the main campus of the University of Pittsburgh in Oakland. The Lab is a 4000 ft² (370 m²) high-bay testing facility with a massive reaction floor. The high-bay testing area is serviced by a 10 ton radio controlled bridge crane and other heavy material handling equipment.

The laboratory maintains a number of computer controlled data acquisition systems that allow for the automated reading and recording of over 130 discrete channels of instrumentation. The lab has full-scale nondestructive evaluation equipment, a digital image correlation system, and field-testing equipment suitable for a variety of in situ test programs. Since 2004, the laboratory has specialized in conducting large scale fatigue testing at load ranges up to 50,000 pounds (220 kN). To date, fatigue tests totaling over 120 million load cycles have been conducted. The largest tests conducted by the Watkins-Haggart lab team where the 2006 tests of a pair of 90 foot long (28 m), 70 ton long prestressed girders recovered from the collapsed Lake View Drive Bridge. The lab has also conducted extensive research for PennDOT, NCHRP and various other public and private agencies. Directed by Kent A. Harries, PhD, FACI, P.Eng.

Major Test Equipment

As a compliment to the reaction floor, the Lab also has an extremely versatile self-contained reaction frame and the following major equipment:

- 200 kip (900 kN) servo-hydraulic universal testing machine (UTM) with 15 ft (4.5 m) opening (customized MTS)
- 200 kip (900 kN) hydraulic UTM with 6 ft (2 m) opening (MTS customized Baldwin)
- 124 kip (550 kN) servo-hydraulic material test frame (Satec)
- 20 kip (90 kN) servo-hydraulic fatigue rated UTM (MTS)
- 500 kip (2220 kN) hydraulic concrete cylinder frame (Gilson)
- 300 kip (1300 kN) reconfigurable test frame
- 50 kip (220 kN) fatigue test capacity (MTS)
- 225 kip (1000 kN) in situ field testing capacity (Enerpac)

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