International Institute for Carbon-Neutral Energy Research

Multiscale Science and Engineering for Energy and the Environment

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Objectives

- **Address a range of challenges facing Japan and the world's energy transition, toward the shift away from a largely fossil fuel-based energy supply toward a carbon-neutral energy system**
  - Conducting socio-techno-economic and policy analysis of the low-carbon energy transition

- **To contribute to this transition, we focus on (i) Carbon separation and capture technologies, (ii) Carbon storage and management using the earth, (iii) Energy efficient technologies, and (iv) Socio-techno-economic and policy analysis of low-carbon energy systems. These streams also have strong linkages with mathematics**
  - **Carbon separation and capture technologies:** Development of CO_2 capture membranes and membrane module formulation
  - **Carbon storage and management using the earth:** CO_2 modelling at the pore and field scale, monitoring of saturation and pressure
  - **Energy efficient technologies:** Heat mass transfer and thermal energy systems

- **Model and analyze complex engineering and socio-economic aspects of energy systems using applied math**

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Objectives

- **Thermal energy conversion:** Fundamental understanding of heat and mass transport phenomena in relation to energy systems in nanoscale thermal transport, phase change heat and mass transfer, and the thermophysical properties of working fluids

Projects, Objectives, and Research Efforts

(i) Carbon Separation and Capture Technologies

Projects	Objectives	Research Efforts	Researchers
Development of CO_2 capture membranes	Capture of CO_2 at multiple concentration levels	• Enhancement of gas permeabilities • Improvement of CO_2 selectivities	Fujikawa, Selyanchyn
	CO_2 capture at power generation and industrial sectors	• Improvement of CO_2 separation properties • Improvement of durability against SO_x and NO_x • Preparation of membrane modules • Optimization of separation processes	Fujikawa, Selyanchyn

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Projects, Objectives, and Research Efforts

(ii) Carbon Storage & Management Using the Earth

Projects	Objectives	Research Efforts	Researchers
Molecular-, pore- and field-scale CO_2 modeling	Understand and model injected CO_2 behavior (residual, solubility, mineral trapping)	• Increase storage capacity and security by enhanced mineral trapping (find optimum lithology) • Increase storage capacity and security by enhanced mineral trapping (find optimum lithology • Investigate behaviors of CO_2-N_2-O_2 mixture (i.e., low-purity CO_2 derived from m-DAC) • Use geological structure for CO_2-N_2-O_2 separation	Sugai, Tsuji, Jiang, Jia
Development of effective CO_2 monitoring systems	Understand CO_2 saturation and pore pressure	• Distinguish natural earthquakes and CCS induced earthquakes • Prevention of CO_2 injection induced earthquake • Develop effective monitoring system using continuous source system and fiber optic cable (DAS) • Develop an automated, continuous monitoring system using autonomous surface vehicle (ASV) and DAS	Tsuji, Ikeda

Projects, Objectives, and Research Efforts

(iii) Energy Efficient Technologies

Projects	Objectives	Research Efforts	Researchers
Heat Mass Transfer: Adsorption	Characterization of functional adsorbents and measurement of adsorption isotherms & kinetics for adsorption heat pump/refrigeration system	• Synthesis and characterization of activated carbon-based composite adsorbent • Synthesis and characterization of MOFs • Heat mass transfer and thermodynamic analysis of adsorbent bed and its geometry	Saha, Miyazaki, Thu, Miyawaki
Thermal Energy Systems 1: Heat-driven adsorption heat pump/ refrigeration system	Development of adsorption heat pump/refrigeration, and energy storage systems for utilization of 50-200ºC waste heat and hybrid heat pump and power cycles	• Analysis of adsorption cycles • Development of compact adsorption heat exchangers • Theoretical and simulation of hybrid heat pump cycles	Saha, Miyazaki, Thu
Zero Emission: Biofuel and edible protein by absorbing CO_2 gas	Understand CO_2 dissolution mechanism in water for algae production by system optimization and growth modeling	• Modelling of growth conditions and quantitative analysis for biomass growth • Impact of physical parameters for biomass production • Optimization of algae growth for industrial production	Saha

Projects, Objectives, and Research Efforts

(iv) Socio-techno-economic and Policy Analysis

Projects	Objectives	Research Efforts	Researchers
Energy Transitions and the People-Technology-Systems Nexus	Develop a low-carbon energy and society transition model	• Theoretical and quantitative evaluation of the energy transition in Japan and at the global level from fossil fuel to renewable energy and low-carbon alternatives • Global energy economy modeling: welfare analysis considering the environment	Chapman, Managi
Techno-economic analyses of carbon management	Analyze carbon neutral and carbon negative technologies	• Economic analyses of Carbon Capture and Storage (CCS), Biomass Energy with CCS (BECCS), Direct Air Capture (DAC) etc. • Policy analyses and societal impact of CCS deployment	Fujikawa, Tsuji
Global Hydrogen and Energy System Modelling	Detail the potential societal penetration of hydrogen by sector and end-use	• Global modelling of the energy system cognizant of carbon targets, technology progress and policy with a focus on hydrogen penetration across the transport, industry, commercial and chemical feedstock sectors	Chapman
Applied Math for Energy	Model and analyze engineering and socio-economic aspects of energy systems using applied math	• Carbon trading and RE deployment optimization and agent-based models • Future grid innovations (wireless charging etc.) and distributed optimization and control for Energy Management Systems (EMS) • Applying network theory and dynamics to energy system and transition analysis • Statistical analysis of energy consumption • Design of demand response programs using inverse optimization • Characterization of dynamic events in flame fronts in turbulent combustion to improve energy efficiency and safety	Chapman, Hoa, Matsue, Hirose, Murata

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Projects, Objectives, and Research Efforts
(v-vii) Thermal Energy Conversion

Projects	Objectives	Research Efforts	Researchers
v.Thermophysical properties of new refrigerants	• Measurement of thermodynamic properties of newly developed environmentally-friendly refrigerants that are candidates for next generation air-conditioning and heat pump systems • Elucidation of thermal characteristics of various working fluids including hydrogen and its mixtures	• Accurate Measurement of *PVT* property, saturated density, critical point, and vapor-liquid equilibrium • Development of new equations of state (EOSs) • Observation of phase equilibrium behavior including near the critical point and accurate measurement of thermophysical properties for working fluids	Y. Takata, Y. Higashi N. Sakoda, K. Thu, A. Miyara, C. Kondo, R. Akasaka
vi. Thermal transport in nanoscale	• Elucidation of thermal transport of nanomaterials for various energy devices • High-performance cooling devices utilizing thermal transport at the nanoscale	• Measurement methods for thermal conductivity and thermal boundary resistance of nanomaterials by Raman and MEMS technique • Observation of micro/nanoscale thermal transport phenomena represented by nanobubbles using TEM/ESEM/AFM	K. Takahashi, X. Zhang, M. Kohno, N. Miljkovic, Q. Li, H. Teshima
vii. Phase change heat transfer	• Elucidation of effect of surface wettability and structure on liquid-vapor phase change process for efficient use of thermal energy	• Mechanism of wettability effects in phase change phenomena by multiscale observation/measurement technique • Development of highly-efficient cooling system for electronic/power devices for energy use	Y. Takata, K. Takahashi, M. Kohno, S. Mori, K. Sefiane, D. Orejon, N. Miljkovic, Y. Kita, Z. Wang

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