Case Western Reserve University and the Indiana Geological and Water Survey are honored to convene the 2018 Great Lakes SedHeat Workshop, held at Dively Hall, Case Western Reserve University, Cleveland, Ohio.

This workshop is a contribution to the SedHeat Research Coordination Network under the direction of TCU Energy Group.

SedHeat is a diverse working group of top scholars, practitioners and leaders dedicated to finding solutions to extracting geothermal power from the earth.

The workshop is made possible by funding from the National Science Foundation.
Rationale for Workshop

Despite the historical focus on high-temperature geothermal resources of the Western U.S., the Great Lakes Region is home to the two largest geothermal heating and cooling systems in the United States—district-scale ground-coupled heat pump systems at Ball State University, Indiana, and Epic Systems in Wisconsin. With numerous other district-scale systems in the region, the Midwest U.S. and Ontario, Canada, are emerging as a hotbed of activity for harnessing shallow geothermal resources. Furthermore, extensive underground mining has created an enormous resource of abandoned mine water reservoirs for heat transfer that is virtually untapped throughout the region. Other opportunities such as the repurposing of depleted oil and gas reservoirs, shallow soil-borehole energy storage systems, or deep well enhanced geothermal systems in areas of anomalously high heat flow have not been explored in this region. Finally, the relative abundance of large, stationary CO₂ emitters, co-located with thick sedimentary basins suggests that there may be great potential for the development of multifluid geoenergy systems in the Great Lakes Region. Such systems could combine geothermal energy production with grid-scale energy storage, geologic carbon sequestration for climate change mitigation, and co-production of valuable minerals from brines as a strategic approach to making large-scale geothermal resource development economically competitive.

Our goal with this workshop is to assemble an outstanding mix of scientists and engineers from the research community and industry to help develop a roadmap for advancing geothermal implementation throughout the region and beyond.

Workshop Co-Chairs

Xiong (Bill) Yu  
Professor, Department of Civil Engineering,  
Case Western Reserve University  
xx21@case.edu

Kevin Ellett  
Research Scientist, Indiana University,  
Indiana Geological and Water Survey  
kmellett@indiana.edu
Pre-workshop

Sunday

February 18, 2018

_Courtyard by Marriott_

1st Floor
Monday  
February 19, 2018  
Dively Hall, Rm. 202

8:00 AM  Continental breakfast
8:45  Welcome: Workshop Chairs and CWRU Administrators
9:00–9:45  Keynote Speaker: John Holbrook, Texas Christian University
9:45–10:00  Break
10:00–11:00  CHARACTERIZATION OF GEOTHERMAL RESOURCES AND RESERVOIRS (12-minute presentations)
   Session 1
   Appalachian Basin Geothermal Play Fairways and Deep Direct Use at Cornell University
   Teresa Jordan, Cornell University
   Hydrogeophysics at the EPIC Systems Project
   Dave Hart, University of Wisconsin
   Deep Direct Use Reservoirs
   Andrew Stumpf, University of Illinois–Illinois State Geological Survey
   Stratigraphy, Lithology, Brine Chemistry, and Subsurface Temperatures in the Michigan Basin
   William Harrison, Western Michigan University
   Energy Lost and Found
   Kevin Ellett, Workshop Co-Convener, Indiana University—Indiana Geological and Water Survey

11:00–11:45  Group Discussion 1
11:45–1:00  Lunch
   Keynote Speaker: Derek Elsworth, Pennsylvania State University
1:00–2:00  MODELING OF GEOTHERMAL SYSTEMS (12-minute presentations)
   Session 2
   Techno-Economic Modeling for Geothermal Energy
   Jeff Bielicki, Ohio State University
   Heat Transfer in Large-Scale Mine-Water Geologic Formation Systems for Geothermal Energy Applications
   Zhen Liu, Michigan Tech University
   Deep Direct Use in the Illinois Basin
   Yu-Feng Lin, University of Illinois–Illinois State Geological Survey
   Geothermal Foundations: Background and Geotechnical Challenges
   Muhannad Suleiman, Lehigh University
   Efficient Design and Operation of Geothermal Energy Systems
   Bill Yu, Workshop Chair, Case Western Reserve University

2:00–2:45  Group Discussion 2
2:45–3:00  Break
3:00–4:00  MONITORING AND MODELING OF GEOTHERMAL SYSTEMS (12-minute presentations)
   Session 3
   Monitoring Epic Systems’ District-Scale Geothermal Exchange System Using a Dynamically Calibrated Fiber-Optic Distributed Temperature Sensing Network
   James Tinjum, University of Wisconsin
   Adaptive Building Enclosure Systems Using Solid-Solid Phase Change Materials with Variable Transparency
   Mingjiang Tao, Worcester Polytechnic Institute
   Hydrogeologic Controls on Near-Surface Thermal Properties with Implications for Ground Heat Exchanger Design and Performance
   Shawn Naylor, Indiana University—Indiana Geological and Water Survey
   Energy Geomechanics
   Dipanjan Basu, University of Waterloo
   Evaluating the Performance of the District-Scale Ground-Coupled Geothermal System at Ball State University, Muncie, Indiana, USA
   Lee Florea, Indiana University—Indiana Geological and Water Survey
**Monday**  
**February 19, 2018**  
*Dively Hall, Rm. 202*

4:00–4:45  Group Discussion 3  
4:45–5:00  Workshop Chair Summary for Sessions 1–3  
5:00–6:00  Break  
6:00–6:45  Reception and Poster Session II  
Location: Marriott, Courtyard University Circle  
6:45–8:00  Dinner and Keynote Speaker  
Location: Marriott, 1st Floor  
*Jeff Urlaub, MEP Associates*

**Tuesday**  
**February 20, 2018**  
*Dively Hall, Rm. 202*

8:00 AM  Continental breakfast – Dively Hall, Rm. 202  
8:45  Update from Workshop Chairs  
9:00–10:00  **LESSONS LEARNED AND THE PATH FORWARD** (12-minute presentations)  
**Session 4**  
*Carbon Dioxide Utilization in Geothermal Power Generation and Geologic Energy Storage*  
*Jimmy Randolph, TerraCOH*  
*Hybrid Solar Earth-Coupled Geothermal Systems*  
*Andrew Chiasson, University of Dayton*  
*Minewater Geothermal*  
*Jay Meldrum, Michigan Tech University*  
*Long-Term Performance of Heat Exchanger Boreholes at Different Climatic Conditions*  
*C. Guney Olgun, Virginia Tech University*  
10:00–10:45  Session 4 Group Discussion  
10:45–11:15  Workshop Photo and Break  
11:15–12:00  Workshop Discussion on Next Steps Led by Panelists  
*(Chair, Keynotes, and Session Leads)*  
12:00–1:00  Lunch and Workshop Summary by Chairs  
1:00  Adjourn
Weatherhead School of Management
Peter B. Lewis Building
11119 Bellflower Road
Cleveland, OH 44106
216.368.2030

George S. Dively Building
11240 Bellflower Road
Cleveland, OH 44106-7166
216.368.0020
Workshop will be hosted in Room 202.

Ford Road Parking Garage
1980 Ford Dr.
Cleveland, OH 44106
PRESENTER BIOS

Dipanjan Basu
Associate Professor, Department of Civil and Environmental Engineering, University of Waterloo

Dipanjan Basu is an Associate Professor in the Department of Civil and Environmental Engineering at the University of Waterloo. Prior to his current appointment, he was a faculty member at the University of Connecticut. He was also a postdoctoral researcher at Purdue University. He received his Bachelor’s in Civil Engineering with honors from Jadavpur University. After a short stint as a Trainee Engineer in Development Consultants Limited (in Kolkata, India), he joined the Indian Institute of Technology Kanpur (in Kanpur, India) from where he received his Master’s in Civil Engineering with specialization in Geotechnical Engineering. Subsequently, he joined Purdue University and obtained his second master’s and doctoral degrees.

Basu has a broad research and teaching interests that includes Foundations and Soil Structure Interaction, Energy Geotechnics, Sustainability and Resilience Quantification in Geotechnical Engineering, Soil Constitutive Modeling, Blast Analysis of Geo-structures, Thermal Management of Rock Stress, Probabilistic Analysis, Soil Dynamics, and Ground Improvement. He has over ninety peer reviewed publications. Dr. Basu has delivered several invited and keynote lectures in the U.S., Canada, South Africa, Argentina, India, China, and Kazakhstan. He has also taught short courses in the U.S., South Africa, and Ethiopia.

Basu is a member of Tau Beta Pi, and is a recipient of the Telford Premium Award, Fugro Fellowship, ExCEEd Teaching Fellowship, and Prof. S. Neogi Award, among other accolades. He is the chair of the ISSMGE technical committee on Sustainability in Geotechnical Engineering, and vice-chairs of the ASCE-GI technical committee on Sustainability in Geotechnical Engineering and the CGS technical committee on Sustainable Geotechnics. He also served as an Associate Editor of the ASCE Journal of Geotechnical and Geoenvironmental Engineering.

Jeff Bielicki
Assistant Professor, Energy Sustainability Research Laboratory, Ohio State University

Jeff Bielicki runs the Energy Sustainability Research Laboratory at The Ohio State University, where he and his students conduct research on issues in which energy and environmental systems and policy intersect. Most of his work has focused on CO₂ emissions mitigation through geologic CO₂ storage and geothermal energy production and storage. Bielicki holds a joint appointment in the Department of Civil, Environmental, and Geodetic Engineering and in the John Glenn College of Public Affairs. He previously held appointments as a Research Associate at the University of Minnesota, a Weinberg Fellow at Oak Ridge National Laboratory, and a Research Fellow with the Energy Technology Innovation Policy group at Harvard University. Bielicki was a mechanical engineer at Fermi National Accelerator Laboratory prior to returning to graduate school. He holds a Ph.D. (Harvard University), an M.P.A. (Harvard University), an M.B.A. (University of Chicago), and a B.S. (Mechanical Engineering, Valparaiso University). In his free time, Dr. Bielicki studies taekwondo, is an improvisational comedian, and is teaching himself how to play acoustic guitar.

Andrew Chiasson
Faculty member, Department of Mechanical & Aerospace Engineering, University of Dayton

Andrew Chiasson teaches courses and conducts research in the areas of thermofluid sciences, renewable and clean energy, geothermal energy, and solar energy engineering at the University of Dayton. He holds a Ph.D., University of Wyoming, 2007; an M.S., Oklahoma State University, 1999; an M.A.Sc., University of Windsor, Canada, 1992; and a B.A.Sc., University of Windsor, Canada, 1989. He has academic and professional practice experience in a wide range of geothermal and hydrogeologic applications related to geothermal heat pumps (geoexchange), direct-use geothermal, small-scale electrical power generation, hydrogeologic site evaluations, and groundwater flow and mass/heat transport modeling. Chiasson has been extensively involved in research and development of design and simulation tools for optimal earth heat exchanger coupling, hybrid geoexchange systems, and underground solar energy storage. As a professional engineer in the United States and in Canada, he has designed numerous closed and open-loop geoexchange systems and HVAC systems for a wide variety of building types. He is a member of ASHRAE Technical Committees and is an IGSHPA member.
William Harrison is Professor Emeritus from the Department of Geological and Environmental Sciences at Western Michigan University and Director of the Michigan Geological Repository for Research and Education, which is the State of Michigan repository and research facility containing subsurface geological samples and data. He has over 35 years of experience in studying Michigan geology, with dozens of publications on Michigan sedimentology, stratigraphy, and petroleum geology. He has also supervised more than 50 master’s theses and Ph.D. dissertations. He has managed or participated in research grants and contracts totaling over $4 million on topics such as geological carbon sequestration, geothermal energy, origin and characteristics of Michigan petroleum reservoirs, secondary and enhanced oil recovery, and classification and delineation of Michigan groundwater resources.

Harrison received his Ph.D. in Geology from the University of Cincinnati in 1974, an M.A. in Geology and a B.A. from the University of South Florida. He is an active member of the American Association of Petroleum Geologists, the Eastern Section of AAPG, and the Michigan Basin Geological Society and has received numerous professional service award recognitions from these societies. He is the founder and continues as the director of the Michigan Geological Survey’s Core and Data repository, which houses the State of Michigan’s subsurface data and sample collections.

Kevin Ellett
Research Scientist, Indiana Geological and Water Survey

Kevin Ellett is a Research Scientist at the Indiana Geological and Water Survey, Indiana University, Bloomington. His research focuses on the sustainability of energy and water resources via expertise in hydrology, geophysics, and environmental engineering. In his 25 years of R&D experience, he has been honored as a Fulbright Scholar to Australia and has been recognized for outstanding achievement by the U.S. Geological Survey, U.S. Department of Energy, National Association of GeoScience Teachers, Institution of Engineers, Australia, and the Chinese Academy of Sciences. With more than 100 research publications and presentations to his credit, Ellett is currently a member of four high-impact research consortia aimed at environmental sustainability and mitigating greenhouse gas emissions: US-China Clean Energy Research Center (U.S. Dept. of Energy and China Ministry of Science and Technology), US-China Ecopartnership for Environmental Sustainability (U.S. Dept. of State and China National Development and Reform Commission), Midwest Geological Sequestration Consortium, and the Midwest Regional Carbon Sequestration Partnership. Ellett holds a B.S. in Geological Sciences from Indiana University, an M.S. in Hydrological Sciences from the University of California, Davis, and is now completing a Ph.D. in Environmental Engineering from the University of Melbourne, Australia.

Lee J. Florea
Assistant Director for Research, Indiana Geological and Water Survey

At the Survey, Lee Florea coordinates and supports the research activities of IGWS staff through project and editorial management and active collaborations. He earned his Ph.D. in Geology from the University of South Florida in 2006 and was a USGS Mendenhall Postdoctoral Fellow in Ft. Lauderdale. Before joining the Survey, Florea spent eight years as a tenure-line faculty in Kentucky and Indiana and most recently was a Fulbright Fellow at Babeș-Bolyai University in Cluj-Napoca, Romania. While on faculty at Ball State University, he investigated the geophysics, stratigraphy, and hydrology associated with the installation of the GCHP system, which at that time was the largest of its kind in the world. An avid cave explorer, Florea has explored and surveyed caves in 30 U.S. states as well as several countries in Europe and the Caribbean.

Kevin Ellett
Professor Emeritus and Director, Michigan Geological Repository for Research and Education

Derek Elsworth is a professor in the Departments of Energy and Mineral Engineering and of Geosciences and the Center for Geomechanics, Geofluids, and Geohazards. His interests are in the areas of computational mechanics, rock mechanics, and in the mechanical and transport characteristics of fractured rocks, with application to geothermal energy, the deep geological sequestration of radioactive wastes and of CO₂, unconventional hydrocarbons including coal-gas, tight-gas-shales and hydrates, and instability and eruption dynamics of volcanoes.

Derek Elsworth
Professor, Department of Energy and Mineral Engineering and Department of Geosciences, Pennsylvania State University,

Kevin Ellett
Research Scientist, Indiana Geological and Water Survey

Kevin Ellett is a Research Scientist at the Indiana Geological and Water Survey, Indiana University, Bloomington. His research focuses on the sustainability of energy and water resources via expertise in hydrology, geophysics, and environmental engineering. In his 25 years of R&D experience, he has been honored as a Fulbright Scholar to Australia and has been recognized for outstanding achievement by the U.S. Geological Survey, U.S. Department of Energy, National Association of GeoScience Teachers, Institution of Engineers, Australia, and the Chinese Academy of Sciences. With more than 100 research publications and presentations to his credit, Ellett is currently a member of four high-impact research consortia aimed at environmental sustainability and mitigating greenhouse gas emissions: US-China Clean Energy Research Center (U.S. Dept. of Energy and China Ministry of Science and Technology), US-China Ecopartnership for Environmental Sustainability (U.S. Dept. of State and China National Development and Reform Commission), Midwest Geological Sequestration Consortium, and the Midwest Regional Carbon Sequestration Partnership. Ellett holds a B.S. in Geological Sciences from Indiana University, an M.S. in Hydrological Sciences from the University of California, Davis, and is now completing a Ph.D. in Environmental Engineering from the University of Melbourne, Australia.

Lee J. Florea
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**John Holbrook**  
Professor of Geology, Texas Christian University  

John Holbrook received his B.S. from the University of Kentucky in 1985, an M.S. in Geology from University of New Mexico in 1988, and a Ph.D. in Geology from Indiana University in 1992. **Over the past five years, he has won more than one million dollars in external funding, mostly from competitive federal research grants. He was selected as AAPG Distinguished Lecturer in 2015–2016. Holbrook has served in a high proportion of the leadership posts for professional organizations dedicated to sedimentology/stratigraphy, including: GCSSSEPM President, GSA Sedimentary Geology Division Chair, SEPM Council (Research Coordinator), and GSA Council (Councillor to Divisions), 2016/2017 Chair of GSA Publications Committee, as well as serving on funding panels for the NSF Sedimentary Geology and Paleontology Program, PRF (Geology), and USGS EDMAP. He won the University of Texas Arlington’s College of Science and Technology Outstanding Undergraduate Teacher award. He has mentored 4 Ph.D and 25 M.S. students, and is currently advising 9 M.S. students. He is leading the NSF-SEES community effort in exploring potential for geothermal energy from sedimentary basins.**

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**Teresa E. Jordan**  
Professor of Engineering, Department of Earth and Atmospheric Sciences, Cornell University  

Geologist Teresa Jordan is a native of the Lake Erie shoreline in rural western New York. She completed a B.S. in 1974 from Rensselaer Polytechnic Institute and a Ph.D. in 1979 from Stanford University. She began work at Cornell in 1979 in a research position, joined the faculty in 1984, and she is now the J. Preston Levis Professor of Engineering. During 2001–2003, she was Associate Dean of Undergraduate Programs in the Engineering College at Cornell, and from 2003–2008, she was the Chair of Cornell University’s Department of Earth and Atmospheric Sciences. In 2005, she received the Lawrence Sloss award of the Sedimentary Geology division of the Geological Society of America. She is a Fellow of the American Geophysical Union and of the Geological Society of America. Her professional activities have focused on southern South America, where she is a Corresponding Member of the Asociación Geológica Argentina and in 2012 was a Fulbright Fellow in Chile.

Jordan’s research follows two distinct paths. A long-lived path focuses on the reconstruction of the history of progressive environmental change in desert regions of western South America. This work focuses currently on learning the histories of climate change and groundwater recharge in the Atacama Desert. A second path, begun 10 years ago, focuses on the geology of energy resources as well as on interdisciplinary geology—engineering education in support of designing environmentally benign energy supplies. Three research topics have looked at energy resources and mitigation strategies from different perspectives: first, the opportunities for sequestration of carbon dioxide in rocks of central New York State; second, the geological processes that created the rocks now exploited for natural gas; third, an assessment of geothermal energy resource potential in the Appalachian Basin. As Cornell University evaluates the suitability of deep-source geothermal energy to heat the campus, Jordan is working to improve knowledge of the subsurface conditions and to appropriately evaluate risks and benefits.

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**Yu-Feng Lin**  
Hydrogeologist, Illinois State Geological Survey, University of Illinois at Urbana-Champaign  

Yu-Feng Forrest Lin is a hydrogeologist at the Illinois State Geological Survey, Prairie Research Institute, University of Illinois at Urbana-Champaign (UIUC). He is also the Director of Illinois Water Resource Center and the Associate Director of Illinois-Indiana Sea Grant College Program. He received his B.S. in Water Resources and Environmental Engineering from Tamkang University in Taiwan (1993), M.S. in Civil and Environmental Engineering from the University of Connecticut (1996), and Ph.D. in Geological Engineering from the University of Wisconsin-Madison (2002). Lin is a licensed Professional Geoscientist and certified Geographic Information Systems Professional. He is also a Clinical Professor in the Department of Civil and Environmental Engineering and a Research Professor in the Department of Natural Resources and Environmental Sciences at UIUC. He has been a Faculty Affiliate in the Center for Nanoscale Science and Technology and in the Illinois Informatics Institute since both institutes were established. In 2006, Lin was a Faculty Fellow at the National Center for Supercomputing Applications.

Lin has devoted his efforts to serving professional communities. He is presently one of the three Executive Editors for the journal Groundwater. He also serves as a university representative to the Consortium of Universities for the Advancement of Hydrologic Science, Inc. at UIUC, as a delegate on the Universities Council on Water Resources, and as a board director for the Chinese American Water Resources Association. His current research collaborations extend both domestically and internationally, including partnerships with Brazil, Canada, China, and Taiwan.

Lin’s current research interests include: groundwater flow and subsurface heat transfer, geothermal exchange and renewable energy, groundwater and surface interactions, fiber-optic distributed temperature sensing applications in water-food-energy nexus, and climate change connection to public health.
Zhen (Leo) Liu
Assistant Professor, Michigan Technological University

Zhen (Leo) Liu is an Assistant Professor in Civil Engineering at Michigan Technological University. He received a Ph.D. from Case Western Reserve University in 2012 and worked as a postdoctoral researcher at CWRU after graduation. With his geotechnical background, Liu conducts research on the multiphysics and multiscale simulation and innovative characterization of porous materials for applications in sustainable infrastructure and materials and energy innovations. He also has worked on the application of machine learning in geosystems for resilient and intelligent infrastructure. He is a licensed professional engineer in Michigan, and has been leading funded projects supported by NSF and Michigan DOT. Liu is an active member on several technical committees in TRB and ASCE Geo-Institute.

Jay Meldrum
Executive Director, Keweenaw Research Center, Michigan Technological University

Jay S. Meldrum has served as the Executive Director of Michigan Tech's Keweenaw Research Center (KRC), in Houghton, Michigan, since July 1997. KRC is an applied research center at Michigan Tech University and employs approximately 30 scientists and engineers to provide a wide range of applied research services in vehicle mobility to clients in government and industry. Meldrum's recent efforts involve reducing the high cost of energy at the Center through implementing a minewater geothermal heating/cooling system, investing in energy efficiency, and exploring other opportunities for energy generation with solar panels. Meldrum has advised an Alternative Energy Student Enterprise project at Michigan Tech since 2006, which has engaged student teams on projects including fuel cells, micro-hydro, solar panels, geothermal heating using water from abandoned mine shafts, battery storage, bio-fuels from woody biomass, and natural gas fired generators. Meldrum was recently named the Executive Director of Sustainability for Michigan Tech and served on the Board of Directors of SAE International 2014–2016.

Shawn Naylor
Hydrogeologist, Center for Geospatial Data Analysis, Indiana Geological and Water Survey

Prior to joining the Indiana Geological and Water Survey, Shawn Naylor gained professional experience in both the private and public sectors while working on projects ranging from contaminated aquifer characterization/remediation to mapping irrigated agricultural lands using geographic information systems (GIS) and remote sensing. He earned an M.S. degree in geology from the University of Montana where he studied alpine glacial geology and landscape evolution. His current research interests include quantifying water and heat fluxes through the unsaturated zones of glaciated terrains, characterizing glacial aquifers in three dimensions, and developing spatial databases to facilitate geothermal energy exploitation in Indiana.

C. Guney Olgun
Research Assistant Professor, Virginia Tech University

Guney Olgun is a Research Assistant Professor at Virginia Tech University. He received his B.S. and M.S. degrees in Civil Engineering from Bogazici University in Turkey, and his Ph.D. from Virginia Tech. He has research expertise on the seismic performance of improved ground and reinforced soil structures, computational modeling of soil-structure interaction, cyclic vulnerability of fine-grained soils, and thermo-active geotechnical structures. In particular, he has directed several research projects investigating the thermo-mechanical behavior of energy piles. He has also worked as a consultant on a variety of projects in North America, Europe, and the Middle East, involving earth dams, seismic hazard analysis, ground improvement, deep foundations, and landslide stabilization. Olgun is a member of the Sustainability Committees of the American Society of Civil Engineering and Deep Foundations Institute. He is also a member of the TRB AFP40 technical committee on Soils and Geoenvironmental Processes. He is a founding member of the International Society on Soil Mechanics and Geotechnical Engineering technical committee on Energy Geotechnics, and he is the thrust leader on energy geosstructures task force within this technical committee.
Jimmy Randolph
Founder and CTO, TerraCOH, Inc., and Research Associate, University of Minnesota

Jimmy Randolph is Founder and Chief Technical Officer at TerraCOH, Inc, a University of Minnesota (UMN) startup based in Minnetonka, Minnesota. He is also a Research Associate in the Department of Earth Sciences at the UMN, Twin Cities. He received a B.A. in physics and mathematics from St. Olaf College in 2006 and a Ph.D. in geophysics from the UMN in 2011. His research is focused on numerical and analytical modeling of geophysical fluid and heat transfer, specifically applied to geothermal energy, geologic CO₂ sequestration, ground source/geothermal heat pumps, and groundwater flow. He holds 17 patents on geothermal systems, including the CO₂ Plume Geothermal (CPG) technology. With TerraCOH, Dr. Randolph is working to commercialize geothermal systems in general and CO₂-based renewable energy systems in particular.

Andrew Stumpf
Associate Geologist, Illinois State Geological Survey, University of Illinois

Andrew Stumpf is an Associate Geologist at the Illinois State Geological Survey, a division of the Prairie Research Institute at the University of Illinois at Urbana-Champaign. Andrew is also an Adjunct Professor at the University of Waterloo, Illinois State University, and Oklahoma State University. For the past 20 years, Andrew has undertaken geological investigations in the glaciated regions of North and South America with a focus on characterizing the geologic materials to help answer basic and applied science questions. Specifically, he has led studies to address water supply and quality issues and mitigate natural hazards. Currently he is involved in studies of the Mahomet aquifer and NSF-funded Intensively Managed Landscapes Critical Zone Observatory, and co-leading a new geothermal research initiative at UIUC.

Muhannad Suleiman
Associate Professor, Geotechnical Engineering, Civil and Environmental Engineering, Lehigh University

Muhannad Suleiman’s area of expertise is geotechnical and foundation engineering. His research focuses on soil-structure interaction of foundation systems, ground improvement (mechanical and bio-mediated and bio-inspired methods), thermo-active geotechnical systems, LRFD of geo-structures, response of deep foundations, and effects of construction and time on foundations and ground improvement methods. His research has been funded through several organizations including the National Science Foundation, Qatar National Research Fund, Departments of Transportation, and the foundation industry. Suleiman is an associate editor of the ASCE Journal of Geotechnical and Geoenvironmental Engineering and the Geotechnical Testing Journal. He is the Chair of the Geo-Institute Deep Foundations Committee and serves as its Co-Chair on the subcommittee on energy (geothermal) piles. He is also a member of the TRB Committee on Foundations of Bridges and Other Structures and the Geo-Institute Soil Improvement Committee. He is the recipient of the Shamsher Prakash 2014 Prize for Excellence in Teaching of Geotechnical Engineering. He is also the recipient of the Precast/Prestressed Concrete Institute’s George D. Nasser Award for 2016, PCI Journal Paper. Suleiman is the author or co-author of 80 refereed technical papers and manuscripts.

Mingjiang Tao
Associate Professor and Interim Associate Department Head of Civil Engineering, Worcester Polytechnic Institute

Mingjiang Tao received a B.S. in Civil Engineering from Fuzhou University, China, in 1997, an M.S. in Geotechnical Engineering from Tongji University, China, in 2000, and a Ph.D. in Civil Engineering from Case Western Reserve University in 2003. He joined Worcester Polytechnic Institute in 2007, where he is an Associate Professor and Interim Associate Department Head of Civil Engineering. He is the author of more than 45 papers on alternative cementitious binders, asphalt concrete, granular materials, and characterization of construction materials at nano- and macro-scales. His research has been funded by the National Science Foundation, Federal Highway Administration, state departments of transportation, and New England Transportation Consortium. Tao is a member of the American Society of Civil Engineers and the Chemical and Mechanical Stabilization Committee (AFS90), Engineering Behavior of Unsaturated Soils Committee, and Physicochemical and Biological Processes in Soils Committee (AFP40) of the Transportation Research Board, and a member of Sigma Xi.
James M. Tinjum
Associate Professor/Associate Chair, Department of Engineering, University of Wisconsin-Madison

James M. Tinjum is an Associate Professor in and Associate Chair of the Department of Engineering Professional Development at the University of Wisconsin-Madison. He is also the Director of Distance Graduate Credit Programming in the College of Engineering. He is responsible for outreach, research, and continuing engineering education in the areas of geotechnical and geoenvironmental engineering and energy geotechnics. Tinjum has specialized (consulting, expert support, and research) recently in foundation investigation, monitoring, and research for wind turbine generator foundations; heat transfer geotechnics for buried power cable design and GHX systems; and composite geomembranes for the containment of volatile organic compounds and greenhouse gases. He is recipient of numerous personal and team/project recognitions from ASCE, FHWA, and other organizations, including a Dwight D. Eisenhower Research Fellowship, the ASCE Zone III Practitioner Advisor of the Year, and the ASCE Wisconsin Section Outstanding Young Engineer. He directs internationally attended engineering short courses, including *Foundation Engineering Design*, *Solid Waste Landfill Design*, *Unsaturated Soil Engineering and Thermal Geotechnics*, and *Wind Turbine Foundation and Tower System Design*.

Jeff Urlaub
Principal/Chief Executive Officer, MEP Associates, LLC

Jeff Urlaub is the founder and CEO of MEP Associates, a full-service mechanical, electrical, and plumbing engineering firm specializing in the design of renewable energy systems for clients across the United States. He is a mechanical engineer with more than 20 years of engineering experience and is passionate about delivering innovative, environmentally responsible designs, with an emphasis on campus utilities.

Urlaub has led MEP Associates to the forefront of technology, delivering innovative, environmentally responsible designs that are cost-effective, long-term solutions. Under his leadership, MEP has designed more than 200 geothermal energy projects, many of which were in campus settings (higher education and corporate). The company’s headquarters in Eau Claire, Wisconsin, utilizes a geothermal system for heating and cooling. He uses a geothermal system at home to heat and cool his house.

He holds a Bachelor of Science Degree in Mechanical Engineering from the University of Florida and is a registered professional engineer in 37 states.

Xiong (Bill) Yu
Professor, Department of Civil Engineering, Case Western Reserve University

Xiong (Bill) Yu is a professor at the Department of Civil Engineering, Case Western Reserve University, and holds secondary appointments from other departments. His current research interests include geoengineering and geomaterials, smart and multifunctional materials, multiphysics processes, sensors, structural health monitoring, smart infrastructure, and intelligent systems. Yu’s research emphasizes the use of interdisciplinary approaches to advance the intelligence and durability of geosystems, civil infrastructure, and energy and environmental systems.

He has published more than 250 papers in journals and referred conference proceedings and holds a number of patents and invention disclosures. He is a recipient of an NSF Career award in 2009, and is a U.S. delegate for academic exchanges with China, Japan, Germany, and the UK. He serves on the editorial board of four journals. He chairs the Geo-Institute Engineering Geology and Site Characterization committee, which received the Geo-Institute Technical Committee of the Year award in 2014. He has been a member of the CWRU Faculty Senate Committee on Undergraduate Education, and served as Chair of the Case School of Engineering (CSE) Undergraduate Committee 2014–2016. He currently serves as Chair of the CSE P&T Committee and chair of the CSE Executive Committee.
A Geothermal Play Fairway Analysis of the Appalachian Basin (GPFA-AB) provided knowledge of the sedimentary-reservoir hosted geothermal resource base, to serve the public in the follow-on assessment of potential geothermal heat utilization projects at specific sites in New York, Pennsylvania, and West Virginia. The basin-scale analysis addressed geothermal exploration and development complexities through the assignment of risk metrics. Three of the risk metrics examined were geological: thermal resource quality, natural sedimentary reservoir quality, and the potential to induce earthquakes. The thermal resource quality and natural reservoir quality underpin the plausibility of extracting a high enough flux of hot fluids to be economically viable relative to costs of drilling without stimulation of a reservoir, and their analyses were based on the extensive records of oil and gas exploration and production wells that are abundant across the AB. The potential to induce earthquakes was examined because of the expectation that public scrutiny of seismic risk will be high for any new energy-extraction technology, and may become critical to securing permits. We analyzed the spatial variability of earthquake risk largely based on a geophysical identification of locations at 1–3 km depth of gravity and magnetic gradients indicative of lateral change in rock properties. Treating that set of lateral boundaries as plausible planes of weakness, these were combined with the modern stress field in a theoretical estimate of the tendency of those subsurface features to slip if fluid pressure were to be changed during fluid extraction and reinjection. The fourth risk metric examined the economics of utilization of the geothermal resource for community district heating, and was based on population density. These methods can be applied to any sedimentary basin with a set of data generated by oil and gas exploration and production.

From the combined risk analysis emerged five Play Fairways, which should be given highest priority for further local investigation.

Two of the Play Fairways host current DOE-funded Deep Direct Use (DDU) projects: the Corning-Ithaca Play Fairway (mostly in NY), and the Morgantown-Clarksburg Play Fairway (WV). In the Corning-Ithaca Play Fairway, Cornell University is analyzing the design and cost of using geothermal heat for 20% of the Cornell space-heating needs, inclusive of dormitories and academic buildings, plus a cascade of uses of lower-grade heat. The objectives of the Cornell DDU project include an analysis of heating system efficiencies that can be achieved by targeted integration of heat pumps, storage, and heat transfer technologies, as well as the development of a model that examines combinations of resources and surface use to identify higher-value geothermal development opportunities. To evaluate the feasibility and value of these combinations, we will compute their levelized cost of heat as well as their values to nonmonetary goals such as pollutant reduction, increased local employment, resiliency, etc.

Although the reservoir analysis within the DDU project must rely on existing data sets and reasonable assumptions, evaluating the feasibility that a significant part of Cornell’s energy consumption can be met with geothermal energy will require new geological studies. Whereas all the potential geothermal reservoirs evaluated for the GPFA-AB are oil or gas fields, near Cornell we need data on potential reservoirs that have not been of interest to the hydrocarbon industry. Our reservoir models would improve markedly if we collect data to differentiate fracture-permeability natural reservoirs from matrix-permeability reservoirs. We also need geophysical studies with which to better locate faults. Numerous properties of metamorphic basement rocks near Cornell need to be constrained, from thermal conductivity to fracture apertures and orientations to fluid properties, all of which require drilling an exploratory well to sufficient depth.
Deep Direct Use Reservoirs

Andrew J. Stumpf, University of Illinois at Urbana-Champaign, Illinois State Geological Survey

Recently, the University of Illinois at Urbana-Champaign (UIUC) with its partners from the University of Wisconsin-Madison, the U.S. Army Construction Engineering Research Laboratory, Loudon Technical Services LLC, MEP Associates LLC, and Trimeric Corporation were awarded a grant from the U.S. Department of Energy to determine the feasibility of developing a geothermal deep direct-use (DDU) application in the Illinois Basin. An important aspect of the project is to extract as much heat as possible using a doublet well system from relatively low temperature aquifers in the Mt. Simon or St. Peter Sandstones. A secondary consideration is to mitigate any complications with the wellbore (e.g., scaling) when extracting brine that may contain up to 150,000 total dissolved solids.

To achieve the maximum extraction temperatures, a thorough understanding of the subsurface geology is required to infer the in situ thermal conditions 2,500–6,000 ft below ground. No deep boreholes penetrate the Mt. Simon Sandstone at the test site (UIUC Energy Farm), so inferences will be made from deep boreholes in the area, including wellbores at the Illinois-Decatur Carbon Sequestration site and the Manlove and Tuscola Gas Storage Fields. Expected fluid temperatures will range from 90–130°F, which are near the minimum for running some heat exchange equipment. Novel insulating techniques that increase the efficiency of the extraction well or preheating the water before entering the surface infrastructure may be needed to increase the AT.

Completed geoxchange studies of the upper 300 ft at the UIUC Energy Farm will assist engineers in designing the near-surface infrastructure and pipeline. Continuous coring, downhole geophysical logging, thermoproperty analyses, and thermal response tests determined that the most thermally conductive geologic materials lie within the glacial sediments and siltstone bedrock. The conduction of heat in the subsurface is further aided by slow moving groundwater in the glacial sand and gravel.

A number of DDU cascading applications will be explored at the UIUC Energy Farm for the geothermal resource. The primary goal is to heat and cool office, laboratory, and classroom spaces, but excess heat could be used in greenhouses, feedstock drying rooms, equipment storage and maintenance buildings, and for snow and ice melting. Future energy needs at the research farm are evolving because of planned expansion, associated with the newly formed DOE-funded Center for Advanced Bioenergy and Bioproducts Innovation.

Stratigraphy, Lithology, Brine Chemistry, and Subsurface Temperatures in the Michigan Basin

William Harrison, Western Michigan University

The Michigan Basin is a deep (maximum 16,000 ft) intracratonic basin filled with Paleozoic sedimentary rocks. In the deeper parts of the basin, the stratigraphic column is composed of 41% carbonate, 30% coarse clastics, 8.5% shale, 16% evaporites, and 4.5% unconsolidated glacial drift. There are more than 70,000 oil and gas and mineral exploration wells drilled throughout the basin that provide stratigraphic, lithologic, subsurface temperature, and fluid chemistry data. Well logging and other tests have recorded subsurface temperatures and produced fluids provide brine chemistry data. Michigan Basin brines are extremely dense with average total dissolved solids over 290,000 ppm. Maximum reported salinities exceed 500,000 ppm. Data from deep boreholes suggest a relatively low gradient of temperature increase with depth in the Michigan Basin. Basinwide average for the present day geothermal gradient from published data and additional drill stem tests and well bottom hole temperature measurements is about 20 degrees C per kilometer. Local areas around the state have slightly higher or lower values, but also generally in this lower range.

Energy Lost and Found

Kevin Ellett, Indiana University—Indiana Geological and Water Survey

Mark Menefee, Assistant Director of Facility Operations, Indiana University, Bloomington

The Indiana Geological and Water Survey (IGWS) and the Indiana University (IU) Office of Sustainability began collaborating in 2016 to explore the potential for implementing geothermal technologies at the IU Bloomington campus. Initial research focused on ground-coupled heat pump systems, with results demonstrating how the explicit integration of advanced geological modeling is a promising and broadly applicable approach for optimizing design and improving affordability. Follow-up research by the IGWS in 2017 led to a startling discovery—the presence of an anomalous geothermal heat reservoir underlying the IU Bloomington campus. Initial investigation suggests that this fortuitous energy resource has developed from long-term heat losses from the buried pipes of the campus district heating system. In this talk, I will present details on this exciting finding, along with our vision for how IU can recover its prior investment and create a truly innovative, first-of-its-kind green energy R&D program that taps this energy resource.
Techno-economic modeling combines the physical and operational performance of a system or technology with the associated economic costs in order to provide a normalized cost metric for comparison with other alternatives. This talk will present a techno-economic analysis of a nascent approach to geothermal energy production: Carbon dioxide (CO₂)-Plume Geothermal Energy. CO₂-Plume Geothermal uses CO₂ as a heat extraction fluid in sedimentary basins, which can facilitate economical heat recovery from lower temperature resources. The methodological approach combines subsurface, well, and plant modeling for physical performance, cost estimates of the relevant systems and their operation for economic performance, and their integration in order to estimate the levelized cost of electricity (LCOE) and the capital costs over a range of potential subsurface conditions.

Heat Transfer in Large-Scale Mine-Water Geologic Formation Systems for Geothermal Energy Applications
Zhen Liu, Michigan Tech

Geothermal energy recovery from water in flooded underground mines has been gaining momentum worldwide since the pioneering work in Canada in 1989. This study investigates the science underlying the low-enthalpy geothermal application with mine water based on a local demonstration project. We explored the energy and mass transport in the large-scale system consisting of mine water and geologic formations to explain a key historically unresolved issue regarding the thermohaline stratification in the mine water. For the purpose, a numerical model for fully coupled double-diffusive convection was first presented and then validated against documented experiments. Multiphysics simulation with unique non-isothermal and non-isosolutal hydrodynamics was conducted using the validated model. The simulation succeeded in reproducing the formation and evolution of thermohaline stairs, which dominate the heat transfer in the mine water. The results also revealed that the water stratification involves layer-merging events in a way similar to processes in oceans. In addition, the buoyancy ratio effect was found to be the key mechanism in the water layering and the associated heat transfer processes. It is the first time, to the best of our knowledge, that thermohaline stratifications in large-scale subterranean waters have been successfully reproduced, which can be used to guide geothermal and other applications involving large subterranean water bodies.

Deep Direct Use in the Illinois Basin
Yu-Feng Lin, University of Illinois, Illinois State Geological Survey

This feasibility study will examine the requirements for developing a heat recovery complex that integrates geothermal energy sources with existing district-scale heating and cooling systems at the campus of the University of Illinois at Urbana-Champaign (UIUC). This work is closely aligned with the aims of the U.S. Department of Energy to advance the development of geothermal deep direct-use (DDU) energy systems to reduce greenhouse gas emissions and the use of fossil fuels, and to contribute to net-zero energy planning by large energy end-users such as university campuses, military installations, and hospitals or medical centers. The GeoHRC proposed in this study will examine the feasibility of developing a DDU using warm waters (90 to 150°F) extracted from depths of 2,000 to 6,000 feet out of geologic strata within the intracratonic Illinois Basin. Identifying the geological, engineering, and equipment needs required to connect this energy source with the existing university infrastructure to improve district-scale energy efficiency will constitute the main goals of this multidisciplinary study.

Specific project objectives include the following:

1. Identifying suitable geologic formation(s) in the Illinois Basin that can provide geothermal energy for large-scale direct use,
2. Designing wellbore systems for efficient extraction and reinjection of geothermal waters,
3. Integrating the GeoHRC design with the portfolio of existing UIUC campus facilities,
4. Identifying commercialization challenges (including regulations and economics) for the technology to be transferred to district-scale heating and cooling at other sites (e.g., universities and military bases) in the Illinois Basin and similar geologic settings, and
5. Developing a plan to deploy the technology at UIUC and identifying other sites suitable for this energy technology, such as regional military installations.

Detailed geological flow models form much of the basis for the subsurface design analyses because they identify potential geothermal water extraction and injection rates, including temperature loss. The models use data on local in situ geological features, including hydraulic and thermal properties, and can contrast closed- versus open-loop configurations for the geothermal well systems and highlight relative efficiencies of vertical or horizontal well orientations. From modeling results, realistic DDU scenarios can be selected for specific wellbore designs, heat recovery design, regulatory implications, techno-economic analyses, and marketing. The UIUC campus has a keen interest in geothermal technology, and this study will be instrumental for similar end-users within the Illinois Basin. Because there are analogous sedimentary basins elsewhere, a high-level assessment will also identify the applicability of this project’s technology to other parts of the central and eastern United States.

The project team at UIUC is collaborating with the University of Wisconsin and U.S. Army Construction Engineering Research Laboratory to undertake the techno-economic analyses and apply these results to military installations. We are also partnering with Loudon Technical Services LLC, MEP Associates LLC, and Trimeric Corporation to design the surface and subsurface infrastructure. The DOE announcement of this program is available at: https://energy.gov/eere/articles/energy-department-announces-4-million-geothermal-deep-direct-use-feasibility-studies.
Geothermal Foundations: Background and Geotechnical Challenges
Muhannad Suleiman, Lehigh University

This presentation will focus on geothermal foundations, commonly known as energy piles. We will discuss the construction, applications, challenges, and include a summary of recent tests performed at Lehigh University. Recent research at Lehigh focuses on investigating the effects of energy piles operation on soil-foundation interaction using small-scale interface tests and 1 g pile tests.

Xiong (Bill) Yu, Case Western Reserve University

Shallow depth geothermal energy (via GCHP or energy piles) is available everywhere and presents a sustainable source of green energy. It features a high coefficient of performance for building heating and cooling applications compared with alternatives. However, the initial installation cost is a major barrier to its wide deployment. This presentation provides an overview of the insights from a computational model and data on strategies to improve the efficiency of the shallow depth geothermal system, thereby reducing the amount of overdesign in current practice. Case studies will include GCHP in rock formations and strategies for expanding energy pile applications for winter bridge maintenance.

Monitoring Epic Systems' District-Scale Geothermal Exchange System Using a Dynamically Calibrated Fiber-Optic Distributed Temperature Sensing Network
James Tinjum, University of Wisconsin

Epic Systems operates a district-scale cooling-dominated ground-source heat pump system that includes 25 km of underground piping, 12 ML of closed-loop circulating water, and more than 6,150 in-service geothermal wells (100 m–160 m in depth). This system has a capacity of 40-MW—the equivalent energy to power 4,000 homes. Epic expects its 12,000-person campus to approach energy neutrality as a result of contributions from the company’s solar fields, wind turbines, and ground heat exchange (GHX) fields. This site provides a natural laboratory with a great number of research advantages. The facility is well monitored to allow the proper evaluation of the energy balance, has been operational for more than six years, includes complex near-surface geology, and an innovative company that actively seeks to enhance the system’s performance and sustainability operates it. Our partnership has drilled and instrumented two 150-m-deep GHX wells (standard U-loop and pipe-within-pipe loop), six internal sentry wells, and two external monitoring wells with fiber-optic distributed temperature sensing (DTS) arrays to monitor site performance.

Subsurface heat exchange research in a low-temperature district-scale GHX borefield is a demanding application for a DTS network. While DTS systems do provide internal calibration routines, external calibration schemes are often needed to achieve desired accuracy and precision. The selection of this calibration scheme is based on the inability of static DTS calibration to prevent measurement drift and the physical requirement of sophisticated cable networks and splices at district-scale field sites. A double-ended and dynamic calibration with centralized and remotely accessible data collection and processing is developed to prevent measurement drift and to solve differential attenuation challenges. The calibration is primarily achieved by two long-term calibration baths that keep reference sections of each fiber-optic cable at continuously known temperatures. After calibration, temperature profiles from fiber-optic cables placed within GHX and sentry boreholes provide valuable knowledge of subsurface heat flow which assists in detection of borefield overheating, comparison of individual GHX performance, and design optimization of future borefields.
Adaptive Building Enclosure Systems Using Solid-Solid Phase Change Materials with Variable Transparency
Mingjiang Tao¹, Gert Guldentops¹, Giuseppe Ardito¹, Sergio Granados-Foci¹, and Steven Van Dessel¹
¹Department of Civil & Environmental Engineering, Worcester Polytechnic Institute, ²Gustaf H. Carlson School of Chemistry, Clark University

Buildings currently consume about 40% of all energy use in the United States and, therefore, play an important role in mitigating global greenhouse gas emissions. Various strategies, such as shallow geothermal energy systems, passive solar design, and thermal energy storage systems, have been developed to limit building heating and cooling demands. Solid-Solid phase change materials (SS-PCM) are currently emerging as alternative materials for thermal energy storage. Here we present an exploratory study on two innovative climate responsive building enclosure systems that employ the transparency change and latent heat storage capacity of SS-PCMs as mechanisms to passively control building temperature. The first system is based on a thin layer of SS-PCM that is placed on top of a highly reflective film to control solar heat gain. The second system uses a layer of SS-PCM foam to store thermal energy and control heat flow. The performance characteristics of the systems are evaluated using finite element modeling techniques. Simulation results shed light on the synergistic interactions between different components of the systems and indicate that both systems can reduce undesirable heat exchange between the building and its environment if designed properly.

Hydrogeologic Controls on Near-Surface Thermal Properties with Implications for Ground Heat Exchanger Design and Performance
Shawn Naylor and Robert J. Autio, Center for Geospatial Data Analysis, Indiana Geological and Water Survey, Indiana University

The National Geothermal Data System (http://geothermaldata.org) includes a contribution from the Indiana Geothermal Monitoring Network (IGMN). Recent analysis of IGMN data provided new insight on the limitations of current standards for optimizing the design of horizontal ground heat exchangers (GHEX). Results indicate that the standard industry practice to estimate thermal properties from soil type can lead to GHEX design lengths that are 44% to 52% longer than necessary to meet performance specifications. This research suggests that characterizing the coupling of hydrology and soil thermal properties in specific settings where horizontal GHEXs are targeted will improve understanding of the dynamic aspects of shallow ground heat exchange and lead to more optimal system designs. In order to quantify ranges of heat transfer under varying regimes, the IGMN utilizes long-term soil thermal and hydrologic monitoring across six locations in Indiana that represent unique hydrogeological settings. Each site represents a distinctive combination of terrain position and underlying glacial sediments and this translates to unique drainage characteristics that exert a fundamental control on transient thermal conductivity. The monitoring approach includes excavating trenches to a depth of 2 m (a typical depth for horizontal GHEX installations) and collecting sediment samples at 0.3-m intervals for a laboratory analysis of thermal conductivity, thermal diffusivity, bulk density, and moisture content. Temperature sensors and water-content reflectometers are installed in 0.3-m increments to monitor changes in temperature and soil moisture with depth. A critical and unique aspect of the IGMN is the in-situ observation of thermal conductivity and diffusivity using a sensor that detects radial differential temperature around a heating wire. Micrometeorological data are also collected to determine the surface conditions and water budgets that drive fluxes of energy and moisture in the shallow subsurface.

The IGMN has now achieved continuous monitoring for more than six years. This long-term record demonstrates the strong correlation between hydrologic conditions and soil/sediment heat transfer properties. Thermal conductivity across the network ranges from 0.8 to 2.0 W m⁻¹ K⁻¹ depending on soil parent material, climatic setting, and particularly, soil-moisture variability. By capturing trends during extreme drought conditions and prolonged periods when wetter conditions persist, the IGMN provides GHEX designers with both seasonal and long-term ranges in soil thermal properties that can be used to appropriately design systems while considering both cost and sustained performance.
Recent Initiatives on Geothermal Energy Research at Waterloo

Dipanjan Basu, University of Waterloo

Geothermal energy development in cold climates, particularly far northern climates in Canada, has some particular interest because other non-carbon energy sources are limited. Wind and solar are not suitable sources for many winter months (and wind power size is constrained by the construction limitation), tidal and hydro are very geographically constrained, and batteries are expensive and cannot store energy on a seasonal basis. Fossil fuels (diesel, fuel oil, natural gas) suffer from extended and fragile supply lines, greenhouse (GHG) emissions, environmental risks (boat accidents, spills, leaks) and safety issues (combustible). The combustible materials (wood, straw) or biofuels are also not a possible option. There are extensive sources of intermediate grade geothermal energy across the Western Canada Sedimentary Basin, where fluids at temperatures ranging from 90°C to 130°C exist at depths from 3 to 6 kilometers. To be technically exploitable, the reservoirs for these fluids must be both porous and permeable to allow sufficient rates of fluid flow to the surface. New approaches are needed to extract energy effectively from these lower-quality Canadian geothermal systems, but the potential rewards are great because of the vast thermal mass at depth.

A potential advantage for geothermal energy development in the North is that both heat and power are needed, in different proportions, and in different amounts during the year. This gives scope for more efficiency and optimization of energy partitioning on a daily to seasonal basis, achieving a better recovery of the overall energy available. Even better for the design of a general energy system for military establishments or communities would be the availability of an additional component—a heat storage facility that could store low-grade heat on a seasonal basis for space heating, using ground-source heat pumps to access the heat with electrical power. This presentation will outline the initiation of these research ideas on intermediate-grade geothermal energy extraction and storage, and the preliminary research performed in the area.

Evaluating the Performance of the District-Scale Ground-Coupled Geothermal System at Ball State University, Muncie, Indiana, USA

Lee J. Florea, Indiana Geological and Water Survey, Muncie, Indiana, USA

Phase 2 of the district-scale ground-coupled heat pump (GCHP) system at Ball State University (BSU) came online in March 2014. Combined with Phase 1, the system comprises more than 3,600 borehole heat exchangers (BHEs) designed to handle the full heating and cooling demand for this campus of 21,000+ students. Temperature profiles from Phase 1 collected from 2011 onward have shown significant heating in the subsurface; maximum temperatures in a well from the center of the field exceeded 30°C by 2013. Those temperature profiles also suggested a correlation between thermal loading and geology; a phenomenon that was not accounted for in the models of ground heating that were developed using industry-standard thermal response tests and an assumption of a homogeneous and isotropic media. Detailed geologic investigations conducted during the development of the Phase 2 BHE field yield a range of thermal conductivity values and groundwater flow conditions within the Ordovician-Silurian carbonates and siliciclastics and the Quaternary glacial deposits that overlie a complex pre-glacial karst.

Hourly temperature data presented in this paper were collected October 2014–October 2016 from a monitoring well approximately 10 m from the southeast corner of the BHE field in Phase 2. Temperatures were collected using a RST Thermarray with nodes spaced every 3 m, spanning depths from 0 to 138 m below land surface (bls). Until March 2015, temperatures held a stable baseline profile with gradual cooling from 14°C at 6 m bls to 12.4°C at 108 m bls. Nodes deeper than 108 m bls reveal slight increases in temperature above the baseline geothermal gradient in this region. Above 6 m bls, the effects of seasonal thermal loading are strongly visible. Starting in April 2015, temperatures began to increase along the profile because of thermal loading when Phase 2 came online. Since that time, temperatures have consistently increased at each node of the profile, and significantly greater during times of higher campus cooling demand (June–October), and less during periods of reduced cooling demand (November–May). Maximum temperatures as of October 2016 were 18.5°C.

The postheating thermal profile at the site is striking, illustrating the role of thermodacies in heat transport associated with GCHPs. Thermal loading by October 2016 was less in the glacial deposits (3°C) than in the dolomite of the Silurian Salamonie dolomite (4°C), the Ordovician limestone of the Whitewater Formation (5.6°C), or the calcareous shale of the Ordovician Dillsboro Formation (6°C). Smaller scale inflections are visible in the heat profile, including a sand-gravel zone in the glacial deposits, the glacial deposit/bedrock interface, and shale horizons within the Paleozoic strata. Of particular importance are the shales at the base of the Silurian Cataract Formation, which not only have lower thermal conductivity, but also act as an aquitard between the unconfined Silurian aquifer and the confined regional aquifer in Ordovician strata.

The trend toward significant subsurface heating at BSU driven by load imbalance leads to a potentially reduced GCHP performance. Chilling towers were installed on campus as one mitigation measure to reduce thermal loading of the BHE fields during peak cooling demand. A key lesson from this investigation is the importance of more detailed geologic data to help model the number, depth, and loading capacity of BHEs needed in district-scale GCHP systems.
Combining solar energy systems with geothermal energy systems is not a new idea, but there are numerous possibilities for these combination systems in the Great Lakes Region. The geologic environment offers suitable opportunities for daily and seasonal underground solar thermal energy storage. The regional climate, consisting of cold winters and warm, humid summers, results in a mix of heating- and cooling-dominated buildings (depending on the building use, such as residential, commercial, educational) that are amenable to geothermal heat pump systems with ground thermal load balancing using solar collectors. This presentation reports on past research that involved the development and use of a new novel simulator for hybrid solar-geothermal heat pump systems and reports on current research on the use of photovoltaic-thermal (PVT) solar panels coupled with geothermal heat pump systems. PVT panels can be used to generate electrical energy while recharging the ground with solar energy during the day as necessary and/or be used as radiant cooling panels to unload thermal energy from the ground at night. It is shown that these systems provide significant progress toward renewable heating, cooling, and electrical needs for buildings.
Minewater Geothermal
Jay Meldrum, Michigan Tech University

Underground mining creates hollows in bedrock. Precipitation over the years drains into these hollows. When mines are being worked, this water is pumped out to allow miners access to the ore seams. In most cases, when mine works are closed this pumping stops and the mined areas fill with water. Each flooded mine can contain millions to billions of gallons of water. The surrounding bedrock acts as an insulation layer while lower depths at higher bedrock temperatures cause thermal currents that heat the water in the mineshaft higher than the ambient air temperatures in the winter months, making them an excellent thermal resource. The temperature in the water can be utilized using geothermal heat pump systems to provide an efficient way of heating and cooling buildings. Michigan Tech has exploited one such resource at the Keweenaw Research Center which sits atop the New Baltic/Arcadia mine shaft. This and other similar projects that are in the planning stages at Michigan Tech area will be discussed. Technical, economic, and social hurdles must be overcome to tap these renewable resources.

Long-Term Performance of Heat Exchanger Boreholes at Different Climatic Conditions
C. Guney Olgun, Virginia Tech University

There is a rapidly developing trend to utilize alternative and green energy resources as a result of the growing global energy demand, depleting natural resources and the adverse effects of greenhouse gases on the environment. Ground can be utilized as a potential renewable energy resource for heating and cooling of buildings. Ground-source heat pump systems consist of heat exchanger boreholes, embedded with circulation tubes, buried in the ground and connected to a heat pump for heating and cooling of buildings. Long-term performance of heat exchanger boreholes is closely related to maintaining a constant ground temperature as progressively changing temperatures can result in the loss of heat exchanger efficiency. The soil around the heat exchanger borehole can be gradually heated up or cooled down at conditions where the seasonal thermal loads are unbalanced and this can be critical in the efficient and sustainable operation of ground-source heat pump systems. This presentation focuses on the long-term thermal performance of borehole heat exchangers. A series of building physics simulations were performed for a medium office building to evaluate the seasonal energy demand profiles for both heating and cooling cycles for more than 100 different climatic conditions selected from all around the world. Required loop lengths of the heat exchangers were then evaluated using numerical approaches for all selected locations. Findings indicate that the amplitudes and durations of the seasonal heating and cooling episodes vary significantly for different seasonal energy demand profiles, consequently suggesting different loop lengths. For unbalanced climates, the required loop lengths are considerably larger than the loop lengths for seasonally balanced cases. Furthermore, progression of ground temperatures around the heat exchanger borehole at each location was investigated using a finite element method to evaluate how the system performs at different climatic conditions. The results indicate that temperature changes around the borehole after 30 years of thermal operation are prevalent for regions with heating or cooling dominant conditions. Findings of the study show that ground temperature progressions can be critical for the efficient and sustainable operation of ground-source heat pump systems at regions with unbalanced seasonal thermal loads.