Opportunities for Realizing Drastic Reductions in Building Sector Carbon Emissions through U.S.-China Collaboration

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ABSTRACT

Today, there is a strong understanding of the potential economic, security, and diplomatic gains for the U.S. and China associated with collaborating on clean energy and climate change. Yet despite the identification of energy efficiency as a clear priority for both countries, which is underpinned by bilateral agreements and broad efforts to date, little analysis has been conducted to understand how the two countries can leverage collective opportunities and common intervention points to reduce building energy use.

Two recently completed detailed studies completed by the authors for the U.S. and China identified possible pathways for drastically reducing energy use and carbon dioxide emissions by 2050. Informed by the identified solutions, this paper outlines collaboration opportunities that support each country to realize the vision. The opportunity assessment takes into account political context, country development status, building energy consumption and stock characteristics (such as age, growth, and turnover), impactful design and technology solutions, building sector reduction potential, and cost effectiveness. The ensuing collaboration assessment, based on these key considerations, identifies the best opportunities for the two countries to capitalize on each other's advantageous position to address shared challenges and yield mutual benefits.

Introduction

In 2011, Rocky Mountain Institute (RMI) published the book Reinventing Fire: Bold Business Solutions for the New Energy Era (Lovins, 2011), which analyzed and examined the potential and associated costs for sharply reducing fossil fuel use in the U.S. by 2050. In 2013, RMI, Lawrence Berkeley National Laboratory (LBNL), and the China Energy Research Institute (ERI) initiated a similar Reinventing Fire (RF) analysis for China (RMI, 2016). The objectives for the two studies were to provide a rigorous, credible, and ambitious vision for energy consumption in all energy using sectors between 2010 and 2050, to better understand the potential for national fossil fuel reduction, and to estimate the impact of cost-effective opportunities. The savings potential identified for each country is drastic. For example for the building sector, the primary energy reduction potential for the U.S. and China is 36.4 and 37.4 Quads or 56% and 69% of projected business-as-usual energy 2050 energy use, respectively. The corresponding carbon emissions reductions are 3560 and 3720 MtCO2.

This paper builds from the authors' involvement in the U.S.-China RF studies to examine collaboration opportunities that support each country's emissions reductions targets, as set forth

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in the Paris Agreement. It provides a side-by-side comparison of findings from the studies and aims to identify an optimum trajectory for U.S.-China bilateral collaboration.

U.S.-China Overview

In order to ascertain an effective strategy for U.S.-China collaboration strategy for building energy efficiency, it is critical to understand and account for over-arching differences between the two countries. Table 1 compares U.S. and China building sector characteristics, political systems, and country development status.

Table 1. Comparison of U.S. – China Characteristics

	China	U.S.
Building Sector	21 Quads (20%) primary energy*	40 Quads (41%) primary energy*
	50% population in urban areas	81% population in urban areas
	30 year commercial building life (lower in rural areas)**	55 – 60 year commercial building life
	6,560 million sq. ft. new construction in 2010	1560 million sq. feet new construction in 2010
	Low energy use intensity due to partial zonal conditioning, wide indoor temperature ranges	High energy use intensity due to central conditioning, tight indoor temperature ranges
Politics and Policies	National level efficiency regulation	State and local level efficiency regulation
	Quick, mandated adoption	Market forces leveraged for adoption (incentives, information, training)
	Poor technical capacity for implementation and enforcement	Robust technical capacity for implementation and enforcement
	Lack of private-sector financing of efficiency	Well-developed energy services market
Development and Economy	2014 GDP $10.35 trillion***	2014 GDP $17.42 trillion ***
	2014 GDP/cap $7400****	2014 GDP/cap $55,230****
	Developing country	Developed country
	Moving from low-end manufacturing to high-end manufacturing and services	Advanced service economy
	Capacity and willingness to invest heavily in R&D	Advanced scientific and institutional capacity

* 2010 energy (EIA, 2012)
** (Cai, 2015)
*** http://databank.worldbank.org/data/download/GDP.pdf
**** http://databank.worldbank.org/data/download/GNIPC.pdf

China's buildings sector consumes about one-half the amount of energy as the U.S. sector. China's energy intensity per unit of floor space and per capita is far less than in many developed countries. China per capita building energy use in 2012 was only about 80% of the global average, and about 20% and 33% of the average levels in the U.S. and the OECD, respectively (IEA, 2015). Energy use per unit of floor space in 2005 for urban buildings was only about 40% of the level of that of the US; this is due to different usage patterns as well as higher Chinese indoor temperatures in the summer and lower in the winter. While the China building sector uses significantly less energy than the U.S., there are still significant opportunities for long-term energy savings through improved construction quality, appliances, equipment, controls, metering, and commissioning

Many Chinese appliance and equipment efficiency standards lag behind international counterparts. Many buildings are not metered or properly controlled and few buildings are being commissioned. Low-quality construction, short lifetime and extensive development are significant issues for China. Energy-saving retrofits of existing buildings are mostly non-existent in China since there is little point to retrofitting buildings that will be soon demolished. High demolition rates also mean higher losses in embodied energy from wasted construction materials. In contrast, the U.S. building stock is comprised of both aging buildings and new construction due to its low rate of new urbanization and longer building lifetime.

Understanding the differences in U.S.-China political systems and country development status can inform effective building energy efficiency collaboration opportunities. For example in the U.S., most efforts to develop building performance standards are at the national level yet codes that reference the standards are regulated at the state and local level. In China, most energy efficiency initiatives originate with the national government, with implementation occurring at the provincial or local level. Chinese building energy policies tend to be implemented through regulation and mandates, whereas the U.S. relies more heavily on market forces to achieve policy outcomes through public-private partnership programs, such as ENERGY STAR, and a robust and transparent market. For example, in the U.S., the federal government mandates energy labeling for building appliances and energy end-use devices while building energy codes are adopted at the state level. On the contrary, in China, building energy codes and standards are developed by the Code Compilation Committees, are reviewed and approved by the public, and then are adopted and enforced at the national level by the China Ministry of Housing and Urban and Rural Development (MOHURD) (Szum, 2015).

China and the United States are at different stages of their development trajectory. The United States is a developed country, richer in total GDP and on a per capita basis than China, has a far more developed scientific community, and enjoys far greater institutional capacity in dedicated personnel and workforce technical training. The U.S. has already constructed most of its infrastructure and completed its urbanization and is now primarily a service economy (Lieberthal and Sandalow 2009). In contrast, despite its recent economic rise to become the world’s second largest economy, China is still considered a developing country. China’s population is four times that of the United States, with only one-third of that population living in well-developed urban areas. China’s average per capita income is still only one-eighth of the United States and two-thirds the world average. Whereas the United States has completed its transition to a service economy, China is still in the early phase of transition from an economy dominated by low-end, labor-intensive manufacturing to an economy that produces high-end indigenous technology for world markets as well as a service economy. To achieve this economic transition, the Chinese government is making significant investment in high-end manufacturing and technology R&D (Szum, 2015).

Leveraging Differences for Mutual Benefit

The differing political structures and levels of development benefits and challenges for each country. A challenge for the U.S. is that there is no single national policy focus addressing shared building efficiency objectives across states. This results in dispersed implementation efforts. China's top-down political system means that policies can be dispensed quickly but implementation lags due to conflicting interests among local officials and enterprises (Lieberthal and Sandalow 2009, 33). China's policies tend not to leverage market forces. While China has a robust energy service company (ESCO) market for the larger industrial sector, offerings for commercial buildings are limited. China suffers from implementation problems and enforcing its regulations due to a lack of adequately trained labor and technical capacity (Lieberthal and Sandalow 2009, 35). However, China's rapid economic development and the desire to transition its economic base to high-end manufacturing and services, can provide both the capacity and the willingness to invest significantly in R&D for technology, policy, and market solutions.

U.S.-China Techno-Economic Savings Potential

The two RF studies conducted for the U.S. and China estimate each country's techno-economic savings potential, which includes identifying mature and emerging cost-effective technologies and evaluating their capital investment and impact on building sector energy consumption and CO2 emissions. The methodology and underlying assumptions for the studies are outlined below (Lovins, 2011) (RMI, 2012) (RMI, 2016). The results from the two studies are presented side by side below to reveal collective opportunities and common intervention points for realizing the RF vision.

Overview of RF Study Methodology

The RF studies quantify the U.S.'s and China's energy efficiency opportunity from 2010 to 2050. Each study developed two forecasts to understand how sector energy consumption will change over the forty-year period. The business-as-usual (BAU) scenario reflects implementation and adoption of energy efficiency measures based on autonomous technological improvements and maintaining the trajectory of currently successful programs and policies. The RF scenario represents a more transformative and cost-effective pathway of development. While the same technologies are adopted in each scenario, the RF scenario has greater penetration. The RF U.S. study is a spreadsheet-based analysis developed with and calibrated against U.S. national survey data (RMI,2012). The RF China analysis incorporates building type, climate, and end use modeling within the LEAP (Long-Range Energy Alternatives Planning) software platform (Zhou, 2014). Both studies model residential and commercial buildings separately, with further distinctions by climate zone, existing versus retrofit buildings, and several levels of new building efficiency.

Substantial Building Sector Growth

The RF studies utilized existing building floor area data, growth forecasts and turnover estimated using retirement curves to project floor area trends over the forty-year study period. Figure 1 reveals that each country's overall percent floor area growth is similar but China's absolute growth is much larger - over 2.5 times that of the U.S. China's urban population is anticipated to increase from 50% of total population in 2010 to 68% by 2030, adding 280 million people to cities (Zhou, 2015). In contrast, nearly 81%[1] of the U.S. population currently live in urban areas, which is expected to increase to 87%[2] by 2030, adding about 60 million[3] people (U.S. Census, 2012). Due to the poor living conditions, with low comfort and amenities, in China's rural areas and greater economic opportunities afforded by cities, urbanization will drive substantial growth in energy use. Urbanization will cause growth in household incomes, lead to larger household size, and increase the use of energy-consuming appliances. New construction rates for commercial buildings tend also to be higher in China due to the relatively short lifespan of buildings.

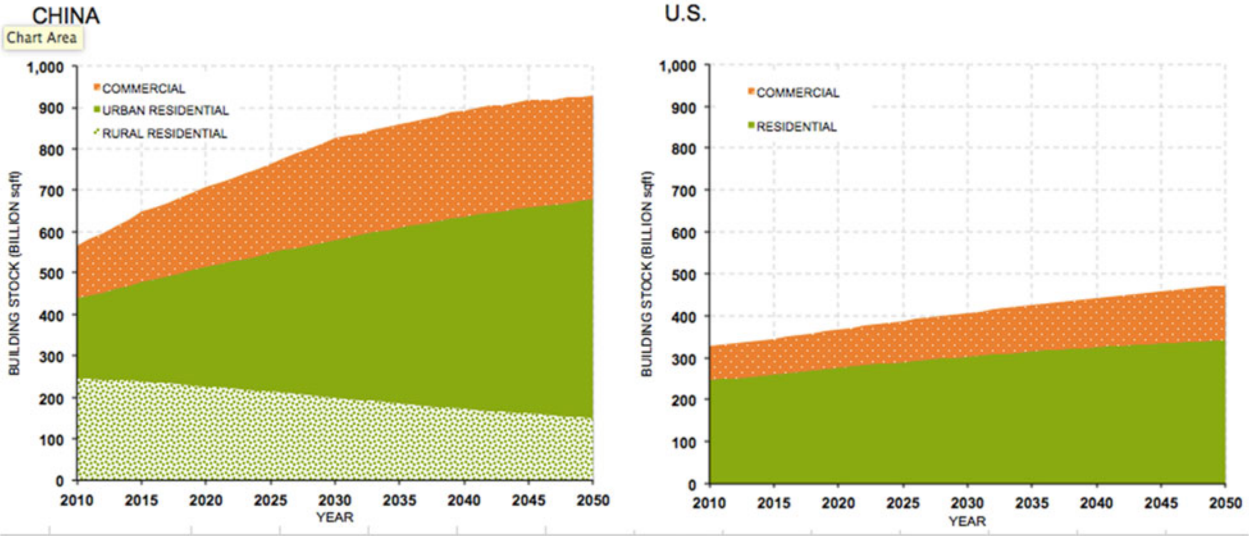

Figure 1: Building Stock Floor Area Projections

Impactful Efficiency Strategies

In the RF U.S. and China studies, efficiency opportunities can be grouped into three categories: integrated design, energy-efficient equipment, and smart controls. In the studies, several different building stock types are defined that go beyond business-as-usual as indicated in Figure 2. In the analysis, each stock type is distinguished by having different technology and design adoption rates. The graphs demonstrate the immense amount of floor area that can be cost effectively impacted, which is dominated by efficient new construction in China and existing building energy retrofits in the U.S.

Figure 3 presents the incremental savings associated with each efficiency category and the overall impact on primary energy use for the RF scenario for China and the U.S. While the RF vision impacts different types and total amounts of floor area for each country, the total and step-wise savings are comparable. The largest savings occur from performance improvements associated with integrated design, which is closely followed by efficient equipment. Additional

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[1] https://www.census.gov/newsroom/releases/archives/2010_census/cb12-50.html

[2] http://www.economist.com/blogs/graphicdetail/2012/01/daily-chart-6

[3] https://www.census.gov/content/dam/Census/library/publications/2015/demo/p25-1143.pdf

less-capital intensive savings are achieved through operational and behavioral improvements resulting from smart controls.

The savings are presented by building stock type in Figure 4. In China, the bulk of the savings, nearly 75% or 27 out of the 37 Quads, occur in new buildings with the remaining attributed to rural and existing urban buildings. In the U.S., the majority of the savings, 60% or 23 out of 38 Quads, occur in existing buildings. Combined, the RF studies reveal a potential savings of 42 Quads for new buildings and 33 Quads for existing buildings, with an additional 5 Quads earned from modernizing rural buildings in China.

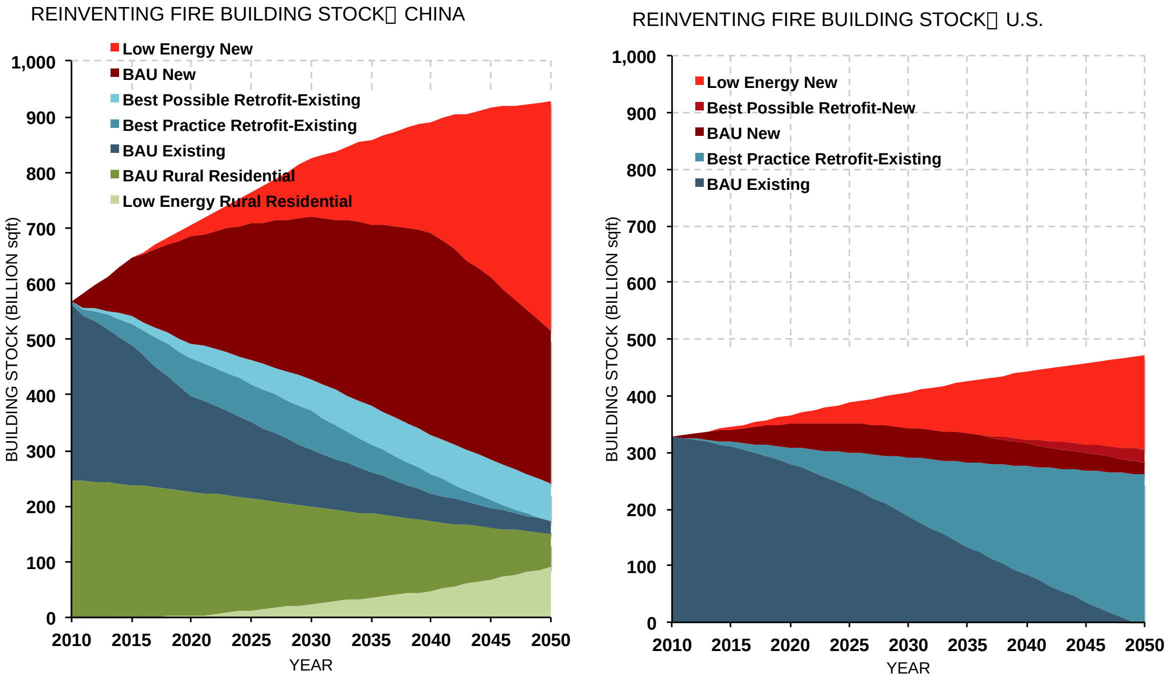


Figure 2: Building Stock Projections by Efficiency Class and Type

The lighter shades of green, blue, and red in the charts indicate the RF scenario floor area that goes beyond the BAU scenario. New building trends are shown in red, existing buildings in blue. China's existing substandard rural and new rural buildings are indicated in green.

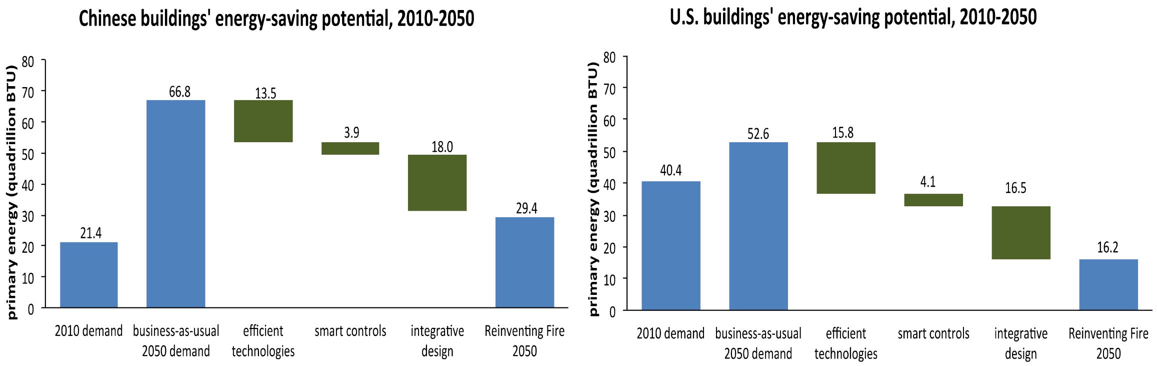
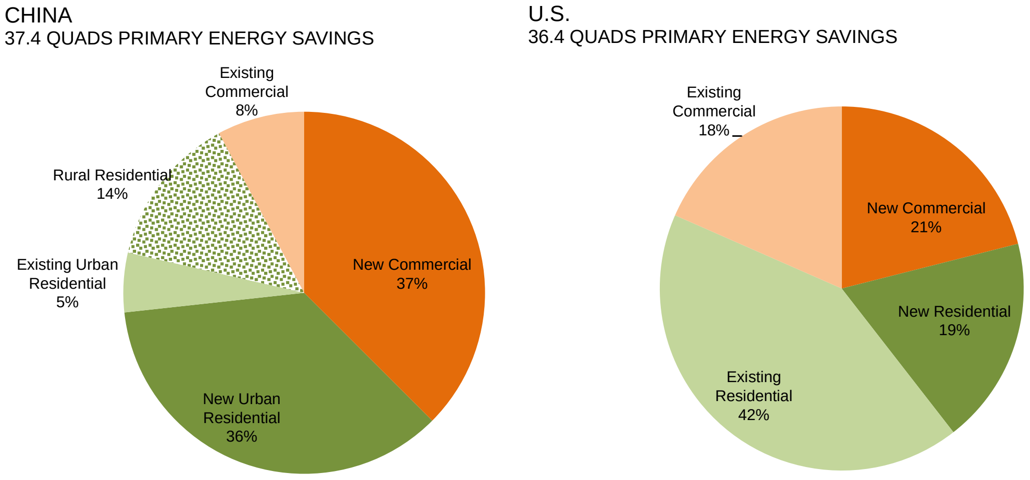


Figure 3: Primary Energy Savings by Efficiency Opportunity

Efficient Technologies captures today's global best-in-class technologies. Improvements in efficiency occur for the various equipment types serving different residential and commercial building energy end-uses, including cooking, water heating, appliances, lighting, plug loads, heating, cooling, and ventilation.
Smart Controls for buildings include sensors, controls, and data access. For commercial buildings it includes, and analytics for fault detection and optimizing operation to respond to real-time price signals. For residential buildings it includes smart meters, in-home displays, communicating thermostats, and web portals.
Integrated Design is an approach to optimize individual technologies and components by making cost-effective tradeoffs across energy-using systems (envelop, appliances, lighting, ventilation, cooling, and heating) to reach a high level of energy performance and other project goals at zero or little added cost.


CHINA
37.4 QUADS PRIMARY ENERGY SAVINGS

U.S.
36.4 QUADS PRIMARY ENERGY SAVINGS

Figure 4: RF Scenario Primary Energy Savings by Stock Type
2050 savings for the three efficiency savings categories

It is worth noting that in the RF U.S. analysis a small population of new buildings built after 2010 are retrofit but no new buildings are retrofit in the RF China analysis. For China, this assumption may exaggerate the savings attributed to new construction. With improved construction practices, longer building life, carbon taxes, energy pricing, or other incentive policies, more savings can be realized in the retrofit market.

Cost Effective Energy Efficiency

The gross energy savings achieved through 2050 with associated incremental costs relative to the BAU scenario are shown in Figure 5. The RF scenarios present cost-effective energy efficiency solutions. For both countries, the return on investment is positive. For China, a total of $2.0 trillion is saved in energy costs by 2050 from an incremental investment of $1.3 trillion. For the U.S., a total of $1.9 trillion is saved in energy costs by 2050 from an incremental investment of $0.5 trillion. While not monetized in the study, both countries would also incur additional non-energy benefits, such as improved occupant satisfaction, reduced health costs, increased productivity, and higher property-derived revenues - that are often far more valuable.

While the total primary savings are nearly equal for both countries, the differences in costs can be attributed to several factors. The value of energy efficiency savings is tied to the cost of energy in each country, which is higher for the U.S. Higher energy efficiency investment costs in China result from more floor area being impacted, a larger share of new construction, and incremental costs associated with improved construction quality and increased building life that are not tied directly to energy use reductions. It is also worth noting that the costing approaches differed between the two studies due to differences in their level of modeling detail.

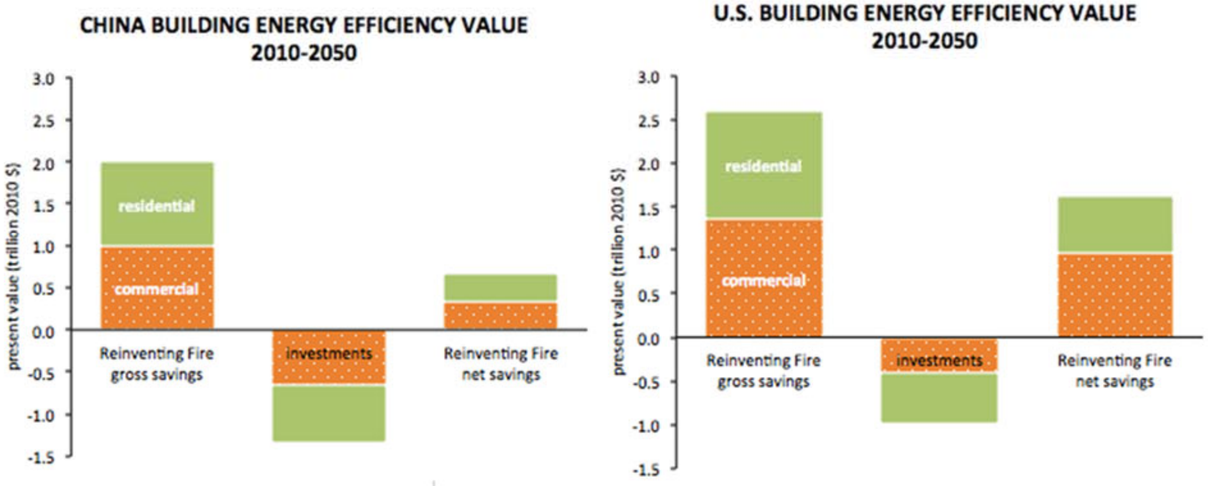


Figure 5: RF Scenario Cost Effectiveness

Capturing the Savings Potential

The total efficiency savings potential determined through the techno-economic savings analysis outlined above is nearly the same for each country (Figure 3). The savings' potential is also of similar magnitude across each of the three savings categories. Thus, the U.S. and China have equal stake in realizing the potential through commonly shared approaches. Zhou aligns RF building efficiency opportunity categories with several policy solutions for overcoming market barriers, including: 1) codes and enforcement, 2) disclosure and transparency, and 3) investment and financing (Zhou 2016).

The policy solutions indicate potential collaboration focus areas with shared benefits for both the U.S. and China. The efforts can leverage each country's market opportunities and other enablers such as policies, initiatives, and implementation mechanisms. Figure 4 depicts a cycle of information sharing between the two countries and describes the potential for a dynamic U.S.-China exchange for mutual benefit over each of the three policy categories. Due to the countries' different growth trends, China will lead the new construction market and the U.S. will lead the retrofit market. While mature supporting policies and frameworks promoting building efficiency are currently in place in the U.S., China will catch up quickly and potentially exceed the U.S. as it addresses its vast need and volume. Working together and sharing information will benefit both countries to accelerate implementation and bolster their economies.

Codes & Enforcement

Current codes systems in the U.S. and in the largest Chinese cities are mature, and deliver very high compliance. Yet as the U.S. and China adopt more aggressive building stock energy performance targets, current code models become limited due to the predominance of prescriptive design-based requirements. As buildings become more efficient, plug and process loads, which are not regulated under code, become a large portion of building energy use. In addition, design-based codes do not consider actual operating energy use or link requirements to actual achieved performance. Both countries are in the process of establishing outcome-based performance requirements to achieve low-energy use targets and to drive production and sales of high-efficiency equipment and systems.

Codes and Enforcement

- U.S. efforts in outcome-based codes provide valuable input to China's pilot projects
- Lessons learned from China pilots address target setting and enforcement challenges
- China's implementation experience accelerate outcome-basesd code adoption for both countries

Disclosure and Transparency

- Major China cities utilize U.S. developed performance disclosure platforms, which stimulates building efficiency investment
- U.S. manufacturers serve new China market
- China's practical deployment experience drives the U.S. retrofit market.

Financing and Investment

- New U.S. PACE programs provide capital for retrofit projects
- PACE success spurs China property tax reform and wide PACE application
- Lessons learned in China foster wider application in the U.S.

Figure 6: Shared Solutions Drive and Accelerate U.S. and China Building Efficiency Implementation

Key challenges to create outcome-based performance requirements include how to set targets, calibrate against existing design/construction codes, establish the compliance process, allocate of responsibility equitably, and define the enforcement mechanism. Advancement of outcome-based codes in the U.S. is slow due to development and implementation challenges, and code adoption occurring at local and not the national level. In China, outcome-based results are being addressed through a new policy known as "energy quotas", which includes setting the target baseline energy consumption of a commercial building and establishing efficiency solutions to attain it.

Activities within both countries indicate a strong opportunity for collaboration. Currently, plans are already underway for three large-scale energy quota pilot projects in the cities of Beijing, Shenzhen, and Shanghai. Over the next two years, each city will test a different method for setting targets and enforcement mechanisms. Meanwhile, in the U.S. the National Institute for Building Sciences and New Buildings Institute held a workshop on the topic of outcome based policies, and a valuable input to the discussions were experiences from the City of Seattle's piloted outcome based code. These sets of activities indicate mutual interests and objectives on advancing the code system, and each effort could benefit from coordination and sharing lessons learned.

Performance Disclosure and Transparency

U.S. and China can develop a strong market for building energy efficiency by promoting performance transparency programs, which include benchmarking, reporting, and sharing building performance data. Benchmarking building energy use data sets allows owners to know how their performance compares against similar buildings. Reporting benchmark data in city, state, and province programs allows policy makers to more effective evaluate and plan building energy resource utilization. Sharing the data on a large scale allows all stakeholders to work toward common energy reduction goals. Public disclosure affects the efficiency market by driving new demand of energy efficiency services, which prompts private sector financing of efficiency, creates jobs, and spurs economic growth (IMT, 2015).

Currently, there are 18 U.S. jurisdictions with benchmarking and disclosure policies for commercial and multifamily buildings that affect more than 5 billion square feet of floor space in major real estate markets (IMT 2015). The U.S. DOE is propelling wider adoption of disclosure programs by developing platforms and protocols to facilitate data collection, reporting, and sharing. The effort includes the Building Energy Data Exchange Specification (BEDES), the open-source Building Performance Data Base (BPD), and the open source Standard Energy Efficiency Data Platform (SEED). Together they provide standardized data field definitions, data cleansing and anonymizing, and a platform to organize, manage, and share large building performance data sets.

China recently initiated a new Ministry of Housing and Urban Research and Development (MOHURD) directed national disclosure/benchmarking program to pilot and advance disclosure policies for public buildings in Beijing and Ningbo, with expected expansion to five additional cities in the near future. China is following a government-led, top-down approach to oversee the whole energy statistics, energy audits and disclosure process. Current leading practices in both countries require reporting annual whole building energy performance, either at the time of sale, or on an annual basis. Recent California legislation mandates utilities to provide the most recent 12 complete calendar months of metered utility data available within 4 weeks of the request to owners of buildings 50,000 square feet and larger, and deliver benchmark data to the energy commission for public disclosure.

While generally informative, disclosure data are only really valuable if they incite action. Buildings can be complex, and not all aspects of performance are readily ascertained from annualized, whole-building energy performance metrics or even annual interval metered data. Thus, it is important to define and include key building-asset parameters as part of disclosure frameworks to better support opportunity assessment, target applications for emerging technologies, measure & verify project savings, and evaluate policies or programs. The asset data can help identify cohorts of buildings benefiting from similar treatment and bulk implementation opportunities.

Financing

Despite significant demand for “green” investments in the secondary capital markets, energy efficiency has not developed as an asset class in neither the U.S. nor China. Significant progress has been made in the U.S. with the development of Property Assessed Clean Energy (PACE), having funded over $2 billion in improvements thus far. PACE financing programs allow for financing of up to 100% of an energy project’s costs and a repayment term of up to 30 years via an assessment added to the property’s tax bill. PACE financing can stay with the building upon sale. PACE can also be used to fund additional incremental efficiency and renewable costs in new building developments. While PACE is not a near term solution in China due to the lack of property taxes, the Chinese property tax collection system is undergoing reform in coming years, offering a significant opportunity to implement a PACE solution that overcomes some of the challenges experienced in the U.S. (e.g. implementation variability across States, requiring local legislation). Lessons learned in the U.S. on PACE and other financing solutions could prove very useful to China, and lead to the opening up of efficiency markets in China for U.S. investors. In turn, a broad scale, streamlined implementation of PACE in China would deliver lessons in the U.S. that can drive activity.

Conclusions

Realizing the RF vision will result in drastic reductions in primary energy and carbon emissions for the U.S. and China. With 70% bigger (140 billion square feet) building stock, U.S. buildings in 2050 are projected to use 54-69% less energy (28 - 37 Quads) than the BAU scenario. In the U.S., a total of $1.9 trillion is saved in energy costs by 2050 from an incremental investment of $0.5 trillion. With 64% bigger (360 B sq. ft.) building stock that includes rapid urbanization, China buildings in 2050 use 58% less energy (38 Quads) than the projected BAU scenario. In China, a total of $2.0 trillion is saved in energy costs by 2050 from an incremental investment of $1.3 trillion.The reward for U.S.-China collaborations, rooted in information exchange on building efficiency solutions, is accelerated progress towards realizing shared energy and carbon reduction opportunities. Through a cyclical exchange of information that leverages each country’s advantages, both countries economies will be bolstered through smarter investment decisions, market competition, consumer choice, and job creation.

The mature building retrofit market in the U.S. is instigating the development of next-generation approaches, tools, and platforms, which can be quickly incorporated into China pilot projects and other initiatives. The scale and volume of efficiency deployment anticipated for China over the next decade far exceeds that for the U.S. The growth in construction along with policies that support the adoption of more stringent codes tied to actual performance, the public sharing building benchmark data, and emerging financing mechanisms will drive a large building efficiency market in China. The U.S. will serve as a supplier of green building materials and high-quality energy-efficient appliances and equipment. Yet while starting out as the follower, China may soon become the leader. China will pratical deployment experience with a desire to transition its economic base to high-end manufacturing and services, China will have the capacity and deployment experience to deliver building efficiency at scale. In time as China’s new building construction market tapers off, each country’s role may shift – with U.S. retrofits becoming the new market for China’s green building materials and energy efficient equipment.

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