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WORKING PAPER

U.S.-CHINA CLEAN ENERGY COLLABORATION: LESSONS FROM THE ADVANCED COAL TECHNOLOGY CONSORTIUM

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EXECUTIVE SUMMARY

Clean energy technology innovation is the key not only to creating a low-carbon global economy, but also to achieving international climate goals. The International Energy Agency's 2015 edition of *Energy Technology Perspectives* indicates that renewables, carbon capture and storage (CCS), fuel switching, and energy efficiency all have critical roles to play over the next 35 years in contributing to achievement of the 2C scenario (IEA 2015). Under this scenario, CCS alone is responsible for capturing and storing almost 6 billion tons of carbon dioxide (CO_2) per year by 2050 in all sectors. However, CCS and many other clean energy technologies require global attention and support to reach the levels of deployment envisioned in the IEA report, due to their high upfront costs and great technological complexity. To help accelerate the development of clean energy technologies, major economies are increasingly sharing knowledge and expertise, discussing policies and regulations, and collaborating on research, development, and demonstration (RD&D) activities. To date, many multilateral initiatives have been formed to directly or indirectly encourage clean energy technology development. They include the Clean Energy Ministerial, Sustainable Energy for All, the Carbon Sequestration Leadership Forum, the Renewable Energy and Energy Efficiency Partnership, and, most recently, Mission Innovation. In addition, countries are building bilateral channels of cooperation on clean energy technology development. One prominent example of this type of cooperation is the U.S.-China Clean Energy Research Center (CERC), which was established in 2009 and renewed for another five years in 2014. The CERC is composed of consortia that focus on building efficiency, clean energy vehicles, advanced coal technology, energy

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Working Papers contain preliminary research, analysis, findings, and recommendations. They are circulated to stimulate timely discussion and critical feedback and to influence ongoing debate on emerging issues. Most working papers are eventually published in another form and their content may be revised.

Suggested Citation: Yang, X. 2016. "U.S.-China Clean Energy Collaboration: Lessons from the Advanced Coal Technology Consortium." Working Paper. Washington, DC: World Resources Institute. Available online at http://www.wri.org/publication/us-china-clean-energy-research-collaboration.

efficiency of medium-duty to heavy-duty trucks, and the water-energy nexus in the two countries.[1]

With the conclusion of Phase I (2011–2015) of CERC and the beginning of Phase II (2016–2020), decision-makers and research collaboration practitioners urgently need a better understanding of CERC's role in advancing clean energy technologies in order to improve its future performance and, more generally, to inform future bilateral technology cooperation between other countries. This working paper focuses on Phase I of CERC's Advanced Coal Technology Consortium (ACTC), which aims to improve technology and practices for advanced coal utilization, and carbon capture, utilization, and storage. This study is unique in that it uses a survey methodology to explore both the rationale underlying the decisions of consortium and project leaders and researchers in the ACTC to join the consortium, and the operation and the effectiveness of the consortium.

Effective bilateral cooperation, particularly joint RD&D through public-private partnerships, can be beneficial to the development of CCS in China and the rest of the world. This working paper shows that effective cooperation will be difficult to achieve because of administrative, organizational, and technical differences across national borders. This study offers recommendations for improving the implementation and performance of CERC to produce more concrete achievements in its second phase. CERC has helped the United States and China to build mutual trust in the realm of climate change collaboration over the past five years and, as more solid achievements are realized in the next five years, CERC can further boost U.S.-China cooperation on climate change.

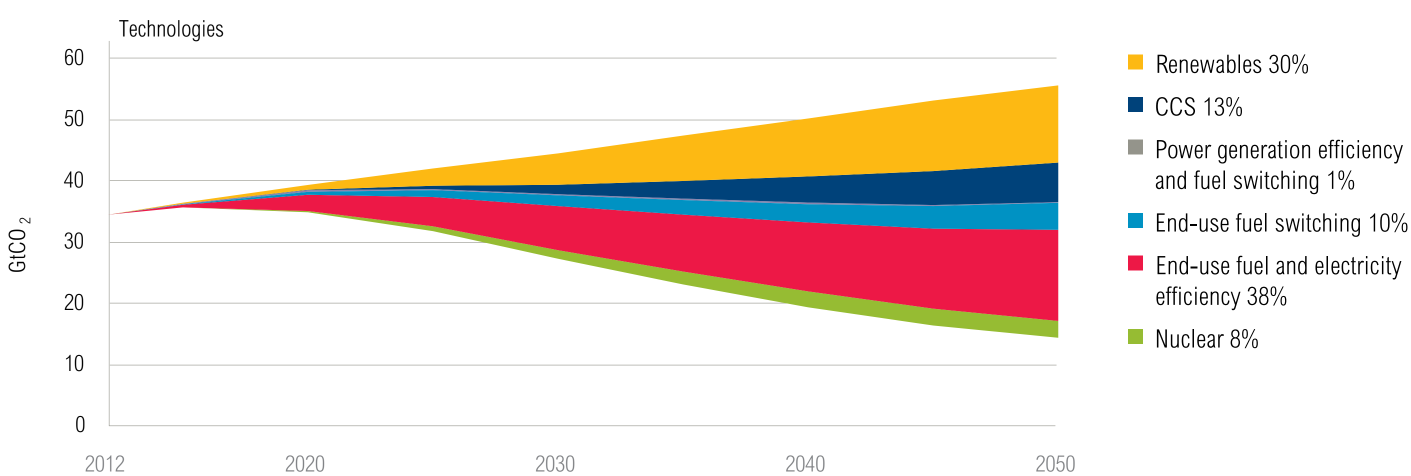
To improve the performance of CERC–ACTC, this working paper recommends:

- further engagement with the private sector during every stage of the collaboration process;
- consolidation of resources to boost joint RD&D activities;
- stronger focus on CCS demonstration projects;
- enhanced communication and coordination at all levels and in all stages of cooperation; and
- re-visioning the CERC as a more open platform to attract more resources.

1. INTRODUCTION

Technology innovation is central to achieving low-carbon energy systems and meeting climate mitigation goals. Influential research articles and reports (Pacala and Socolow 2004; IEA 2014, 2015; IPCC 2014) have reached a consensus that achieving our climate change goals requires a portfolio of low-carbon technologies. The International Energy Agency recently updated its annual technology modeling for achieving the 2-degree goal (IEA 2015) (Figure 1). Under the 2°C scenario, CCS is the third

Figure 1 | **Cumulative CO_2 Reductions, by Technology, under the 2°C Scenario**



Source: IEA (2015).

most important component of emissions reductions, accounting for 13 percent of required total emissions reductions between 2015 and 2050. Renewable energy sources and improving end-use efficiency contribute 30 percent and 38 percent respectively. In the IEA study, CCS includes emissions reductions from the use of CCS in electricity generation, fuel transformation, and industry. The most recent 1.5°C goal put forward in the Paris Agreement might require a larger contribution from CCS in the short term. However, multiple challenges continue to hinder mass deployment of these technologies, which will require government support worldwide.

Technology innovation is an interactive and multi-stakeholder process. It requires not only scientific research and engineering development, but also policy and market frameworks and social engagement (Gallagher et al. 2012). It usually involves several stages, including research, demonstration, development, and deployment; on the other hand, it is by no means always a linear process. Various stakeholders and policy tools are embedded in different stages of technology advancement. The development of clean energy technology is more difficult than the development of many other commercial products, given its intensive capital requirements, longevity of capital stock, and the long timeline needed for learning and experimentation (Grübler and Wilson 2014). The government has long played a role in technology development and, in scholarly literature, its involvement usually falls into two categories: technology push and market pull. Technology push is defined as measures to reduce the cost and improve the efficiency of a particular technology through RD&D and learning by doing, whereas market pull attempts to increase the economic pay-off of these clean energy technologies by increasing the cost of emissions and/or offsetting incremental costs of low-carbon technologies in order to expand market uptake. International collaboration on clean energy, initiated by national governments, can be used in both of these ways to promote technology RD&D and establish a global market for clean energy technology. In the case of CERC, collaboration has been used mainly to integrate human and technological resources beyond borders to speed up the technological innovation process.

A survey study by the IEA showed that 28 multilateral clean-energy-related initiatives are operating currently, with the majority created since 2005. They include the IEA Implementing Agreements, Clean Energy Ministerial, Sustainable Energy for All, and the Carbon Sequestration Leadership Forum (IEA 2014). The number is higher if bilateral initiatives are included, such as the U.S.-China Clean Energy Research Center (CERC), the U.S.-India Climate and Energy Collaboration, and Australia's bilateral energy cooperation with Japan, to name a few. These initiatives all vary greatly in collaborative structure, mechanisms, and scope of activities. Some focus on mobilizing political resources, some provide a platform for researchers and practitioners to share information and experience, and some create and undertake research tasks based on common interests. However, the most prevalent types of activity within the existing bilateral and multilateral initiatives are policy dialogues and expert networks. CERC is an exception, focusing on promoting joint research and development activities through public-private partnerships in both countries. Given the urgency of mitigating climate change and the importance of technology innovation in achieving a low-carbon society, it is valuable to further examine the role of international cooperation in clean energy technology, particularly efforts to integrate resources for RD&D. This study uses the opportunity presented by planning for the second phase of operation of CERC—its mandate was extended from 2016 to 2020—to systematically investigate one consortium within the center. This working paper focuses on the Advanced Coal Technology Consortium under CERC, which is concerned primarily with CCS technologies.

CERC was initially launched in 2009 by President Obama of the United States and former Chinese President Hu, and was renewed through 2020 and expanded in scope in the November 2014 Presidential Joint Announcement. The CERC Phase I was designed to strengthen collaboration between the United States and China in order to work toward a shared low-carbon future through development and deployment of a variety of clean energy technologies, including technologies for vehicles, buildings, and coal. For the second phase, CERC added two new tracks: energy efficiency of medium- to heavy-duty trucks and energy-water nexus research. Five principles were put forward at CERC's inception: equality, mutual benefit, and reciprocity; timely exchange of information relevant to cooperative activities; effective protection of intellectual property (IP) rights; peaceful, non-military uses of the results of collaborative activities; and respect for the applicable legislation of each country.[2]

CERC was mentioned in the two countries' historical presidential climate announcement, made in late 2014.

In this announcement, the United States pledged to reduce its greenhouse gas emissions to 26–28 percent below the 2005 level by 2025, and China pledged to peak its carbon emissions around 2030 and make its best efforts to peak early. CERC's mandate extension was included in this joint statement and is considered a concrete step toward realizing these goals.

This working paper aims to answer the following research questions:

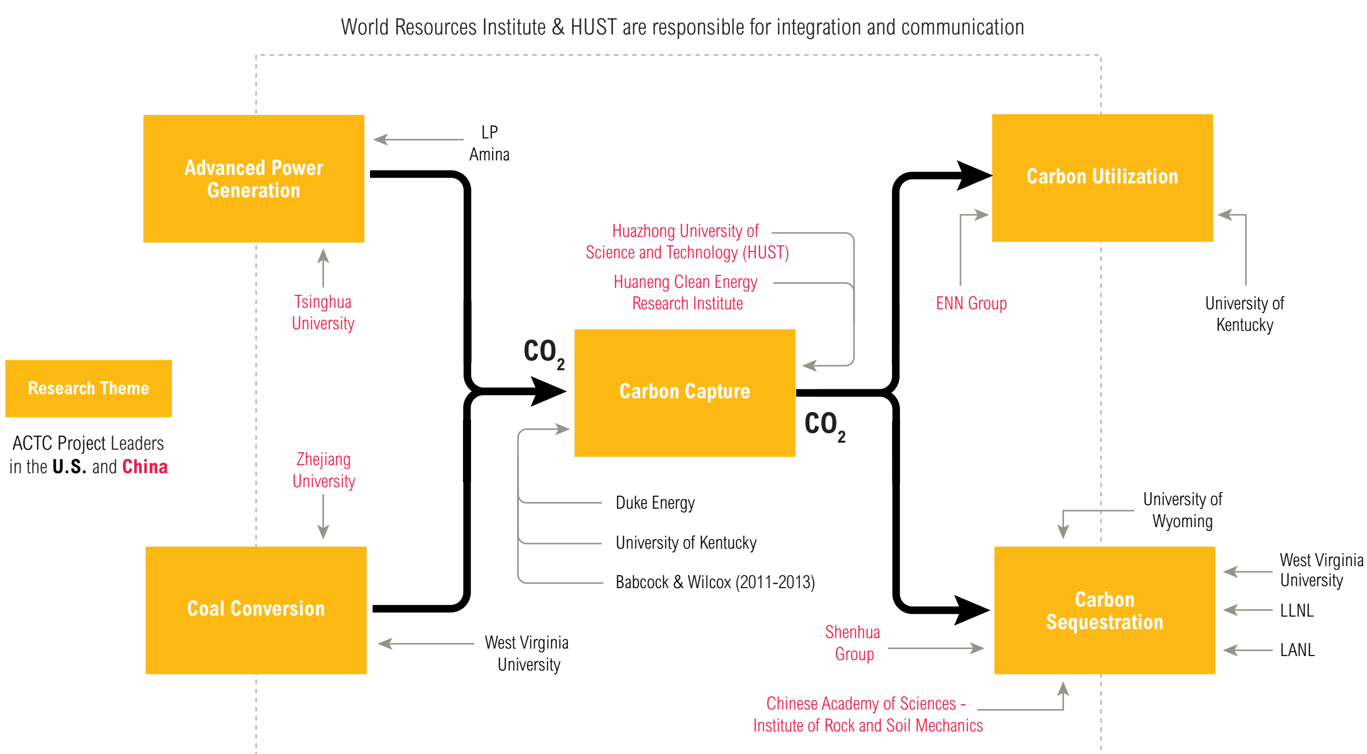
- What can be learned from the U.S.-China CERC-ACTC with regard to the rationale for participation, collaborative mechanisms, effectiveness of operation, and satisfaction with the results?
- With CERC I completed and CERC II beginning in U.S. Government fiscal year 2016, in what ways can policymakers and collaboration practitioners improve their collaboration and accelerate technology learning?
- In what ways has the CERC–ACTC helped speed up the clean energy technology innovation process?

This working paper offers recommendations to policymakers on ways to motivate international cooperation on clean energy technology, to assist practitioners to better engage with other collaborators, and to drive discussion among scholars in this field of innovation. The paper is structured as follows: the next section will introduce the CERC–ACTC; Section 3 explains the research design and methods; Section 4 presents our findings; and the last two sections provide discussions, a conclusion, and policy recommendations.

2. THE U.S.-CHINA CLEAN ENERGY RESEARCH CENTER ADVANCED COAL TECHNOLOGY CONSORTIUM

As one of the original three consortia within CERC, the ACTC aims to advance cleaner coal technologies and practices for capturing, storing, and utilizing carbon dioxide emissions, which together will result in reduced emissions. ACTC includes RD&D in advanced power generation, coal conversion technologies, CO_2 capture technologies, CO_2 sequestration, CO_2 utilization, and simulation and modeling (Figure 2).

Figure 2 | **The Structure of the ACTC**



2.1 Membership and Governance

In China, the consortium is administered by the Ministry of Science and Technology (MOST), led by Huazhong University of Science and Technology, and co-led by Tsinghua University and Huaneng Clean Energy Research Institute.[3] In the United States, the consortium was competitively awarded to a team led by West Virginia University. Funding was allocated each of the following years from 2011 to 2015. Both the China- and U.S.-based elements of the ACTC include industrial participants, academic institutions, and NGOs including, in the United States, Duke Energy, Babcock and Wilcox (B&W) (between 2011 and 2013), LP Amina, and the World Resources Institute. The main governance mechanism for the collaboration is the Technology Management Plan agreed to by both sides in 2010, which covers research objectives, background, and technical approach; task statements, roles and responsibilities of leads, performers, and partners; equipment, resources, sites, facilities, and materials to be supplied; work schedule, with interim milestones, deliverables, and dates; estimated costs; reporting requirements; and a technical management plan. The issue of intellectual property is also addressed in the technology management plan.

2.2 Finance

The United States and China both contributed US$25 million to the consortium over the five years of Phase 1; however, each side has its own funding mechanism for project awardees. In the United States, the initiative is funded in equal parts by private-sector partners in the consortium and by the Department of Energy (DOE), each contributing $12.5 million. In China, MOST is the main funding body. Chinese participants also co-funded some research projects (in-kind costs). The U.S. funds are only applied to the U.S.-based research projects and the same rule is applied on the Chinese side.

3. RESEARCH DESIGN AND DATA ANALYSIS

Data collection for this study was completed primarily through a survey of the consortium's project leaders and core researchers. Because the young and still growing CERC–ACTC provided a small sample population, a non-probabilistic sampling approach was taken that strove to cover all theme leaders and core researchers. In the fall of 2013, 60 surveys were distributed to consortium directors, project leaders, and core researchers of ACTC at its annual meeting in the United States. The sampling frame is the list of meeting participants from both countries. The annual meeting usually serves two purposes: it allows the leadership team to review performance and to determine or revise strategic directions, and provides a platform for researchers to share and discuss collaborative research. A copy of the survey questionnaire was included in every registration packet, and the U.S. director introduced the survey during his opening speech. After the meeting, follow-up with the researchers continued through the end of May 2014. In total, 40 survey questionnaires were returned, indicating a response rate of 67 percent. The survey questionnaire included open-ended, ranking, and Likert-type questions. In addition to survey research, the

Table 1 | **Funding Agreement of the U.S.-China Clean Energy Research Center, Phase I**

		UNITED STATES		CHINA	CONSORTIUM
5-Yr. Totals		DOE	Partners	MOST & Partners	Totals
	Advanced Coal	$12.5	≥$12.5	≥$25.0	≥$50.0
	Buildings	$12.5	≥$12.5	≥$25.0	≥$50.0
	Clean Vehicles	$12.5	≥$12.5	≥$25.0	≥$50.0
	Total	**$37.5**	**≥$37.5**	**≥$75.0**	**≥$150.0**

Notes: Figures in US$ millions.

Source: The U.S.-China CERC Annual Report, 2012.

author has been in close communication with practitioners on both sides regarding the progress of, challenges facing, and recommendations for the ACTC.

3.1 Analytical Model

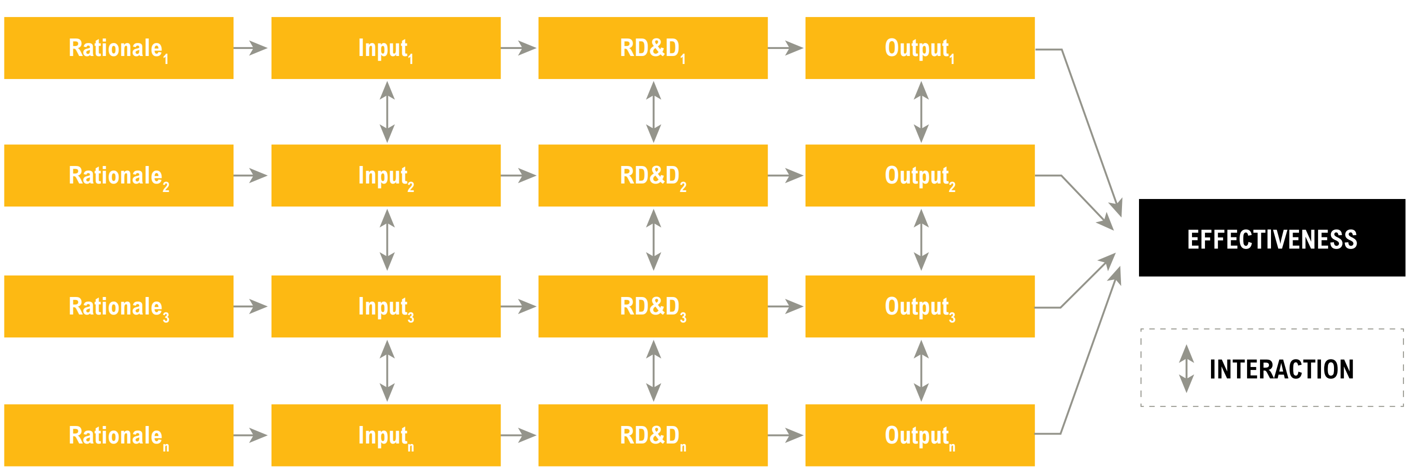
The unit of analysis of this study is ACTC member institutions, and information was gathered from individual researchers as well. It was assumed that each participating organization in this bilateral cooperation effort had its own rationale for joining, contributed in its own ways to the consortium, and also interacted in its own ways with other members by sharing knowledge and information. The collective inputs of each organization eventually contributed to technological learning. Given the small sample size, quantitative analytical methods were not used in this working paper, but simple statistical analysis is applied to each variable.

- *Rationale* is defined as the logical basis for the decision of the institutes to join the bilateral initiative.
- *Input* is defined as resources invested by the participants in the bilateral process, including facilities, materials, human resources, and financial resources.
- *RD&D* is defined as activities related to knowledge, product development, and technology scale-up conducted by the participants.
- *Output* is defined as knowledge products, including patents, scientific publications, and progress reports, as well as training of researchers.
- *Interaction* is defined as the format and frequency of information and knowledge-sharing activities and the types of information and knowledge shared.
- *Effectiveness* is defined as whether or not the progress achieved meets the goal of each participating organization.

4. SUMMARY OF FINDINGS

This section presents key findings relating to the following issues: the rationale underlying institutions' decision to join the initiative; RD&D, knowledge and information sharing among partners; the impact of ACTC on participant organizations and researchers; and practitioners' satisfaction and concerns regarding the bilateral initiative. Some results are presented comparatively from the perspective of both countries.

Figure 3 | **Analytical Model of the Study**



Note: Each row represents an individual organization.

4.1 Rationale for Joining the Consortium

Ranking is calculated based on the average value of 29 responses in six defined categories of motive to join the consortium (Table 2). In the overall ranking, establishing foreign relationships is recognized as the most important motivation, followed by seeking expertise and skills, and access to funding opportunities. On the Chinese side, access to expertise and skills received the highest average score, whereas the U.S. side more highly values building foreign relationships through ACTC.

Table 2 | **Rationale (Ranked) for U.S. and Chinese Participants to Join ACTC (n=29)**

RATIONALE	RANKING – CHINA	RANKING – U.S.
1 - Establish foreign relationships	2	1
2 - Access to expertise or particular skills	1	4
3 - Access to funding	4	3
4 - Obtaining prestige, visibility, or recognition	3	2
5 - Access to equipment and resources	6	5
6 - Access to market	5	6

4.2 Research, Development, and Demonstration

As noted in the CERC protocol,[4] RD&D is central to any type of technology collaboration. Respondents were asked about the stages and types of research they had been undertaking through the ACTC, and about RD&D inputs (e.g. human and capital resources) and outputs (e.g. type and quantity).

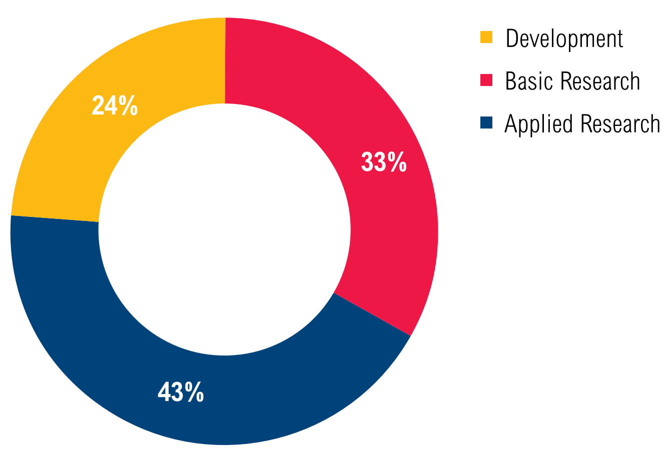
4.2.1 Inputs

ACTC partners devote human and financial resources and facilities to the bilateral research activities. The organizations usually devote 5–25 researchers to ACTC projects and some research groups have one or two full-time PhD students funded through ACTC projects. The average number of researchers in one Chinese research organization is eight, while the average on the U.S. side is six (n=30). On the financial side, records show that the U.S. ACTC members all matched government support with their own funds (though some matching funds were in the form of in-kind contributions); most of the Chinese partners are primarily funded by the government for ACTC activities (n=25). In terms of staff, official documents show that there are 240 researchers supported by CERC–ACTC, 200 from China and 40 from the United States. Because most of the funding on the Chinese side of the ACTC is from the government, it is directed toward more public research institutions and more researchers than in the United States.

4.2.2 Activities

The ACTC research projects cover basic research, applied research, and development. Definitions of each stage were presented in the questionnaire. When the eight research themes are combined, results indicate that more research projects fall into the applied research stage than either of the other two stages (Figure 4). Applied research was defined as “systematic study to gain knowledge or understanding necessary to determine the means by which recognized and specific need may be met.” The U.S. and Chinese research teams also share a similar research pattern by design. In China, basic research, applied research, and development account, respectively, for 32 percent, 46 percent, and 22 percent

Figure 4 | **Types of Research within the ACTC (n=37)**

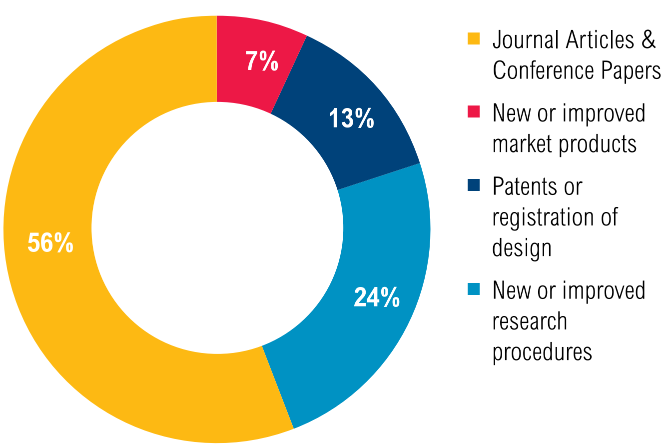


of the total research; in the United States the figures are 33 percent, 42 percent, and 26 percent. The percentage of development projects in the United States is a little higher than on the Chinese side.

4.2.3 Outputs

In the ACTC 2013 annual bilateral meeting, one consortium leader stated that 300 papers, 20 patents, 85 conferences, and five MOUs between the U.S.-China partners were produced out of the bilateral initiative between 2010 and 2013. Our survey identified fewer joint outputs, and our in-depth interviews confirmed that many of the products included in the totals provided by this consortium leader were not jointly produced.[5] One example of a joint paper is "Char Burnout of U.S. and Chinese Coals under Oxy-combustion Conditions," which was co-produced and presented by the researchers from China's Huazhong University of Science and Technology and the United States company Babcock and Wilcox (B&W) at the 2013 Pittsburgh conference. No joint patent has been produced to date. Joint products are mostly co-authored conference papers and journal articles. The number of joint papers is estimated to be around 50, based on the survey and interviews. Figure 5 indicates that the majority of research outputs are journal articles and conference papers.

Figure 5 | **ACTC RD&D Outputs Profile (n=34)**



High-level joint outcomes highlighted by consortium partners include:

- joint research on post-combustion capture processes at Shidongkou plant in Shanghai and at the Duke Gibson plant in Indiana;
- knowledge sharing about Huazhong University of Science and Technology and B&W's oxy-fuel combustion test platform;
- collaboration among Shenhua, Lawrence Livermore National Laboratory, West Virginia University, and University of Wyoming to identify suitable CO_2 storage sites in Ordos Basin, China and Rock Springs Uplift, Wyoming, USA;
- a CO_2-enhanced oil recovery project involving Yanchang Petroleum and University of Wyoming;
- data sharing on CO_2 utilization with microalgae among the University of Kentucky, Duke Energy, and ENN Energy Group, China.

4.3 Knowledge and Information Sharing

Knowledge and information sharing act as the bridge between the U.S. and Chinese research partners under the ACTC. In this study, survey informants were asked about the type and frequency of knowledge sharing. Thirty-six respondents had shared published articles and research methodologies with partners; however, only 13 respondents indicated that they shared engineering information (Figure 6). Compared with published articles and conference papers, engineering information is more commercially sensitive. Participants exchanged emails a few times per quarter and held personal exchanges and in-person workshops a few times per year. Video conferences were rarely mentioned in the survey.

4.4 General Impact of ACTC on Participant Organizations and Core Researchers

Project leaders were asked whether the collaboration helped their organization gain research funding, establish research partnerships, and most importantly strengthen their RD&D capacity. Answers from both countries follow similar patterns—around 85 to 90 percent of project leaders stated that ACTC had a positive impact on their organizations across all three indicators by strengthening R&D capacity, establishing research partnerships, and finding research funding (Figure 7).

Figure 6 | **Types of Knowledge and Information Shared within ACTC (n=40)**

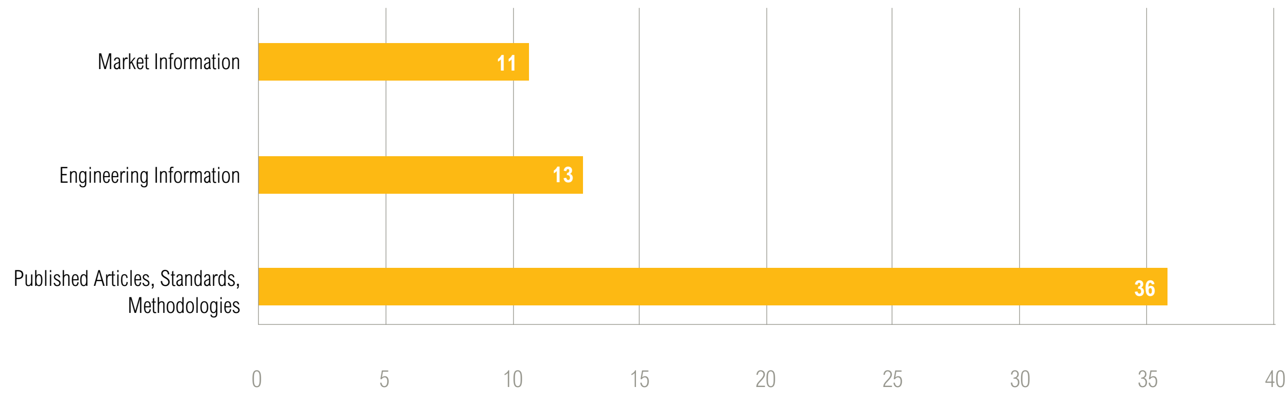
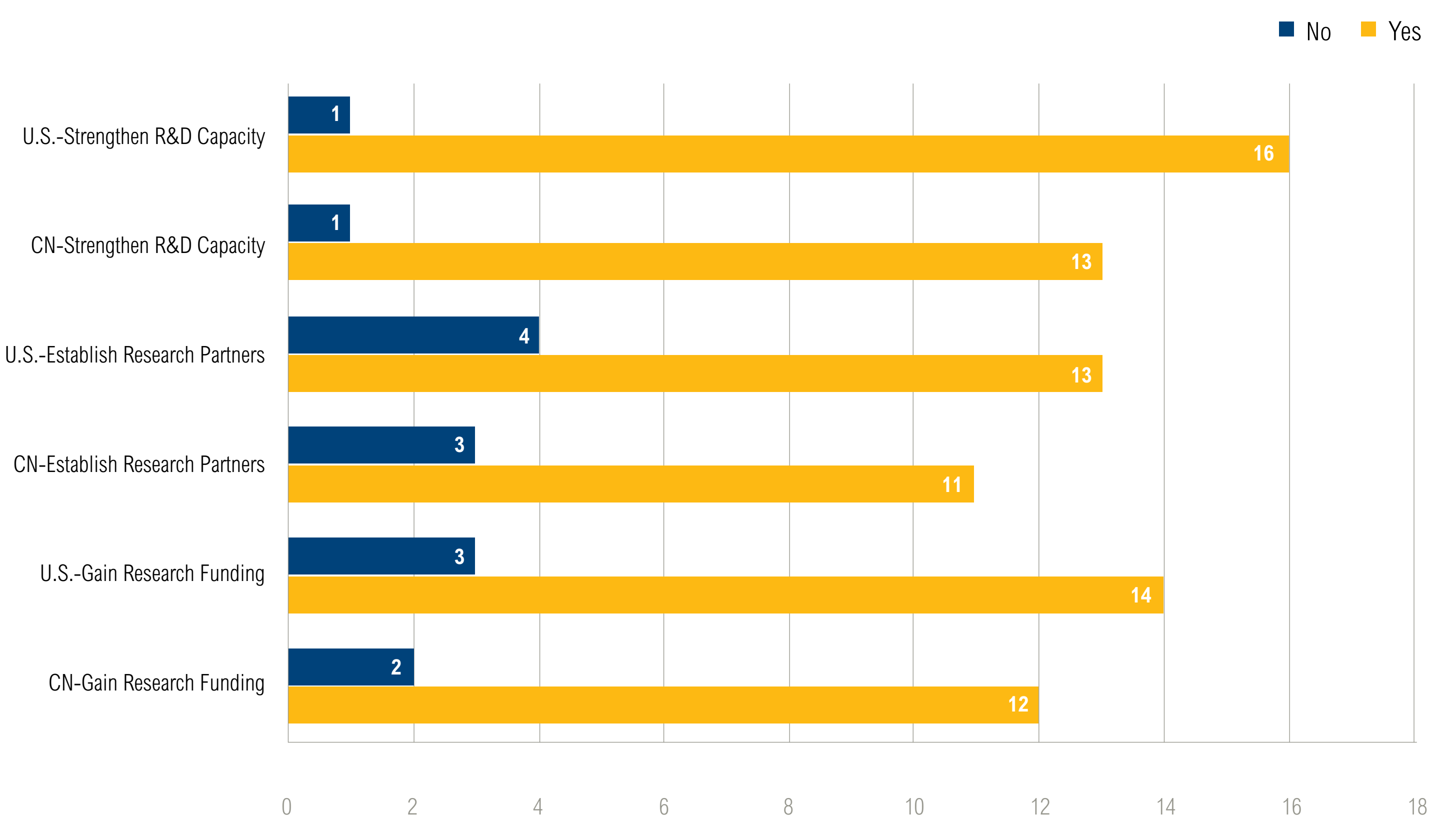


Figure 7 | **The Impact of ACTC on Organizations: Project Leaders' Responses (n=31)**



Note: U.S. – United States; CN – China.

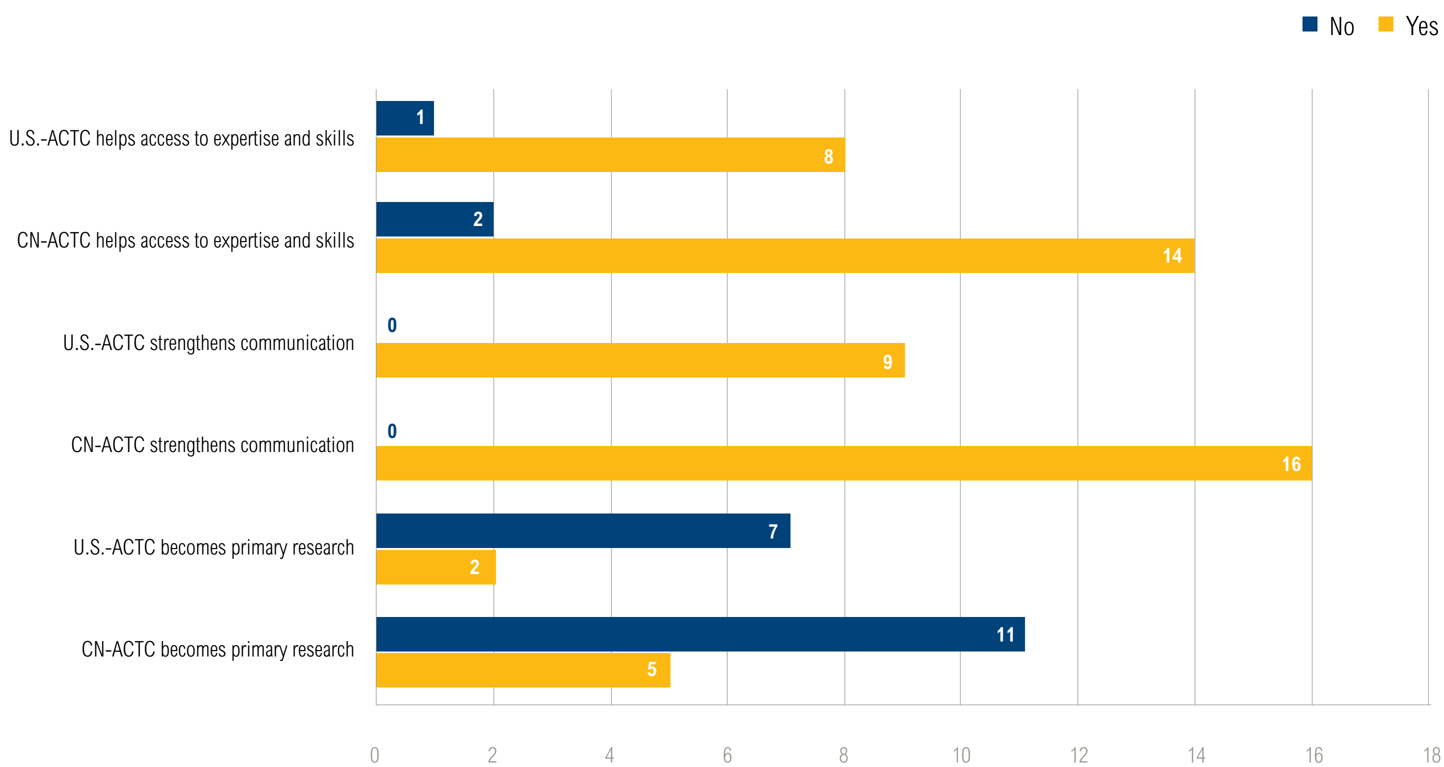
Core researchers were also asked whether the collaboration had become their primary research task, strengthened the communication between researchers, and helped gain access to new expertise and skills. A high proportion of researchers from both countries indicated that ACTC has not become their primary task. However, the ACTC has benefitted them through improved communication and access to others' expertise and skills (Figure 8). It is worth noting that the number of researchers who answered these questions is low (n=25), which might affect the findings.

4.5 Satisfaction and Concerns Regarding Collaboration, Funding, and Intellectual Property Arrangements

The final part of this section is about the satisfaction and concerns of project leaders and core researchers.

Leaders from consortia, themes, and projects are generally satisfied with collaboration, with an average of 3.83 in a Likert-scale (Figure 9) (5=very satisfied; 3=neutral; 1=very dissatisfied; n=29). The Chinese average score of 3.75 is similar to that of the United States at 3.88, and the two are not significantly different (the t-value is -0.48724; the p-value is 0.315012; the result is not significant at $p < 0.05$). Most of the informants chose "dissatisfied" or "neutral" with regard to their satisfaction with funding mechanisms, with an average of 2.76 (China=2.66 and the U.S.=2.82). (The t-value is -0.49417; the p-value is 0.312591; the result is not significant at $p < 0.05$.) (Figure 10). Regarding intellectual property protection, informants are generally neutral (Figure 11).

Figure 8 | **The Impact of ACTC on Research: Core Researchers' Responses (n=25)**



Note: U.S. – United States; CN – China.

Figure 9 | **General Satisfaction with the U.S.-China ACTC Agreement (n=29)**

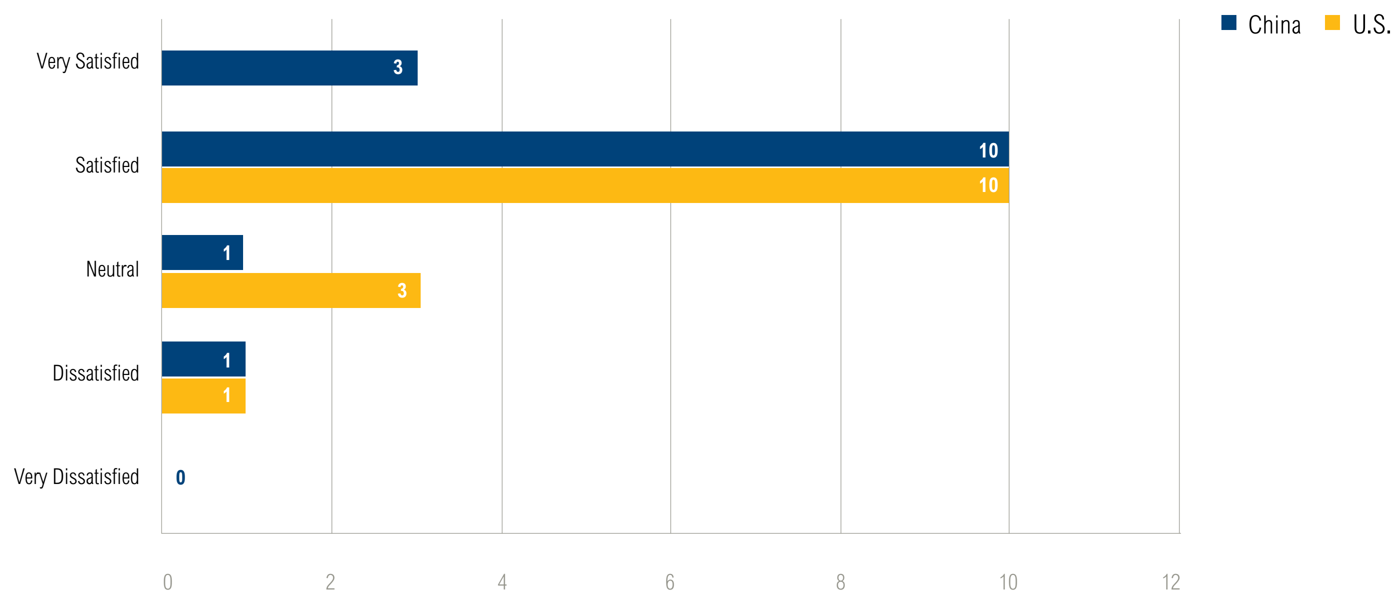


Figure 10 | **General Satisfaction with the U.S.-China ACTC Funding Mechanism (n=29)**

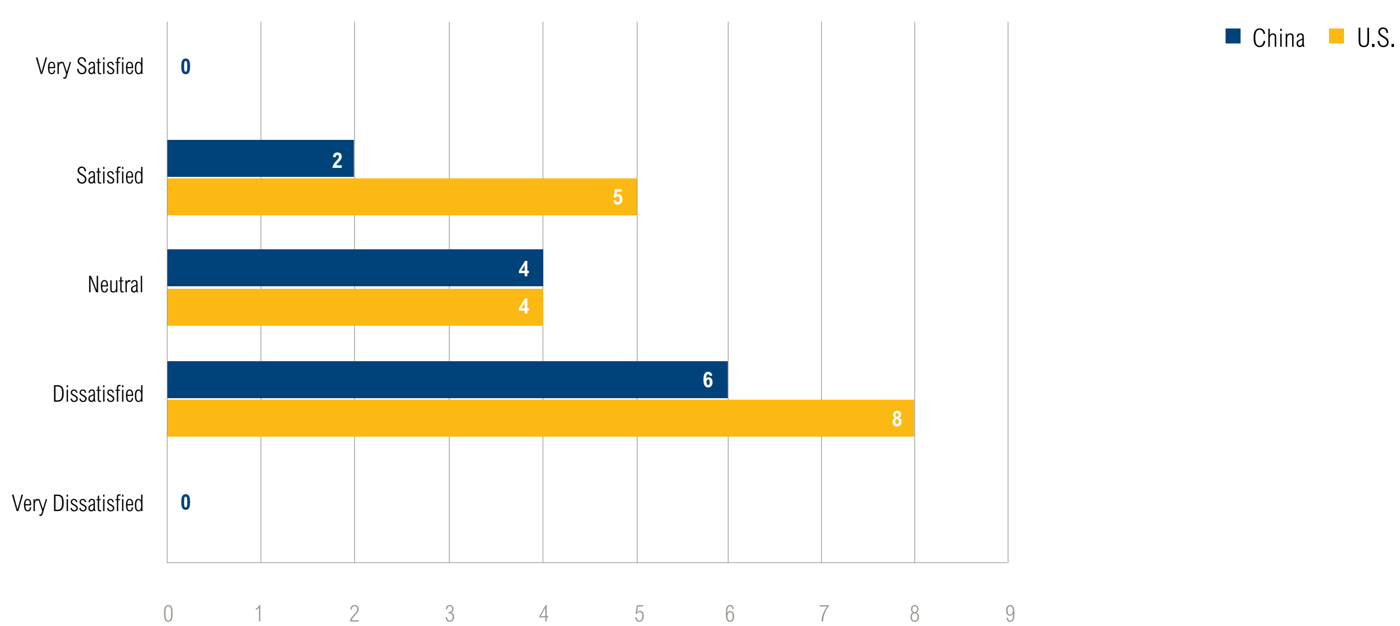
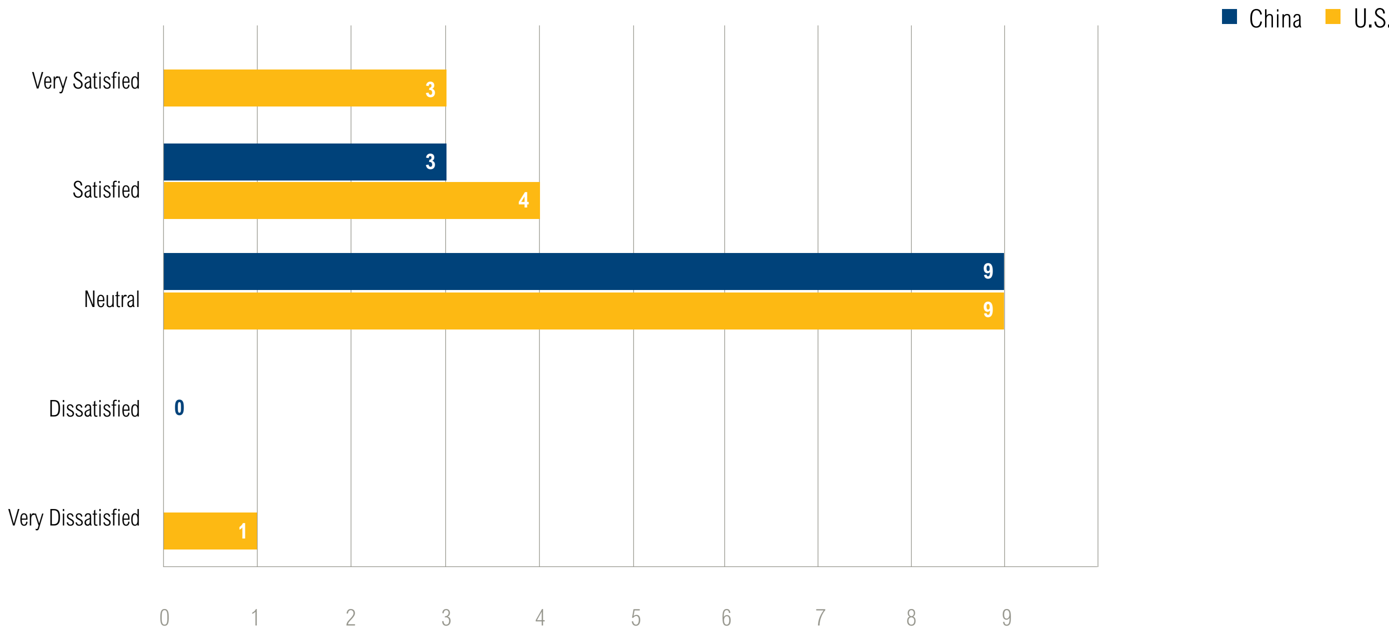


Figure 11 | **General Satisfaction with the U.S.-China ACTC IP Protection Agreement (n=29)**



Survey respondents were given opportunities to answer open-ended questions about their concerns and suggestions for CERC–ACTC for the next five years. Their feedback falls into five main areas: improving work relations and coordination, strengthening management structure, enhancing data sharing among partners, further improving funding mechanisms to add transparency and flexibility, and better understanding the interests of private-sector partners (Figure 12). Specifically, survey respondents hope to improve coordination between the two countries at the consortium leadership and project levels through continual trust building. Results indicated that the funding allocation on both sides should be more flexible and transparent, with clearer criteria for allocation decisions. Knowledge sharing should be strengthened and prioritized in all collaboration. Finally, under stable leadership and technical guidance, this platform should attract more private interests in the second phase.

5. DISCUSSION

This section begins with a discussion of mismatched research interests, motivations, and priorities between ACTC partners in the United States and China. Next, we explain why there have been difficulties associated with communication, coordination, and team building within this bilateral platform, which leads to an explanation of the lack of joint patents and products. However, despite the challenges, the ACTC has benefited both sides in many ways at the national and project levels, resulting in technology learning effects for CCS.

5.1 Balancing Research Interests, Motivations, and Priorities

The mismatch of research interests and unclear expectations set by participating institutions at the beginning of the partnership created barriers to collaboration. One American company joined ACTC at the beginning with the expectation of accessing the Chinese oxy-fuel combustion technology market and participating in pilot or large-scale demonstration projects in China. However, at the operational level, the company was hesitant to share some of its engineering information with its Chinese partners. Meanwhile, its Chinese counterpart, a leading research institution on oxy-fuel combustion research, aimed to better understand the technology

Figure 12 | **Main Concerns and Suggestions from Survey Respondents (n=29)**

status in the United States, and had no intention of prioritizing the U.S. company's interest in China's future oxy-fuel combustion market. These mismatched research interests led the research partners to be hesitant about sharing engineering data information with each other. After several attempts to get involved in China's large-scale oxy-fuel CCS project, this American company withdrew from the consortium in 2014, citing a shift in the organization's research strategy. The survey results show that the participant organizations had many reasons to become affiliated with the consortium. As a result, the participants might not have prioritized conducting joint RD&D as long as their other goals were being achieved, e.g., establishing foreign contacts and gaining access to funding opportunities (Table 2).

Second, as the survey suggested, CERC–ACTC research rarely dominated the participants' daily work, and instead served as additional support to established projects. For example, the most visible pilot projects within CERC–ACTC were all established or planned before CERC, including Huaneng's IGCC project, Shenhua's Ordos CO_2 storage project, and the University of Kentucky's algae program. Thus, it is hard to see to what extent the consortium members prioritized ACTC activities and how much effort was made specifically to support this initiative.

5.2 Communication, Coordination, and Team Building

Several differences in the two countries' approaches also brought complexity to this bilateral initiative. After its formation, the U.S. Department of Energy (DOE) strengthened its human resources capacity specifically for CERC by, among other things, employing one dedicated officer in DOE's Beijing office to coordinate with the Ministry of Science and Technology (MOST). China's rigid civil service system did not allow the responsible office at MOST to immediately hire a full-time employee for CERC work, so the workload went to existing staff that might already have been occupied by other tasks. This uneven capacity slowed down information flows and decision-making in the CERC secretariat in both the United States and China.

Second, although both countries agreed to contribute $50 million to the ACTC annually, MOST and DOE took different approaches to providing and distributing this funding. China's MOST used established technology support programs, like 973 National Basic Research Program and 863 National High Technology Development Program. In the United States, DOE designed a new funding program for CERC, with DOE providing half the funds directly and the other half coming through a cost-sharing mechanism with industrial partners. This uncoordinated funding allocation process between the U.S. and Chinese governments created mismatched capacity for the research tasks that were agreed to by researchers on both sides, and also made tracking the money spent on cooperative activities more challenging. During Phase I, there were no true jointly funded ACTC projects at the theme and task level, based on the official definition. The ACTC Technology Management Plan defines a jointly funded research project as "cooperative activities whose scope of work/work plan involves signatories to the CERC Protocol from both countries providing collaborating research performers employed or sponsored by them and/or *joint funding* of such scope of work/work plan" (ACTC 2011).

Lack of coordination in the initial team-building process in the United States and China reduced the opportunities for both sides to pair up with suitable collaborators. The United States had a competitive process for the funding award for the consortium, with potential U.S. teams built before funding applications were submitted. In China, MOST selected the research institutions and state-owned energy enterprises that were well established in the area of coal technology. Because there was no joint team-building process between the two countries, the U.S. team was selected without consideration for potential Chinese partners and compatibility of their research interests, and vice versa. As a result, in some cases, research partners in each country were not able to find appropriate counterparts in the other. An improved process would select the Chinese and U.S. research teams on the basis of common research interests.

Geographic location on the two sides of the Pacific Ocean creates challenges for timely knowledge and information sharing between the participants in the two countries. Cultural and language differences can also create difficulties. For example, while email is becoming more prevalent in work communication in China, it is still not the most popular communication tool among Chinese researchers. On the other hand, email dominates communication among U.S. researchers. Compared with face-to-face meetings and video conferences for international cooperative work, email is the lowest-cost and most time-efficient tool. True collaboration requires the U.S. and Chinese researchers to exchange email several times a week instead of a few times a quarter. A former executive at the Babcock & Wilcox (B&W) Company, who is currently an ACTC leader said, "... in the private sector, engineering activities pass daily between various company subsidiaries without problems. At B&W, we would download design information from B&W Beijing each morning (U.S. East Coast time), make comments, revisions, and additions, then upload it to Beijing just before East Coast close-of-business. While the East Coast slept, B&W Beijing picked up the work and added content. This continued throughout a project and was cost effective and timely."

5.3 Lack of Joint Patents and Private-Sector Participation

The previous U.S. Energy Secretary considered joint patents to be the most desirable outcome of this CERC bilateral initiative. Official documents state that patents were produced through CERC–ACTC activities, yet no joint patents were filed on behalf of the U.S. and Chinese research teams. Joint products included journal articles and conference reports. The CO_2 geological storage group, where developing technology was not the main goal, co-produced more research papers than the other seven themes. For example, Chinese and U.S. researchers co-authored the paper "A Feasibility Study of the Integration of Geologic CO_2 Storage with Enhanced Oil Recovery (CO_2 Flooding) in the Ordos Basin, China." One leader who wished to remain anonymous said that most CERC–ACTC activities are occurring at the lab stage with limited data sharing between the two sides, due to the early stage of the CCS development. In the existing dynamic, creating co-patents appears unattainable, and this statement was validated by survey results.

Lack of sufficient participation from the private sector in CERC–ACTC is likely the reason why most of the current research projects are focused on the lab stage rather than demonstration and pilot projects. Several survey informants hoped to better understand why this initiative has not attracted a stronger private-sector presence.

Our survey results find that small private companies are motivated to join the ACTC to build foreign relationships, receive access to government funding, and gain prestige, visibility, or recognition. Nevertheless, some multinational energy technology corporations, which dropped out at the beginning of the ACTC, were seeking neither government support for RD&D nor a boost to their prestige in the United States and China. For example, a former ACTC member entered the Chinese market in 1991 and has had a major R&D facility in Shanghai for 15 years. For those giant energy technology providers, the access to specific skills, foreign markets, and ability to gain public prestige that CERC offers would not be huge incentives, according to an anonymous ACTC leader.

The CERC Technology Management Plan requires that "the participants shall have access to and a free right to use such Intellectual Property created or invented during this cooperative activity, for purpose of execution of the project/work plan for the particular Jointly Funded Research Project" (ACTC 2011). This provision can further complicate the participation of well-established private companies. By 2014, LP Amina and Duke Energy were the only two private-sector companies left in the consortium on the U.S. side. LP Amina is a small firm specializing in advanced coal technology with hopes of gaining a foothold in the Chinese market. Duke is a large American power company, not a technology provider, meaning it is not in direct competition with other partners working on technology development.

Without sufficient participation from the private sector, ACTC clearly cannot achieve large-scale CCS demonstration projects and facilitate the commercialization of major CO_2 control technologies expected by initial architects of this initiative. The CERC ACTC Phase II needs to consider how to re-position itself not only to attract more private-sector partners, but also to support their efforts to achieve large-scale integrated CCS projects. The alternative position is that this type of effort is best focused on lab-level collaboration, rather than the deployment phase, which tends to be commercially sensitive.

5.4 ACTC is Helping CCS Technology Learning

At the organizational level: Many project leaders and researchers expressed the view that this platform provides excellent opportunities for interaction with peer research organizations, which allows them to broaden their research scope and to be aware of the latest relevant information in the field. The initial consortium-building process involved rounds of extended negotiations over research interests among partners. Mapping RD&D of clean coal technologies in both countries was a major component of that process. During an interview, a leading Chinese member of ACTC said that he made a presentation about the history and progress of CCS RD&D in China to the U.S. delegations in the spring of 2010, which enabled the American partners to better understand the state of this technology in China. Over the years of interaction, although it is challenging to achieve effective collaborative RD&D, the bilateral initiative has helped participants to secure additional research funding, establish domestic and foreign relations, and eventually strengthen their research capacity. Although it is challenging to achieve true joint RD&D work, most of the participating institutions have benefited from CERC–ACTC to some extent.

An industrial-scale, fully integrated CCS project combines hundreds of technologies across several major sectors: the power sector, the chemical industry, pipeline companies, and petroleum operators. The CERC–ACTC provides a global platform to gather appropriate players, technology researchers, equipment vendors, policymakers, and finance players to discuss the development of CCS, which potentially increases the rate of technology learning. One Chinese ACTC leader explained that, without this platform, it was hard to convene key project stakeholders in China, and harder still to convene them from both countries.

At the national level: The U.S.-China cooperation in clean energy technology has become one of the most crucial components under the two largest economies' climate change cooperation framework, and was featured prominently during both presidents' state visits, the U.S.-China Strategic and Economic Dialogue, and other high-level bilateral engagements. With the recently concluded COP21 negotiations and resulting Paris Agreement, technology innovation is all the more important to achieving CO_2 emissions mitigation goals. Countries are looking to the United States and China for climate change leadership and for examples of cooperation, such as this bilateral initiative to facilitate low-carbon technology development. Because of the increasing importance of addressing climate change and the high profiles of the

United States and China, CERC is significant in the context of international climate politics. Collaboration on clean energy technology is also helping the two countries build trust in climate change negotiations with shared responsibility.

The U.S.-China collaboration on CCS can achieve fast technology learning by integrating the comparative advantages of the two countries. Large-scale fully integrated CCS projects are capital and technology intensive. For example, the newly built Kemper County IGCC project in Mississippi cost $6 billion, which was $4 billion over the initial budget. However, building and operating industrial-scale CCS projects is the only way to achieve future commercial deployment of CCS. Combining the world-class U.S. research infrastructure and competitive financial market for technology innovation with China's huge resource mobilization capacity, excellent facilities for translating scientific advances into prototypes, and the world's largest clean coal technology market may considerably reduce the cost of technology learning and allocate sufficient resources to one or two large-scale CCS demonstrations. In spite of the challenges to achieving effective collaboration from both sides, the first phase of CERC–ACTC has shown some promise, including a newly built and operated 3 MW oxy-fuel combustion pilot facility; one economic and technical analysis of post-combustion carbon capture using novel amine capture technology; a model of carbon capture, transportation, and storage; and a demonstration of using captured CO_2 to cultivate microalgae.

6. RECOMMENDATIONS

Given the urgent need to develop CCS to help achieve our climate goals, international collaboration is critical. True collaboration between the United States and China can benefit CCS technology learning in the two countries as well as the rest of the world. However, designing and implementing effective collaboration that leads to CCS commercialization remains a challenge. China and the United States announced the continuation of CERC from 2016 through 2020 in their historic joint climate statement announced in November 2014; decision-makers and practitioners should therefore consider how to further strengthen bilateral cooperation to achieve effective joint RD&D. Findings from this study suggest several recommendations:

6.1 Strengthen Communication at Several Levels

- At the consortium level, enhance communication between directors and coordinate on project planning, funding allocation, membership recruitment, and research progress through a stable communication channel and regular two-way personal visits; allow flexibility in resource allocation among tasks; assign a point of contact at the consortium level on both sides and hold regular check-in meetings.
- At the project level, increase the frequency of communication (e.g. once every two weeks); increase personal exchanges and work together in real time (in-person workshop once a year in addition to the annual meeting); assign a point of contact at the project level.

6.2 Strengthen Private-Sector Participation

- Involve private-sector partners in the initial discussions to set up the research agenda; understand the needs of the private sector and present what the consortium can offer to help meet those needs; involve private sector partners in establishing an IP framework that satisfies stakeholders, based on the national law on IP issues; involve private-sector participants in evaluating research performance.
- It may be useful to implement two or three outreach events in Washington, DC and Beijing during the spring of 2016, in order to present ACTC information to relevant companies, research institutions, and provincial government officials. This type of roadshow could provide an opportunity for consortium and research leaders to present Phase I achievements and spur interest in research topics for Phase II.

6.3 Strengthen Joint RD&D

- Research should be centered on industrial-scale demonstration projects; therefore, research resources need to be consolidated (there are currently too many research projects and individual projects receive inadequate resources).
- Resources should be prioritized toward projects that are of interest to researchers in both countries and are truly collaborative. As our results show, not all research tasks attract equal levels of interest from both sides.

6.4 Create Flexibility in Changing Research Direction and Membership

- Identification of appropriate partners at all stages should be a priority, and a mechanism for quick acceptance or withdrawal of membership should be considered; establish a mechanism that allows new members to quickly join the collaborative activities.[6]
- CERC–ACTC can also serve as a platform to facilitate technology advancement in clean coal, and could regularly hold workshops for public outreach to attract new resources and members.

6.5 Barriers to Implementing the Recommendations

The CERC–ACTC has fundamental value in two areas: international politics and science and technology development. CERC has clearly demonstrated its political value through its role in bringing the United States and China together to mitigate climate change. As Minister Wan Gang of MOST indicated in the 2015 CERC Steering Committee meeting, CERC has greatly enriched the development of the new type of Great Power relationship between the United States and China. Furthermore, both the 2014 and 2015 U.S.-China Presidential Joint Announcements included CERC, and stated that the two countries will continue to support and expand this collaborative technology platform. Providing strong support to technology development through CERC–ACTC now will drive CCS technology learning to achieve commercialization, ideally by 2030. In order to implement the recommendations above, it will be key to convert CERC's political value to its technology motivation: a collaborative platform, with high-level support and hundreds of leading scientists and engineers in the United States and China, which can speed up the technology learning process.

One primary barrier to faster learning is lack of clarity about each institution's role, including public research institutes and private players, in terms of who leads demonstration and who supports research. The ideal situation for the CERC–ACTC type of bilateral research platform may be that governments provide funding, private companies lead demonstration projects, and public research institutes tackle the scientific and engineering problems around the demonstration projects. Only with mutually agreed-upon roles will this learning system create a united vision and suitable plans to achieve it. A second barrier is lack of integration of commercial and research interests, which was not achieved in the first phase of collaboration. With a view to better integration, the U.S.-side ACTC plans to establish a council composed of private companies that will provide strategic research guidance and evaluate the RD&D activities from the market perspective in 2016. Overall, market-oriented climate mitigation is the only way forward for CCS technology.

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ENDNOTES

1. The U.S.-China Clean Energy Research Center has two phases – Phase I (2011–2015) and Phase II (2016–2020). This working paper reviews the Phase I collaboration.

2. U.S.-China Clean Energy Research Center. N.d. “U.S. President Obama and China President Xi Jinping make Joint Announcement on the Extension and Expansion of CERC.” Online at: http://www.us-china-cerc.org/index.html

3. Huaneng is one of China’s largest state-owned power companies. Huaneng Clean Energy Research Institute is a subsidiary of the company.

4. U.S.-China Clean Energy Research Center. 2009. “Protocol between the Department of Energy of the United States of America and the Ministry of Science and Technology and the National Energy Administration of the People’s Republic of China for Cooperation on a Clean Energy Research Center.” Online at: http://www.us-china-cerc.org/pdfs/US/US_China_CERC_Protocol_and_IP_Annex_English_17_Nov_2009.pdf

5. Joint products, defined as patents, journal articles, conference papers, and technical reports, are co-produced by at least one U.S. and one Chinese ACTC partner.

6. The U.S. DOE and China’s MOST have already taken actions regarding adding new members; there is a procedure in place that enables the two directors to agree and then add members accordingly.

ACKNOWLEDGMENTS

The author would like to thank WRI peer reviewers Paul Joffe, Ranping Song, and Geoffrey Henderson as well as external peer reviewers Sarah Forbes, Jim Wood, and Cliff Davidson for their thoughtful review of the draft document. This work also benefitted substantially from the insights and feedback of WRI's Kevin Kennedy and Laura Malaguzzi Valeri. My appreciation also extends to Katie Lebling, who provided assistance in the final stage of this publication. Finally, I would like to thank Emily Matthews for her copyediting and proofreading and Jenna Park for the publication layout and design.

This working paper is based in part upon Ph.D. dissertation research supported by the U.S. National Science Foundation under Award Number SMA-1262278. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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ABOUT WRI

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