International Institute for Carbon-Neutral Energy Research

Thermal Science & Engineering Revised Roadmap

July 2015

KYUSHU UNIVERSITY

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ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Division Objectives

- Expand material thermophysical property information and thermal science and engineering to help enable the most effective use of materials in carbon-neutral energy society technologies and to improve the energy efficiency of thermal processes.
  - Expand our knowledge base of thermophysical properties of hydrogen and alternative refrigerants to enable their most efficient use to reduce CO2 emissions.
  - Improve the understanding of the basic science of heat and mass transfer to enable the develop of more efficient energy systems.
  - Research new thermal energy heat pump and refrigeration systems focused on the use of waste heat and new refrigerants resulting in improved overall energy efficiencies and reduced CO2 emissions.

Division Projects, Objectives, Research Efforts

Projects		Objective	Research Efforts	Researchers
Area1: Thermophysical properties (TP)	**TP-1:** High Pressure Hydrogen	Measurement of thermophysical properties of hydrogen and development of its database in a wide range of temperatures and pressures needed for hydrogen energy system	・Accurate measurement of PVT relationship, viscosity, thermal conductivity, velocity of sound ・Development of thermophysical properties database	Y. Takata, M. Kohno, N. Sakoda D. Orejon
	TP-2: New refrigerants	Measurement of thermodynamic properties of newly developed environmentally-friendly refrigerants that are candidates for next generation air-conditioning systems	・Measurement of thermodynamic properties and critical point ・Development of a new equation of state (EOS)	Y. Takata M. Kohno N. Sakoda
	TP-3: Thermal transport in nanoscale	Elucidation of thermal transport of nano materials and interfaces for various energy devices (e.g. adsorbent of adsorption heat pump/refrigeration system and electrode of fuel cell).	・Measurement of thermal conductivity of nanowires ・Development of new measurement methods of thermal/electrical/optical properties of nano materials	K. Takahashi X. Zhang M. Kohno D. Cahill

Division Projects, Objectives, Research Efforts

Projects		Objective	Research Efforts	Researchers
Area 2 : Heat/Mass Transfer (HMT)	**HMT-1:** Phase change heat transfer	Elucidation of effect of surface wettability and structure on liquid-vapor phase change process for effective heat removal for high-heat flux conditions	・Mechanism of bubble nucleation and condensation in nanoscale observation by AFM and FIB-ESEM ・Elucidation of heat transfer characteristics by pool boiling for various wettability surfaces ・IR measurement and numerical simulation of liquid drop evaporation on heated substrate	Y. Takata K. Takahashi M. Kohno D. Orejon B. Shen
	HMT-2: Adsorption	Characterization of functional adsorbents and measurement of adsorption isotherms for adsorption heat pump/refrigeration system	・Synthesis of activated carbon-based composite adsorbent ・Measurement of adsorption characteristics in a wide range of temperature and pressure ・HMT analysis of adsorbent bed	S. Koyama B.B. Saha T. Miyazaki

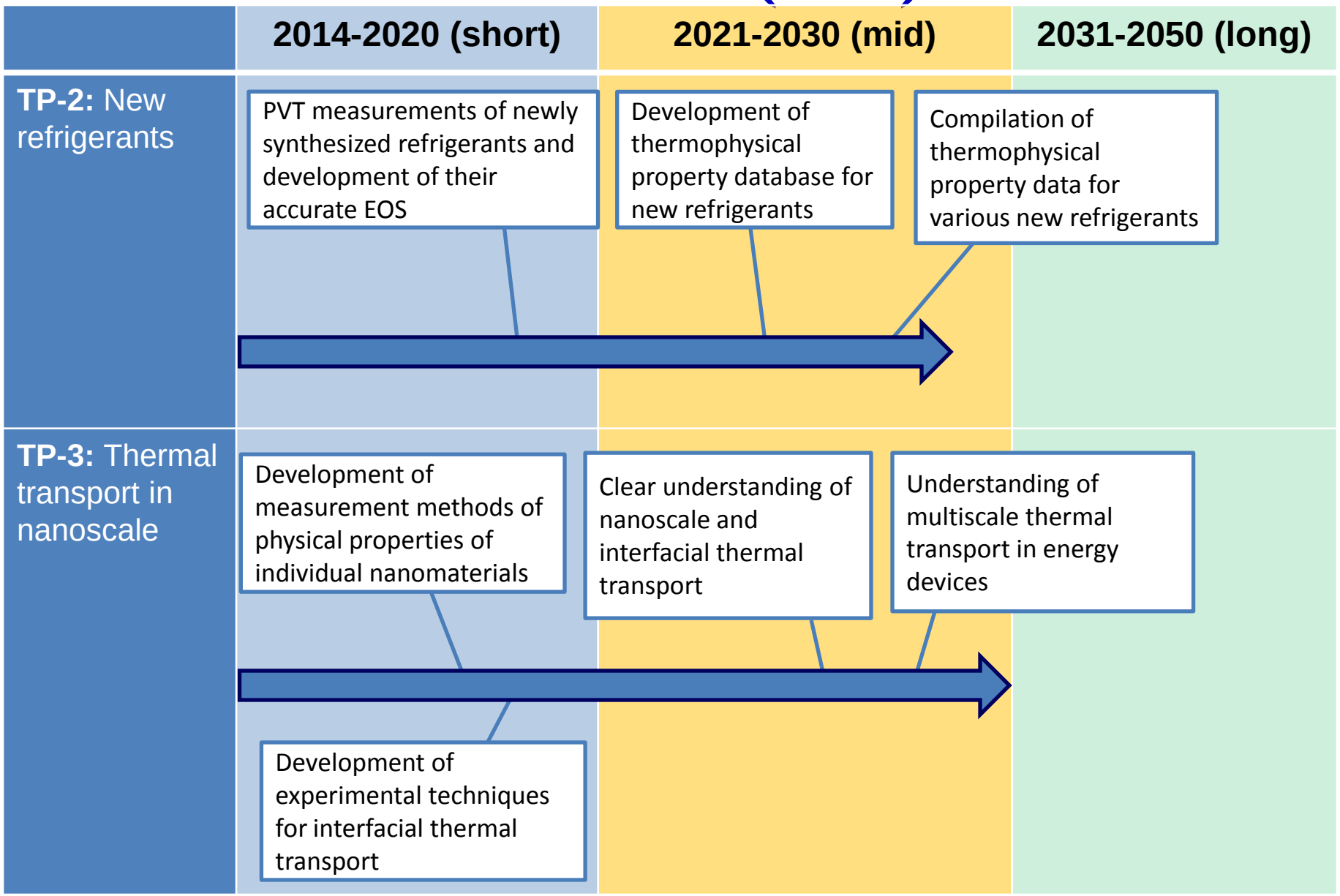
Division Projects, Objectives, Research Efforts

Projects		Objective	Research Efforts	Researchers
Area 3 : Thermal Energy Systems (TES)	**TES-1:** Waste heat-driven adsorption heat pump/ refrigeration system	Development of adsorption heat pump/refrigeration and energy storage systems for utilization of 50-200□C level waste heat	・System analysis of adsorption thermodynamic cycles ・Development of compact adsorption heat exchangers	S. Koyama B.B. Saha T. Miyazaki
	TES-2: Vapor compression heat pump/ refrigeration system using new refrigerants	Development of heat pump/refrigeration system using low GWP refrigerants with high COP	・Optimization of thermodynamic cycle using thermophysical property data ・Design and optimization of evaporator and condenser	S. Koyama B.B. Saha T. Miyazaki Y. Takata N. Sakoda

Milestones (new)

	2014-2020 (short)	2021-2030 (mid)	2031-2050 (long)
TP-1: High Pressure Hydrogen	Development of new hydrogen EOS up to 100MPa and 500°C Measurement of hydrogen viscosity up to 100MPa and 500□C by vibrating wire method Accurate prediction of transient pressure and temperature behaviors in H2 refueling process Establishment of prediction method for hydrogen permeation through metal wall	Development of technique for accurate measurement of thermal properties Establishment of technique for accurate measurement of thermal properties	

Milestones (new)



Milestones (new)

	2014-2020 (short)	2021-2030 (mid)	2031-2050 (long)
HMT-1: Phase change heat transfer	Development of boiling surface with onset of boiling at less than 2K in ΔT_{sat} and with CHF by 2.5 times higher than copper surface Clear understanding of wettability effects in liquid-vapor phase changettability effects in liquid-vapor phase change	Measurement of heat transfer characteristics of micro liquid layer in boiling and evaporation process by making use of thermoreflectance method Clear understanding of heat transfer performance and pressure drop of new refrigerants in evaporator and condenser	Clear Understanding of liquid-vapor heat transfer from nano to macro scale
HMT-2: Adsorption	Accumulation of adsorption isotherm and kinetics data of natural or low GWP refrigerant onto activated carbon Clear understanding of adsorption/desorption process of activated carbon	Atomic scale understanding of adsorption phenomena for carbon-based adsorbents Establishment of adsorption kinetic enhancement technique	Development of HMT enhancement technique for adsorption heat exchanger

Milestones (new)

	2014-2020 (short)	2021-2030 (mid)	2031-2050 (long)
TES-1: Waste heat-driven adsorption heat pump/ refrigeration system	Clarification of the best suitable adsorbent and refrigerant combination for adsorption heat pump and refrigeration systems	Demonstration of systems and optimization of operating conditions	Development of rapid adsorption/desorption heat exchanger using activated carbon based composite adsorbent
TES-2: Vapor compression heat pump/ refrigeration system using new refrigerants	Development of high temperature heat pump system up to 200□C using new HFO refrigerants	Establishment of design criteria and performance prediction technique for heat pump/refrigeration with new refrigerant	Development of prototype heat pump system by using adsorption process

Ultimate Targets

		Ultimate targets	Current Benchmarks
Area1: Thermophysical properties (TP)	**TP-1:** High Pressure Hydrogen	• Clear understanding of thermophysical properties of hydrogen from cryogenic temperature to 500°C and up to 100MPa with an accuracy of ±2%	• PVT up to 100MPa and 500°C by HYDROGENIUS • Viscosity up to 100MPa and 400°C by HYDROGENIUS • Thermal conductivity up to 100MPa and 500°C by HYDROGENIUS
	TP-2: New refrigerants	• Development of equation of state for new HFO refrigerants and their mixtures • Elucidation of heat transfer characteristics for new HFO refrigerants and their mixtures	• PVT, critical point and vapor pressure of HFO refrigerants by Higashi et al. at Iwaki Meisei Univ.
	TP-3: Thermal transport in nanoscale	• Multiscale analysis of thermal transport in and around nanomaterials • Elucidation of thermal transport at complex interfaces	• Measurement of thermal conductivity of carbon nanotube(CNT) by T-junction technique by Zhang, Takahashi and Fujii. • Measurement of heat conduction at simple interface by TDTR method developed by Cahill

Ultimate Targets

		Ultimate targets	Current Benchmarks
Area 2 : Heat/Mass Transfer (HMT)	**HMT-1:** Phase change heat transfer	• Elucidation of wettability and structure effects in liquid-vapor phase change phenomena	• Mixed-wettability boiling surface by Takata et al.
	HMT-2: Adsorption	• Ethanol-Activated carbon system: 0.5kg/kg	• AQSOA®-Water system: 0.2kg/kg ® Mitsubishi Plastics
Area 3 : Thermal Energy Systems (TES)	**TES-1:** Waste heat-driven adsorption heat pump/ refrigeration system	• HP systems with large specific heating/refrigeration power • Raise COP toward 0.9 at heat source temperature level of 80℃	• COP 0.6@60℃ by Maekawa MFG
	TES-2: Vapor compression heat pump/ refrigeration system using new refrigerants	• COP 10 on the basis of electricity input using non-GWP refrigerant	• COP 6 on the basis of primary energy by air-conditioning/refrigeration makers