U.S.–CHINA CLEAN ENERGY RESEARCH CENTER
中美清洁能源联合研究中心

ANNUAL REPORT 2013–2014

Accomplishments of the
U.S.-China Clean Energy Research Center
July 2013–September 2014

Establishment of the U.S.-China Clean Energy Research Center

In the 35 years of renewed diplomatic ties between our two great nations, China and the United States have developed a rich legacy of bilateral cooperation for the advancement of science and technology. In the field of energy, it is important for the two countries to work together. They are not only the world's largest economies; they are also the largest energy producers and energy consumers. Together, they account for about 40% of annual global greenhouse gas emissions. Both rely on imported oil, face similar energy-related environmental challenges, and share strategic motivations for accelerating innovation in clean energy.

The U.S.-China Clean Energy Research Center (CERC) is a presidential initiative by U.S. President Barack Obama and China's former President Hu Jintao. It was announced in November 2009. Its purpose is to accelerate the development and deployment of advanced energy technologies for the benefit of both countries. Joint research plans were mutually agreed in January 2011. In subsequent meetings, U.S. President Obama and China's current President Xi Jinping have reinforced the two countries' commitments to cooperation on science, technology and clean energy innovation, including this Center.

With top-level support and encouragement, CERC provides an attractive and robust platform for accessing top talent and leveraging formidable technical assets. The Center provides a jointly developed and government-backed framework for protecting and sharing intellectual property that is compliant with the laws of both countries and international standards. The Center's three research consortia—the Building Energy Efficiency Consortium, Advanced Coal Technology Consortium, and Clean Vehicles Consortium—are equally funded by both countries and collectively have a budget of US$150 million over five years, with half of that funding coming from affiliated partners and collaborators.

The Center has been recognized as an innovative and productive model for U.S.–China bilateral science and technology cooperation. It has attracted interest among a growing number of businesses and other countries. The Center is seen as a platform that enables a new kind of intellectual relationship, built on trust, understanding, and friendship.

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Pictured on front cover: Xingye Building in Zhuhai, China, one of five CERC BEE demonstration buildings under development (top); wireless charging pad being developed by CERC CVC researchers (middle); Duke Energy's Gibson Station in Indiana, evaluated by CERC ACTC engineers for its applicability to an innovative post-combustion capture process (bottom)

Foreword

As the U.S.-China Clean Energy Research Center approaches its fifth year, we are highlighting some of the impressive successes of this collaborative initiative and clarifying our aspirations for the future. This is done against a backdrop of energy and climate issues that are coming into sharper focus—underscoring the critical value and timeliness of the Center's contributions.

As described in the following pages, the past 15 months have seen the development of valuable tools and technologies. They aim to improve energy efficiency, diversify technical options for both transportation and energy supply, improve clean technology performance, reduce costs, and accelerate a global transition to a low-carbon energy future.

Accomplishments herein are presented in alignment with the Center's three technical tracks: building energy efficiency, advanced coal technology, and clean vehicles. The Center also continues to strengthen its groundbreaking framework for the protection of intellectual property (IP). Its government-backed Technology Management Plans enable partners to bring forward their best ideas with confidence that IP will be protected and new innovations will be allocated fairly.

In the longer view, the Center has established itself as a model for U.S.-China collaboration, leveraging and complementing the strengths of each country. The Center's novel framework enables and stimulates critical technical progress and enjoys strong support at the highest levels in both governments. Relationships among researchers have deepened, businesses are recognizing the value of the Center's access to showcase demonstration platforms, and outside contributions to the Center's research agenda have increased.

The Center owes a debt of gratitude to its technical leaders and their research teams. We salute their creativity, hard work, and commitment to work collaboratively and successfully across distances, cultures, and languages to fulfill the vision of our Presidents. Innovation in clean energy will move both nations toward a more prosperous, clean, and energy-efficient future.

Dr. Robert C. Marlay, PhD
Center Director for the United States
U.S. Department of Energy

Cai Jianing
Counselor, Department of International Cooperation
China Ministry of Science and Technology

Introduction

The Center is now nearing the end of its fourth year of operation. It is at a critical juncture in its initial 5-year term as it considers extending and expanding its scope of research. It is fitting to ask what has been accomplished to date and whether it is well-positioned for a productive future. This Report covers the period from June 30, 2013, through September 30, 2014. It provides an opportunity to take stock of the Center's achievements over the past 15 months and offers a glimpse of the promising paths ahead. The Center's methods for encouraging cooperation are leading to accelerated research and development of key technologies, evidenced by successes across 58 joint projects.

Simultaneously, the Center is transitioning its approach toward more applied research and leveraging a number of large and unique demonstration platforms that can have real-world impacts in the near-term. It is maintaining its focus on business partnering, paths to commercialization, and means for facilitating widespread technology deployment. These activities are critical for the two countries to remain leaders in energy innovation, respond to a heightened urgency with respect to energy and environmental challenges, and support expanded markets for businesses in the clean energy sectors in both countries.

Senior Chinese and U.S. officials at the CERC Steering Committee meeting in Beijing, China, in July 2014 (pictured left to right): Cai Jianing, Counselor, Department of International Cooperation, Ministry of Science and Technology (MOST); Chen Jiachang, Deputy-Director General of High Tech Department, MOST; Li Chaochen, Minister Counselor for Science and Technology of Chinese Embassy in U.S.A; Robert Ivy, Director of Department of Energy (DOE) China Office; Cao Jianlin, Vice Minister, MOST; Ernest Moniz, Secretary of Energy, DOE; Jonathan Elkind, Acting Assistant Secretary of Energy, DOE; Wan Gang, Minister, MOST; Max Baucus, U.S. Ambassador to China; Wang Jun, President of China Academy of Building Research (CABR); Robert Nachtrieb, Chief Scientist, Lutron; Robert Marlay, U.S. CERC Director, DOE; Xu Wei, President, Institute of Building Environment and Energy of CABR; Helena Fu, Deputy Director-Clean Energy, DOE China Office; Nan Zhou, U.S. CERC BEE Director

At CERC's foundation is a **COMMITMENT** from the top levels of government and business leaders in both countries, providing a platform for **COOPERATION** among researchers that is leading to tangible **PROGRESS** that will have a lasting **IMPACT** in building a clean energy future

Cooperation

Engagement with 132 businesses and research partners on 58 joint projects

Expertise shared by more than 1,000 scientists

Confidently share information and retain intellectual property rights through novel IP framework

Contributions by governments and partners in both countries of at least $15 million per year

Progress

20+

New commercial products, technologies, and software tools created

400+

Papers published

20+

Patents and invention disclosures filed in the United States

Impact

100M TONS

CERC building technologies could avoid 100M metric tons of CO_2 per year in 2025

175M TONS

CERC advanced coal technologies could avoid 175M metric tons of CO_2 per year in 2025

1M VEHICLES

CERC clean vehicle technologies could be used in 1M electric and plug-in hybrid electric vehicles in 2025

Commitment

Launched at Presidential level, led by Energy Ministers

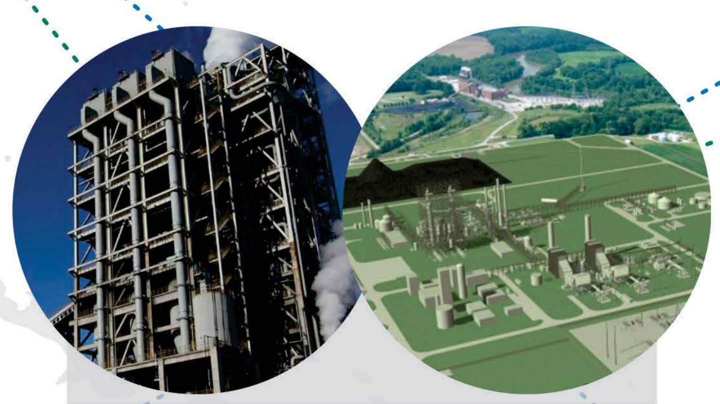
Committed $150 million over 5 years

Agreed among leaders that success of CERC central to achieving energy, economic, and environmental goals in each country

Selected **JOINT R&D PROJECTS ILLUSTRATE CERC'S SUCCESS** in fostering collaborative efforts, capitalizing on unique assets and complementary strengths in both countries

Microalgae testing at the ENN research facility in Langfang, China (left), and at Duke Energy's East Bend Station, Kentucky (right), demonstrating the use of microalgae for CO_2 capture at coal-fired power plants and developing cost estimates for the technology

Hardware for hybrid and electric vehicle control architecture development at Shanghai Jiao Tong University, China (left), and a hybrid vehicle test cell at University of Michigan (right)



An integrated gasification combined cycle (IGCC) GreenGen project of the China Huaneng Group, Tianjin, China (left), and a Duke Energy IGCC plant in Edwardsport in Indiana (right)

A bi-directional charging station, a component of an intelligent transportation system, being developed at Tsinghua University in Beijing, China (left), and electric vehicle charging stations, a component in a microgrid testbed, being developed at Ohio State University in Columbus (right)

Black, white, and garden roofs being tested at a building in Chongqing, China (left), and cool roof technologies being tested at FLEXLAB at Lawrence Berkeley National Laboratory (right)

Liquid air flashing technology being demonstrated at China Academy of Building Research in Beijing, China (left), and being tested by Dow Chemical in Midland, Michigan (right)

- - - Project Location
- Building Energy Efficiency Consortium
- Advanced Coal Technology Consortium
- Clean Vehicles Consortium

Building Energy Efficiency Consortium

Overview

Globally, energy used in buildings accounts for 40% of carbon dioxide (CO_2) emissions. The two largest contributors are the United States and China, which together represent about 40% of the world's energy consumption in buildings. That share could increase rapidly, as two billion square meters of new construction are undertaken in the United States and China each year, presenting an opportunity for curbing energy consumption and reducing CO_2 emissions from new and existing buildings.

The CERC Building Energy Efficiency (BEE) Consortium works to improve the energy efficiency of new and existing buildings, reduce greenhouse gas emissions, increase indoor comfort, and integrate renewable energy resources. Teams of researchers are developing high-impact, cost-effective technologies that could save the United States and China a total of up to $2 billion and avoid 100 million metric tons of CO_2 emissions annually by 2025. Industrial partners, recognizing the value of BEE, have increased their cash and in-kind contributions/cost-share by more than 30% each year.

By integrating the advanced research capabilities of world-class national laboratories and universities with the real-world knowledge of industry experts and policy makers, the consortium accelerates technology development and drives market growth in both countries.

Notable BEE accomplishments include:

- Enabled the application of U.S. technologies into Chinese demonstration buildings
- Facilitated the adoption of 13 new codes and standards for more energy-efficient buildings, including one ISO standard in China
- Supported work selected to receive an R&D 100 Award, and was recognized by ClimateMaster, a BEE industry partner, as instrumental to its success

Current Focus Areas

BEE has developed a collaborative research agenda involving 12 research projects that are focused on six critical areas of building energy efficiency.

Building Design

BEE researchers explore advanced systems for collecting data and modeling energy use in buildings to identify opportunities for more energy-efficient building design. Their latest methods and simulation tools characterize human behavior and quantify its impacts on building energy performance. By integrating human behavior into design calculations, these simulation tools can potentially improve control systems in existing buildings and reduce energy use by 70% or more in new buildings.

Building Envelope

Working with industry partners, BEE researchers develop new building envelope materials and related control and integration systems that improve building comfort and efficiency. Innovative white (cool) roof coatings are delivering superior reflectance, durability, and self-cleaning properties for U.S. and Chinese markets. Researchers have developed accelerated environmental aging methods based on natural exposure tests to reduce testing periods from three years to three days.

The performance of low-emittance windows with manually operated roller shades (left) being compared to automated switchable electrochromic windows (right) in the Saint-Gobain Research Shanghai building

Building Equipment

Researchers improve the performance and expand the market uptake of advanced building equipment technologies, such as lighting, heating, ventilation, and cooling systems, by strengthening integration with metering systems and optimizing management software. Testing and development has begun to identify high-performance controls strategies and cost-effective approaches are being developed for new and existing buildings.

Distributed Energy and Renewable Energy Utilization

By helping optimize the selection, integration, and operation of renewable energy technologies in buildings, researchers are helping convert buildings from energy consumers into net energy suppliers by minimizing the cost and carbon footprint of building energy services. For example, BEE researchers developed a simple investment and planning model called WebOpt for the optimization and control of building equipment and microgrids. WebOpt can help reduce building energy consumption by at least 20%. It is freely available online and has an English and Chinese language interface.

The Trilogy™ 40 Q-Mode™ ground source heat pump developed by Climate Master and Oak Ridge National Laboratory that won an R&D 100 Award

Whole Building

Collaborative research teams are studying building energy use in the United States and China to improve technologies for whole-building energy efficiency and low-carbon energy supply. Five industry-funded pilot buildings in China and other demonstrations in the United States make a significant commercial impact by highlighting the value of BEE-developed technologies and help reduce costs. Research is also being conducted to analyze the performance of the technologies and integration of these technologies.

Policy and Market Promotion

Policy makers need a sound knowledge base to support effective decision making. BEE researchers produced a benchmarking tool that uses detailed data from Chinese commercial buildings to inform new policies for designing and operating more efficient buildings. Currently, Chinese commercial building standards are being revised for 2015. BEE researchers, U.S. national laboratories, and Chinese government research institutes are evaluating energy savings and cost-effectiveness of proposed standards that will reduce energy use in new Chinese commercial buildings by 80% compared to 1980s levels. The revision of these standards has significant business implications for U.S. building technology vendors and service providers.

In Focus

Developing breakthrough air leakage prevention technologies

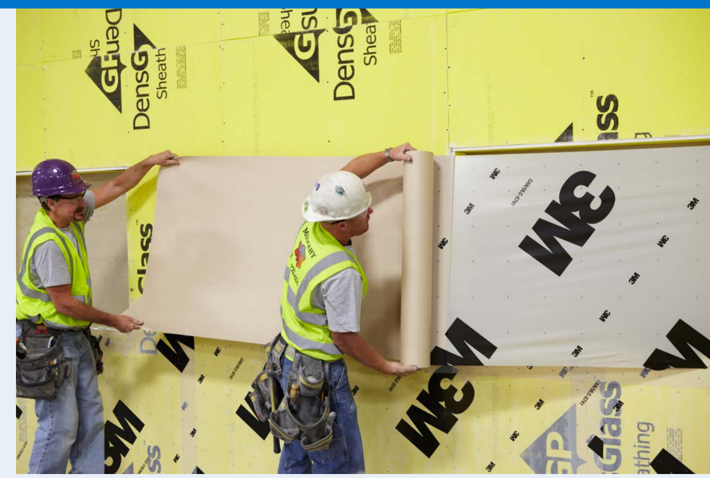
In buildings around the world, air enters and exits through gaps around windows and walls. This seemingly small issue can have a huge impact—air leakage from buildings is responsible for 4% of U.S. energy consumption. In addition to increasing energy bills, air leakage can lower occupant comfort, reduce ventilation system effectiveness, and increase the risk of mold.

Current air barrier systems can prevent air leakage but are time-consuming and complicated to install, which restricts their usage and effectiveness. A BEE research project successfully developed two revolutionary technologies that make it much faster and easier to install effective air barrier systems.

Sprayable liquid flashing: Dow Chemical, a BEE industry partner, developed an environmentally friendly, water-based, sprayable liquid flashing technology to seal penetrations in air barrier systems (e.g., gaps around windows). This technology is four times faster to install than peel-and-stick flashing, because it can be applied with a regular professional sprayer and requires no bridging materials for gaps of less than one-quarter inch.

Primer-less self-adhering membrane: 3M worked with BEE to develop another breakthrough method for reducing air leakage—a primer-less, self-adhering membrane. Similar membranes applied to buildings during construction to provide an air barrier require the prior application of a primer, which increases time and labor costs and increases worker exposure to volatile organic compounds. 3M's primer-less self-adhered membrane can reduce installation time by up to 50% when compared to traditional self-adhered membranes.

Dow's sprayable liquid flashing technology and 3M's primer-less, self-adhered membrane are



The primer-less self-adhered membrane (above), which can be installed on most construction materials without a primer

Demonstration building (left) with liquid flashing (right) sealing the gaps around penetrations and joints

currently being demonstrated at the China Academy of Building Research in Beijing and in select U.S. markets. The success of these technologies in China is critically dependent on educating construction workers about the extent of efficiency loss due to air leakage and the correct implementation of these technologies. As CERC continues to facilitate demonstrations of these air barrier products in China, the acceptability and markets for these technologies are expected to grow, providing increased business opportunities.

In Focus

Testing U.S. building efficiency technologies in five demonstration buildings in China

Successful demonstrations of high-impact, cost-effective technologies to improve building energy performance enable powerful energy and cost comparisons that can have broad policy implications. Through the BEE consortium, U.S. and Chinese researchers are working with industrial partners to demonstrate a range of building technologies in five climate zones across China. Demonstrating these cutting-edge technologies fosters wider technology adoption, informs market strategies, and helps guide BEE research and development—the core of the consortium's work.

These demonstration projects give BEE research teams the opportunity to analyze real-time operations data and evaluate the performance, efficiency, and cost-effectiveness of BEE-developed technologies (e.g., lighting controls, ground-source heat pumps, and air barriers) in integrated systems. Testing the technologies in diverse climates allows comparisons of technology performance and potential in each climate.

Advancing the research and development of these particular technologies is crucial because they represent scalable, cost-effective solutions with robust applications worldwide:

- The alternative ground heat exchangers require 21%–36% less drilling depth than conventional ground heat exchangers, resulting in improved operational efficiency.
- With 25% market penetration, lighting controls could avoid 38 million metric tons of CO_2 emissions in the United States and China each year.
- Improved air barriers could greatly reduce the energy impacts of air leakage.

While the governments of the United States and China co-fund BEE research efforts, the building demonstrations are supported entirely by industry. As part of this project, BEE researchers are assessing the cost implications of the new Chinese commercial building energy standard and developing a Chinese reference building model to

The China Academy of Building Research (CABR) in Beijing, China, where a range of building technologies are being demonstrated

Xingye Building in Zhuhai, China, one of the five CERC BEE demonstration buildings under development in each of China's climate zones

enable a comparison between the Chinese and U.S. commercial building standards.

CERC's innovative collaboration model provides a platform for U.S.-developed technologies to be demonstrated in Chinese markets, and it provides an opportunity for businesses to learn firsthand about the energy efficiency needs of Chinese markets. By working together under the CERC umbrella, U.S. and Chinese partners are able to exchange knowledge, identify best practices, and conduct R&D on potentially game-changing technologies.

Chinese project collaborators include the China Academy of Building Research, Xing Ye Solar, Rixin Solar, Kelong Insulation, and Futai Construction. U.S. collaborators include Dow Chemical, 3M, ClimateMaster, Lutron, Lawrence Berkeley National Laboratory, Oak Ridge National Laboratory, and Massachusetts Institute of Technology.

Advanced Coal Technology Consortium

Overview

Together, the United States and China generate about 40% of the world's carbon dioxide (CO_2) emissions. Avoiding a 2° Celsius rise in global temperature will require a dramatic reduction in the CO_2 emitted by coal-fired power plants. About 75% of electricity in China and about 40% of electricity in the United States is generated by burning coal.

CERC's Advanced Coal Technology Consortia (ACTC) are developing advanced technologies to capture, store, and utilize the carbon emissions of coal-fired power plants so that both countries will be able to make safe, effective, and efficient use of their coal resources while addressing climate change. Carbon capture, use, and storage (CCUS) offers a least-cost approach to generating power from coal while effectively reducing CO_2 emissions.

Current Focus Areas

ACTC's research and development strategy focuses on seven areas, all of which ultimately improve the efficiency of coal combustion and reduce carbon emissions. ACTC also provides robust support to help its researchers protect and manage the intellectual property that they develop in the course of their work in advanced coal technology.

Advanced Power Generation

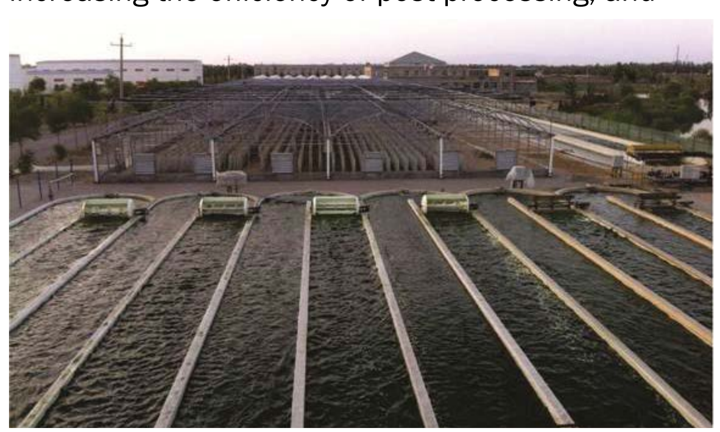
Advanced power generation technologies can significantly increase the efficiency of existing coal power plants. Among other activities, ACTC researchers are developing ultra-supercritical power generation plants and upgrading pulverizing systems for subcritical power plants.

Pre-Combustion CO_2 Capture

ACTC researchers are developing integrated gasification combined-cycle (IGCC) technologies that incorporate carbon capture systems. As in other areas of CERC, this ACTC research benefits from close collaboration and knowledge exchange among U.S. and Chinese researchers. For example, plants using the IGCC technology have been constructed in the United States (Edwardsport) and China (Tianjin GreenGen), with the expectation that shared operational data, knowledge, and technologies will enhance operations at both plants.

CO_2 Utilization with Microalgae

Algae is the fastest-growing photosynthetic organism on the planet and utilizes CO_2 at a rapid rate as it grows, incorporating carbon into its cellular structure as proteins, carbohydrates, and lipids. ACTC R&D is focusing on harnessing this promising biotechnology to turn carbon emissions into usable byproducts such as fuels, feed, or chemical feedstocks. Current research initiatives include screening algae strains, optimizing growth systems, increasing the efficiency of post-processing, and conducting techno-economic analyses. For example, after examining various reactor designs and the utilization of CO_2 by a number of U.S. and Chinese algae strains, ACTC researchers identified a promising strain that grows 15% faster than most and is remarkably tolerant of extreme environments.



Demonstration of open pond microalgae cultivation at ENN research facility in Langfang, China, using CO_2 from a coal gasification plant

Advanced Coal Conversion Technology

Novel technologies for efficiently converting coal into fuel, power, and other products are helping to reduce carbon emissions. ACTC is exploring technologies to improve cogeneration systems; combined pyrolysis, gasification, and combustion; chemical looping gasification with CO_2 capture; gasification properties of direct coal liquefaction residue; coal/biomass co-conversion processes; and coal-to-chemical production of ethylene glycol. The research is also producing measurement modeling and environmental technologies for unconventional coal gasification.

Oxy-Combustion Technology Development

ACTC R&D efforts in this area focus on fuel and emission characterization, pilot-scale evaluation, steady-state and dynamic process modeling simulations, feasibility studies for large-scale deployment, and evaluation of staged oxy-fuel combustion for CO_2 capture.

The Shenhua Shenmu project, a 200 megawatt (MW_e) large scale demonstration of an oxy-combustion facility in Shanxi, China

Post-Combustion CO_2 Capture

Within this area, ACTC researchers are developing a two-phase solvent for use in separating CO_2 from utility flue gas, catalysts to enhance CO_2 capture kinetics in the scrubber, ultra-thin membranes for separating CO_2 from utility flue gas streams, and strategies to enrich post-CO_2 scrubber solvent. For example, post-combustion capture technologies are being examined for application at the Duke Gibson power plant in the United States using the technology demonstrated at the Shidongkou station in China.

Evaluation Technology of CO_2 Geological Storage Sites

ACTC is studying the long-term feasibility of using geological formations to sequester carbon and prevent its escape into the atmosphere. Research in this area explores stacked systems at the basin scale with utilization targets (e.g., enhanced oil recovery, enhanced coal bed methane, and enhanced water recovery) overlying deeper saline reservoirs. For example, ACTC researchers evaluated the Illinois Basin to determine its potential for combined utilization and deeper saline reservoir CO_2 storage in an 80 km radius around Duke Energy's Gibson plant. In China, the team is involved in an active enhanced oil recovery project with Yangchang Oil in the Ordos Basin and a preliminary study of enhanced water recovery tied to the Huaneng Group's GreenGen IGCC facility in Tianjin. Results from these projects are providing guidance for next-generation models in both China and the United States.

In Focus

Better understanding the management of CO_2 in deep saline storage sites

Saline formations present a promising opportunity to permanently store large amounts of CO_2 underground. The global capacity of deep saline storage sites is hundreds of times greater than required to accommodate the annual CO_2 emissions from industrial sources. In addition, saline formations are widespread, so CO_2 captured from virtually any large source in the United States or China could be at a reasonable distance from a saline formation injection point.

Despite this promise, geological carbon sequestration in saline aquifers poses numerous questions, and research on the topic is in its early stages. For example, the effects of high volumes of CO_2 stored in saline aquifers over long periods of time at formation pressures are unknown. For project developers, these uncertainties present risks and increase costs (e.g., insurance, post-closure financial instruments [such as bonds], permits, and operational contingencies).

ACTC researchers from both countries collaborated on a pioneering study to determine the feasibility of managing a formation with stored CO_2 in two major saline aquifers in China—the Guantao and Dongying aquifers. These aquifers are critical because of their close proximity to large sources of CO_2, including Huaneng GreenGen, a 400-megawatt (MW) integrated gasification combined-cycle (IGCC) facility that will begin capturing CO_2 emissions in early 2015.

As part of the study, ACTC researchers examined the potential to inject CO_2 and extract briny water from the aquifers. They determined that the aquifers were likely suitable for high-volume, high-pressure, and long-term CO_2 management. Researchers also determined that the placement of dual-purpose, injection-withdrawal wells might offer formation management techniques that would ameliorate risks and reduce project costs associated with saline aquifer storage and water production. As a result of these successful findings, the researchers agreed to proceed with a follow-on study to examine the feasibility of storing the captured CO_2 from the GreenGen facility at the aquifers. This study will also investigate the possible reuse of briny water produced at the CO_2 injection wells. CERC partners recommend implementing a pilot project once the study and engineering analysis are complete, paving the way for future large-scale CO_2 emissions reductions at this facility and at similar future projects throughout the world.

The Huaneng GreenGen, an integrated gasification combined-cycle (IGCC) facility that is located in close proximity to the Guantao and Dongying saline aquifers in China

Partners include China Huaneng Clean Energy Research Institute and West Virginia University Water Research Institute, in collaboration with Huaneng Power International, the University of Wyoming, Los Alamos National Laboratory, and Lawrence Livermore National Laboratory.

In Focus

Reducing the cost uncertainty of post-combustion carbon capture technologies

The United States and China are both heavily dependent on fossil fuel for electricity generation, and meeting aggressive CO_2 reduction goals will likely require retrofitting existing coal-fired power plants with post-combustion capture technologies. By doing so, billions of tons of CO_2 can be avoided over the remaining life of these facilities. Key challenges to this approach include uncertainties about the high cost of today's capture technologies and the technical risk involved in scaling them up for use in large plants. These uncertainties increase financial risks, reduce vendor guarantee certainty, and impel lenders to charge higher rates. Uncertainty also complicates investment decisions and obscures the technology's potential role in a low-carbon economy.

To reduce the cost uncertainty of post-combustion capture technologies in both countries, CERC facilitated a breakthrough arrangement for data sharing between similar projects, enabling development of a consensus model that supports consistent cost analysis for CO_2 capture. The researchers sought to reconcile the reported costs for two comparable coal-fired facilities, one in China and one in the United States. In an unprecedented step, under CERC's framework, both plants provided operating and cost data to researchers engaged in the analysis.

In China, Huaneng Power International, the world's largest power company, installed a side stream capture system on one of its 600 MW units at the 2,400 MW Shidongkou power station near Shanghai. Huaneng reported capture costs approaching $30 per metric ton, excluding compression and transportation costs. In the United States, Duke Energy, North America's largest utility, is considering retrofitting its 600 MW Unit 3 at its 3,100 MW Gibson power plant in Indiana with a similar capture system.

CERC-sponsored researchers at Lawrence Livermore National Laboratory developed a model of the two systems and performed a one million metric ton per year capture simulation using the model, which estimates capture costs at Gibson Unit 3 using the Huaneng capture system, at full scale, to be $60–$68 per metric ton. The major variance between reported costs at the two plants appeared to be the cost of capital for the scaled-up system. The model appears sufficiently robust that CERC researchers will use it to conduct additional simulations using competing solvents, and will model the capture system using natural gas-fired power generation like that used at Duke Energy's Dan River power plant. Results from this work will better define CO_2 capture costs, ultimately helping to reduce uncertainty for investors and other decision makers.

Joint CERC project on post-combustion capture processes at Shidongkou plant in Shanghai, China (top), and at the Duke Gibson plant in Indiana, U.S. (below)

Clean Vehicles Consortium

Overview

As the world's largest consumers of automobiles and oil, the United States and China can significantly reduce their energy demand by improving the efficiency of vehicle technologies. The CERC Clean Vehicles Consortium (CVC) seeks to develop technologies that can improve vehicle fuel efficiency and reduce dependence on oil. This goal has attracted many industrial partners, making CVC a platform for strong collaboration with industry and academia.

In its first four years, CVC filed 12 intellectual property (IP) disclosures in China, 21 disclosures in the United States, and established a strong research portfolio. In early 2014, CVC identified several "pathway to implementation" projects that foster industrial participation to translate technology into practice.

Current Focus Areas

CVC research is progressing in the following six areas:

Advanced Batteries and Energy Conversion

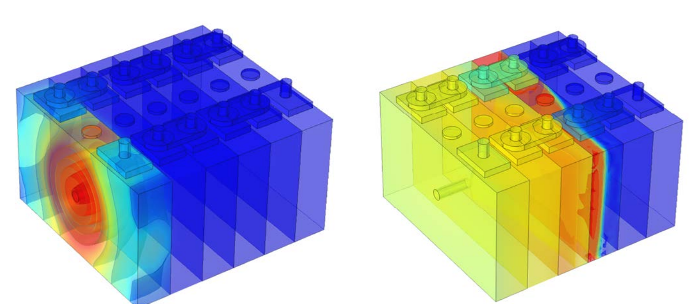
CVC researchers are examining the degradation of lithium-ion batteries and new battery chemistries. Research currently includes characterizing degradation mechanisms to improve battery performance, developing highly energy-dense lithium-sulfur batteries, and developing a solid electrolyte to address safety issues associated with the volatile liquid electrolytes in lithium-ion systems. CVC researchers have successfully developed new materials for safety improvement, determined the typical trigger and propagation mechanism for thermal runaway of a lithium ion battery, and established thermal runaway models. Technologies like balancing and charging control and on-board diagnosis have been incorporated into the battery management system (BMS). Researchers have also proposed a method to estimate the state of safety, which has been integrated into the BMS.

Advanced Biofuels, Clean Combustion, and Auxiliary Power Unit

Researchers are working to develop advanced biofuels technologies, powertrain and after-treatment control systems, and energy conversion technologies. Researchers have developed a new self-propagating method to synthesize novel thermoelectric materials, and have achieved significantly improved efficiency converting waste heat into electricity.

Vehicle Electrification Technologies

To support market growth for hybrid electric vehicles and plug-in hybrid or battery electric vehicles, CVC researchers are conducting R&D on technologies that include fast, safe, and efficient wireless power transfer; multi-mode power split hybrid powertrains; and functional safety and fault-tolerant operation of electric drive systems. To help guarantee the safety of battery and electric drive systems, CVC is developing functional safety protocols for battery management systems and electric traction drive control systems as well as tools to facilitate technology adoption and transfer to industry.



Models developed by CVC researchers that simulate thermal runaway and capacity fading of large format prismatic lithium-ion batteries

Advanced Lightweight Materials and Structures

An effective way to reduce fuel consumption is to use lighter materials. Two of the technical challenges are joining dissimilar materials and developing models to achieve a lightweight product without sacrificing structure integrity and safety. A few advanced joining methods, including friction stir welding, collision welding, and explosion welding, were tested on a wide range of metals and their performance has been characterized. CVC researchers have also developed a model that simulates the performance of vehicle bodies and battery enclosure made of lightweight materials under crash tests. The model is being validated through experimental results and will enable the design of lightweight body structure for better safety, cost, manufacturability, and aerodynamics.

Electrical component of a hybrid engine test cell

Vehicle Grid Integration

CVC researchers completed simulations of electric vehicle (EV) charging station location strategies to optimize coordination of the electricity and transport systems. When renewable energy is used to provide electricity to the grid, close coordination of the EV charging was found to have the potential to reduce the grid system operation costs, wind curtailment, and emissions, as well as effectively reducing the carbon footprint of EV charging. CVC researchers also developed a high-efficiency wireless power transfer method for the charging of electric vehicles. The new wireless charging method results in a greatly improved overall efficiency, with direct current to battery efficiency exceeding 96% at 8-kilowatt output power.

Systems Analysis, Technology Roadmaps, and Deployment

Policy and technology analysis help to achieve vehicle energy and greenhouse gas targets. CVC researchers are exploring fuel economy standards, life cycle analysis, and labeling for plug-in hybrid electric vehicles (PHEV). Researchers studied the travel patterns of PHEVs to optimize battery design, and they developed life cycle models to guide PHEV deployment.

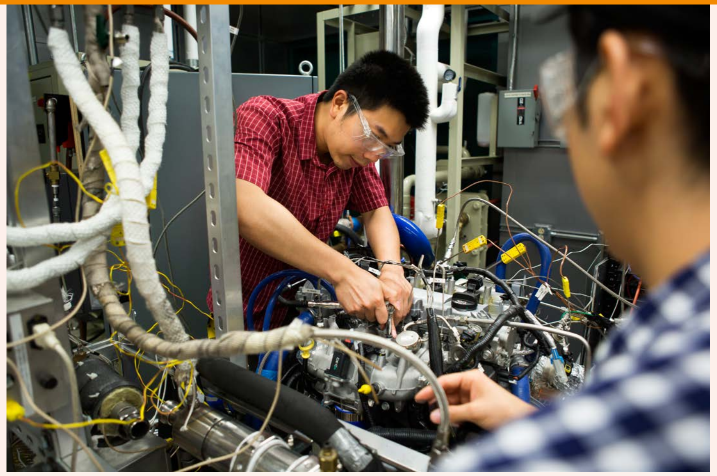
In Focus

Using system integration technologies to improve electric vehicle safety, reliability, and performance

Consumers considering the purchase of an electric or hybrid electric vehicle will want to know that the vehicle can equal or surpass the performance and convenience of a conventional vehicle. To appeal to these markets, electric vehicle designers are exploring innovative ways to integrate critical systems and cost-efficiently maximize range, power, reliability, and other attributes. This task is not an easy one. Powertrains, which consist of all the components that deliver power and motion (engine, transmission, drive shafts, and so on), are particularly complex in these vehicles. The battery and electric engine introduce new design options for optimizing the efficient delivery of power to the wheels. By offering more efficient, cost-effective, and less polluting powertrains, electric and electric hybrid vehicles will be able to compete successfully in the marketplace and reduce global reliance on fossil fuels.

CVC researchers and industry partners have developed novel tools for accelerating and optimizing the design and integration of powertrains in clean vehicle systems. These tools assign a weighting factor to conflicting parameters, such as fuel economy, acceleration, and towing, and provide optimal design solutions. These decision-making tools are helping the industry gain critical insight into the realistic performance of powertrain components and optimal designs. U.S. and Chinese researchers have worked collaboratively on these tools, with the Chinese focusing on pure electric vehicles and U.S. researchers on hybrid and electric vehicles.

CVC researchers are working on a “pathways to implementation” project with Ford Motor Company, which will apply a power-split hybrid powertrain design to the F-150 truck. At Ford’s suggestion, CVC researchers have developed a systematic methodology to analyze the vehicle’s drivability under certain conditions, such as towing, climbing, and acceleration. As part of this effort, CVC engineers developed a novel, power-based algorithm that rapidly computes the optimal input of the powertrain component to achieve top acceleration performance.



Researchers calibrating a hybrid vehicle test cell at the University of Michigan

In addition, CVC researchers successfully applied their decision-making tools to identify a new, optimal design for the 2010 Toyota Prius. This tool considers design solutions for all possible powertrain configurations with an arbitrary number of planetary gears and clutch locations. This design method is approximately 12,000 times faster than conventional, exhaustive optimization methods, such as dynamic programming. By using the insights gained from these advanced decisions tools, CVC is helping industry improve reliability, efficiency and safety for electric vehicles that will hasten market adoption of these technologies.

Partners include University of Michigan and Ohio State University in the United States and Shanghai Jiao Tong University and Tsinghua University in China. The industry partners are Ford, Denso, and Eaton.

In Focus

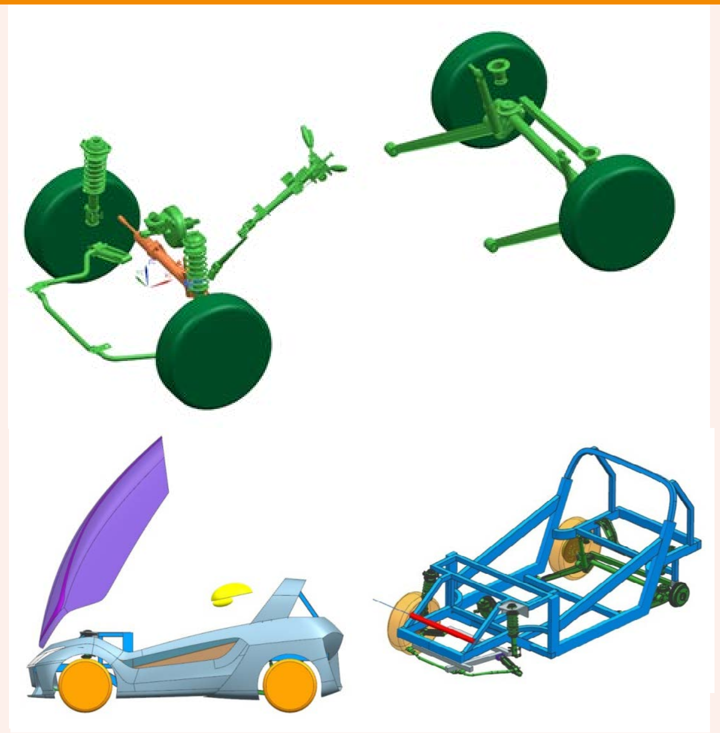
Optimizing the integration and manufacturing of lightweight body subsystems

Advanced lightweight materials give vehicle manufacturers a powerful means to improve vehicle fuel economy while maintaining safety and performance standards. Reducing vehicle weight by just 10% can boost fuel economy by an impressive 6%–8%. In hybrid and electric vehicles, lightweight materials (including high-strength steel, magnesium alloys, and carbon fiber) can help to offset the weight of the batteries and electric motors. Lighter materials even make it possible to use smaller and less expensive batteries.

The CVC team developed a series of models that help manufacturers incorporate lighter-weight materials into their vehicle designs without compromising vehicle performance or safety. The models analyze the effects of battery layouts on crashworthiness, optimize vehicle aerodynamics, and simulate the performance of lightweight vehicles in crash safety tests. These simulations enable engineers to rapidly explore thousands of variations on structural and geometrical parameters to optimize the safety, cost, manufacturability, and aerodynamics of clean, lightweight vehicles.

A separate, joint effort by CVC researchers in the United States and China produced a decision making tool for selecting specific lightweight materials for use in vehicle components. Components made of aluminum, magnesium, and high-strength steel/ultra-high-strength steel can be incorporated to provide maximum weight reduction benefit without sacrificing other properties essential to safety or performance.

Recent modeling efforts by CVC researchers focused on optimizing specific manufacturing processes for lightweight vehicles, such as the “stamping” and



Computational model of lightweight electric vehicle body structure

“high-strength steel bending” processes. These models provide insight into optimizing processing efficiency within specified cost constraints. U.S. and Chinese researchers are sharing ideas and solutions for the use of lightweight materials in vehicles. In the United States, a computer-aided design (CAD) model of the Toyota Venza is being used to benchmark design guidelines. In China, a CAD model of a micro-electric vehicle performs a similar role.

Partners include Tongji University and Tsinghua University in China and the University of Michigan in the United States.

Intellectual Property

Protection of intellectual property (IP) has been shown to foster joint technology innovation. CERC provides a unique framework that builds trust among participants and encourages knowledge- and technology-sharing. The framework provides a flexible platform, jointly negotiated and agreed upon by the participating parties, that instills confidence that participants' work is protected. The framework, consisting of the CERC Protocol and the accompanying IP Annex, allocates a right to each country for joint innovation, supports the fair resolution of disputes according to internationally accepted standards, and encourages real collaboration among partners. The jointly developed Technology Management Plans (TMPs) ensure IP protection by specifying the rules of partner engagement, defining procedures for allocation, protecting rights to new inventions, and providing a guaranteed right to exploit IP in the other country. Both governments have endorsed the TMPs, reinforcing the authority and collaborative nature of this framework.

CERC provides practical IP support, offering tools and technical assistance to help with the IP protection process. This assists scientists to successfully collaborate and innovate. The core work of CERC's IP support program is to educate and inform CERC participants about IP law and practices in both the United States and China. For example, the CERC IP program collaborated with U.S. and Chinese IP experts to develop bilingual, annotated TMPs to build greater understanding of the TMPs. The annotated TMPs explain certain TMP provisions and their implications in depth and provide insight about implementing them in specific projects.

The CERC IP program established an Intellectual Property Experts Working Group to review and adopt approaches that further enhance innovation and facilitate the utilization, protection, and management of IP. The Working Group also offers IP education and technical assistance to CERC participants.

Focus Areas and Future Plans

The IP program is currently surveying CERC participants to better understand IP-related challenges that researchers and partners are facing and will develop an IP protection strategy in response to participants' needs. Planned case studies will elucidate IP best practices, successes, and challenges. In addition, the TMPs will be articulated at the project level and accompanied with appropriate technical legal support.

Guidance and instructional resources will be developed to help participants implement the IP aspects of the CERC Protocol, its IP Annex, and the TMPs. A prospective IP Workshop will complement this effort by educating participants about implementing the resources and understanding each country's applicable laws.

Yu Xiang of Huazhong University of Science & Technology (left) and Stacy Baird of Clean Energy Forum (right) speaking at the Steering Committee meeting in July 2014 on the IP accomplishments of CERC

The IP program is planning two upcoming events:

- An IP Experts Working Group Meeting in mid-November 2014 in Beijing
- An IP summit during the first quarter of 2015, to build on the progress made during previous workshops in Hainan, China, and Palo Alto, California

The IP program has ambitious future plans, including the following:

- Develop a simple, online, bilingual "CERC IP and Technology Management Guide" for non-lawyers. CERC is working with Chinese and U.S. law firms to develop the guide, which will be based on the widely accepted handbook authored by the University of Michigan Technology Transfer Department.
- Develop short "IP Monographs" that explain individual IP issues, such as licensing, to help researchers and executives from small and medium sized enterprises (SME) better understand the TMPs. The monographs will be based on content from the "CERC IP and Technology Management Guide."
- Strengthen IP training, education, and technical assistance to help researchers and executives better understand IP management benefits, risks, and best practices under the two countries' laws.
- Maintain the www.ipknowledge.org website, which provides valuable IP information for CERC participants and executives, and jointly develop a similar resource in the Chinese language.
- Develop model contract language to enable participants to incorporate best practices into their IP sub-agreements under the TMPs.
- Pilot innovative approaches to address issues affecting IP protection and sharing.
- Conduct widespread outreach to disseminate the benefits of the CERC IP model, along with its IP Annex, TMPs, and Sub-Agreement Framework.

Working under the CERC IP framework, CERC ACTC partners LP Amina and Gemeng International entered into a joint venture, facilitating commercialization for one of LP Amina's technologies that enables power plants to co-produce electricity along with other high value coal by-products

A series of meetings between the CERC IP Leadership and IP Experts Working Group laid the groundwork for IP discussions at the annual ACTC meeting in Hangzhou, China, in September 2014. At the meeting, CERC IP leaders from both countries developed a mutually acceptable work plan and strategy for IP work—anticipating that CERC's work will be extended past the initial five-year commitment period.

Industry Partners

The CERC collaborative model empowers industry partners to assume a central role, enabling business and government research teams in both countries to work together to accelerate innovation and commercial success. Benefits to industry partners include the following:

Special intellectual property protections

- Ownership or licensing of IP for commercial purposes
- Protection of existing intellectual property in both countries (through use of CERC's innovative IP framework) and access to new IP arising from joint work

Opportunity to guide research planning and focus

- Early and continuing involvement in the innovation process
- Insights into ongoing research processes

Insider access to clean energy markets

- Exposure to large markets for new technologies in the United States and China
- Increased understanding of potential new markets

Collaboration with top researchers

- Relationships with leading institutions and technology innovators
- Opportunities to demonstrate technologies across a variety of operating environments and run experiments on new or unique laboratory facilities
- Accelerated development by avoiding research redundancies

Preeminent manufacturing and technology development firms are co-leading selected research projects, spearheading planning efforts and information exchanges, and providing essential funding that amplifies the research investments made by the U.S. and Chinese governments. Over 130 businesses and NGOs from the United States and China are CERC partners.

How to Join CERC

Innovative partners are paramount to the success of CERC. CERC welcomes new member participation within its consortia. New members must meet the following criteria:

- Support the mission of CERC and the vision and goals of the respective CERC Consortium
- Support projects that align with CERC areas of research
- Bring additional capacity or expertise to the projects
- Agree to be bound by the same obligations of existing members
- Agree to the provisions of the Protocol and the Technology Management Plans

Prospective members are encouraged to apply to their respective country's CERC Consortium Director. Contact information may be found at www.us-china-cerc.org.

U.S. Ambassador Max Baucus, U.S. Energy Secretary Ernest Moniz, and China Energy Minister Wan Gang at a Steering Committee meeting session in Beijing, China, in July 2014

BEE: **Lawrence Berkeley National Laboratory** (U.S. Consortium lead) • **MOHURD Science and Technology Committee** (China Consortium lead) • 3M • Anhui Roba Energy Saving Technology Co., Ltd. • Beijing Ever Source Science & Technology Development Co., Ltd. • Beijing Huaqing Geothermal Development Co., Ltd. • Beijing Huayi Leye Energy Service Co., Ltd. • Beijing Lampower Photoelectric Co., Ltd. • Beijing Persagy Energy Saving Technology Co., Ltd. • Beijing Zhongchengke Green Building Technology Co., Ltd. • Bentley Systems Incorporated • C3 Energy • China Academy of Building Research • China Lanp Electrical Co., Ltd. • China Society for Urban Studies • Chint Solar (Zhejiang) Co., Ltd. • Chongqing University • Chongqing Zhonghai Industry Co., Ltd. • CISDI Engineering Co., Ltd. • ClimateMaster • CSUS Green Lighting Science & Technology Research Center • Dasheng Roller Shutters (Shanghai) Co., Ltd. • Dongguan Vanke Building Technology Research Co., Ltd. • Dow Chemical Company • East-West Control Group (Shenyang) Co., Ltd. • Energy Foundation, China Sustainable Energy Program • ENN • Guangzhou Zhengli General Electric Co., Ltd. • Himin Solar Energy Group • ICF International • Jiangsu Aide Solar Energy Technology Co., Ltd. • Jiangsu Disimai Ground Source Heat Pump Air Control Co., Ltd. • Jiangsu Refrigeration & Heating Saving Equipment Co., Ltd. • Jiangxi Lattice Lighting Co., Ltd. • Jilin Kelong Building Energy-Saving Technology Co., Ltd. • Landsea Group • LH Technology Co., Ltd. • Liaoning Solar Energy R & D Co., Ltd. • Lutron Electronics • Massachusetts Institute of Technology • Nanjing Fullshare Energy Technology Co., Ltd. • Nari Technology Development Co., Ltd. • Natural Resources Defense Council • Oak Ridge National Laboratory • Saint Gobain • Shanghai Convertergy Energy Technology Co., Ltd. • Shanghai Fuka Construction & Engineering Co., Ltd. • Shanghai Futian Air Conditioning Equipment Co., Ltd. • Shanghai Qingying Industrial Shares Co., Ltd. • Solatube CECIC Daylight Technology Co., Ltd. • TelChina (Shandong) Co., Ltd. • Tianjin University • Tongguang Jiangong Group Co., Ltd. • Tongji University • Tsinghua University • University of California, Davis • Walt Disney Imagineering • Wuxi Suntech Power Co., Ltd. • Xinghua Green Industry International Low Carbon Technology Development (Beijing) Co., Ltd. • Xinjiang Green Refreshing Angel Environment Technology Co., Ltd. • Yingli Energy (Beijing) Co., Ltd. • Zhejiang Dun'an Artificial Environmental Equipment Co., Ltd. • Zhongji Yuanxiong Energy Storage Technology Co., Ltd. • Zhuhai Singyes Green Building Technology Co., Ltd.

ACTC: **Huazhong University of Science and Technology** (China Consortium lead) • **West Virginia University** (U.S. Consortium lead) • China Huaneng Group Clean Energy Research Institute • China Huaneng Group Power International, Inc. • China Power Engineering Consulting Group Corporation (CPECC) • China Power Investment Corporation • China University of Mining and Technology • Dongfang Boiler Group Co., Ltd • Duke Energy • ENN (XinAo Group) • Gemeng International Energy Co. Ltd • Harbin Institute of Technology • Indiana Geological Survey • Institute of Rock and Soil Mechanics, Chinese Academy of Science • Lawrence Livermore National Laboratory • Los Alamos National Laboratory • LP Amina • National Energy Technology Laboratory • Northwest University • Research Center for Energy and Power, Chinese Academy of Sciences • Shaanxi Yanchang Petroleum (Group) Co., LTD. • Shanghai JiaoTong University • Shenhua Group Corporation LTD. • Tsinghua University • U.S.-China Clean Energy Forum, China Relations Council • University of Kentucky • University of Wyoming • Washington University in St. Louis • World Resources Institute • Zhejiang University

CVC: **Tsinghua University** (China Consortium lead) • **University of Michigan** (U.S. Consortium lead) • Aramco Services • Argonne National Laboratory • Beihang University • Beijing Institute of Technology • Changzhou ECTEK Automotive Electronics Limited • China Automotive Engineering Research Institute Co., Ltd • China Automotive Technology & Research Center • China Potevio • Chinese Academy of Sciences • Delphi • Denso • Eaton • Ford Motor Company • Geely Group • Honda R&D Americas, Inc. • Hunan University • JAC Motors • Jingjin Electric Co., Ltd • Joint Bio Energy Institute • KeyPower • Massachusetts Institute of Technology • North China Electric Power University • Oak Ridge National Laboratory • PJM Interconnection • SAIC Motor • Sandia National Laboratories, Combustion Research Facility • Shanghai General Motor Muling • Shanghai Jiao Tong University • TE Connectivity • The Ohio State University • Tianjin Lishen Battery Joint-Stock Co., LTD. • Tianjin University • Tongji University • Toyota Motor Company, Toyota Motor Engineering and Manufacturing North America • Wanxiang • Wuhan University of Technology

Path Forward

As described in this report, CERC achieved tremendous success during 2013–2014. CERC-developed technologies and solutions support the United States and China in achieving tangible progress toward a clean energy future. CERC's innovative collaboration model is accelerating and enriching the benefits of research and development for both countries. CERC partners continue to be closely involved in the research, and other countries are taking an active interest.

As CERC begins the final year of its initial five-year commitment period, leaders from the United States and China are preparing for a second phase (2016–2020). In July 2014, the Steering Committee held its sixth meeting to review CERC's plans and progress to date and discuss next steps.

CERC Goals for Future Work

1. Move more technologies to market to make a measurable reduction in emissions.
2. Strengthen, build, and expand research under the existing tracks.
3. Explore and develop relationships with an expanded set of contributing business partners.
4. Deepen CERC's intellectual property program, embedding its tenets throughout the partnership model.
5. Create new market opportunities for U.S. and Chinese companies, reducing costs through economies of scale and ensuring that both countries remain leaders in clean energy technology innovation.

U.S.-China CERC Extension and Expansion

The United States and China applaud the cooperative progress and achievements made under the U.S.-China Clean Energy Research Center. Through consortia of government agencies, national laboratories, universities, research institutes, and companies, the Center has strengthened collaboration among scientists, engineers, and business partners from China and the United States, and has promoted research, development, and deployment of clean energy technologies in both countries.

The United States and China have agreed to extend and expand the Center in its next phase, from 2016 through 2020. They will jointly fund the Center at the level of at least 200 million US dollars. Priority research tracks will include clean coal (including carbon capture, utilization and storage), clean vehicles, and building energy efficiency. The two sides will also add a research track on the nexus of energy and water. Under the Center's framework, both sides will also explore potential collaboration in additional clean energy areas, such as non-CO_2 greenhouse gas mitigation technologies, unconventional oil and gas, including shale gas and other areas. For more information see www.us-china-cerc.org.

As mutually agreed by U.S. Department of Energy and China's Ministry of Science and Technology, November 2014

CERC Executive Leadership

Steering Committee Members

Dr. Ernest Moniz
Secretary
U.S. Department of Energy

Dr. Wan Gang
Minister
China Ministry of Science and Technology

Dr. Wu Xinxiong
Administrator
China National Energy Administration

Dr. Qiu Baoxing
(Ex-officio) Former Vice Minister
China Ministry of Housing and Urban-Rural Development Secretariat

Secretariat

Jonathan Elkind
Acting Assistant Secretary for International Affairs
U.S. Department of Energy

Dr. Robert C. Marlay
U.S. CERC Director
U.S. Department of Energy

Alan Yu
Director
Office of East Asian Affairs
U.S. Department of Energy

Cao Jianlin
Vice Minister
China Ministry of Science and Technology

Ma Linying
Deputy Director General
China Ministry of Science and Technology

Li Ye
Chief Economist
China National Energy Administration

Han Aixing
Deputy Director General
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Dr. Jun Ni
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Dr. Qiu Xinping
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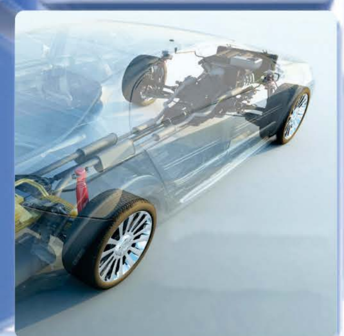
Bruno Vanzieleghem
Operations Manager
University of Michigan

Pictured on back cover: CO_2 injection at the Ordos Basin in China (top); a model of a lightweight vehicle (second from top); CVC researchers calibrating a hybrid motor at University of Michigan (third image from top); and electrochromic windows by Sage being installed at the LBNL Advanced Windows testbed (bottom)

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