CHINA'S WATER-ENERGY-FOOD ROADMAP

A Global Choke Point Report

By
Susan Chan Shifflett
Jennifer L. Turner
Luan Dong
Ilaria Mazzocco
Bai Yunwen

创绿中心 GREENOVATION:HUB

Wilson Center

March 2015

Acknowledgments

The authors are grateful to the **Energy Foundation's China Sustainable Energy Program** and **Skoll Global Threats Fund** for their core support to the China Water Energy Team exchange and the production of this Roadmap. This report was also made possible thanks to additional funding from the **Henry Luce Foundation, Rockefeller Brothers Fund, blue moon fund, USAID, and Vermont Law School**. We are also in debt to the participants of the **China Water-Energy Team** who dedicated considerable time to assist us in the creation of this Roadmap. We also are grateful to those who reviewed the near-final version of this publication, in particular, **Vatsal Bhatt, Christine Boyle, Pamela Bush, Heather Cooley, Fred Gale, Ed Grumbine, Jia Shaofeng, Jia Yangwen, Peter V. Marsters, Sun Qingwei, Vincent Tidwell, Yang Fuqiang, Zhang Chao, and Zhao Lijian**.

Our CEF research assistants were invaluable in producing this report from editing and fine tuning by **Darius Izad** and **Xiupei Liang**, to **Siqi Han's** keen eye in creating our infographics. The *chinadialogue* team—**Alan Wang, Huang Lushan, Zhao Dongjun**—deserves a cheer for their speedy and superior translation of our report into Chinese. At the last stage we are indebted to **Katie Lebling** who with a keen eye did the final copyedits, whipping the text and citations into shape and CEF research assistant **Qinnan Zhou** who did the final sharpening of the Chinese text. Last, but never least, is our graphic designer, **Kathy Butterfield** whose creativity in design always makes our text shine.

All errors and omissions are those of the authors and not those acknowledged here. The views expressed in this report are those of the authors and not necessarily those of the Wilson Center, Greenovation Hub, or the funders.

Woodrow Wilson International Center for Scholars
One Woodrow Wilson Plaza
1300 Pennsylvania Avenue, NW
Washington, DC 20004-3027
(202) 691-4000, fax (202) 691-4001
www.wilsoncenter.org

Table of Contents


NEI MONGOL
Sonid Zuoqi
Erenhot
Chifeng
Habirag
Chengde
Yan Shan
Fengning
Miyun
Jixian
Derst
Huade
Zhangjiakou
Jining
Huai'an
Beijing
Langfang
Renqiu
Datong
Laiyuan
Baoding
HEBEI
Wutai Shan
3058
Daixian
Xinzhou
Yangquan
Taiyuan
Yuci
Xingtai
Handan

About the Roadmap

The water-energy-food choke point is forcing a new reckoning. Three colliding trends—declining freshwater reserves, booming energy demand, and uncertain grain supplies—are disrupting economies, governments, and environments around the world. As the world's most populous country and biggest energy consumer, China's energy, food, and environmental security is threatened as it hits these choke points. How Chinese policymakers deal with these water-energy-food confrontations will have significant domestic and global consequences.

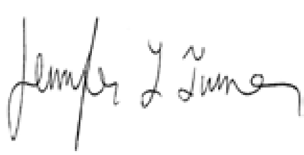
In 2010, the Woodrow Wilson Center's China Environment Forum (CEF) teamed up with the Michigan-based Circle of Blue to launch the *Choke Point: China* initiative, which created a broad assessment and narrative of the water-energy-food confrontations in the world's second largest economy. We were the first to report that 20 percent of China's annual water use goes to produce energy from coal. Our reporting also raised sobering questions on the large and overlooked energy footprint of water in China. Over 20 multimedia reports on China's choke points have attracted considerable interest from policymakers, researchers, and NGOs in and outside China, catalyzing new research, policy discussions, and programming.

To deepen these dialogues and highlight potential solutions, the China Environment Forum began a partnership with the Beijing-based environmental group Greenovation Hub to organize the first China Water-Energy Team (China WET) exchange in August 2013. During the week-long exchange, the team participated in six closed and two public roundtable discussions in Beijing with Chinese government research institutes, think tanks, environmental NGOs, universities, and businesses.

This Roadmap captures insights from the China WET exchange and numerous in-depth interviews with Chinese and U.S. environmental and energy practitioners. The three main goals of this Roadmap are to:

1. Provide a snapshot of the water-energy-food trends and major players in China;
2. Identify research and policy gaps for addressing China's water-energy-food choke points; and,
3. Propose potential solutions moving forward, with an emphasis on the role of China-U.S. collaboration to address the water-energy-food confrontations in both countries.

The work of the China Environment Forum and Greenovation Hub aims to cross silos both within and across the U.S. and Chinese governments, research, business, and NGO communities to inform, and hopefully catalyze, better policymaking and a greener environment. We hope this Roadmap will play a small part in helping both countries better address the water-energy-food challenge.



Jennifer L. Turner
Director, China Environment Forum
Woodrow Wilson Center

Lo Sze Ping
Founder, Greenovation Hub

Executive Summary

The water-energy-food nexus is creating a complicated challenge for China and the world. Energy development requires water. Moving and cleaning water requires energy. Food production at all stages—from irrigation to distribution—requires water and energy. As the most populous country and the world's manufacturing hub, China demands all three resources in ever increasing amounts, leading to shortages that are creating serious choke points to the country's development. Pressure on water is at the heart of these resource constraints facing China.

Roadmap for the Roadmap

How China can secure enough clean water to maintain agricultural and energy production to meet its population's needs is a challenge that holds far-reaching consequences for the country's future. As a systematic attempt to summarize China's choke point challenges and spark innovative thinking and pragmatic action, the Roadmap begins with an overview of the water-energy-food nexus trends in China, starting with the energy sector's thirst for water—from coal and hydropower to renewables and natural gas. The second section examines the often-overlooked energy footprint of China's water sector, and the third outlines the water and energy demands of China's food sector. The Roadmap then pulls in lessons from the U.S. experience dealing with water-energy-food challenges, and closes with suggestions on how Chinese policy practitioners, businesses, and civil society groups could embark on a comprehensive assessment of the current situation and initiate action to address China's choke points.

This report builds on the China Environment Forum's (CEF) extensive research in partnership with Circle of Blue, and draws heavily on a weeklong exchange with American and Chinese water, energy, and food experts that took place in China in August 2013. Since 2010, CEF and Circle of Blue have raised awareness of the water-energy-food confrontation in China and served as "matchmakers," helping to build knowledge partnerships among the government, NGOs, and the private sector to further choke point research. We were greatly encouraged when, in November 2014, President Barack Obama and President Xi Jinping jointly announced—as part of a new climate accord to curb carbon emissions—the launch of a $50 million water-energy nexus program under the U.S.-China Clean Energy Research Center (CERC). This partnership could serve as a model for

future bilateral and multilateral water-energy management cooperation. With this Roadmap we seek to provide a comprehensive look at the water-energy-food challenges China faces and highlight further opportunities for U.S.-China cooperation.

Water for Energy

Coal remains China's main energy source; according to the International Energy Agency (IEA), about 80 percent of the country's power in 2013 came from coal.[1] Initial research into coal's thirst in China estimates that between 11 and 20 percent of all water used in the country goes to coal mining, processing, coal ash control, and cooling of coal-fired power plants.[2] The lifecycle of coal is water intensive around the world, however its "thirst" presents a significant quandary for a country already facing a water scarcity crisis; China's water availability per capita is only one-third of the global average.[3] Moreover, most water resources are in the south while much of the agricultural production and coal reserves are in the north.

The country's efforts to alleviate air pollution may add pressure on water resources given a new energy strategy[4] to replace some coal-fired power generation with more water-intensive coal-to-gas plants. Hydropower is currently the second-largest source of electricity in China and the 12th Five Year Plan has accelerated dam construction to increase hydroelectric generation capacity from 199 GW in 2010 to 420 GW by 2020. However, increasingly frequent droughts and damage to downstream communities could hinder this continued hydropower development.[5] While nuclear, natural gas, wind, and solar power production have a relatively low carbon footprint, they have significant water requirements. Electricity generation requires significant inputs of water globally, and in China its use is aggravated by massive and growing energy demand and significant water use inefficiencies in agriculture and industrial production.

Energy for Water

While water use efficiency is gaining traction as a policy priority in China, policymakers continue to emphasize supply-side management solutions, such as building large and highly energy-intensive water transfers (e.g., the South-North Water Transfer Project) and desalination plants. Water pollution is also placing pressure on China's energy resources. As the government steps up its efforts to reduce water pollution from municipalities, industries, and agriculture, more wastewater treatment plants will be needed, consuming even more energy.

Adding Food to the Choke Point Mix

While often overlooked, the inter-linked role that food plays in the choke point must not be understated. At every step of the process, from irrigation to processing to distribution, food production requires both water and energy. Droughts coupled with competition over water access with cities and power plants (especially coal plants) are reducing crop yields. Moreover, as more Chinese people adopt meat-rich diets, industrial farms specialized in animal husbandry are expanding. These farms are more energy and water intensive, and the animal waste they produce is often left untreated and leaches into soil and water, creating soil pollution and toxic algae blooms.

Finally, China's shift to a more industrial agricultural model to improve food security and raise rural incomes also requires increasing amounts of water and energy. China's agricultural sector alone uses over half the country's water due to heavy reliance on irrigation and high levels of water wastage.[6]

Insights from Choke Point Issues in the United States: Finding Solutions in Connections

China is not alone in facing the water-energy-food confrontation. The United States faces similar resource clashes. A historic three-year drought in California has hammered the state's hydropower production and forced the state to rely more on natural gas, wind, and solar power.[7] California's farming industry has been pummeled; some farmers have been forced to shrink production, switch to less water-intensive crops, or simply stop farming altogether.[8] Moreover, debates surrounding the U.S. shale gas "revolution" and biofuels have brought more attention to the water-energy-food nexus issues.

Over the past decade, U.S. national energy laboratories, think tanks, universities, and NGOs have been at the forefront of global research on water-energy-food choke points, raising the issue on policy and business agendas. These developments in the United States could offer valuable insights on a possible path forward for China.

Action Areas

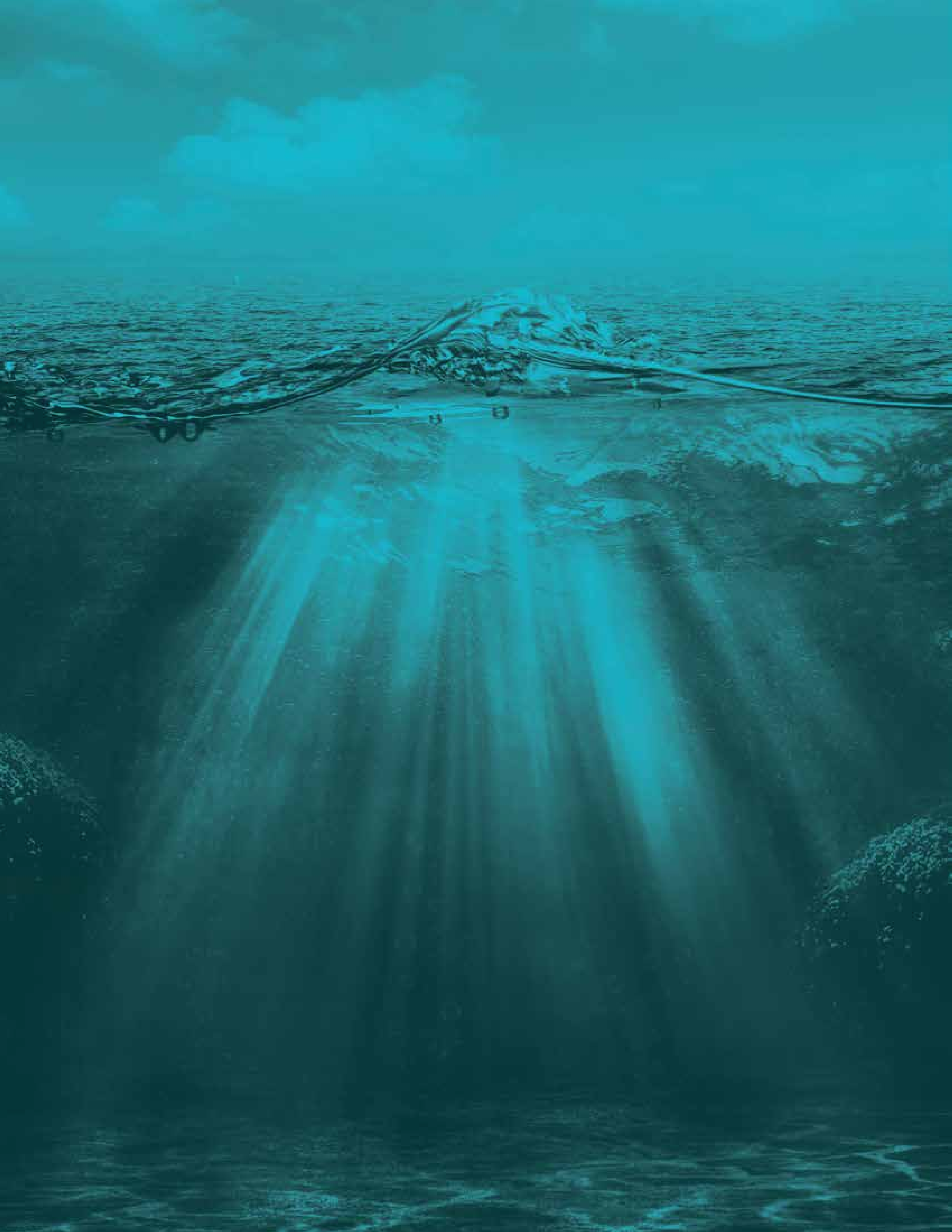
The Roadmap identifies three main areas for choke point research and policy development in China that are particularly promising areas for collaboration.

1. **Fill data gaps on choke point issues, particularly on the energy use for water.** A top priority for Chinese researchers and policymakers should be to calculate the financial and environmental costs of water-energy-food interactions in China. Having concrete, quantifiable numbers will help to create the case and framework for implementing comprehensive water, energy, and food management policies and laws. Data needs to be collected not just nationally, but at provincial and municipal levels, as water resources vary significantly throughout the country. While the water footprint of energy has gained some recognition as an important development challenge, the energy footprint of water is often overlooked—generally because water is seen as a free or low cost resource. Once collected, data regarding the energy demand of water will help shape policies to achieve important water, energy, and food savings.

2. **Ramp up demand-side management practices and policies.** It is critical to focus on integrated planning to reshape water, energy, and food conservation policies. Data revealing the costs of energy use for water treatment and irrigation will likely add more urgency to existing energy efficiency policies—such as the Chinese Energy Conservation Law and the Demand-Side Management (DSM) Regulation. Existing policies and projects for energy DSM should be used to shape more comprehensive and integrated regulations on water use. In addition to mandated energy intensity reductions and water consumption limits, Chinese planners need to strengthen integrated approaches that look at the link between water and energy use, particularly in the building and industrial sectors.

3. **Strengthen China-U.S. collaboration on choke point issues.** While some U.S. researchers, NGOs, and foundations are starting to address water-energy-food confrontation issues in China, the U.S. and Chinese government and business communities have lagged behind in engaging on these interconnected natural resource challenges in China. A promising step forward was the announcement of a new water-energy nexus program under CERC as part of the November 2014 U.S.-China climate accord announced at the APEC Leaders' meeting in Beijing. Institutionally, bilateral and multilateral choke point collaboration should continue to be integrated into existing energy and environmental programs. Moreover, because states, provinces, and cities in the United States are some of the most innovative in dealing with water-energy-food linked constraints, local-to-local cooperation across countries will be crucial. Finally, from a corporate perspective the United States and China are significant markets for water and energy saving technologies, creating opportunities for joint technology development in these sectors.

While there are no easy solutions to these water-energy-food issues, this Roadmap aims to spark discussions and debates empowering Chinese stakeholders and their partners to explore appropriate frameworks to address China's water-energy-food choke points.



China's Choke Points: Where's My Water?

Water shortage is the most important challenge to China right now, the biggest problem for future growth. It's a puzzle that the country has to solve.

—Wang Yahua, Deputy Director of the Center for China Study at Tsinghua University

China's unprecedented economic growth over the past three decades has relied on three inextricably linked resources: water, energy, and food. Water is essential through the entire energy lifecycle, energy is needed to move and clean water, and food production is increasingly demanding more of both resources.

Water is at the center of China's interlinked choke points. While the country has the fifth largest endowment of fresh water resources in the world, by per capita standards it is strained at one-third of the world average.[9] As in many other countries, China's water resources are considerably undervalued leading to overuse, waste, and contamination. Consequently, the central government warns that despite existing water-saving measures China's water demand will exceed supply by 2030,[10] with much of the added pressure coming from China's energy sector.

Climate change is further aggravating China's water scarcity. Over the past 20 years, main stem water flows have decreased by 41 percent in the Hai River Basin and 15 percent in the Yellow and Huai river basins—these declines are particularly concerning because these three rivers supply water to much of China's populous and dry northeast.[11] Climate change has contributed to 65 percent of that change in river flow [12] and the rest is from the overexploitation by cities, industry, agriculture, and mining.

Water quality is as dire a challenge as water quantity in China, where the World Bank estimates that pollution accounts for nearly half of the 2.3 percent of GDP lost annually to the country's water crises.[13] The Chinese government, in an effort to emphasize the interconnection between water quantity and water quality, coined the term "water pollution-induced scarcity." The following sobering

Photo courtesy of Circle of Blue © J. Carl Ganter

statistics illustrate the severity and urgency of China's water pollution:

- Overall, water quality in most river basins in China has been improving since 2009, yet in most urban areas approximately three-quarters of the surface water and 55 percent of the groundwater is still considered unsuitable for drinking.[14]
- Nearly 15 percent of the water in China's major rivers is not fit for any use.[15]
- In 2013, Chinese environmental regulators categorized 28 percent of water in China's main rivers as so polluted to be unfit for human contact.[16]
- About 4.05 million hectares (7.4 percent) of the nation's irrigated lands are irrigated with polluted water.[17]

The geographic distribution of China's water resources is uneven, which affects energy development choices. Eighty-three percent of the country's water resources are concentrated in provinces south of the Yangtze River, providing rich potential for hydropower generation there. North China, in contrast, is an arid region where 17 percent of the country's water supply is overexploited to support 41 percent of its population, 56 percent of its cultivated land, and a majority of the country's coal bases.[18] The Hai River Basin, which supplies water to Beijing and Tianjin, has just 1.5 percent of China's water resources to support 10 percent of the country's total population (or 130 million people).[19]

During the summer of 2014, China's Shaanxi province suffered from its worst drought in a century, affecting a quarter of a million people.[20] This was the first time corn harvests shrunk in the greater North China Plain since 2009.[21] Even in the traditionally water-abundant south, droughts have become increasingly frequent and intense since 2010.

China's projected water demand for 2030—818 billion m^3—is expected to outstrip supply, which currently amounts to 618 billion m^3.[22] Significant industrial and domestic wastewater pollution makes the "quality adjusted" supply-demand gap even greater.[23] As some 350 million more people move into urban areas over the next 15 years, groundwater around urban centers is being pumped faster than it can be naturally recharged and water levels are falling fast.

China's Water Crisis

Water is scarce; water is dirty; water is not distributed equally in China. Supplying water, treating wastewater and transporting water requires large amounts of energy.

Sources: The 2030 Water Resources Group, Circle of Blue, World Bank.

Box 1. Water Definitions

Terminology about water can be a bit “slippery,” below is how we used the following terms.[28]

- **Water withdrawal** is the water taken from a source and used for some human need. It includes water that is consumed, as well as water that is not.
- **Water use** is used interchangeably with water withdrawal in this Roadmap.
- **Water consumption** is water withdrawn from a source and made unavailable for reuse in the same basin, because of conversion to steam, losses to evaporation, seepage to a saline sink, or contamination. For example, water that is incorporated into goods or plant and animal tissue is unavailable for reuse, and thus is also considered a consumptive use.
- **Water footprint** is the total volume of fresh water that is consumed in the production of goods and services; one can calculate the water footprint of a product, a city, or a country.

Water for Energy

While water use in China is near its peak, energy demand will double by 2040. How to meet this energy demand and quench its thirst is more serious than the current water crisis.

— Jia Shaofeng, Deputy Director, Center for Water Resources Research at the Chinese Academy of Sciences[24]

Among all energy sources in China, coal is the thirstiest. Yet other growing energy sources—from hydropower to nuclear power and natural gas—are also impacting water supply and quality in profound ways. Wind and solar power use the least amount of water per megawatt of electricity produced, but their contribution to water saving is still minimal as they only make up 5.2 percent of the overall electricity generation capacity.[25] Few countries prioritize the water footprint of energy in their development plans—an omission that leads to investments and development that undermine water security.

There is a paucity of data on water use in energy globally, underscoring the need for greater attention and research on this issue. A recent study done at Harvard University's Belfer Center for Science and International Affairs estimated China's total annual energy production is responsible for 61.4 billion m^3 water withdrawals, 10.8 billion m^3 water consumption, and 5.0 billion m^3 wastewater discharges in China, which are equivalent to 12.3%, 4.1%, and 8.3% of the national totals for each water category respectively.[26] Our own *Choke Point: China* research found that coal production's full lifecycle accounts for approximately 20 percent of water withdrawals in the country and is driving the increases in water use in north China to levels exceeding the available resources. Chinese researcher Liu Pei estimated that coal's water use was closer to 11 percent.[27] These varying estimates point to the need for more data and uniform standards for measurement and terminology. (See Box 1 on page 7 for water definitions).

Photo courtesy of Circle of Blue © J. Carl Ganter

Water for Energy

Coal is King, Thirsty and Dirty

In 2011 China accounted for 47% of global coal consumption.

47%

Currently coal supplies 70% of China's electricity.

70%

20% of China's national water withdrawals* goes to coal mining, processing, coal ash control, and coal-fired power plants.

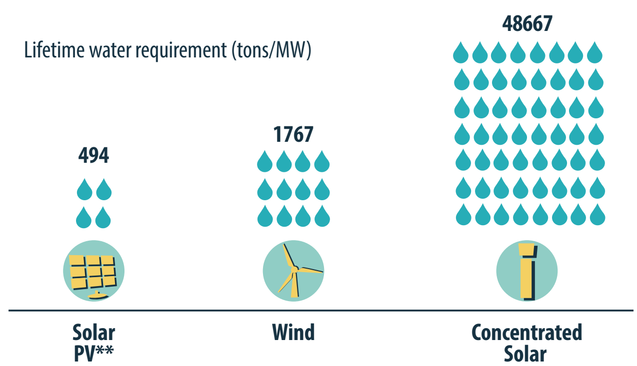
Hydropower - China's Energy Queen

Hydropower is China's **2nd largest** source of electricity

22% of total installed electricity capacity

Besides changing water flows and damaging river ecosystems, the current hydropower boom in southwest China is also fostering energy- and pollution-intensive industries such as aluminum and steel production.

Clean Energy Needs Water Too



* lifecycle water withdrawals
** mono- and poly- crystalline silicon

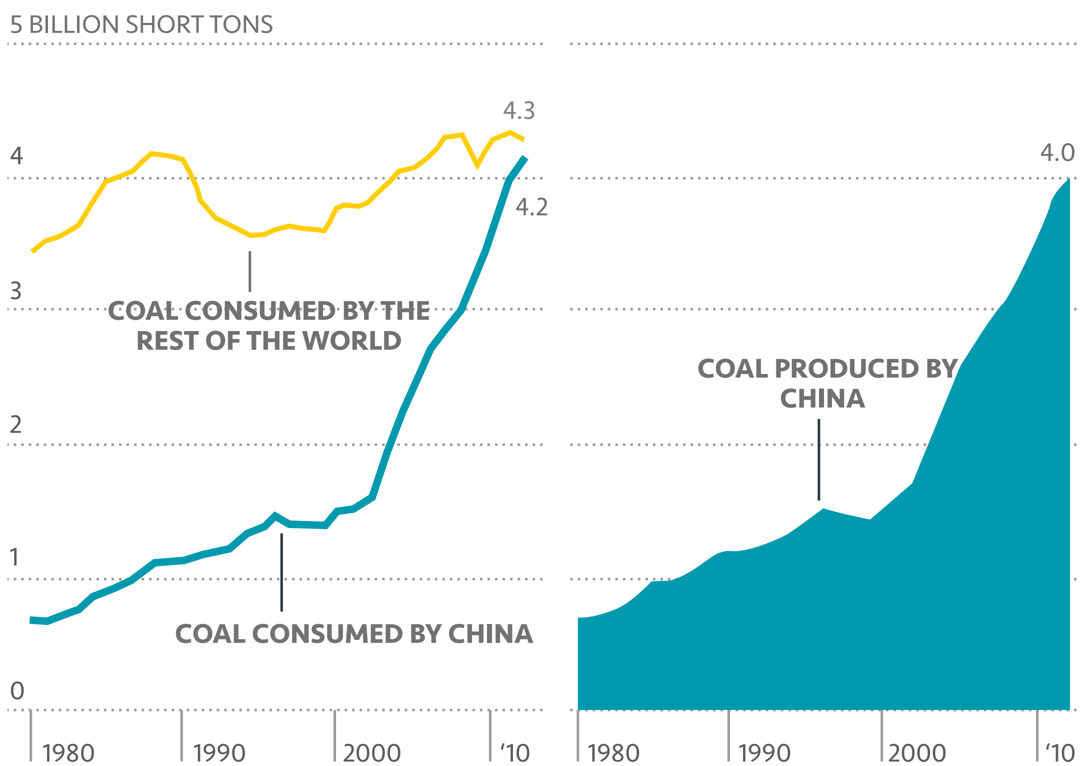
Sources: U.S. Energy Information Administration, China Country Analysis, Chao Zhang and Laura Diaz Anadon.

Coal is the Thirsty King

China has been the world's largest coal consumer since 1986.[29] In 2011, China accounted for 47 percent of global coal consumption—almost as much as the rest of the world combined.[30] (See Figure 1). Since 2000, China has accounted for 82 percent of the global growth in coal demand.[31] Coal's contribution to air pollution has become a major sociopolitical flashpoint, catalyzing swift responses in Chinese policy. For example, in August 2014, Beijing announced it would ban all coal use in the city's six major districts by 2020[32] and in September 2014, policymakers announced limits on low-quality, smog-producing coal imports.[33]

China's State Council also issued an Airborne Pollution Action Plan in September 2013 with several sweeping measures, which includes mandated nationwide air quality improvements. Vice Premier Zhang Gaoli recently pledged that by 2020 the country will reduce its carbon intensity by 40 to 45 percent from 2005 levels. On-the-ground efforts that could support this pledge are the commitments by 12 provinces that account for 44 percent of the country's coal consumption to control coal use; six have even included caps in their action plans.[34] (See Box 2).

Figure 1. Energy Mix and/or Coal Consumption Figure



Sources: Richard Martin (2014),[35] and Energy Information Administration (2014).[36]

Box 2. Cracking Down on Air Pollution

In response to mounting public outcry over the level of air pollution in major cities, China's State Council issued the Airborne Pollution Prevention and Control Action Plan in September 2013. The Action Plan includes a number of unprecedented policy measures:

- **Decrease coal consumption:** Construction of new coal-fired power plants (excluding combined heat and power) is banned in the Beijing-Tianjin-Hebei, Yangtzee Delta, and Pearl River Delta regions. Known as the "key-three-city clusters," these three major metropolises must also achieve negative coal consumption by 2017.

- **Ramp up regional fine particulates reduction targets:** The Beijing-Tianjin-Hebei cluster must reduce the concentration of small particulate matter (PM2.5) by about 25 percent by 2017, based on the 2012 level. The target reduction for the Yangtze River Delta and Pearl River Delta regions is 20 and 15 percent, respectively.

- **Mandate nationwide air quality improvements:** By 2017, the concentration of PM10 in China must fall by at least 10 percent compared to 2012.

- **Diversify energy sources:** The plan pushes the construction of another 150 billion cubic meters of natural gas pipeline capacity by 2015. Nuclear power installed capacity is slated to reach 50 million kilowatts, raising the share of non-fossil fuels in China's overall energy consumption from 10 percent in 2013 to 13 percent by 2017.

The Action Plan is not a panacea for China's air pollution problems, but it indicates Beijing is serious about decreasing coal's share in China's energy mix. In November 2013, the Third Plenum of the 18th Communist Party of China Central Committee listed environmental protection as an urgent priority. The political momentum continued in the spring of 2014 with Chinese Premier Li Keqiang's declaration of a "war on pollution" and the National People's Congress approval of the first amendments to China's Environmental Protection Law in 25 years. The amendments include higher fines against polluters, opportunities for public interest litigation in environmental matters, and moves to strengthen environmental tribunals. These changes are significant efforts to strengthen enforcement at the local levels, which has been typically weak in China.

The enormous water footprint of coal has only recently become an area of interest to Chinese policymakers and international organizations engaged in energy and environmental issues in China. Freshwater used for mining and processing coal accounts for the largest share of industrial water use in China, though statistics on water withdrawals for coal are scarce. Even partial analyses underscore the magnitude of coal's thirst. For example, a World Resources Institute analysis of the water footprint of China's coal mining, chemical production, and conversion, but not water used for power plant cooling or ash pond control, estimated that if all coal plants planned in 2012 were built, by 2015 China's coal sector would account for 10 billion m^3 of water withdrawals every year.[37] That is equivalent to one-fourth of all water available for withdrawal every year from the Yellow River, the third longest river in Asia. (See Box 3).

China's 12th Five-Year Plan, the central government issued social and economic development roadmap for 2011-2015, calls for the consolidation of the country's coal production and coal-fired power generation capacity in the country's northwest. In theory the policy would better contain pollution, promote resource recycling, and safeguard coal miners, who work in one of the world's most deadly mining sectors. The plan calls for developing fourteen large-scale coal-mining bases and sixteen coal-power generation bases mostly in China's west—one of the most water-stressed regions in the country.

Based on projections from 2012, Greenpeace China estimated that by 2015 water demand in the coal sector (including mining, power, and coal-to-chemicals) in Inner Mongolia, Shanxi, Shaanxi, and Ningxia will exceed current water consumption of the region's entire industrial sector.[38] Greenpeace China also predicted water demand in these and other existing large-scale coal bases will reach a yearly 9.975 billion m^3 in 2015[39]—more than one-quarter of the water volume of the Yellow River available in a normal year. Approximately two-thirds of this water demand will be for mining, 11 percent for coal-to-chemicals, and the remaining 22 percent for power plants.[40] Some of the water is used to cool power plants and some evaporates, but much is returned to the waterways.

The coal sector can recycle water for washing and mining, however that water still needs to be available for use in the coal industry, which limits its allocation to other sectors. Coal companies that operate illegally in protected areas, such as those denounced by Greenpeace China in Qinghai, or those violating regulations on wastewater management pose a further challenge; this translates into additional withdrawals and pollution which may not be accounted for in official statistics.[41]

Box 3. Thirsty at Every Stage

Coal is the most water-intensive form of energy—water is needed in every stage of its lifecycle. Circle of Blue and Wilson Center *Choke Point* research found that in 2010, China's coal sector used 120 billion cubic meters of water, or about 20 percent of the 599 billion cubic meters that were used nationally. Other studies have placed the percentage of water used for coal between 11 and 17 percent, highlighting the need for more and better data. By 2020 the coal lifecycle is expected to use 28 percent of the 670 billion cubic meters of total water used in the country.[42] Water's role at each stage is outlined below:

- **Mining:** During mining, water is predominantly used for cooling equipment, reducing dust levels, and washing tunnels.
- **Washing:** Coal is washed to reduce the levels of ash and sulfur and thereby improve the energy content. Fifty-five percent of all coal in China is now washed, up from 30 percent a decade ago. Washing coal requires 0.11 to 0.15 cubic meters of water per metric ton, or 178 million to 238 million cubic meters of water annually.[43]
- **Generating Power:** In the generation stage, power plants withdraw large quantities of water for producing steam and for cooling. Around 95 percent of China's thermal power plants use water for cooling. Though most of the water remains in the power station and is re-circulated, around 12 percent is lost through evaporation.[44]
- **Disposing of Coal Ash:** Coal ash control is the second most water-intensive process in the coal lifecycle, following cooling. Half of a coal-fired power plant's water use is for controlling coal ash, often in ponds or "irrigated" fields. Runoff from such ponds contains heavy metals, and sometimes mercury, and can contaminate surrounding surface and groundwater.
- **Coal Conversion:** China's growing coal-conversion sector is also increasing water use. Depending on the product—diesel fuel, chemicals, or natural gas—for every metric ton of coal converted, 3 to 15 cubic meters of water is used. China's coal conversion program is currently consuming more than 5 billion cubic meters of water annually, and it will continue to expand as this use of coal is significantly more profitable than that in coal-fired power plants.[45]

Polluting Too

Besides gulping down water, the coal industry also pollutes water that is returned to nearby water bodies, often with heavy metals like lead and arsenic. Without proper treatment or recycling, water used in power plant boilers and cooling systems can be discharged into lakes or rivers. Sludge and coal ash waste is often disposed in unlined landfills and reservoirs. Heavy metals and toxic substances contained in the waste can contaminate drinking water supplies and harm local ecosystems. Water ecosystems are also threatened by sulfur dioxide and nitrous oxides emitted through coal burning that create acid rain, which increases the acidity of lakes and streams.

Hydropower – China's Energy Queen

Hydropower has played a significant role in supporting China's economic growth over the past few decades. More than 46,000 hydropower dams have been constructed on virtually every river in the country.[46] Approximately half of all dams in China are used to produce energy; the remainder serve for a combination of agricultural and flood control uses.[47] Today hydropower is the second largest source of electricity in China and constitutes 22 percent of the country's total electricity generation capacity,[48] making it the queen of electricity. By the end of 2013, the country reached an installed capacity of 280 GW of hydropower—just 10 GW shy of the 12th Five-Year Plan's 2015 end goal, and well on the way to reach the government's targeted 420 GW by 2020.[49]

Serious droughts have plagued the country's southwest over the past five years and are set to limit the expansion and effectiveness of China's ambitious dam rush. In early 2010, a prolonged drought gripped the flows of the Mekong, Salween, and Yangtze rivers, and nearly shut down the 6.4 GW Longtan Dam, China's second largest. At the peak of the spring 2011 drought, water levels at the Three Gorges Dam reservoir were four meters (13 feet) below the minimum level required to run its turbines effectively.[50]

While dam reservoirs facilitate irrigation upstream and play a role in flood control, they also have negative social and environmental impacts. Due to high evaporation rates in reservoirs, hydropower draws water away from other sectors and makes downstream communities, farms, and industries less resilient to drought.[51] Changing water flows damage river ecosystems, which can threaten livelihoods and biodiversity. Finally, the current hydropower boom in southwest China is also facilitating the growth of energy- and pollution-intensive industries such as aluminum and steel production that contaminate water sources for agriculture, fisheries, and local communities.[52] Policymakers in China have yet to adopt policies addressing the connections between hydropower and pollution.

Natural Gas – The Emerging Energy Prince

With large conventional and unconventional gas reserves, China's natural gas development has been heralded as a potential game changer to help the country reduce its dependence on coal. As the government embarks on a "war on pollution," Hengwei Liu of the Harbin Institute of Technology says, "A central part of the battle includes capping coal use to below 65 percent of total energy consumption by 2017, down from 69 percent in 2012. To this end, the central government is boosting the share of natural gas in the energy mix from 4.7 percent in 2012 up to an ambitious 10 percent by 2020." This represents a 178 percent increase in production volume in only eight years—from 144 billion m^3 to 400 billion m^3. To put this in perspective, U.S. natural gas production over the last eight years—the so-called shale gas revolution—only increased 31.2 percent.[53]

As demand for cleaner fuels in China has soared and pressure has increased to reduce emissions, Chinese national oil companies are pursuing a broad strategy in the gas sector, ramping up investments into conventional natural gas, tight gas, synthetic natural gas (SNG), and gas imports to meet the country's short-term demand. Though it emits less air pollution than coal-fired power plants, production of SNG from coal tends to be highly water intensive. Each cubic meter of SNG produced requires 6 to 12 liters of water —50 to 100 times more than shale gas, which is often criticized for its intensive water use.[54] Only two coal-to-gas plants are currently in operation, but four dozen are under construction or planned, with five of these in arid Xinjiang or Inner Mongolia. These areas already have significant water shortages, and while these plants may seem like a good option in the short run, eventually they could prove both damaging to the environment and unwise economically.[55]

Water availability may also be a serious constraint to the much-hyped shale gas development in China. While the country is estimated to have the world's largest technically recoverable shale gas reserves, the current recovery process requires large quantities of water.[56] In the United States, the amount of water used in hydraulic fracturing (fracking) for shale gas varies between 7,570 and 18,927 m^3 per well. With thousands of wells drilled in each shale play this translates to a significant growth in water demand.[57] In China, reaching a production target of 6.5 billion m^3 – China's stated shale gas output goal for 2015[58] – would require 13.8 million m^3 of water. Although water use for hydraulic fracturing is modest when compared to total industrial water usage, this increase in water consumption can have a significant impact locally.[59] In 2010, five relatively water-rich provinces in China's southwest (Chongqing, Guangxi, Guizhou, Sichuan, and Yunnan) that hold 40 percent of the national shale gas reserve, suffered a six-month severe drought.[60] Drier areas have witnessed competition for water between fracking and other end uses: officials in northern Shaanxi Province temporarily cut off a city's water supply during a shale drilling test.[61]

Hydraulic fracturing technology is evolving quickly to reduce the amount of water used in shale gas operations, yet the challenge also lies in regulating pollution. Water used during fracking—often called flow back or produced water—can contain chemicals from the fracturing fluid, salts dissolved from the source rock, various minerals, volatile organic chemicals, and radioactive nucleotides; all of these pose potential environmental and public health risks.[62]

Despite the ambitious targets and accelerated investment into this sector, the Chinese shale gas industry is still nascent and growing slowly. This slower rate of shale development is linked to the relative lack of geologic mapping of China's basins and a fairly closed market that does not encourage the entry of small and experimental producers—two factors that were critical to accelerating U.S. shale gas production. In fact, China's 100 shale gas test wells in 2013 were dwarfed by the over 100,000 in the United States.[63] However, this relative slowness has the upside of giving Chinese regulators time to integrate lessons learned from the United States into their laws and practices, particularly on protecting and conserving water.

The Promise of Clean (but Thirsty) Energy

While China leads the world in coal and hydropower generation, it has also, since 2010, become the world's largest and fastest growing market for nuclear, wind, and solar power. The 12th Five-Year Plan promotes further increases in clean energy in China's energy mix, setting targets of 11.4 percent of primary energy consumption from non-fossil sources by 2015 and 15 percent by 2020.[64]

Renewables

Though most non-fossil energy sources require far less water than coal-fired power plants, the extensive scale of planned deployment of renewables translates into burgeoning water use.[65] According to Lawrence Berkeley National Laboratory researchers, the projected 813 million m^3 of water needed for wind and solar development from 2010 to 2030 in China is roughly a year's worth of total water supply for all Beijing residents—a population greater than that of the entire state of New York.[66] Water is used both in the actual production of wind and solar equipment, and for cleaning panels at solar farms.

The lifecycle water requirement (water use) of an on-shore wind turbine is 1,767 m^3 per MW, and that of solar PV ranges from 25 m^3 per MW to 615 m^3 per MW depending on the specific cell technology.[67] Most of the water is used in manufacturing and production of wind turbines and solar panels, thus as these two industries grow, so will their water consumption.

Unlike the molten salt technology recently deployed in the United States, China's concentrated solar power (CSP) projects are still using water to generate steam and spin turbines. Consequently, they require by far the most water among renewable technologies, with a lifetime average of 48,000 m^3 of water per MW.[68] While CSP is still in its pilot project stage, future plans are big—China's current 50 MW capacity is projected to increase to 1 GW by 2015 and to 3 GW by 2020.[69] CSP is a promising type of large-scale distributed generation that can supply power to local users and feed into the grid; however water consumption should be a critical factor determining whether and where the CSP technologies used in these pilot projects should be scaled up.

Both wind and solar resources are heavily concentrated in China's dry northwest. The four leading provinces for wind development—Inner Mongolia, Hebei, Liaoning, and Jilin—all rank in the bottom 10 provinces in terms of water resource availability.[70] As development scales up, even renewable energy will not be able to escape north China's water choke point.

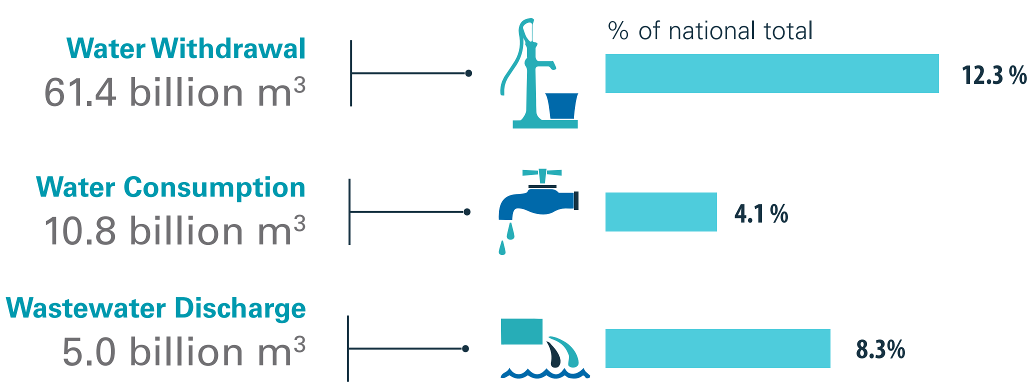
Nuclear Power Boom

While nuclear power only constituted 2.1 percent of all electricity production in 2013 with 14 GW,[71] Chinese officials have high hopes for nuclear power. China currently has 20 nuclear plants and 28 under construction and hopes to have more than a threefold increase in nuclear capacity to at least 58 GW by 2020.[72]

Nuclear is perhaps one of the few energy sources in China for which water has been taken into account in the planning process, likely drawing lessons from shutdowns of nuclear power plants in the United States and Europe due to droughts.[73] These shutdowns are expected to become even more frequent due to climate change; the likelihood of extreme drops in nuclear power generation, either complete or almost-total shutdowns, is projected to almost triple in the United State and Europe.[74]

The 27 nuclear plants that are currently under construction in China are all located on the coast, strategically placed to be near steady water supplies for cooling.[75] A standard nuclear plant in China that uses seawater for direct once-through cooling uses 8 million m^3 of water per day, greater than the average water usage in a conventional fossil fuel plant.[76] The central government has reportedly advised caution in the development of inland nuclear plants, yet it is likely that some of the already planned pilot inland nuclear plants will be built during the 13th Five-Year Plan period to test new technologies and safety measures.[77] In this light, the addition of nuclear plants may add to the water stress of China's inland regions.

Energy Industry as a Major User of China's Water*



** Lifecycle water withdrawls*
Sources: U.S. Energy Information Administration, China Country Analysis, Chao Zhang and Laura Diaz Anadon.

Energy for Water

Population and economic growth, as well as climate change, will require China to develop new and more energy-intensive ways to obtain and use water.

— Wang Dong, Water Researcher, Chinese Academy for Environmental Planning[78]

With its mismatch between geographic distribution of water availability and centers of water usage, China is looking to engineer its way out of future water shortages—a feat that demands large-scale, energy intensive engineering projects. If any country has the engineering expertise and financial resources at hand to out-engineer water scarcity, it would be China. However, there has been only limited discussion among policymakers of the tremendous energy costs involved in transporting water to arid regions.

One 2004 study estimated that electricity accounted for 33 percent of the cost of producing and distributing water in China, and since then, the energy footprint of water diversion and pumping has risen dramatically.[79] To our knowledge, no recent study has fully calculated the percentage of electricity used for water supply, transfer, and treatment in China. Around the world, countries are using increasing amounts of electricity to move, clean, and use water, for example:

- Saudi Arabia uses up to nine percent of its total annual electricity energy consumption for ground water pumping and desalination.[80]
- In the United States, 13 percent of energy use is devoted to water extraction, conveyance, treatment, distribution, end use, and wastewater collection, treatment, and disposal.[81]
- California has by far the most energy intensive water sector in the United States, consuming 19 percent of the state's energy for the whole cycle of water use from source to user to treatment.[82]

Re-plumbing the Nation: The South-North Water Transfer Project

For centuries, China has excelled at constructing massive water infrastructure projects—such as the Beijing-Hangzhou Grand Canal—to irrigate agriculture and tame floods. In 1952, while reflecting on North China's dryness, Mao Zedong is quoted

Photo courtesy of Circle of Blue © Aaron Jaffe as saying that “it would be good to borrow some water from the south to the north.”[83] Fifty years later, construction began on the largest water-transfer project in human history: the $62 billion South-North Water Transfer Project (SNWTP).[84] The SNWTP seeks to divert approximately 28 billion m^3 of freshwater each year—ten times the volume of the California state water transfer project—for hundreds of miles to slake the thirst of the North China Plain and its 440 million people.[85] The eastern canal was the first of three major routes to be completed. The central route opened and began piping water to Beijing in December 2014. The far western route, which would bring much needed water to the coal-rich northwest, is still being planned as it will take over a decade to construct through the high mountains on the Tibetan plateau.[86]

Moving water demands energy. But statistics of the SNWTP energy consumption—both for moving the water and for the embedded energy in construction materials—have not been calculated. Another energy intensive piece of the project that merits scrutiny is the extensive network water treatment plants. The low quality of water being pumped out of the Yangtze for the eastern route has required the construction of more than 400 sewage treatment plants to clean the water before it is transferred to Tianjin. Water pollution control on the eastern route takes up a whopping 44 percent of the $5 billion investment.[87] There are 474 water treatment plants planned for the central route. However, as of December 2013—half a year before the route was scheduled to come online—only 10 percent of these facilities had been completed.[88] (See Box 4).

The project cost and energy input significantly raised the price of transferred water. While the higher cost of water could be viewed as a way to incentivize conservation, it has actually prompted many northern cities to favor seawater desalination—an energy intensive water supply strategy that is discussed below.

Box 4. China’s South-North Water Transfer Project

While the South-North Water Transfer Project is currently the largest water transfer infrastructure project in the world, water transfers have long been used to relieve regional water shortages across the China, particularly to rescue the parched capital, Beijing. Since the 1980s, at least 20 major cross-basin water transfer projects have been built within, and sometimes between, Jiangsu, Tianjin, Guangdong, Hebei, Shandong, Gansu, Shanxi, Liaoning, and Jilin,[89] and countless more middle- and small-sized projects have connected water sources to urban regions to meet municipal demand, quench industrial thirst, feed agricultural irrigation, and facilitate pollution reduction.

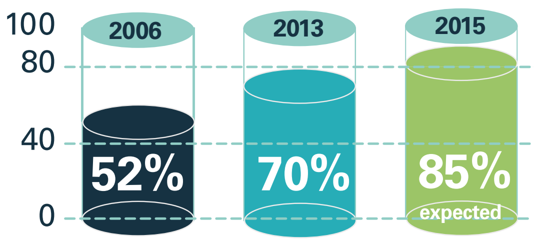
In the United States, the dry state of California has its own costly water diversion project. The California State Water Project moves water from the north to the south, sustaining Los Angeles and agriculture where rainfall cannot sustain current population and rate uses. This lift, the largest in the world, carries 7.4 billion cubic meters of water per year across 200 kilometers crossing through rich Central Valley agricultural regions and then up nearly 2,000 feet over the Tehachapi Mountains, consuming 2-3 percent of the entire state’s electricity.

Energy for Water

Wastewater Treatment:
The Forgotten Energy Intensive Industry

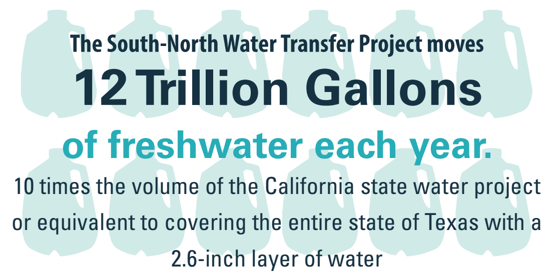
With diminishing water resources, water treatment and recycling have become critical for providing clean water needed for human consumption and ecosystem health.

China's municipal wastewater treatment rate (%)



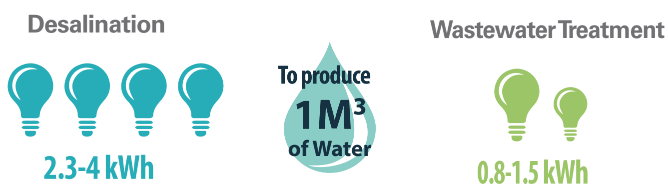
Chinese local governments do not consistently turn on wastewater treatment plants due to high energy costs.

Moving Water Demands Energy



Desalination to "Make" New Freshwater

Removing salt from seawater can require twice as much energy as wastewater treatment. China is expanding its desalination plans, seeking to engineer its way out of water scarcity.



But statistics of the SNWTP energy consumption – both for moving the water and for the embedded energy in construction materials – is unknown.

Sources: Pacific Institute, U.S. Energy Information Administration, G.K. Pearce, Office of the South-to-North Water Diversion Project Commission of the State Council.

A Bet on Desalination to "Make" New Freshwater

Following the footsteps of water-stressed countries such as Israel and Saudi Arabia, the Chinese government has heralded desalination as another key strategy for China to engineer its way out of water scarcity. The desalination industry in China marked its start in 2011, with the opening of a desalination industrial park in Hangzhou.[90] Besides quenching residential and industrial thirst along China's coastline, Chinese planners have considered using desalinated water to help the water-stressed coal industry inland.

By the end of 2012, 95 seawater desalination plants scattered across China's coastal provinces produced 778,182 m^3 of freshwater every day,[91] which represents less than one percent of the country's daily 1.6 billion m^3 of water consumption. With plans to increase its seawater reverse-osmosis desalination capacity threefold by 2015,[92] the critical question is how to balance growing energy demands from existing consumers and this added industry. Desalination requires more energy than most other water supply and treatment options.[93] Currently, China's desalination plants consume 2.3-4 kWh of electricity to produce one cubic meter of freshwater, making it more than twice as energy intensive as wastewater treatment, which uses 0.8-1.5 kWh/m^3 of water.[94] The central government's seawater desalination target in 2015—2.2 million m^3 per day—would equal about two to four percent of the Three Gorges Dam's total electricity generation. Much of the electricity supplied to desalination plants is sourced from coal-fired power plants, underscoring that China's most water-intensive forms of energy are being used to produce more water. (See Box 5).

Energy use significantly raises the price of desalinated freshwater. In the coastal city of Zhoushan, energy inputs are responsible for 58 percent of the cost of desalinated water.[95] Although the cost of China's desalinated water is on par with the global average,[96] seawater desalination is fundamentally an energy intensive, capital intensive, and land intensive way to help address China's dire water challenges.[97]

Box 5. Desalination: A Fledgling But Growing Industry

China's 12th Five-Year Plan designates Tianjin, Dalian, and Qingdao—cities along the northeast coast—as research bases for seawater desalination. The Beijiang Power and Desalination Plant, China's biggest of such plants to date, is located in the Tianjin Binhai New Area and carries a hefty price tag of $4 billion.[98] With 64 percent state investment, Beijiang is a cornerstone for an ambitious national desalination industry, in which China will invest some 20 billion yuan ($3.2 billion) by 2015.[99] This growing infusion of money is aimed at catalyzing expansion and technology innovation in desalination to satisfy not only domestic thirst, but also to build up a new major technology export industry.

Pricy Fluid

The Beijiang Plant is a model of China's circular economy policy, which encourages recycling and reuse of waste resources. Following this idea, four 1 GW coal-fired plants power the seawater pump and desalination system that is used to produce freshwater.[100] The concentrated seawater produced after desalination is then used to produce industrial salt, while the cinder from the power plants is put into construction materials.[101]

Even with the waste reuse efforts, desalinated water is more expensive than China's current water prices. In 2012, Tianjin's residential and industrial users paid 4 yuan and 7 yuan per ton, respectively, while desalinated water was 8 yuan per ton. According to David Cohen-Tanugi at MIT, desalination is "multiple times the cost of water-saving measures, with local governments subsidizing the extra cost."[102] More often than not, local governments cannot afford to keep subsidizing desalination. Several desalination plants in China have had to reduce or shut down their operations; the Beijiang plant reportedly only produced 18,000 tons of water every day in 2012, much lower than its 100,000 ton capacity.[103]

Costly Technology

Another challenge facing the Beijiang and other Chinese plants is that most of the desalination technology comes from abroad. Currently only four of the large (capacity larger than 160,000 tons/day) desalination plants in China are built without foreign technological support—the equipment for the Beijiang plant is imported from Israel. The price of these machines, the steep learning curve to train Chinese technicians, and the inconvenience in maintenance hinder the development of China's slow-growing desalination industry. In light of these hurdles, tapping the significant potential in expanding water treatment and reuse could be a more cost-effective strategy to ensure water supplies.

Wastewater Treatment: The Forgotten Energy Intensive Industry

While the skies over many Chinese cities are blanketed in grey smog, the country's rivers and lakes are turning a rainbow of colors from pollutants emitted by industries, crop production, and factory farms. According to Hong Kong-based China Water Risk, in 2012 the total discharge of wastewater in China reached 68.5 billion m^3, which is comparable in volume to the annual flow of the Yellow River.[104] It may prove more costly to clean up China's rivers and lakes than to clean up the air pollution.

In Yale University's 2014 Environmental Performance Index, China ranked 67th out of 178 countries for wastewater treatment, falling behind other emerging economies such as Mexico (49th) and South Africa (56th).[105] The indicator tracks how well countries treat wastewater from residential and industrial resources before releasing the water back into the environment.[106] In September 2013, the State Council released a municipal infrastructure development plan that aims for an 85 percent treatment rate by 2015.[107] This goal is admirable, but as China lacks infrastructure for tertiary treatment of solid sludge waste, most wastewater treatment plants only address secondary treatment of water. Unchecked dumping of this often toxic sludge has exacerbated contamination of soil, water, and crops in China, which is very difficult to clean up. Preventing this type of toxic pollution justifies increased energy use to implement tertiary treatment; it also calls for improving the efficiency of waste management. In the United States, nearly all wastewater goes through tertiary treatment, which makes the process very energy intensive, accounting for up to 30 to 40 percent of the energy consumption in some U.S. municipalities, but also much safer for the environment and human health.[108] Some U.S. cities are exploring off-grid renewable energy and waste-to-energy options to lower the energy footprint of wastewater treatment.

Wastewater treatment represents a major outlay for local governments—sometimes as much as a third of the total budget of a small county or a city.[109] Thus, despite the impressive expansion of wastewater treatment plants over the past decade, local officials often will turn off these plants to save money. Without any support from Beijing, many governments have no choice but to let the treatment plants sit idle, and let the wastewater pollute other water sources.

In June 2014, China's Ministry of Environmental Protection (MEP) submitted the draft Water Pollution Action Plan to the State Council for approval. The final plan includes a $321 billion (2 trillion yuan) investment into this sector, adding facilities for water and sludge treatment, recycling, and grey water utilization across the country.[110] These long-overdue steps to improve water quality could result in an increased, but necessary, energy footprint for water treatment in China.

A Path Forward: Energy for Water

Looking ahead, as water is arguably the most critical element of the nexus—inextricably involved in both food and energy development—regulating and monitoring its use will become increasingly crucial to China's continued ability to develop and prosper. Current Chinese policy reflects a historical tendency to try and engineer away problems, but as water scarcity and water pollution continue to spur popular discontent and require ever larger financial and engineering commitments, the role for conservation and demand side management will likely become more evident.

Adding Food Choke Points to the Mix

Soil and water are being lost, the land is degrading, crop diversity is falling, natural disasters are frequent, and the excessive and inappropriate use of fertilizer and pesticides mean that both farms and villages are badly polluted. Agricultural and rural pollution will cause a range of problems, including with food security.

— Zhang Yang, Central Rural Work Leading Group Office[111]

Every step of the food production process—from irrigation to processing to distribution—requires both water and energy. While often overlooked, the water-energy-food choke point is intense and growing in China's agricultural sector. Crops and livestock use 62 percent of the China's total freshwater[112] and produce 17-20 percent of the nation's greenhouse gas emissions.[113] Interviews conducted by Circle of Blue in China revealed that industries and cities often "save" energy by turning off wastewater treatment facilities; the resulting emissions have polluted nearly 10 million of China's 120 million hectares of cultivated land.[114] The agricultural sector is also a culprit in water pollution with fertilizer, pesticides, and animal waste runoff ranked as the top polluters of rivers and lakes in China. Coal development in north China notably clashes with agriculture for access to water. (See Box 6).

With rising incomes and rapid urbanization, Chinese citizens are adopting more meat-rich diets, which is significant because meat requires significantly larger water and energy inputs than vegetables. Urbanites consume more meat than their rural counterparts, so as the urban population more than doubled from 300 million in 1990 to 721 million people last year,[115] meat demand has quadrupled.[116]

The mass exodus from rural to urban China has caused a precipitous decline in the number of farmers in the country. Furthermore, "the food system is much more fossil-fuel dependent as human and animal resources are replaced with diesel-powered equipment and synthetic fertilizer," says Fred Gale, senior economist at U.S. Department of Agriculture (USDA) Economic Research Service.[117]

Photo courtesy of Circle of Blue © J. Carl Ganter

To respond to its citizens' changes in food demand, the Chinese government is implementing land consolidation and accelerating agricultural modernization. According to Christine Boyle, co-author of a World Bank report on China's water and food security, "modern China has only gone through major rural land restructuring twice, in the early 1950s and early 1980s."[118] She argues that while the Chinese government has not announced any new official nationwide land consolidation policy, there is a push to improve land management irrigation systems, and overall agricultural productivity. However, in China's dry north, agricultural expansion requires pumping more groundwater, which in turn requires more electricity as groundwater levels drop.

Photo courtesy of Circle of Blue © J. Carl Ganter

Box 6. Coal and Agriculture: Water Competition or Cooperation?

Extracts from Choke Point: China Reporting by Keith Schneider and Nadya Ivanova [119]

With one of the country's largest coal bases, 20 power plants and coal-to-chemical facilities, 20,000 workers, and 20 GW electrical generating capacity, the Ningdong Energy Base in Ningxia Autonomous Region illustrates China's capacity to fuel the world's second largest economy, while also contending with national anxiety about northern China's steadily diminishing freshwater supplies. Agriculture uses about 93 percent of Ningxia's water resources, but by the end of the decade, agricultural water use is projected to drop to 78 percent in order to provide more water to cities and to coal production, coal combustion, and coal-based chemicals.

To reconcile the potential conflict over water between energy and agriculture, Ningxia's energy sector, which uses enormous amounts of Yellow River water, has begun financing irrigation improvements to conserve water for agricultural users. Under this water trading program industries and electricity generators invested in the remodeling of more than 60 kilometers (37 miles) of centuries-old canals and about 170 kilometers (105 miles) of substreams, along with rebuilding more than 2,500 ancillary buildings in Ningxia. The water that is saved—64 million cubic meters annually—is transferred from agriculture to industry.

In order to effectively use the water traded, Ningxia electricity generators are adopting cutting-edge water-saving technologies. Huadian Power Corporation is operating a 1 GW, supercritical, air-cooled coal-burning unit at the Lingwu Power Plant. It uses 9,000 cubic meters of water a day for industrial operations and cooling, while a similarly sized conventional coal-fired plant would use 44,660 cubic meters of water daily, or nearly five times as much. Mines here also recycle 100 percent of the water needed to process coal, and the power plants recycle more than 95 percent of the water used for operations.

Such water rights trading programs illustrate how setting a value for water can trigger powerful behavioral changes in the energy sector. Such water trading mechanisms are almost certain to become more common in the basin as China's coal production and consumption rise as water supplies drop.

Water for Food

At the heart of China's quest for food security and food safety is not only ensuring sufficient water resources, but the availability of clean freshwater.

High and Dry

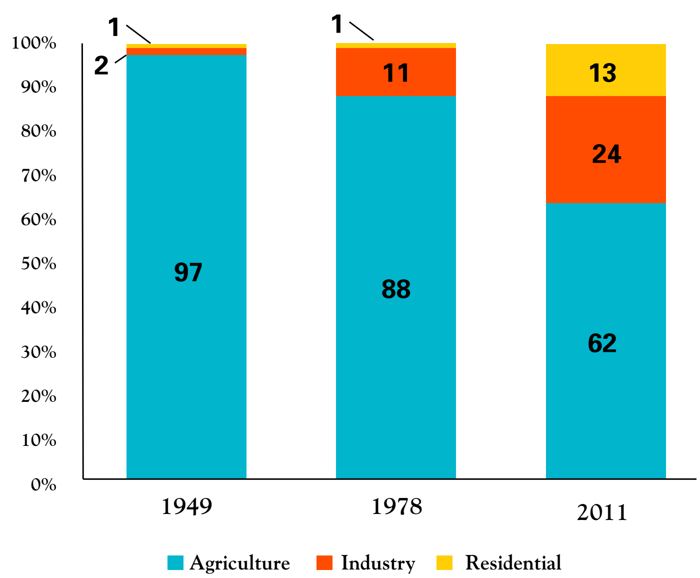
Henan Province, located in central China, is the second largest food producing region in the country and in 2014 experienced its worst drought in 40 years.[120] Crops withered and nearly 260,000 people and 80,000 head of cattle were affected by the lack of water.[121] Water scarcity has plagued much of northern China for decades, but growing pressure on water has increased the region's vulnerability to droughts, which are growing more numerous and lasting longer.[122]

China feeds approximately 20 percent of the world's population with just 6.5 percent of the world's water resources[123] and 9 percent of the world's arable land.[124] The central challenge to China's food security is a spatial mismatch between available freshwater and arable land. China's north is home to two-thirds of the country's arable land but only one-fifth of its water resources,[125] so its farmers are overexploiting aquifers in an area where 70 percent of water used for irrigation is fed by groundwater.[126] From the 1950s to the 2000s, groundwater extraction increased tenfold,[127] and as a result, the water table under the North China Plain is dropping by roughly three meters per year.[128]

Rapid industrialization and urbanization over the past 60 years in China has gulped an increasingly larger share of the country's water; the portion used for agriculture has declined dramatically from 97 percent in 1949 to 62 percent in 2011.[129] (See Figure 2). The government invested to improve irrigation infrastructure during the 1960s and 1970s, which helped to raise crop yields and farmer incomes, but the water efficiency of irrigation in China remains low.[130] Only 45 percent of the water withdrawn for agriculture is actually consumed by the target crops because of poor infrastructure and use of inefficient irrigation methods.[131] For example, traditional flood irrigation uses water very inefficiently; sprinklers can raise efficiency of water usage to 70 percent, while with drip irrigation as much as 90 percent of water used can reach crops.[132]

Changes in China's dietary demands, particularly the increase in meat consumption, are further straining its freshwater supplies, which has caused water use in food production to more than triple between 1961 and 2003, from 255 to 860 m^3.[133] Per calorie, meat production uses significantly more water than crops; the water footprint of one calorie of beef is twenty times that of one calorie of cereal.[134]

Figure 2. Water Use in China (by Sector)



Source: Wang, Jinxia, Jikun Huang, and Scott Rozelle (2014)[135]

Multicolored Toxic Rivers

Increasingly, polluted water – from livestock manure, industrial runoff, and over-fertilization – bleeds into drinking water supplies, irrigates the farmlands, and feeds the fisheries, raising alarm over the integrity of the nation's food supply.

While maintaining adequate supplies of water for food production is increasingly problematic, so too is ensuring that water is clean and safe. With one-fifth of China's arable land contaminated with heavy metals and other toxins[136] and three-quarters of urban surface water unsuitable for drinking or fishing,[137] public concern over food safety is mounting.[138] Investigative journalism, such as the now-famous 2011 *Century Weekly* report that 10 percent of China's rice is contaminated with cadmium from industrial runoff, has raised awareness on the magnitude of the problem within the country as well as abroad.[139]

In 2010, China's first National Pollution Census found that agriculture, and livestock in particular, was a greater source of water and soil pollution than industry.[140] The dominance of livestock pollution stems from the shift in pork production from a predominantly smallholder farm structure to larger, confined animal feeding operations, or "factory farms," that amplify certain types of environmental damage.[141] Currently, more than one-third of the world's meat is produced in China and half of the world's pigs reside in the country.[142]

While factory farms are arguably a more efficient use of land, Fred Gale of the USDA says that the manure created by such concentrated livestock is now seldom used for fertilizer as most farms prefer using chemical fertilizers. Nearly 80 percent of the waste from factory farms is released untreated into rivers and streams, posing grave environmental and food safety threats.[143] Pathogens, heavy metals, and high concentrations of nitrates hidden in dung can form toxic algae blooms that create dead zones, killing off fish and causing fishermen and others who come in contact with the water to develop skin rashes.

Industrial waste is another threat to China's food safety, as waste from heavy metal and mining leaches into soil and water sources.[144] In 2013, the city of Guangzhou found that roughly half of the rice tested at restaurants had levels of cadmium, a cancer-causing heavy metal, above the level deemed safe for human consumption.[145] A significant portion of the cadmium-laced rice was traced back to Hunan Province, which is one of the top-producing provinces for both non-ferrous metals and rice. The online news journal *chinadialogue* cited a report that Hunan's non-ferrous metals industry is responsible respectively for 32 percent, 59 percent, and 25 percent of China's emissions of cadmium, mercury and lead.[146] Given the magnitude of the problem, the amount of energy required to clean up the pollution in China's waterways is massive. As a consequence calculating the growing energy footprint of water use and water pollution merits more attention from researchers and policymakers both in China and worldwide.

Energy for Food

From growing, processing, and packing to storing and distribution, energy is a critical input at every stage of the food system. For example, natural gas and petroleum are used to manufacture chemical pesticides and fertilizers and power agricultural machinery, while fossil fuels are burned to produce electricity for food refrigeration, processing, and packaging. In an effort to increase food quality, Chinese food manufacturers, trucks, warehouses, and retailers are installing new cold storage systems, all of which ramp up the energy needs for the food sector.[147] Although China does not have comprehensive nationwide data on the total energy use of the food system, worldwide it is estimated that the food sector accounts for 30 percent of the world's total energy consumption and for 22 percent of total greenhouse gas emissions.[148]

As China's food system moves towards larger farms and a more supermarket-based distribution system, greater investments are made in irrigation, machinery, transport, and infrastructure, all of which require significant energy inputs.[149] For example, increased fertilizer use and substituting mechanization for human and animal labor is improving production efficiencies but also raising the energy intensity of China's agriculture.[150]

According to Gale, government subsidies to promote agricultural 'modernization' are encouraging China's food system to become more energy intensive. Since 2006, the government has also given farmers general input subsidies to offset any increases in fertilizer and diesel fuel prices. The government subsidizes agricultural machinery purchases by as much as 30 percent, and farmers access irrigation water and electricity at reduced rates. The downside of these policies is that farmers have little incentive to invest in improving the efficiency of their irrigation infrastructure and electricity usage. In fact, irrigation systems are one of the government's largest items of expenditure on agriculture.

Food market vendors also get reduced electricity rates, says Gale.[151]

Facing falling water-table levels, Chinese farmers are using more energy to pump water from deeper aquifers in order to sustain irrigated agriculture.[152] Irrigation in China releases 33 million tons of carbon dioxide, which is equivalent to the entire annual emissions of New Zealand.[153]

At the consumer level, as China's burgeoning middle class demands more refrigerators, microwaves, and dishwashers, food-related household energy consumption will continue to rise. From 1995 and 2007, China's domestic refrigerator-ownership numbers jumped from just 7 percent to 95 percent of urban families.[154] In 2007, China's refrigerated storage capacity was 250 million cubic feet; by 2017, it is expected that the capacity will be 20 times the 2007 level.[155] Refrigerators and freezers account for an estimated 40 percent of household food-related energy use.[156]

Food for Energy

Biofuels

While the government views biofuels as a strategic source of renewable energy, it is cautious not to promote the industry at the expense of the country's food security. Because China is relatively poor in terms of arable land, the government instituted a ceiling for first-generation biofuels, which are made from sugars and vegetable oils found in arable crops. This cap is set at 1.8 million metric tons annually.[157]

In the early 2000s, the Chinese government put in place biofuel-friendly subsidies and incentives, approving four plants to use corn and wheat to produce bioethanol.[158] Nevertheless, in an effort to reduce the country's dependence on imported oil, the National Development and Reform Commission (NDRC) in 2005 set a target that 15 percent of transportation energy needs should be met with biofuels by 2020.[159] To this end, the government has made bioethanol use mandatory in six grain producing provinces since 2008 (Anhui, Guangxi, Heilongjiang, Henan, Jilin, and Liaoning). Within these provinces, PetroChina and Sinopec are required to incorporate a 10 percent blend of ethanol into their petroleum.

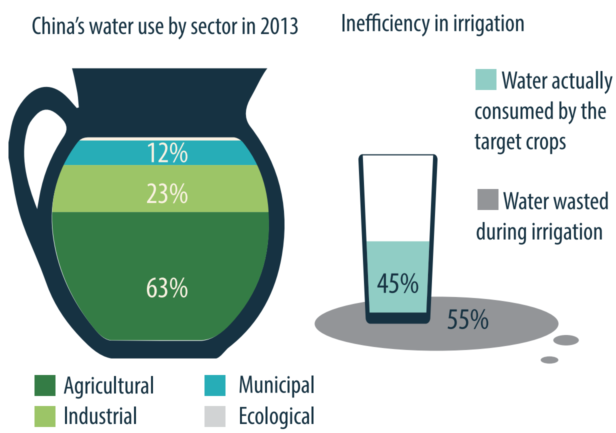
Even though a 2012 World Bank report predicts that it is unlikely that China will be able to meet its overall 2020 biofuel targets due to lack of non-grain feedstock, poor policy incentives, and slow growth in advanced technology, China's use of grains for biofuels used in the transportation sector is still large in absolute numbers.[160]

Even though second and third generation biofuels do not affect food stocks directly, their production is water intensive. According to the IEA, 30 percent of the 70 billion m^3 of water needed for energy production globally between now and 2035 will be attributed to biofuel production.[161] In this respect, biofuels may siphon away some of the available water needed for food crops.

Ways Forward for Food Choke Points

As Chinese policymakers implement structural changes to facilitate agricultural modernization, there are many opportunities to reduce the water and energy footprint in the agricultural sector. Addressing these choke points will require focusing both on supply-side efficiencies in production and reducing food and water waste. (See Box 7). In order for Chinese policymakers to create appropriate and efficient agricultural and water pricing reforms, they must first gain a better understanding of virtual water flows between provinces and in China's food exports.

Water for Food



Sources: See page 31

Box 7. Big Footprint of Waste in China's Food Sector

Where there is food loss, water and energy are also embedded in that loss. According to a rough estimate by the United Nations Food and Agricultural Organization, one-third of food produced in the world is wasted through food loss and food waste.[162] Food loss refers to losses along the supply chain at the production, post-harvest, and processing stages, while food waste refers to waste that occurs at the retail and consumer levels.[163]

While there are no official statistics on food-sector inefficiency in China, research shows that China suffers from significant postharvest loss.[164] Because China's agricultural system is still largely decentralized with 240 million small-holder farmers, a lot of the work is still done manually, reducing efficiency and increasing processing time.[165] For example, over 80 percent of grain is unloaded and loaded by hand,[166] and last year China lost 35 million tons of cereal grains because of inadequate loading and handling systems;[167] this represents a significant waste of not only food, but also water.

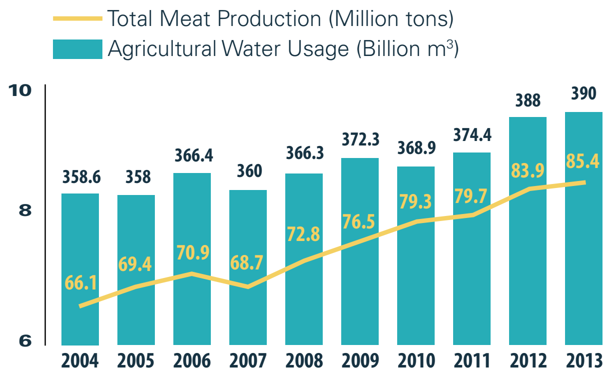
There are encouraging signs of increasing awareness of food waste—many restaurants in Beijing and Shanghai are putting up signs reminding customers not to waste food. As part of Xi Jinping's "eight rules" (ba xiang gui ding), the Chinese leadership has ordered crackdowns on lavish government banquets partly to reduce food waste. In light of the magnitude of the problem in China, continued public awareness campaigns and improving supply chains for distribution would serve an important purpose in reducing food waste and its related water and energy consumption.

Energy and Water for Food

At every step, food production—from growing, processing, packing to storing and distribution—requires water and energy, putting increasing pressure on China's already-scarce resources.

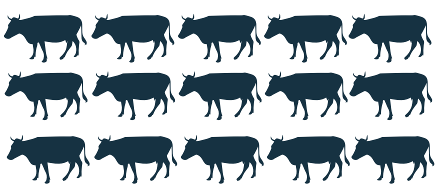
The "Juicy" Meat Industry

Rising meat consumption is further straining its freshwater supplies.



Water requirement for producing a kilogram of...

Beef

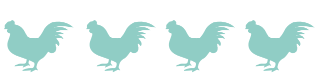


15 m³ of water

Pork

4.9 m³ of water

Chicken

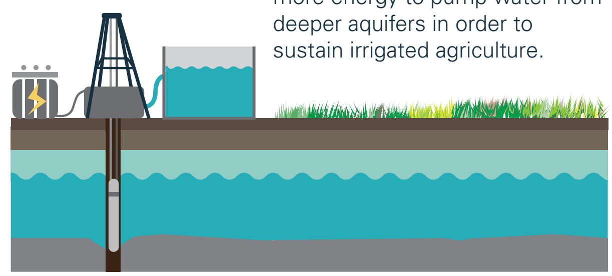


3.9 m³ of water

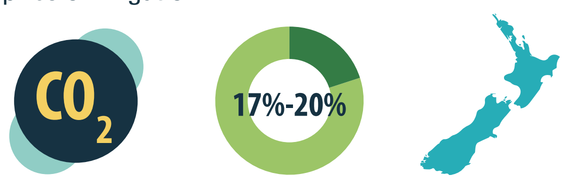
Sources: FAO, Ministry of Water Resources of China, The Guardian, National Bureau of Statistics of China, Junlian Zhang, New York Times.

Pumping to Rock Bottom

Facing declining water table levels, Chinese farmers are using more energy to pump water from deeper aquifers in order to sustain irrigated agriculture.



Also, don't forget there are climate costs to the price of irrigation.



33 million tons emissions per year

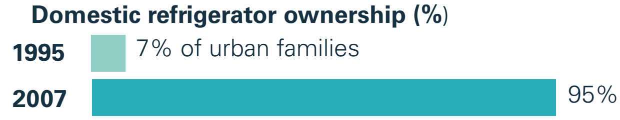
of China's greenhouse gas emissions

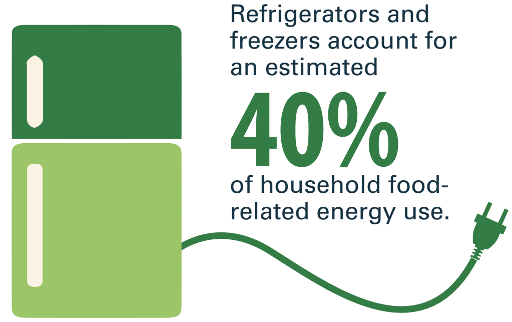
equivalent to the entire emissions of New Zealand

Refrigerators Have Big Appetites for Electricity Too

As China's burgeoning middle class demands more refrigerators, microwaves, and dishwashers, food-related household energy consumption will continue to rise.

Domestic refrigerator ownership (%)





Refrigerators and freezers account for an estimated

40%

of household food-related energy use.

Insights from Choke Point Issues in the United States

The U.S. Department of Energy can bring its strong science, technology, and analytic capabilities to bear to help the Nation move to more resilient energy-water systems.

—*Ernest Moniz, U.S. Secretary of Energy*[168]

Chinese policymakers, research institutes, and environmental NGOs are increasingly recognizing the importance of the water-energy-food nexus, which has been catalyzed in part by the Wilson Center/Circle of Blue *Choke Point: China* research and convenings. This nascent trend opens up new opportunities for Sino-U.S. collaboration building on nearly 44 years of energy and environmental cooperation by government agencies, NGOs, and research institutes. Below we provide an overview of how the United States is starting to address growing choke point issues, which will lay the groundwork for potential steps China could take and highlights areas in which the two countries can collaborate. This overview of choke point activities by U.S. government agencies, NGOs, research centers, and businesses is by no means exhaustive, but is meant to highlight a range of organizations which have been helping to lead integrated research and action to address water-energy-food confrontations in the United States.

U.S. Government Choke Point Activities

- **U.S. Department of Energy Water-Energy Roadmap Program:** In 2008 Congress tasked the Department of Energy (DOE) with undertaking a detailed scoping study to understand how water-energy nexus issues were challenging the United States.[169] DOE invited Sandia National Laboratory to form a Water-Energy Nexus team—made up of national laboratory and university scientists—to build a National Energy-Water Roadmap Program. The subsequent research and convenings were integral in assessing the vulnerabilities in the U.S. energy system from major choke

point trends and evaluating the effectiveness of existing programs within DOE and other federal agencies in addressing water and energy linked issues.

- **U.S. Department of Energy's Water-Energy Tech Team (WETT):** In the fall of 2012, DOE initiated the department-wide WETT to increase awareness of the water-energy nexus. In June 2014, WETT published a report—Water-Energy Nexus Challenges and Opportunities—that frames the integrated water-energy challenges facing the United States and sets six priorities for coordinating research between DOE and its partners.[170]

- **U.S. Engagement with APEC on Water-Energy Initiatives:** The United States is working with other countries in the Asia-Pacific Economic Cooperation (APEC) forum to develop modeling capabilities to examine water use in energy production and energy use in water production, and identify potential vulnerabilities—especially in urban areas. The project, co-sponsored by the United States, China, and Australia, and carried out under APEC's Energy Smart Communities' Initiative, aims to develop standardized definitions and data collection strategies for water-energy nexus issues and to gather relevant data from APEC economies. These activities will help develop a baseline understanding of the energy-water nexus in the region, and identify water-energy data gaps and potential vulnerabilities the countries face from water-energy confrontations. The goal is to help prioritize strategies to mitigate energy-water nexus impacts and encourage more efficient and sustainable use of energy and water.[171] APEC's Energy Working Group's Expert Group on Clean Fossil Energy also started looking into the energy-water nexus, particularly coal-based energy systems. This project—cosponsored by the United States, China, Japan, and Australia—will share information on: (1) developments to make coal-based energy systems, including power generation and conversion to synthetic natural gas and chemicals, more efficient and less-water intensive; (2) recovery and reuse of water from coal-based energy production, including use of alternative sources of water and coproduction of water with carbon capture, utilization, and storage; and (3) policy and regulatory developments in APEC member economies related to the water-energy nexus for coal-based energy production.

Regional and Basin-level Choke Point Planning and Action

- **Great Lakes Energy-Water Nexus (GLEW) Initiative:** This initiative developed new metrics to measure the impact on aquatic resources of water used for power generation. GLEW also examined policies that govern electric energy markets, utilities, and power plant siting, to identify opportunities for better integrating environmental resource impacts into future energy policy and regulatory efforts. With support from the Great Lakes Protection Fund, this 21-month effort was led by the Great Lakes Commission under the guidance of a diverse Project Advisory Team. Principal project partners included: Cornell University, Sandia National Laboratories, the Great Lakes Environmental Law Center, and the Environmental Law and Policy Center.[172]

- **Delaware River Basin Commission (DRBC):** Since 1961 the DRBC has been charged with water resource planning, development, and regulation in a river basin that supplies water to more than 15 million people, or roughly five percent of the U.S. population, across Delaware, New Jersey, New York, and Pennsylvania. Core mandates of the commission's compact are to apportion water equitably, balance competing demands on river flows, and maintain high water quality in the main stem Delaware River. The water-intensive shale gas development boom targeting the Marcellus Shale formation poses significant new water quality and quantity challenges for the basin. The DRBC has played a central role in engaging community members, NGOs, and the shale gas industry to find solutions to protect the basin's waters, which are vital to the economic future and quality of life of residents in all four states.

Research and Nongovernmental Organization Choke Point Activities

- **Pacific Institute:** The California-based NGO, Pacific Institute, has conducted extensive research on the energy usage of California's water diversion project. A member of our China Water-Energy team, Heather Cooley, leads the Institute's work examining the energy footprint of water and identifying strategies to reduce water-energy conflicts in the United States and abroad.
- **Union of Concerned Scientists:** This nonprofit science advocacy organization has published several reports that offer in-depth analyses of the connections between energy and water, looking at how much water is used by power plants fueled by natural gas, nuclear, and coal. They published the 2011 report, *Freshwater Use by U.S. Power Plants: Electricity's Thirst for a Precious Resource*.[173]
- **Alliance to Save Energy:** In 1997, the Washington D.C.-based NGO launched the Watergy program to address the link between water and energy in municipal water and wastewater treatment systems. The Alliance offers a portfolio of services that include energy assessments, training, outreach, and advocacy with electric and gas utilities, as well as financing mechanism research and policy analysis. Since 1997, the Watergy program has designed and carried out projects in over 100 cities across the globe and has saved more than 20.8 million kWh of electricity and $5 million in operating costs.

U.S. Business Choke Point Investments

Water has become a significant concern for many businesses.[174] Corporate leaders are increasingly aware of how choke point issues pose serious risks to their businesses. In 2013 when the U.S. Chamber of Commerce Foundation held a meeting to help companies better manage their energy and water use, companies expressed that their "most pressing challenge was to create business operations that are resilient to energy, water, and food shortages." The next year the Foundation published the report, *The Energy-Water-Food Nexus: Insights for the Business Community*.

According to a survey by Vox Global and Pacific Institute, 60 percent of companies surveyed indicated that water would negatively affect profitability within the next five years. And 80 percent of the respondents said that water availability would affect companies' choice of where to locate their facilities. Some noteworthy examples of U.S. companies prioritizing choke point issues include:

- **Coca-Cola:** The global beverage and food giant has set a 2020 goal to safely return to communities and nature an amount of water equal to what the company uses in its finished beverages and production processes. The company is increasingly addressing water stewardship in the context of the water-energy-food nexus in its work with the World Resources Institute and 2030 Water Resources Group.
- **Dow Chemical:** Dow Water and Process Solutions, a business unit of The Dow Chemical Company, has published several reports, including *The Sustainability Challenge: Meeting the Needs of the Water-Energy Nexus*[175] *and China's Thirst for Water*. The company uses a concept known as valuation of ecosystem services to account for and incorporate the value of nature in its business decisions.[176]
- **General Electric (GE):** The multinational conglomerate has made a company-wide effort to improve the water-efficiency of its operations, focusing especially on its plants located in water-scarce areas like Bangalore, India. The corporation and one of its subsidiaries have also committed $20 million to building infrastructure and healthcare in Africa, which includes a program to improve access to clean and safe water in hospitals by installing water-scarcity systems.[177] GE has also been a supporter of the World Resources Institute Aqueduct project, which began its water-energy risk analysis tool building in China.

Finding Solutions in Connections

We need to find a new growth model. This is especially true in the water and energy areas…This is the choke point for the country.

— *Zhang Yongsheng, Senior Fellow at the Development Research Center of the State Council of China*[179]

With China's rapid urbanization and industrialization, its water-energy-food choke points are tightening and Chinese policy, research, and civil society communities have not yet coalesced around a unified and comprehensive strategy to address these growing challenges. The country's power and agricultural sectors are competing for an ever-decreasing water supply, and at the same time, more energy is needed to move and treat its increasingly polluted waters. China is facing a confluence of pressures that are threatening its already vulnerable resources, catalyzing risks to its water, energy, and food security.

However, just as there can be a negative domino effect in the interlinked competition for water, energy, and food, there can also be a positive multiplier effect when all three are effectively managed together. Specifically, efficient management practices for one of these resources could have significant co-benefits for the others. For example:

- Energy efficiency reduces water use in the energy sector, leaving more water available for food production and other sectors;
- Preventing water pollution lowers the energy requirements of treatment plants and avoids contamination of food crops;
- Promoting less water-intensive crops and lowering food waste help to save significant amounts of water and energy and enhance rural livelihoods;
- Incorporating the cost of water in electricity production and reforming energy pricing policies accordingly could be an effective market tool to promote more efficient energy use.

Recognizing the connections between these different issues creates opportunities for new thinking on policies, regulations, incentives, and investments for more aggressive resource conservation. Through our

Choke Point: China research, exchanges, and interviews, we have identified three priority action areas that Chinese policy, research, and civil society organizations could focus on to build a strong foundation for action on water-energy-food management:

1. Identify the magnitude of choke point issues in China.
2. Optimize water-energy-food nexus management.
3. Strengthen China-U.S. collaborative networks.

Action Area #1. Identify the Magnitude of Water-Energy-Food Issues

Integrating the management of water, energy, and food is a significant hurdle for China due to the paucity of baseline data, particularly concerning the amount of energy needed for the water sector. Some of the data exists, but is spread across different agencies and research centers that do not generally collaborate or do not use the same methodology. To overcome this fragmented data management, China needs to create permanent research hubs and networks to collect baseline data and analyze the complete lifecycle use of water, energy, and food, by sector and by region. Below are recommendations on how to build information clearinghouses on choke point research and dialogue in China.

1 **Create permanent centers and research networks for multidisciplinary choke point research.** To help the collection of baseline data on choke point issues, it will be valuable for the Chinese government to assemble a crosscutting R&D team made up of top researchers from energy, water, and agriculture policy think tanks and universities. Ideally, a relevant Chinese government agency, for example the NDRC, Ministry of Water Resources, or Ministry of Science and Technology could provide some of the initial funding for this data collection and research. The National Energy Administration under the NDRC has begun to study water-energy issues. Thus, the NDRC could be the logical hub for further choke point research.

2 **Collect baseline data.** China urgently needs more complete baseline data on water and energy interactions. Filling such vital data gaps will inform more accurate projections in models guiding Chinese policy, research, and civil society communities to take action to reduce water-energy-food confrontations and improve management of these resources. Box 8 outlines some examples of data and analysis priorities:

3 **Generate water-energy-food models.** Drawing from challenges and lessons learned in the U.S., China could develop models that help policymakers better understand the current situation and project future needs. Models should:

- Integrate the management and planning of water, energy, and food resources, and consider climate change, population growth, urbanization, economic development and technology evolution;
- Evaluate how smart agriculture techniques could lower water use and maintain yields in the most cost-effective manner;
- Inform the timing and severity of choke point issues;
- Evaluate the efficacy and unintended consequences of alternative mitigation and adaptive strategies to deal with choke points;
- Create tools that help household users understand the energy and climate impacts of their daily water use, looking to the Pacific Institute's Water-Energy-Climate Calculator as an example;[183]
- Equip energy-water policymakers and managers with tools to help them evaluate energy-water interactions—examples of this include the **Brookhaven National Laboratory** model for New York City Energy-Water analysis[184] or the **National Renewable Energy Laboratory** Regional Energy Deployment System model. These models have incorporated water constraints into a long-term capacity-expansion model for the deployment of electric power generation technologies and transmission infrastructure throughout the United States.

China's ambition to maintain prolonged growth in a resource-constrained environment calls for a new, proactive model of decision-making that sets development priorities according to local water conditions. The data, research, and modeling discussed above will help to establish a choke point framework to help central and local policymakers and researchers better evaluate tradeoffs and costs of various water, energy, and food production and conservation goals. With sufficient data and modeling Chinese experts will be able to:

- Establish joint planning exercises among water, energy, and food managers at all levels of government in China;
- Undertake a comprehensive, nationwide assessment of hydropower and its impacts on water flows and pollution;
- Coordinate data collection across key government and research entities. For example, in the United States, the U.S. Energy Information Administration and U.S. Geological Survey were required to set standards on how to collect uniform data on water usage by power plants as a result of the Department of Energy's push to better manage the water-energy nexus.

Box 8. Water and Energy Research Agenda for China

Energy for Water Data

- **Calculate water intensity (differentiating withdrawal and consumption) of all power generation technologies.**
- **Conduct lifecycle water use analysis of energy production, manufacturing, food production, processing, and distribution.** As the world's factory, it would be valuable to estimate how much water is embedded in products China imports and exports (e.g., through importing water-intensive crops and energy, and exporting clothes, electronics, and fuels). Lifecycle analysis of energy and water flows used in food processing is also a critical gap and this type of tracking could also be used to strengthen food safety oversight.
- **Estimate national, provincial, and city data for energy that is used for conveying and treating water.** This would include pumping water for irrigation, water transfers, and wastewater and desalination plants.

Water for Energy Data

- **Water for Coal.** As China's main source of electricity, securing accurate data on coal's water footprint is critical. Currently, the few estimates made by international and Chinese organizations vary considerably, in part because of differing measurement criteria and also because accurate data is often hard to come by in such a rapidly developing and vast country. Some estimates also do not take into account the entire lifecycle of coal production; rather they focus only on water use at the point of electricity generation. For example, one recent Ministry of Water Resources report cited China's total industrial water withdrawals as 22.5 percent of the national total, and indicated that thermal power with once-through cooling systems accounted for 7.5 percent of the national total water withdrawals. However, this estimate for thermal power focuses exclusively on the plant-level use, rather than a full assessment of the supply chain and does not include coal-to-gas or coal-to-liquids industries in the estimate.[180]
- **Water for fuels.** Studying the amount of water used in fuel extraction (particularly for coal and natural gas) and production (especially SNG and oil) combined with basin-wide water surveys will be vital in managing choke points.

Baseline Data to Assess Choke Point Risks

- **Gather and analyze provincial and/or regional water-energy data.** Subnational water-energy nexus analyses will be vital to make assessments on the future water needs in key regions of the country. The Pacific Institute's *Water for Energy: Future Water Needs for Electricity*[181] and *Energy Down the Drain*[182] are useful models for studies that quantify energy requirements for water systems at regional levels.
- **Examine supply chain water risks.** These risks include mapping out the magnitude of water pollution and waste created by China's energy and industrial supply chains, as well as understanding the problems energy and other industries face in accessing clean water.
- **Calculate the co-benefits of addressing choke point issues.** This will require estimating how decreasing the energy footprint of water could lower air pollution and greenhouse gas emissions, among other benefits.

Action Area #2. Optimize Water-Energy-Food Nexus Management

Increasing efficiency in the management of water, energy, and food—often referred to as demand-side management strategies—warrants greater attention in China. Policies for improving efficiency should target water use in energy production, electricity generation, and consumer end use. Policies should also address energy efficiency in water management, treatment, distribution, and end use operations. The water pricing reform announced in 2014 by the NDRC could be a good first step in this direction.[185] The push by Chinese policymakers to prioritize energy efficiency in the past two Five-Year Plans has led to significant energy savings, as well as improvements in the efficiency of irrigation and reducing water pollution.[186] Targets included decreasing energy intensity by 16 percent and obtaining 11.4 percent of total energy from non-fossil energy sources.[187] There are many opportunities to make China's economy even more energy efficient – saving energy ultimately saves water.

1

Improve standards and efficiency codes for water and energy. Another way that government can help incentivize energy and water-saving consumption patterns would be to implement and enforce standards and codes of conduct. For instance, California has set maximum flow rates for showerheads, toilets, and other appliances and created rebates to encourage individuals and industry to switch out older inefficient appliances and fixtures for water or energy saving ones.[188] Moreover, there are significant opportunities for improving lighting, heating, and cooling efficiency in Chinese buildings.

2

Prioritize water efficiency and pollution control:

- **Reigning in energy's water footprint.** While the Chinese government has been quick to create comprehensive policies and investments to promote energy efficiency and the development of renewables, it has lagged behind in its response to the country's water wastage, particularly in the energy sector. The 12th Five-Year Plan for Energy Development highlighted for the first time that the water footprint of coal is an issue for the government to begin addressing. The Ministry of Water Resources issued water allocation rules for China's coal plants and coal producers in early 2014. Expanding and rigorously enforcing water efficiency targets in the energy sector as well as in other industries and municipalities would be a vital step to protecting the country's vulnerable water resources.

- **Reduce water pollution through cleaner energy.** The new top-down measures from the 2013 Pollution Action Plan (to the amended Environmental Protection Law) represent important steps in improving pollution control to protect China's water quality. Filling the governance gaps to promote accountability at the local level will be crucial to enforcement of existing water pollution control regulations. The high-energy costs can hinder water treatment—so much so that tertiary treatment is almost nonexistent in China. This treatment gap is saddling the country with mountains of often toxic sludge. To address this energy burden that hampers wastewater treatment, the central and provincial governments could:

  1) Prioritize off-grid distributed renewable energy generation for wastewater treatment;

  2) Deploy biodigesters on factory farms to prevent animal waste from entering river and lakes.

3

Increase incentives for end-use conservation by industries and consumers:

- **Continue to raise efficiency targets.** A recent study by the Natural Resources Defense Council and Tsinghua University concluded that during the 11th Five-Year Plan period, the water saved through efficiency programs across China's entire power sector could satisfy Beijing's water demand for three years.[189] Energy efficiency's positive implications for water management should be further emphasized. Conversely, water conservation could prove more appealing if the energy savings are compared to the costs of building desalination and water transfer infrastructure.

- **Raise water prices and improve tracking of water use.** Although water prices in China have gradually increased in the past twenty years, water is still underpriced compared to other countries, especially in the agricultural sector.[190] Raising fees and expanding pilot water rights trading markets would promote water conservation and efficiency.

- **Create public awareness campaigns.** Besides targets and pricing, highly visible public awareness campaigns on energy-saving, food-saving, and water-conservation could also be a powerful tool, as evidenced by Chinese basketball superstar Yao Ming's heralded involvement in a campaign against shark fin soup, which likely contributed to the 70 percent reduction in sales.[191]

- **Educate local officials about choke point linkages.** Water conservation and pollution control regulations have been on the policy agenda for many years in China, but enforcement has generally been weak. Inclusion of water-energy-food nexus classes and training in Party schools, both at the central and local levels would provide officials with a basic foundation of how integrated water-energy-food nexus management could be used to alleviate water and energy stresses while working towards greater food security.

Action Area #3. Strengthen Choke Point Collaboration Between China and the U.S.

As the two largest energy producers and users in the world, the inter-linkages among water, energy, and food are having great impacts on the economic and ecological health of the United States and China. The establishment of a water-energy nexus program under the existing Clean Energy Research Center (CERC) mechanism, which is slated to begin in October 2015, is a positive development. The program will receive $50 million over five years and aims to catalyze joint research to address water-energy challenges facing both countries.[192] The funding will be evenly shared by the two countries through a mix of government and private sources. Other recommendations for collaboration include:

1 **Establish a bilateral water-energy-food nexus research center that focuses on mutual choke point challenges in both countries.** The new CERC water-energy program provides a platform for joint choke point research and technology development by teams of university, industry, government, and NGO scientists, engineers, and policy experts. Potentially fruitful areas of joint work include:

- **Interactive mapping of virtual water flows in the economy.** Such mapping could use models from existing studies[193] to make it easier for policymakers to comprehensively visualize water in production, consumption, and trade stages both within and beyond each country's borders.

- **Enhance joint research and development into water and energy saving technologies.** For example, a recent study of 11 Chinese provinces found that the use of improved irrigation management measures such as flow metering, irrigation scheduling, or simply regular maintenance can reduce the amount of pumped water by up to 20 percent.[194] Many of these technologies have been already launched as pilot programs at the local level.

2 **Build subnational collaboration.** In the United States some of the most creative and innovative solutions to water-energy-food management have emerged from city governments and regional organizations. Chinese cities are already being pushed to quickly address increasingly severe energy, water, and pollution challenges and therefore represent ideal partners for testing new policies and pilots to increase their water, energy, and food resilience.

- **Incorporate water into local energy planning.** In the United States, Arizona and Colorado have moved to the forefront of incorporating water into state energy planning. For example, the Arizona state electricity regulatory agency has included water consumption in its electric resource planning for over a decade. The agency has denied permits for proposed natural gas power plants to protect groundwater supplies and encouraged the state's largest electric company to build new solar farms to lower water use.[195] Another example is the Watts to Water Program, a metro-wide sustainability program based in Denver, Colorado dedicated to the reduction of energy and water consumption. Buildings and businesses in the city that opt-in share their energy and water consumption data in exchange for complimentary technical support from Energy Star technicians, and they receive rebates to make building operations more efficient and materials that will lower their water and energy consumption.[196]

- **Encourage city-to-city exchanges.** Cities often lack data on how water, energy, and food flows interact in their communities. Generating such metrics would help guide leaders identify where they can make the greatest impact. For instance, in some regions, pipeline leaks and uneven pressure mean that significant water, and thus energy, is lost in distribution. As an indication of economic loss, 50 percent of London's municipal water cost is non-revenue; in China, that number is 20-30 percent in large cities and 6-7 percent in smaller or newer cities.[197] U.S. and Chinese cities are participating in growing networks focused on urban climate collaboration (e.g., C-40), creating smart cities, and even some U.S.-China sister city programs are becoming more committed to environmental issues. Brookhaven National Laboratory paired up eight U.S. cities with seven Chinese cities for collaboration on energy and environment and led a U.S.-China Joint EcoCities project involving six Chinese cities and four U.S. cities.[198] Recently, the Ports of Los Angeles and Shanghai have formulated an EcoPartnership under a program managed by the U.S. Department of State and the NDRC.[199] Cities in the United States and China that face similar water-energy challenges, such as port cities in Oakland, CA and Shenzhen or Guangzhou, could build business and policy dialogues under existing sister city or EcoPartnership programs that share knowledge on best practices on lowering their energy and water footprints.

3

Expand engagement with civil society, multilateral, and business communities. Box 8 provides an overview of some water-energy-food-related initiatives that have been launched in China over the past two years. These nongovernmental players could be valuable to help bring business, community, and policy stakeholders together for choke point research, projects, and policy development. NGOs can help shine a light on the impacts of unsustainable water use on communities and encourage more transparent and participatory decision making in future project development. As industrial water withdrawals rise in China, Chinese businesses will face increased risks as energy and food production squeeze the country's water supplies.[200] Therefore it will be important to engage the private sector to help raise awareness on how water and energy waste is exacerbating risks to sustainable business.

4

Incorporate water-energy-food programming in the U.S.-China Agriculture and Food Partnership and pursue further trade opportunities in agribusiness between the two countries.

- Trade may offer the most sustainable way forward for China to meet its domestic grain demand and would also create an opportunity for U.S. agricultural exports. China's growing imports of grain and other foods are driven in part by water shortages and represent an import of "virtual" water. Greater understanding of the role of trade, with respect to managing virtual water flows inter-provincially and internationally, will be critical for China's food and resource future. The United States has arable land that could more sustainably meet China's meat demand if the right policies are in place to incentive such investments. According to Fred Gale, senior economist at the United States Department of Agriculture, "Importing meat from more land abundant countries, like the United States…is probably going to reduce the environmental footprint of Chinese people eating more meat compared to China being self-sufficient, producing all its own pork and all its own chickens."[201]

- In April 2014, the U.S. agribusiness community launched the U.S. Agriculture and Food Partnership as the key public-private sector coordinator for bilateral food and agriculture cooperation between the two countries. The partnership has seven key task forces including: crop chain, livestock chain, machinery, food processing, investment, financial services, and food safety. Particularly under the livestock chain and food safety task forces, there is a ripe opportunity for U.S. agribusiness to reevaluate their supply chain practices in China from a water-energy-food management perspective and in doing so, also work with China's agri-food industries to introduce best practices that conserve these crucial resources and limit pollution.

Box 9. Examples of Emerging Choke Point Work in China

- **The Wilson Center's China Environment Forum** is continuing its **Choke Point: China** work with Circle of Blue and other U.S. and Chinese partners to expand research and dialogue on water-energy-food confrontations in China and to continue identifying opportunities for U.S.-China collaboration. The next major initiative is the **Choke Point: Port Cities** that is investigating the water-energy choke points in Shenzhen and Oakland, California, with an eye on the pollution reduction co-benefits.

- **The World Bank's Thirsty Energy Initiative** recently began working in China to design and implement an integrated water and energy model for the **National Energy Administration (NEA)**, as part of the institution's 13th Five-Year Plan for Energy Development. Besides NEA, the Bank will work with the Institute for Water and Hydropower Resources—which works directly with China's Ministry of Water Resources—to ensure that the country's energy planning tools properly incorporate water constraints and investment required to produce power and cooling in the major energy basins in the country. Preliminary results are expected to be ready by February of 2015 in time to be used for the design of the 13th Five-Year Plan.

- **The Natural Resources Defense Council's** China Coal Consumption Cap Plan and Policy Research, which is bringing together China's leading energy and environmental think tanks to conduct in-depth research and dialogues, has incorporated water into its coal consumption cap co-benefits research. This broad-ranging research work will produce policy recommendations and concrete action plans on decreasing coal consumption in China.

- **China Water Risk,** a Hong Kong-based NGO, has expanded its water risk research and reporting heavily into coal-water confrontations since 2012—most notably with the *No Water No Power: Is There Enough Water to Fuel China's Power Expansion* report for HBSC and an extensive series of stories and infographics on the coal-water link.[202]

- **The Pacific Environment and Waterkeeper Alliance** are working with grassroots environmental groups across China to reduce the country's reliance on coal by engaging in public outreach on the impacts of coal on air and water through local industry transparency initiatives and citizen pollution monitoring of coal and heavy industries.

- Chinese Universities and think tanks are beginning to dive into choke point analyses. **BP-Tsinghua Clean Energy Center** was the first Chinese university research center to assess the water footprint of China's coal production cycle. On the flip side of the water-energy confrontation, **Nanjing University Center for Environmental Management and Policy** is the first Chinese research group to begin estimating and modeling the energy footprint of water in China, focusing in part on how conserving urban water can decrease pollution and greenhouse gas emissions.[203] China's **Energy Resources Institute** under the National Development and Reform Commission has undertaken some initial analyses of the water footprint of different energy technologies in China.

- **The World Resources Institute (WRI) Water Team** in Beijing is reviewing the policies and regulations on energy and water resources management at the national and provincial levels in China with the goal of identifying gaps that pressure water ecosystems in the country. WRI's Aqueduct project has created online maps and tools to help companies, investors, governments, and communities better understand where and how water risks are emerging around the world. Their initial prototype tool focused on the Yellow River in China.

- **Greenpeace China** continues its Thirsty Coal campaign, undertaking on-the-ground research and advocacy on how expanding coal bases in north China are exacerbating China's current water crises. A 2014 Thirsty Coal report on pollution and excessive water extraction from Shenhua coal-to-liquids plants highlighted the growing groundwater depletion and contamination problems linked to coal production in China's north.

- In the spring of 2014, the **World Coal Association**—based out of the Shenhua Science and Technology Institute—published a special issue on coal and water that featured several articles focused on China by not only Shenhua researchers, but also by WRI and the BP-Tsinghua Clean Energy Center.[204]

China's Opportunities to Address the Choke Points

To reconcile the water-energy confrontations, the only way out is to manage the whole thing in a more efficient way—from the design, through the construction, to the operation.

— Ma Jun, Director, Institute for Public and Environmental Affairs and Wilson Center Global Fellow[205]

China's ability to manage its tightening water-energy-food choke points may seem like a battle of Goliathan proportions. Water pollution and shortages are shrinking the amount of cropland that can be used safely for food production; this has pushed China dangerously close to the government's "red line" of 120 million cultivated hectares required to ensure its grain security. Northern cities are increasingly thirsty; Beijing was estimated to be 515 million m^3 short of water for the year 2011, and even with the SNWTP the deficit will still be 190 million m^3.[206] Meanwhile, the country's coal powered generation capacity is set to rise to 1,250 GW by 2020.[207] Even with the new fleet of efficient coal plants, this increase in capacity translates to roughly 34 billion m^3 of water used annually by 2020.[208] Chinese policymakers have only recently begun to recognize these choke points, but as this Roadmap has outlined, some progressive steps are already being taken, such as the recent announcement of the U.S.-China Clean Energy Research Center's water-energy nexus program. Here are some other promising trends to build on:

China has shown that when there is the political will, changes will be enacted, though implementation lags. The central government has earmarked $608 billion (4 trillion yuan) this decade to clean up its rivers and lakes, fix its water supply systems, and boost water conservation.[209] Chinese officials are also pushing policies to raise water efficiency in the agricultural sector. In the energy sector, the government now requires use of dry cooling on new ultra-super critical coal-fired power plants in the northern provinces, making them among the most water-efficient power plants in the world.

Improvements in China's infrastructure offer more conservation opportunities. Beijing is erecting new buildings that include gray water systems to deliver recycled wastewater for washing cars and flushing toilets.[210] The city has reduced industrial water use by more than 40 percent, is set to increase its wastewater recycling rate to 75 percent and sewage treatment rate to 98 percent by 2015.[211] Since 1995, Shanghai has spent $8.1 billion (50.3

billion yuan) to construct a network of 52 sewage plants that now treat nearly 80 percent of the city's wastewater.[212] If the Shanghai municipality expands its rooftop solar investments and policy incentives into the wastewater treatment sector, they could launch a new model for low-carbon development that has the co-benefit of protecting water. In rural areas, as the country transitions from family farms to industrial agriculture, there are also new opportunities to implement water and energy saving technologies.

China's strong manufacturing base and large population gives the country an unparalleled ability to scale-up effective technologies. The Chinese government's investments and policies to encourage clean energy have made the country a leader in solar, wind, and cleaner coal technologies. China has become a global laboratory for testing and improving clean energy technologies from carbon capture and sequestration to integrated gasification combined cycle. China has the opportunity to also play a leadership role in addressing its water-energy-food confrontations, including more energy efficient desalination and wastewater treatment, and new waste to energy technologies.

Water-energy-food confrontations are complex and no single document can solve these problems, but we hope that this Roadmap lays out some foundational ideas that can empower Chinese stakeholders and their partners to develop a comprehensive framework for alleviating China's growing choke points.

Appendix A: China Water-Energy Team Itinerary

August 4-7, 2013
Strategic Water-Energy Roundtables

- Natural Resources Defense Council
- Syntao Co., Ltd. – *held at Johnson & Johnson's Beijing office*
- Development Research Center of the State Council
- Institute of Public and Environmental Affairs
- Institute for Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences
- Energy Research Institute of the National Development and Reform Commission
- Chinese Academy of Environmental Planning
- Beijing University
- Beijing Energy and Environment Roundtable (BEER)

Appendix B: China Water-Energy Team Member Bios

Vatsal Bhatt is Senior Policy Advisor at Brookhaven National Laboratory of the United States Department of Energy and is a senior policy advisor to the U.S.-China EcoPartnerships Secretariat.

Pamela Bush is the Secretary and Assistant General Counsel of the Delaware River Basin Commission.

Heather Cooley is Co-Director of the Pacific Institute's Water Program.

Jia Shaofeng is the Deputy Director of the Center for Water Resources Research at the Chinese Academy of Sciences.

Jia Yangwen is Vice Director of Department of Water Resources, China Institute of Water Resources & Hydropower Research.

Keith Schneider is Senior Editor at Circle of Blue where he leads their Choke Point work.

Sun Qingwei previously worked with Greenpeace East Asia as a Climate and Energy Campaigner where he led the coal-water nexus research.

Vincent Tidwell is a Distinguished Member of the Technical Staff at Sandia National Laboratories conducting basic and applied projects in water resource management.

Yang Fuqiang is Senior Adviser on climate change, energy and environment at the Natural Resources Defense Council, Beijing office where he leads the Coal Consumption Cap Program.

ENDNOTES

1 International Energy Agency. “The Impact of Global Coal Supply on Worldwide Electricity Prices.” 2014. http://www.iea.org/publications/insights/insightpublications/ImpactGlobalCoalSupply_Worldwide-ElectricityPrices_FINAL.pdf

2 Pan, Lingying; Liu, Pei; Ma, Linwei; and Li, Zheng. “A Supply China Based Assessment of Water Issues in the Coal Industry in China.” *Energy Policy*. 2012. 48:93-102. China’s Water Resources Bulletin; The Ministry of Water Resources of the People’s Republic of China. “*2012 China Water Resources Bulletin*.” December 15, 2013. http://www.mwr.gov.cn/zwzc/hygb/szygb/qgszygb/201405/t20140513_560838.html; Cai, Beiming; Zhang, Bing; Bi, Jun; and Zhang, Wenjing. “Energy’s Thirst for Water in China” *Environmental Science & Technology.* 2014. 48(20):11760-11768 http://dx.doi.org/10.1021/es502655m

3 World Bank. “Renewable Internal Freshwater Resources Per Capita (cubic meters).” *World Bank Data Bank.* 2012. http://data.worldbank.org/indicator/ER.H2O.INTR.PC

4 Cai, Beiming; Zhang, Bing; Bi, Jun; and Zhang, Wenjing. “Energy’s Thirst for Water in China,” *Environmental Science & Technology.* 2014. 48(20):11760-11768 http://dx.doi.org/10.1021/es502655m

5 “China Falling Behind on 2020 Hydro Goals.” *China Digital Times.* March 11, 2014. http://chinadigitaltimes.net/2014/03/china-falling-behind-2020-hydro-goals/

6 China Water Risk. “Sectors: Agriculture.” http://chinawaterrisk.org/sectors/

7 Garthwaite, Josie. “California Drought Dries Up Hydro, But Power Stays On.” *National Geographic*. March 11, 2014. http://news.nationalgeographic.com/news/energy/2014/03/140311-california-drought-dries-up-hydro-but-power-stays-on/

8 Bjerga, Alan. “California Drought Transforms Global Food Market.” *Bloomberg*. August 11, 2014. http://www.bloomberg.com/news/2014-08-11/california-drought-transforms-global-food-market.html

9 World Bank. “Renewable Internal Freshwater Resources Per Capita (cubic meters).” *World Bank Data Bank.* 2012. http://data.worldbank.org/indicator/ER.H2O.INTR.PC

10 The 2030 Water Resources Group. “Charting Our Water Future: Economic Frameworks to Inform Decision-Making.” 2009. http://www.2030waterresourcesgroup.com/water_full/Charting_Our_Water_Future_Final.pdf

11 National Development and Reform Commission. “China’s National Climate Change Programme.” June 2007. http://en.ndrc.gov.cn/newsrelease/200706/P020070604561191006823.pdf

12 Piao, Shilong; Ciais, Philippe; Huang, Yao; Shen, Zehao; Peng, Shushi; Li, Junsheng; Zhou, Liping, et al. “The Impacts of Climate Change on Water Resources and Agriculture in China.” Nature. 2010. 467:43-51.

13 Xie, Jian; Lieberthal, Andres; Warford, Jeremy; Dixon, John; Wang, Manchuan; Gao, Shiji; Wang, Shuilin, et al. “Addressing China’s Water Scarcity: Recommendations for Selected Water Resource Management Issues.” *The World Bank. 2009.* http://documents.worldbank.org/curated/en/2009/01/10170878/addressing-chinas-water-scarcity-recommendations-selected-water-resource-management-issues

14 China Water Risk. “Big Picture: Pollution Status.” 2011. http://chinawaterrisk.org/big-picture/pollution-status/; Turner, Jennifer. “In Deep Water: Ecological Destruction of China’s Water Resources.” *Water and Energy Futures in an Urbanized Asia*. 2007. Center for Strategic and International Studies. http://www.wilsoncenter.org/sites/default/files/turner_csis_article.pdf.

15 Ivanova, Nadya. “Toxic Water: Across much of China, Huge Harvests Irrigated With Industrial and Agricultural Runoff.” Circle of Blue. January 18, 2013. http://www.circleofblue.org/waternews/2013/world/toxic-water-across-much-of-china-huge-harvests-irrigated-with-industrial-and-agricultural-runoff/

16 China Water Risk. “2013 State of Environment Report Review.” July 9, 2014. http://chinawaterrisk.org/resources/analysis-reviews/2013-state-of-environment-report-review/

17 Xie, Jian; Lieberthal, Andres; Warford, Jeremy; Dixon, John; Wang, Manchuan; Gao, Shiji; Wang, Shuilin, et al. “Addressing China’s Water Scarcity: Recommendations for Selected Water Resource Management Issues.” *The World Bank.* 2009. http://documents.worldbank.org/curated/en/2009/01/10170878/addressing-chinas-water-scarcity-recommendations-selected-water-resource-management-issues

18 National Bureau of Statistics. “China Statistical Yearbook.” 2005. China Statistics Press, Beijing.

19 Xie, Jian; Lieberthal, Andres; Warford, Jeremy; Dixon, John; Wang, Manchuan; Gao, Shiji; Wang, Shuilin, et al. “Addressing China’s Water Scarcity: Recommendations for Selected Water Resource Management Issues.” *The World Bank.* 2009. http://documents.worldbank.org/curated/en/2009/01/10170878/addressing-chinas-water-scarcity-recommendations-selected-water-resource-management-issues

20 Ministry of Water Resources of the People’s Republic of China. “China Focus: Central, North China Hurt by Drought.” August 1, 2014. http://www.mwr.gov.cn/english/Medianews/201408/t20140801_572264.html

21 Bloomberg News. “China’s Drought to Shrink Corn Harvest First Time Since 2009.” *Bloomberg.* August 8, 2014. http://www.bloomberg.com/news/2014-08-08/china-s-drought-to-shrink-corn-harvest-first-time-since-2009.html

22 The 2030 Water Resources Group. “Charting Our Water Future: Economic Frameworks to Inform Decision-Making.” 2009. http://www.2030waterresourcesgroup.com/water_full/Charting_Our_Water_Future_Final.pdf

23 The 2030 Water Resources Group. Ibid.

24 China Water-Energy Team exchange at the Chinese Academy of Environmental Planning. August 7, 2013.

25 U.S. Energy Information Administration. “China Country Analysis.” February 4, 2014. http://www.eia.gov/countries/cab.cfm?fips=CH

26 Zhang, Chao; Anadon, Laura; Mo, Hongpin.; Zhao, Zhongnan.; and Liu, Zhu. “The Water-Carbon Trade-off in China’s Coal Power Industry.” October 7, 2014. 48:19. *Environmental Science and Technology.*

27 China Environment Forum. “The Thirsty King: Digging into the Water Footprint of China’s Coal.” Woodrow Wilson Center, 5th Floor. July 24, 2012. Event. http://www.wilsoncenter.org/event/the-thirsty-king-digging-the-water-footprint-china’s-coal

28 Interview via email with Heather Cooley, Director of Water Program, Pacific Institute. June 27, 2014.

29 Sun, Guodong. “Coal in China: Resources, Uses, and Advanced Coal Technologies.” 2010. *Coal Initiative Reports.* Pew Center on Global Climate Change. http://www.circleofblue.org/waternews/wp-content/uploads/2011/03/Coal-in-China.pdf.

30 U.S. Energy Information Administration. “China Consumes Nearly as Much Coal as the Rest of the World Combined.” January 29, 2013. http://www.eia.gov/todayinenergy/detail.cfm?id=9751

31 U.S. Energy Information Administration. Ibid.

32 Al Jazeera. “China Plans to Ban Coal Use in Beijing by 2020.” August 5, 2014. *Al Jazeera America.* http://america.aljazeera.com/articles/2014/8/5/china-to-ban-allcoaluseinbeijingby20201.html

33 Hornby, Lucy; Smyth, Jamie; and Hume, Neil. “China Ban on Low Grade Coal Set to Hit Global Miners.” September 16, 2014. *Reuters.* http://www.ft.com/intl/cms/s/0/7b025356-3d3d-11e4-a2ab-00144feabdc0.html - axzz3G41onzAg

34 Duggan, Jennifer. “China Pledges to Cut Emissions at UN Climate Summit.” September 23, 2014. *The Guardian.* http://www.theguardian.com/environment/chinas-choice/2014/sep/24/china-pledges-to-cut-emissions-at-un-climate-summit

35 Martin, Richard. “China’s Great Coal Migration.” July 11, 2014. *Forbes.* http://fortune.com/2014/07/11/coal-china/

36 Energy Information Administration. “China Country Analysis.” February 2014. http://www.eia.gov/countries/cab.cfm?fips=ch

37 Luo, Tianyi; Otto, Betsy; and Maddocks, Andrew. “Majority of china’s Proposed Coal-Fired Power Plants Located in Water-Stressed Regions.” World Resources Institute. August 26, 2013. http://www.wri.org/blog/2013/08/majority-china’s-proposed-coal-fired-power-plants-located-water-stressed-regions

38 Greenpeace East Asia. “Thirsty Coal: A Water Crisis Exacerbated by China’s New Mega Coal Power Bases.” August 2012. Greenpeace. http://www.greenpeace.org/eastasia/publications/reports/climate-energy/2012/thirsty-coal-water-crisis/

39 Greenpeace East Asia. Ibid.

40 Greenpeace East Asia. Ibid. The Ministry of Water Resources has strictly controlled water allocations in the Yellow River Basin since the late 1990s when the river stopped flowing to the ocean for over 250 days each year.

41 Kalman, Jonathan. “Illegal Coal Mine Encroaching on Nature Reserve in North-West China.” August 6, 2014. *The Guardian.* http://www.theguardian.com/environment/2014/aug/07/illegal-coal-mine-nature-reserve-china; Greenpeace International. “World’s Biggest Coal Company Shenhua to Stop Exploiting Groundwater in China.” April 8, 2014. Greenpeace. http://www.greenpeace.org/international/en/press/releases/Worlds-biggest-coal-company-Shenhua-to-stop-exploiting-groundwater-in-China/

42 Schneider, Keith. “Double Choke Point: Demand for Energy Tests Water Supply and Economic Stability in China and the U.S.” June 22, 2011. Circle of Blue. http://www.circleofblue.org/waternews/2011/world/choke-point-china-us-comparison/

43 Schneider, Keith. “Bohai Sea Pipeline Could Open China’s Northern Coal Fields.” April 5, 2011. Circle of Blue. http://www.circleofblue.org/waternews/2011/world/desalinating-the-bohai-sea-transcontinental-pipeline-could-open-chinas-northern-coal-fields/

44 Chan, Wai-shin. “The Water Challenge Facing China’s Coal and Power Sector is ‘Inescapable’.” July 8, 2013. *Chinadialogue.* https://www.chinadialogue.net/article/show/single/en/6187-The-water-challenge-facing-China-s-coal-and-power-sector-is-inescapable-

45 Schneider, Keith. “Bohai Sea Pipeline Could Open China’s Northern Coal Fields.” April 5, 2011. Circle of Blue. http://www.circleofblue.org/waternews/2011/world/desalinating-the-bohai-sea-transcontinental-pipeline-could-open-chinas-northern-coal-fields/

46 China Census for Water. “Bulletin of First National Census for Water.” March 26, 2013. Chinese Ministry of Water Resources, and Chinese National Bureau of Statistics. http://www.mwr.gov.cn/2013pcgb/merge1.pdf

47 China Census for Water. Ibid.

48 U.S. Energy Information Administration. “China Country Analysis.” February 4, 2104. http://www.eia.gov/countries/cab.cfm?fips=CH

49 David Stanway. “China Falling Behind on 2020 Hydro Goals as Premier Urges New Dam Building.” March 10, 2014. *Reuters.* http://uk.reuters.com/article/2014/03/10/china-parliament-hydropower-idUKL3N0M70VN20140310

50 Ivanova, Nadya. “Rains bring relief for six-month China drought, but chronic water problems loom.” June 10, 2011. Circle of Blue. http://www.circleofblue.org/waternews/2011/world/rains-bring-relief-for-six-month-china-drought/

51 Ivanova, Nadya. Ibid.

52 Luan, Dong. “Rock, Metal, and Electronic: Yunnan’s Environmental Discord Between Mining, Aluminum, and Hydropower.” 2013. Wilson Center. http://www.wilsoncenter.org/sites/default/files/Rock, Metal %26 Electronic_1.pdf

53 Luan Dong (Ed.). “Clearing the Air: Is Natural Gas China’s Game Changer for Coal?” 2014. *Insight Out: Expert Voices on China’s Energy and Environmental Challenges. Issue 1*. Page 2. Woodrow Wilson Center.

54 Gass, Henry and ClimateWire. “China Push into Synthetic Natural Gas has Pollution Consequences.” *Scientific American.* October 2, 2013. http://www.scientificamerican.com/article/china-push-into-synthetic-natural-gas-has-pollution-consequences/

55 Liu, Coco and ClimateWire. “Can China’s Bid to Turn Coal to Gas Be Stopped?” October 29, 2014. *Scientific American.* http://www.scientificamerican.com/article/can-china-s-bid-to-turn-coal-to-gas-be-stopped/

56 Wall Street Journal, China Edition. “China’s Shale Gas Reserves Rank First in the World: Begin Mining or Disaster.” September 3, 2014. *Wall Street Journal.* http://wallstreetcn.com/node/207784

57 Vincent Tidwell, Interview by Susan Shifflett in Beijing, August 8, 2013.

58 Bloomberg News. “China Shale Boom Seen by Honghua as Pollution Cuts Coal Use.” *Bloomberg.* April 25, 2014. http://www.bloomberg.com/news/2014-04-25/china-shale-boom-seen-by-rig-maker-honghua-as-coal-use-recedes.html

59 Forbes, Sarah. “The United States and China: Moving Toward Responsible Shale Gas Development.” September 2013. Brookings Institution. http://www.brookings.edu/~/media/events/2014/2/06 china clean energy/uschina moving toward responsible shale gas development_sforbes.pdf

60 Accenture. “Water and Shale Gas Development: Leveraging the U.S. Experience in New Shale Developments.” 2012. Accenture. http://www.accenture.com/sitecollectiondocuments/pdf/accenture-water-and-shale-gas-development.pdf

61 Forbes, Sarah. “The United States and China: Moving Toward Responsible Shale Gas Development.” September 2013. Brookings Institution. http://www.brookings.edu/~/media/events/2014/2/06 china clean energy/uschina moving toward responsible shale gas development_sforbes.pdf

62 Veil, John; Puder, Markus; Elcock, Deborah; and Redweik, Robert. “A White Paper Describing Produced Water from Production of Crude Oil, Natural Gas, and Coal Bed Methane.” Prepared for the U.S. Department of Energy, Energy Technology Laboratory. January 2004. http://www.circleofblue.org/waternews/wp-content/uploads/2010/08/prodwaterpaper1.pdf

63 Marsters, Peter V. “A Revolution on the Horizon: The Potential of Shale Gas Development in China and its Impacts on Water Resources.” 2013. *China Environment Series,* Issue 12.

64 China Dialogue. “China’s Green Revolution: Energy, Environment, and the 12th Five Year Plan.” April 2011. https://www.chinadialogue.net/UserFiles/File/PDF_ebook001.pdf

65 China Dialogue. Ibid.

66 Zheng, Nina and Fridley, David. “Quenching China’s Thirst for Renewable Power: Water Footprint of Solar, Wind, and Hydro Development.” 2013. *China Environment Series,* Issue 12.

67 Zheng, Nina and Fridley, David. Ibid.

68 Zheng, Nina and Fridley, David. Ibid.

69 China Committee of Nuclear Power Operators. “2013 Annual Nuclear Power Operation Summary.” February 11, 2104. http://www.china-nea.cn/html/2014-02/28745.html

70 Zheng, Nina and Fridley, David. “Quenching China’s Thirst for Renewable Power: Water Footprint of Solar, Wind, and Hydro Development.” 2013. *China Environment Series,* Issue 12.

71 Ministry of Industry and Information Technology. “Limiting Factors and Investment Perspectives for 2014 Chinese CSP Industry.” March 31, 2014. http://cyzy.miit.gov.cn/node/4362

72 World Nuclear Association. “Nuclear Power in China.” October 2014. http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/China--Nuclear-Power/

73 Wald, Matthew L. “Heat Shuts Down a Coastal Reactor.” August 13, 2012. The New York Times. http://green.blogs.nytimes.com/2012/08/13/heat-shuts-down-a-coastal-reactor/

74 Reuters. “Nuclear, Coal Power Face Climate Change Risk-Study.” June 4, 2012. http://www.reuters.com/article/2012/06/04/climate-water-energy-idUSL3E8H41SO20120604

75 World Nuclear Association. “Nuclear Power in China.” September 30, 2014. http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/China--Nuclear-Power/

76 World Nuclear Association. Ibid.

77 Xinhua News. “National Energy Administration to Re-open Inland Nuclear Power Plants, Writing in the Next Five-Year Plan.” March 7, 2014. Xinhua http://news.xinhuanet.com/energy/2014-03/07/c_126233138.htm.

78 China Water-Energy Team exchange session at Chinese Academy of Environmental Planning. 2013, August 7.

79 Kahrl, Fredrich; and Roland-Holst, David. “China’s Water-Energy Nexus.” 2008. Water Policy. 1-16. http://are.berkeley.edu/~dwrh/Docs/Cn_H2O_Erg_KRH080109.pdf

80 Siddiqi, Afreen; and Anadon, Laura Diaz. “The Water-Energy Nexus in Middle East and North Africa.” Energy Policy. Belfer Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University. May 20, 2011. 39:4529-4540.

81 Copeland, Claudia. “Energy-Water Nexus: The Water Sector’s Energy Use.” Congressional Research Service. January 3, 2014. http://fas.org/sgp/crs/misc/R43200.pdf

82 Copeland, Claudia. Ibid.

83 Kuo, Lily. “China Has Launched the Largest Water-Pipeline Project in History.” March 7, 2014. The Atlantic. http://www.theatlantic.com/international/archive/2014/03/china-has-launched-the-largest-water-pipeline-project-in-history/284300/

84 Kuo, Lily. Ibid.

85 State Council of China. “South-to-North Water Diversion Project General Planning Summary.” Office of the South-to-North Water Diversion Project Commission of the State Council. http://www.nsbd.gov.cn/zx/gcgh/200308/t20030825_195165.html

86 Wong, Edward. "Plan for China's water crisis spurs concern." The New York Times. June 1, 2011. http://www.nytimes.com/2011/06/02/world/asia/02water.html

87 Wong, Edward. Ibid.

88 "Dirty Water From South to North." Caixin. February 24, 2014. http://magazine.caixin.com/2014-02-21/100641443.html

89 China Renewable Energy Engineering Institute. "The State, Challenges, and Solutions to China's Cross-Basin Water Transfer Projects." November 17, 2003. Beijing: Chinese Ministry of Water Resources. http://www.giwp.org.cn/upload/file/history/ 86 003-18.doc

90 Cohen-Tanugi, David. "A Pinch of Salt. Why China's Brute Force Push Toward Desalination May Leave the World Better Off." 2013. China Environment Series, Issue 12, pp. 32-34. http://www.wilsoncenter.org/sites/default/files/China Environment Series 12 Small_0.pdf

91 "State Oceanic Administration Released 2012 Report on National Seawater Utilization." Chinese Central People's Government. December 27, 2013. http://www.gov.cn/gzdt/2013-12/27/content_2555516.htm.

92 Cohen-Tanugi, David. "A Pinch of Salt. Why China's Brute Force Push Toward Desalination May Leave the World Better Off." 2013. China Environment Series, Issue 12, pp. 32-34. http://www.wilsoncenter.org/sites/default/files/China Environment Series 12 Small_0.pdf

93 Cooley, Heather. "Desalination and Energy Use…Should We Pass the Salt?" May 28, 2013. Pacific Institute. http://pacinst.org/desal-and-energy-use-should-we-pass-the-salt/

94 Pearce, G.K. "UF/MF Pre-treatment to RO in Seawater and Wastewater Reuse Applications: A Comparison of Energy Costs." May 2007. Desalination. 2008. 222: 66-73.

95 "CPC Representatives Discuss High Electricity Price in Seawater Desalination, Suggest Using Residential Price." January 19, 2014. People.cn. http://energy.people.com.cn/n/2014/0119/c71890-24161985.html

96 Xinhua News. "State Oceanic Administration: China seawater desalination price approaching global price, 5 to 8 yuan per ton." June 13, 2014. Xinhua. http://news.xinhuanet.com/energy/2014-06/13/c_1111131705.htm

97 David Cohen-Tanugi interview by Luan (Jonathan) Dong, June 24, 2014.

98 Wines, Michael. "China Takes a Loss to Get Ahead in the Business of Fresh Water." October 25, 2011. The New York Times. http://www.nytimes.com/2011/10/26/world/asia/china-takes-loss-to-get-ahead-in-desalination-industry.html?pagewanted=all.

99 "12th Five-Year Plan Sets Targets for Desalination." December 24, 2012. Xinhua News. http://news.xinhuanet.com/fortune/2012-12/24/c_124135979.htm

100 "Tianjin Desalinated Water to Provide Point-to-Point Supply." January 8, 2014. Xinhua News. http://news.xinhuanet.com/local/2014-01/08/c_118878844.htm

101 Branigan, Tania. "One-third of China's Yellow River 'Unfit for Drinking or Agriculture." November 25, 2008. The Guardian. http://www.theguardian.com/environment/2008/nov/25/water-china

102 Cohen-Tanugi, David. "A Pinch of Salt: Why China's Brute Force Push Toward Desalination May Leave the World a Better Place." 2013. Wilson Center. China Environment Series, 12.

103 Bao, Xiaodong. "Is Desalination's Spring Really Here?" March 19, 2012. Southern Weekly. http://www.infzm.com/content/64678

104 Hu, Feng; Tan, Debra; & Lazareva, Inna. "8 Facts on China's Wastewater." March 12, 2014. China Water Risk. http://chinawaterrisk.org/resources/analysis-reviews/8-facts-on-china-wastewater/

105 Yale University. "What's Behind the Numbers in China's Wastewater Treatment Plan." 2014. Environmental Performance Index. http://epi.yale.edu/the-metric/whats-behind-numbers-chinas-wastewater-treatment-plan

106 Yale University. Ibid.

107 Yale University. Ibid.

108 Alliance to Save Energy. "The Water Energy Nexus." August 12, 2013. https://www.ase.org/projects/watergy

109 Interview by Jennifer Turner of several mayors participating in a Georgetown University exchange program who visited the Wilson Center in Washington, DC on January 16, 2013.

110 Nanjiang Daily. "China Proposing 2 Trillion RMB Investment in Water Pollution Control Action Plan." June 11, 2014. http://www.njdaily.cn/2014/0611/860558.shtml

111 96 Meng, Yang. "The Damaging Truth About Chinese Fertilizer and Pesticide Use." July 9, 2012. Chinadialogue. https://www.chinadialogue.net/article/show/single/en/5153-The-damaging-truth-about-Chinese-fertiliser-and-pesticide-use

112 Li, Y., et al. "China's Water-Energy Nexus: Greenhouse Gas Emissions From Groundwater Use By Agriculture." 2012. Environmental Research Letters. http://www.tyndall.ac.uk/publications/journal-article/2012/china%E2%80%99s-water%E2%80%93energy-nexus-greenhouse-gas-emissions-groundwater

113 Wang, Jinxia; Rothausen, Sabrina; Conway, Declan; Zhang, Lijuan; Xiong, Wei; Holman, Ian; and Li, Yumin. "China's Water-Energy Nexus: Greenhouse Gas Emissions from Groundwater Use for Agriculture." Environmental Research Letters. 2012. http://iopscience.iop.org/1748-9326/7/1/014035/pdf/1748-9326_7_1_014035.pdf

114 Schneider, Keith. "Food supply, fracking, and water scarcity challenge China's juggernaut economy." October 17, 2012. Circle of Blue. http://www.circleofblue.org/waternews/2012/world/choke-point-china-ii-introduction/

115 World Bank DataBank. "World Development Indicators: Urban Population." 2014. http://databank.worldbank.org/data/views/reports/tableview.aspx

116 PBS Newshour. "Food for 9 Billion: Satisfying China's Growing Demand for Meat." November 13, 2012. PBS. http://www.pbs.org/newshour/bb/world-july-dec12-china_11-13/

117 Fred Gale from to Susan Chan Shifflett on July 22, 2014.

118 Christine Boyle email from to Susan Chan Shifflett and Jennifer Turner on July 28, 2014.

119 Schneider, Keith. "China's Other Looming Choke Point: Food Production." May 26, 2011. Circle of Blue. http://www.circleofblue.org/waternews/2011/world/chinas-other-looming-choke-point-food-production/; Ivanova, Nadya. "Water Rights Transfers and High-tech Power Plants Hold off Energy-Water Clash in Northern China." Circle of Blue. March 8, 2011. http://www.circleofblue.org/waternews/2011/world/from-agriculture-to-industry-efficiency-upgrades-transfer-water-use-rights-on-china's-yellow-river/

120 Anhui News. "China Focus: Central, North China Hurt By Drought." August 1, 2014. http://english.anhuinews.com/system/2014/08/01/006503164.shtml

121 Anhui News. Ibid.

122 Yu, M.; Wand, S.; Rothausen, D.; Conway, L.; Zhang, W.; Xiong, W.; and Holman, IP. "Are Droughts Becoming More Frequent or Severe in China Based on the Standardized Precipitation Evapotranspiration Index: 1951–2010?" International Journal of Climatology. 2013. 34: 545–558. http://www.tyndall.ac.uk/publications/journal-article/2012/china's-water–energy-nexus-greenhouse-gas-emissions-groundwater

123 Zhang, Moran. "Field of Dreams? Seven Reasons You Don't Want to be a Farmer in China." August 22, 2013. International Business Times. http://www.ibtimes.com/field-dreams-7-reasons-why-you-dont-want-be-farmer-china-1394965

124 Zuo, Changsheng. "Developments and Patterns of Trade in Agricultural Commodities Between China and Latin America." United Nations Food and Agriculture Organizations. http://www.fao.org/fileadmin/templates/tci/pdf/presentations/Zuo_Changshen_-Developments_and_patterns_of_trade.pdf

125 Kinver, Mark. "Growing Pains of China's Agricultural Water Needs." June 24, 2014. BBC News. http://www.bbc.com/news/science-environment-27978124

126 Yu, M.; Wand, S.; Rothausen, D.; Conway, L.; Zhang, W.; Xiong, W.; and Holman, IP. "Are Droughts Becoming More Frequent or Severe in China Based on the Standardized Precipitation Evapotranspiration Index: 1951–2010?" International Journal of Climatology. 2013. 34: 545–558. http://www.tyndall.ac.uk/publications/journal-article/2012/china's-water–energy-nexus-greenhouse-gas-emissions-groundwater

127 Wang, Jinxia. "China Water-Energy Nexus: Greenhouse Gas Emissions From Groundwater Use For Agriculture." March 14, 2012. Environmental Research Letters. http://m.iopscience.iop.org/1748-9326/7/1/014035/article

128 World Bank. "Urban China: Toward Efficient, Inclusive, and Sustainable Urbanization." July 2014. The World Bank and The Development Research Center of the People's Republic of China. P.345. https://openknowledge.worldbank.org/handle/10986/18865?hootPostID=7922558b9cdda4d2a2b1267dea350b11.

129 World Bank. "China: 1.3 million Farmers to Benefit from Increased Agricultural Water Productivity and Incomes." May 10, 2012. http://www.worldbank.org/en/news/press-release/2012/05/10/china-1300000-farmers-to-benefit-from-increased-agriculture-water-productivity-and-incomes

130 Huang, Qiuqiong; Rozelle, Scott; Lohmar, Bryan; Huang, Jikun; and Wang, Jinxia. "Irrigation, Agricultural Performance, and Poverty Reduction in China." Food Policy. 2006. 31: 30-52. http://www.sciencedirect.com/science/article/pii/S0306919205000485

131 United Nations Food and Agriculture Administration. "China." 2010. Aquastat. http://www.fao.org/nr/water/aquastat/countries_regions/china/index.stm

132 Marlow, Jeffrey. "Business Booming at Drip Irrigation Company." September 17, 2009. New York Times. http://green.blogs.nytimes.com/2009/09/17/business-booming-for-drip-irrigation-firm/

133 McGlade, J., Werner, B., Young, M., Matlock, M., Jefferies, D., Sonnemann, G., Aldaya, M., et al. "Measuring water use in a green economy, a report of the working group on water efficiency to the International Resource Panel." 2012. United Nations Environment Programme.

134 Water Footprint Network. "Product Gallery: Beef." 2012. http://www.waterfootprint.org/?page=files/productgallery

135 Wang, Jinxia, Jikun Huang, and Scott Rozelle. "Urbanization, Agricultural Water Use and Crop Production in China." 2013. World Bank and Development Research Center of the State Council, Center for Chinese Agricultural Policy. P.344 https://openknowledge.worldbank.org/handle/10986/18865?hootPostID=7922558b9cdda4d2a2b1267dea350b11

136 Duggan, Jennifer. "One Fifth of China's Farmland Polluted." April 18, 2014. The Guardian. http://www.theguardian.com/environment/chinas-choice/2014/apr/18/china-one-fifth-farmland-soil-pollution

137 Xie, Jian; Lieberthal, Andres; Warford, Jeremy; Dixon, John; Wang, Manchuan; Gao, Shiji; Wang, Shuilian, Jiang, Yong; and Zhong Ma. "Addressing China's Water Scarcity." 2009. The World Bank. http://www-wds.worldbank.org/external/default/WDSContentServer/IW3P/IB/2009/01/14/000333037_20090114011126/Rendered/PDF/471110PUB0CHA0101OFFICIAL0USE0ONLY1.pdf

138 Wang, Hongyi. "Food Safety Tops Public's Concerns." August 21, 2013. China Daily. http://usa.chinadaily.com.cn/china/2013-08/21/content_16909023.htm

139 Jing, Gong. "China's tainted rice trail." April 11, 2012. China Dialogue. https://www.chinadialogue.net/article/show/single/en/4197

140 Schneider, Mindi. "China's Pollution Census, Manure and Biogas." July 19, 2010. Institute for Agriculture and Trade Policy. http://www.iatp.org/blog/2010/07/chinas-pollution-census-manure-and-biogas and Levitt, Tom. "U.S. Style Intensive Farming Isn't the Solution to China's Meat Problem." March 3, 2014. The Guardian. http://www.theguardian.com/environment/blog/2014/mar/03/us-intensive-farming-chinas-meat-problem

141 Levitt, Tom. "U.S. Style Intensive Farming Isn't the Solution to China's Meat Problem." March 3, 2014. The Guardian. http://www.theguardian.com/environment/blog/2014/mar/03/us-intensive-farming-chinas-meat-problem

142 Levitt, Tom. Ibid.

143 Shifflett, Susan C. "Surf and Turf: The Environmental Impacts of China's Growing Appetite for Pork and Seafood." May 7, 2014. New Security Beat. http://www.newsecuritybeat.org/2014/05/surf-turf-environmental-impacts-chinas-growing-appetites/

144 Schneider, Keith. "Food Supply, Fracking, and Water Scarcity Challenge China's Juggernaut eEonomy." October 17, 2012. Circle of Blue. http://www.circleofblue.org/waternews/2012/world/choke-point-china-ii-introduction/

145 Buckley, Chris. "Rice Tainted With Cadmium is Discovered in Southern China." May 21, 2013. The New York Times. http://www.nytimes.com/2013/05/22/world/asia/cadmium-tainted-rice-discovered-in-southern-china.html?_r=0

146 He, Guangwei. "China Faces Losing Battle to Clean Up Its Polluted Soil." July 14, 2014. China Dialogue. https://www.chinadialogue.net/article/show/single/en/7079-China-faces-long-battle-to-clean-up-its-polluted-soil

147 Twilley, Nicola. "What do Chinese Dumplings Have to do with Global Warming?" The New York Times. July 25, 2014. http://www.nytimes.com/2014/07/27/magazine/what-do-chinese-dumplings-have-to-do-with-global-warming.html

148 United Nations Food and Agriculture Organization. "Policy Brief: The Case for Energy smart Food Systems." 2011. http://www.fao.org/docrep/014/i2456e/i2456e00.pdf

149 United Nations Food and Agriculture Organization. Ibid, page 7.

150 United Nations Food and Agriculture Organization. Ibid, page 20.

151 Fred Gale email to Susan Chan Shifflett on July 22, 2014.

152 Zhang, Junlian. "Barriers to Water Markets in the Heihe River Basin in Northwest China." Agricultural Water Management. August 1, 2006. 87:32-40.

153 Watts, Jonathan. "China Irrigation System Responsible for Rising Emissions, Research Shows." March 14, 2012. The Guardian. http://www.theguardian.com/environment/2012/mar/14/china-irrigation-emissions

154 Twilley, Nicola. "What Do Chinese Dumplings Have to Do With Global Warming?" July 25, 2014. The New York Times. http://www.nytimes.com/2014/07/27/magazine/what-do-chinese-dumplings-have-to-do-with-global-warming.html

155 Twilley, Nicola. Ibid.

156 United Nations Food and Agriculture Organization. "Policy Brief: The Case for Energy smart Food Systems." Page 15. 2011. http://www.fao.org/docrep/014/i2454e/i2454e00.pdf.

157 Mukherji, Biman. "Future of Energy Could Lie in Fuel from Agricultural Waste." July 4, 2014. The Wall Street Journal. http://blogs.wsj.com/moneybeat/2014/07/04/future-of-energy-could-lie-in-fuel-from-agricultural-waste/

158 Riedel, Michael. "Peoples Republic of China: Grain and Feed Annual." March 29, 2013. USDA. http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Beijing_China%20-%20Peoples%20Republic%20of_9-9-2013.pdf

159 Bogdanski, A.; Dubois, O.; and Chuluunbaatar, D. "Integrated Food-Energy Systems. Project Assessment in China and Vietnam." Page 13. 2010. Final Report. FAO. http://www.fao.org/energy/33467-0140d2e14b981e9923be4670c73e05c95.pdf.

160 Chang, Shiyan; Zhao, Lili; Timilsina, Govinda; and Zhang Xiliang. "Development of Biofuels in China: Technologies, Economies and Policies." October 2012. The World Bank. http://www-wds.worldbank.org/external/default/WDSContentServer/IW3P/IB/2012/10/17/000158349_20121017152604/Rendered/PDF/wps6243.pdf.

161 Lavelle, Marianne and Thomas Grose. "Water Demand for Energy to Double by 2035." Janurary 30, 2013. National Geographic News. http://news.nationalgeographic.com/news/energy/2013/01/130130-water-demand-for-energy-to-double-by-2035/

162 Food and Agriculture Organization. "Food Wastage Footprint: Impacts on Natural Resources." 2013. UN FAO. http://www.fao.org/docrep/018/i3347e/i3347e.pdf

163 FAO. Ibid.

164 Liu, Gang. "Food Losses and Food Waste in China: A First Estimate." June 15, 2013. Department of Energy and Process Engineering, Norwegian University of Science and Technology. Page 3. http://www.oecd.org/site/agrfcn/food%20losses%20and%20waste%20in%20china_gang%20liu.pdf

165 Liu, Gang. Ibid. Page 3.

166 Liu, Gang. Ibid. Page 11.

167 Marshall, Andrew. "China 'No Cash Cow': ANZ." July 5, 2014. The Land. http://www.theland.com.au/news/agriculture/agribusiness/general-news/china-no-cash-cow-anz/2703729.aspx

168 Department of Energy. "Department of Energy Releases Water-Energy Nexus Report." June 18, 2014. Energy.gov. http://www.energy.gov/articles/department-energy-releases-water-energy-nexus-report

169 U.S. Department of Energy. "Energy Demands on Water Resources—Report to Congress on the Interdependencies of Energy and Water." 2006. http://www.sandia.gov/energy-water/docs/121-RptToCongress-EWwEIAcomments-FINAL.pdf

170 U.S. Department of Energy. "The Water-Energy Nexus: Challenges and Opportunities." 2014. http://www.energy.gov/downloads/water-energy-nexus-challenges-and-opportunities

171 Thomas-Kerr, Elena. "Clean and Efficient Use of Energy and Water Resources – Initiating an APEC Road Map and Best Practices for the En-

ergy-Water Nexus." 2014. APEC. https://aimp2.apec.org/sites/PDB/Lists/Proposals/DispForm.aspx?ID=1561

172 149 The Great Lakes Commission. "Integrating Energy and Water Resources Decision Making in the Great Lakes Basin." October 2011. Great Lakes Water-Energy Nexus Team. http://glpf.org/sites/default/files/project_files/922 GLEW-Phase-I-Report-FINAL.pdf

173 Union of Concerned Scientists. "Freshwater Use by U.S. Power Plants: Electricity's Thirst for a Precious Resource." November 2011. http://www.ucsusa.org/clean_energy/our-energy-choices/energy-and-water-use/freshwater-use-by-us-power-plants.html

174 Vox Global and Pacific Institute. "Bridging Concern With Action: Are U.S. Companies Prepared for Looming Water Challenges?" April 2014. http://voxglobal.com/wp-content/uploads/Water_Study_Executive_Summary__2014-04-12.pdf

175 Desai, Snehal. "The Sustainability Challenge: Meeting the Needs of the Water-Energy Nexus." June 2013. Dow Chemical. http://msdssearch.dow.com/PublishedLiteratureDOWCOM/dh_08d7/0901b803808d7f4b.pdf?filepath=liquidseps/pdfs/noreg/609-02232.pdf&fromPage=GetDoc

176 Gerholdt, Jennifer. "How Dow Chemical Ingrained Sustainability into the Company's DNA." June 3, 2014. U.S. Chamber of Commerce Foundation. http://www.uschamberfoundation.org/blog/post/how-dow-chemical-ingrained-sustainability-companys-dna/31788

177 CSR Wire. "GE Announces Expansion of Water Scarcity Relief Efforts in Africa; GE Water Scarcity Solutions Creating Critical Supplies of Fresh Water." October 4, 2005. http://www.csrwire.com/press_releases/25674-GE-Announces-Expansion-of-Water-Scarcity-Relief-Efforts-in-Africa-GE-Water-Scarcity-Solutions-Creating-Critical-Supplies-of-Fresh-Water

178 Vox Global and Pacific Institute. "Bridging Concern with Action: Are U.S. Companies Prepared for Looming Water Challenges." April 2014. http://voxglobal.com/wp-content/uploads/Bridging-Concern-with-Action-Are-US-Companies-Prepared-For-Looming-Water-Challenges_v14.pdf

179 Schneider, Keith. "China takes a keen interest in water-energy connections." August 12, 2013. Circle of Blue. http://www.circleofblue.org/waternews/2013/cob/choke-point-china-2/china-takes-a-keen-interest-in-water-energy-connections/

180 The Ministry of Water Resources of the People's Republic of China. "2012 China Water Resources Bulletin." December 15, 2013. http://www.mwr.gov.cn/zwzc/hygb/szygb/qgszygb/201405/t20140513_560838.html

181 Cooley, Heather; Fulton, Julian; and Peter Gleick. "Water for Energy: Future Water Needs for Electricity in the Intermountain West." November 3, 2011. Pacific Institute. http://pacinst.org/publication/water-for-energy-future-water-needs-for-electricity-in-the-intermountain-west/

182 Wolff, Gary; Cohen, Ronnie; and Berry Nelson. "Energy Down the Drain: The Hidden Costs of California's Water Supply." August 24, 2004. Pacific Institute. http://pacinst.org/publication/energy-down-the-drain-the-hidden-costs-of-californias-water-supply/

183 WECalc. "Your Home Water-Energy-Climate Calculator." 2010. Pacific Institute. http://www.wecalc.org/

184 Bhatt, Vatsal; Friley, Paul; and Lee, John. "Integrated Energy and Environment Systems Analysis Methodology for Achieving Low Carbon Cities, Journal of Renewable and Sustainable Energy, of the American Institute of Physics." *Renewable Sustainable Energy.* 2010.

185 Spegele, Brian and Kazer, William. "To Conserve Water, China Raises Prices for Top Users." January 8, 2014. *Wall Street Journal.* http://online.wsj.com/articles/SB10001424052702303870704579297410328066466

186 Larson, Christina. "China Begins to Get Serious About Water Conservation." January 2014. Wilson Center, China Environment Forum. http://www.wilsoncenter.org/sites/default/files/Christina Larson_Water Conservation_0.pdf

187 Lewis, Joanna. "Energy and Climate Goals of China's 12th Five Year Plan." March 201. Center for Climate and Energy Solutions. http://www.c2es.org/international/key-country-policies/china/energy-climate-goals-twelfth-five-year-plan

188 Cooley, Heather; Donnely, Kristina, and Ajami, Newsha. "Energizing Water Efficiency in California: Applying Energy Efficiency Strategies to Water." December 2013. Pacific Institute. http://pacinst.org/wp-content/uploads/sites/21/2013/12/energizing-water-efficiency-pacinst.pdf

189 Gu, Alun; Teng, Fei; Wang, Yu; and Liu, Mingming. "Evaluation of the Water Saving Effect of China's National Energy Conservation Policy." 2013. Natural Resources Defense Council and Institute of Energy, Environment and Economy, Tsinghua University.

190 Spegele, Brian and Kazer, William. "To Conserve Water, China Raises Prices for Top Users." January 8, 2014. *Wall Street Journal.* http://online.wsj.com/articles/SB10001424052702303870704579297410328066466

191 Duggan, Jennifer. "Sales of Shark Fin in China Drop by Up to 70%." August 7, 2014. *The Guardian.* http://www.theguardian.com/environment/chinas-choice/2014/aug/08/sales-of-shark-fin-china-drop-70

192 Walton, Brett. "U.S.-China Climate Deal Includes Provision on Water-Energy Nexus." November 13, 2014. Circle of Blue. http://www.circleofblue.org/waternews/2014/world/u-s-china-climate-deal-includes-provision-water-energy-research/

193 Zhang, Chao; and Anadon, Laura. "A Multi-Regional Input-output Analysis of Domestic Virtual Water Trade and Provincial Water Footprint in China." *Ecological Economics*. April 2014. 100:159-172. http://www.sciencedirect.com/science/article/pii/S0921800914000421; Guan, Dabo and Hubacek, Klaus. " Assessment of Regional Trade and Virtual Water Flows in China." *Ecological Economics*. February 2007. 61:159-170. http://www.sciencedirect.com/science/article/pii/S0921800906000930; Feng, Kuishuang; Hubacek, Klaus; Pfister, Stephan; Yu, Yang; and Sun, Laixiang. "Virtual Scarce Water in China." *Environmental Science and Technology*. 2014. 48(14):7704-7713. http://pubs.acs.org/doi/abs/10.1021/es500502q; Dalin, Carole; Hanasaki, Naota; Qiu, Huanguang; Mauzerall, Denise; and Rodriguez-Iturbe, Ignacio. "Water Resources Transfers Through

Chinese Interprovincial and Foreign Food Trade." *PNAS*. 111(27): 9774-9779. http://www.pnas.org/content/111/27/9774; Guan, Dabo and Hubacek, Klaus. "Assessment of Regional Trade and Virtual Water Flows in China." *Ecological Economics*. February 2007. 61(1):159-170. http://www.sciencedirect.com/science/article/pii/S0921800906000930 ; Wildau, Gabriel. "Small Chinese Cities Steer Away from GDP as a Measure of Success." August 13, 2014. *Financial Times.* http://www.ft.com/intl/cms/s/0/a0288bd4-22b0-11e4-8dae-00144feabdc0.html?siteedition=intl#axzz3A3WRY9It ; "Pay for Public Transit Pass or Phone Card With Recycling." August 17, 2014. *Pangea Today.* http://www.pangeatoday.com/get-free-public-transit-pass-or-phone-rebate-for-recycling/

194 Zhang, Qingtao; Xia, Qing; Liu, Clark; and Geng, Shu. "Technologies for Efficient Use of Irrigation Water and Energy in Chiana" August 2013. Journal of Integrative Agriculture. 12(8):1363-1370. http://www.sciencedirect.com/science/article/pii/S2095311913605444

195 Zerrenner, Kate. "Energy-Water Nexus Spans Across Western United States." August 22, 2013. *Forbes.* http://www.forbes.com/sites/edfenergyexchange/2013/08/22/energy-water-nexus-spans-across-western-united-states/

196 ACEEE. "Watts to Water: Tap the Power." http://www.wattstowater.org/

197 China Water-Energy Team exchange session at SynTao Co., Ltd. August 5, 2013.

198 Bhatt, V. and Ginsberg, M. "Metro Solutions to Macro Visions: Partnerships between US-China-India Cities Promote Efficient, Green Futures, Proceedings of the ACEEE 2010 Summer Study." August 15–20, 2010. The 15th Biennial ACEEE Conference on Energy Efficiency in Buildings.

199 For more information on this or other sub-national partnerships, see: https://ecopartnerships.lbl.gov//

200 World Economic Forum. "Water Security: The Water-Food-Energy-Climate Nexus." 2011. http://www.weforum.org/reports/water-security-water-energy-food-climate-nexus

201 Shifflett, Susan C. "Surf and Turf: The Environmental Impacts of China's Growing Appetite for Pork and Seafood." May 7, 2014. *New Security Beat.* http://www.newsecuritybeat.org/2014/05/surf-turf-environmental-impacts-chinas-growing-appetites/

202 Tan, Debra. "No Water No Power: Is There Enough Water to Fuel China's Power Expansion?" October 2012. *China Water Risk.* http://chinawaterrisk.org/resources/analysis-reviews/china-no-water-no-power/

203 Zhou, Yuanchun; Zhang, Bing; Wang, Haikun; and Bi, Jun. "Drops of Energy: Conserving Urban Water to Reduce Greenhouse Gas Emissions." *Environmental Science and Technology.* June 11, 2013. http://pubs.acs.org/doi/abs/10.1021/es304816h

204 Shenhua Science and Technology Institute "Cornerstone: The Official Journal of the World Coal Industry's Special Issue on Reducing Energy's Water Footprint." Spring 2014. 2(1). http://www.nxtbook.com/nxtbooks/wiley/cornerstone_2014spring/#/10

205 Ganter, J. Carl. "Q&A: Ma Jun on China's Economic Development and Water Resources." April 11, 2011. Circle of Blue. http://www.circleofblue.org/waternews/2011/world/qa-ma-jun-on-chinas-economic-development-and-water-resources/

206 Ivanoca, Nadya. "Off the Deep End: Beijing's Water Demand Outpaces Supply Despite Conservation, Recycling, and Imports." May 3, 2011. Circle of Blue. http://www.circleofblue.org/waternews/2011/world/off-the-deep-end-beijings-water-demand-outnumbers-supply-despite-conservation-recycling-and-imports/

207 Schneider, Keith. "Bohai Sea Pipeline Could Open China's Northern Coal Fields." April 5, 2011. Circle of Blue. http://www.circleofblue.org/waternews/2011/world/desalinating-the-bohai-sea-transcontinental-pipeline-could-open-chinas-northern-coal-fields/

208 Schneider, Keith. Ibid.

209 Ivanoca, Nadya. "Off the Deep End—Beijing's Water Demand Outpaces Supply Despite Conservation, Recycling, and Imports." May 3, 2011. Circle of Blue. http://www.circleofblue.org/waternews/2011/world/off-the-deep-end-beijings-water-demand-outnumbers-supply-despite-conservation-recycling-and-imports/

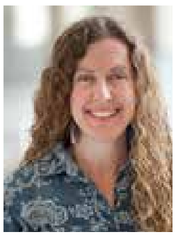
210 Schneider, Keith. "Bohai Sea Pipeline Could Open China's Northern Coal Fields." April 5, 2011. *China Environment Series 12*.

211 Ivanova, Nadya. "Off the Deep End: Beijing's Water Demand Outpaces Supply Despite Conservation, Recycling, and Imports." May 3, 2011. Circle of Blue. http://www.circleofblue.org/waternews/2011/world/off-the-deep-end-beijings-water-demand-outnumbers-supply-despite-conservation-recycling-and-imports/

212 Hite, Brittany. "Beijing Now Has Almost As Many People As Australia." June 19, 2014. *Wall Street* Journal. http://blogs.wsj.com/chinarealtime/2014/06/19/beijing-now-has-almost-as-many-people-as-australia/ and Schneider, Keith. "Building China's 21st-Century Megacity: Shanghai's Experiment with Water and Nature." September 30, 2011. Circle of Blue. www.circleofblue.org/waternews/2011/world/manmade-lake-and-nature-preserve-at-center-of-new-shanghai-borough/

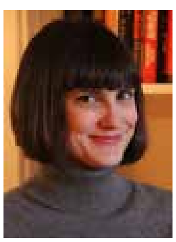
Roadmap Authors

Susan Chan Shifflett is program associate at the Wilson Center's China Environment Forum where she focuses on China's food safety and food security. She previously interned at the U.S. Department of State's Office of Global Food Security, working on the Feed The Future initiative. From 2007-2010, she lived in Beijing where she worked as a program assistant at China's Center of Disease Control and Prevention researching high-risk HIV/AIDS populations in Yunnan Province. Susan received an M.A. in International Economics from Johns Hopkins University's School of Advanced International Studies and a B.S. in Biology from Yale University.



Jennifer L. Turner has been the director of the China Environment Forum at the Woodrow Wilson Center for 15 years where she creates meetings, exchanges and publications focused on a variety of energy and environmental challenges facing China. Water-energy nexus challenges and environmental civil society are at the heart of her current research interests. She received a Ph.D. in Public Policy and Comparative Politics in 1997 from Indiana University, Bloomington where she examined local government innovation in implementing water policies in China.

Luan "Jonathan" Dong is a project assistant at the Natural Resources Defense Council office in Beijing where he works on their Coal Cap project. From January 2013 to July 2014 he was a research assistant and consultant for the Wilson Center's China Environment Forum. Jonathan also worked as the Global Warming Research Assistant at Greenpeace in Washington DC and as a research assistant for the Institute of Public and Environmental Affairs in Beijing. He completed a Master's in International Affairs and Sustainable Development at George Washington University in 2013.



Ilaria Mazzocco is a research assistant at the Woodrow Wilson Center's China Environment Forum and a program associate at the SAIS China Africa Research Initiative. She is currently pursuing an M.A. in International Relations and International Economics at the Johns Hopkins School of Advanced International Studies. Previously she worked at the Asia Society in New York City and was a research fellow at the Global Environmental Institute in Beijing. She holds a Master's in International Relations and European Studies from Central European University in Hungary and a B.A. from Bard College.

Bai Yunwen is the co-founder and the deputy director of Greenovation Hub where she leads the Climate and Finance Policy Centre. Her research focuses on international financial flows, climate and energy policy and financing schemes. She leads Greenovation Hub's evidence-based research and policy analysis, which aims to influence debates to accelerate China's green development. She has over 10 years of experience working with international NGOs and foundations on climate issues. She also serves on the board of the China Climate Action Network. Yunwen holds MSc degrees in Environmental Science and Environmental Policy & Management.

Wilson Center

One Woodrow Wilson Plaza
1300 Pennsylvania Avenue, N.W.
Washington, DC 20004-3027

www.wilsoncenter.org/cef
cef@wilsoncenter.org
facebook.com/chinaenvironmentforum
@WilsonCEF
202.691.4000