CHINA

Travis Clayton | Spencer Jones | Katy Wang
Edited by: Sarang Shidore

Supervised by: Dr. Joshua Busby
http://blogs.utexas.edu/mecc/

Major Economies and Climate Change Research Group

ACRONYMS AND ABBREVIATIONS

BAU	Business as Usual
BOF	Basic Oxygen Furnace
CCS	Carbon Capture and Sequestration
CO2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
EAF	Electric Arc Furnace
EIA	Energy Information Administration
EPL	Environment Protection Law
FERC	Federal Energy Regulatory Committee
FYP	Five-Year Plan
GDP	Gross Domestic Product
GHG	greenhouse gases
$GtCO_2e$	Giga tonnes of CO2 equivalent
GW	Gigawatt (of electricity)
HELE	High-efficiency, Low-emission Technology
IEA	International Energy Agency
JICA	Japan International Cooperation Agency
LNG	Liquefied Natural Gas
MEP	Ministry of Environmental Protection, People's Republic of China
MMBTU	One Million British Thermal Unit
$MtCO_2e$	Metric tonnes of CO2 equivalent
MW	Megawatt (of electricity)
NDRC	National Development and Reform Commission
NH_3	Ammonia
NO	Nitrogen Oxide
OECD	Organization for Economic Cooperation and Development
SO_2	Sulfur Dioxide
SOE	State-Owned Enterprise

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EXECUTIVE SUMMARY

China has overtaken the United States with respect to greenhouse gas emissions (GHG). GHG emissions have been driven by economic and industrial growth, which have historically relied heavily on fossil fuels to meet energy demands. Despite serious efforts that have been made to shift the energy mix in favor of non-fossil fuels, as of 2011, China still requires 50% higher energy intensity than the US. China's proportion of global GHG emissions is projected to rise from 17% in 2005 to 26% in 2030, reaching 16.664 $GtCO_2e$. China must continue its current emissions mitigation efforts, but it must also take further action in line with a 2 degrees Celsius warming scenario.

CHINA'S COAL DEPENDENCY WILL PERSIST AS IMPORTANT ENERGY SOURCE

- Coal will likely remain the primary fuel source for China's energy production. Dealing with the emissions associated with coal will prove vital to China's internal security as well as its ability to generate sustainable economic growth. As China continues to develop, its citizens will increasingly demand government policy to mitigate pollution and the negative health externalities associated with coal-intensive power production.
- The leadership in China has not set up the necessary regulatory framework for encouraging development of carbon capture and sequestration (CCS) or the deployment of high-efficiency low-emission (HELE) coal plants.
- HELE coal generation technology in the medium-term will help to reduce emissions in pursuit while CCS technology becomes commercially feasible.

THE SHALE GAS REVOLUTION NEEDS ASSISTANCE TO TAKE OFF GLOBALLY

- Currently, the US and Canada are the only countries that commercially extract domestic shale gas, which is ultimately driving the natural gas transition in these countries.
- China possesses large natural gas reserves but currently lacks the infrastructure and regulatory framework to take advantage of it. In the short-term, China will continue to burn domestic coal in order to meet its growing demands for electricity.

INDUSTRIAL STRUCTURE REQUIRES REFORM

- The iron and steel industry poses the greatest source of emissions abatement within energy efficiency. Managing China's enormous steel output must be seen in the context of lower carbon emissions and national stability, as the industry employs a significant number of the Chinese population. As urbanization increases, action must be taken to lock-in high efficiency steel technologies.
- China currently plans to reduce iron and steel overproduction while raising energy intensity targets; however, regulatory overlap, iron ore and coke imports, industry employment, and financial risk can stymie government action in this area.

RECOMMENDATIONS

ENERGY PRODUCTION

- **Policymakers in China should enact clearer regulatory guidelines around the implementation of CCS technology.** This will assure that investors and firms making investments in CCS technology will face more certainty with respect to their potential returns, legal liability, and land use rights. Regulatory certainty will help to speed the development of the technology from current levels of limited deployment and testing towards a mature and practical solution.
- **Policymakers should move towards limiting CO_2 emissions in an effort to spur the adoption of high-efficiency low-emission technology in new coal generation.** This includes increasing supercritical generation capacity while further developing ultra-supercritical and advanced ultra-supercritical technologies. Phasing out legacy, less-efficient coal plants will play a crucial role in reducing emissions. Access to finance to support cleaner coal may be an issue.
- **Continued investment and development of carbon capture and sequestration technology could provide long-term mitigation of carbon emissions from coal-generated electricity.** Further investment will help to speed the development of the technology from its current levels of limited deployment and testing towards a mature and practical solution.
- **The Chinese government should relax rigid electricity market structures that reduce incentives to invest in renewable technologies**. Long-term contracts lock different regions into selling at fixed prices, often at a loss, thus discouraging investment in renewables capacity.

INDUSTRY

- **Adopt scrap steel collection programs and Electric Arc Furnace (EAF) subsidies.** Incentivize greater scrap steel collection and increase adoption of less carbon intense EAF technology instead of the traditional Basic Oxygen Furnace (BOF).
- **Create domestic energy efficiency programs.** Chinese adoption of an energy efficiency program will help smaller sized firms evaluate performance, energy efficient management, and forecast energy demand, facilitating adoption of capital intensive investments.
- **Expand the availability of emissions data.** Access to Chinese industrial level emissions data by international firms can ease joint venture partnerships and the transfer of technologies to less energy efficient firms.
- **Develop local natural gas resources.** Iron reduction can be done through natural gas as a reducing agent, rather than the more CO_2 intensive coking coal.
- **Engage in multilateral and bilateral technology programs.** Further consolidation of international energy efficiency programs that China is a part of can transform foreign assistance into iron and steel emissions reduction projects.

CHINA

A discussion of anthropogenic carbon emissions and future mitigation is not complete without including China. Since 2000, energy-related GHG emissions have increased at an average rate of 10 percent per year.[1] According to the McKinsey Climate Desk projections of business-as-usual (BAU) emissions, China's proportion of global greenhouse gas (GHG) emissions will rise from 17% in 2005 to 26% in 2030, reaching projected annual GHG emissions of 16.664 $GtCO_2e$.[2] Although reports vary when exactly this happened, there is a general consensus that China surpassed the US to become the largest aggregate emitter of carbon dioxide (CO_2) emissions in the mid-2000s.[3]

Figure 1: China's Proportion of Global GHG Emissions

	2005 emissions ($GtCO_2e$)	% Global	2030 BAU Projections ($GtCO_2e$)	% Global	% Change
China	7.519	17%	16.664	26%	+55%
USA	6.599	15%	7.289	11%	+9%

Source: McKinsey Climate Desk, 2009[4]

Historically, GHG emissions were driven by economic and industrial growth, which relied heavily on fossil fuels to meet energy demands. Although serious efforts have been made to shift the energy mix in favor of non-fossil fuels, nonetheless as of 2011, China still requires 50% more energy to produce one unit of gross domestic product (GDP) than the US, i.e. it still has a high energy intensity.[5] Economically, China has enjoyed tremendous success, surpassing Japan as the world's second largest economy in 2010.[6]

However, the tremendous growth has not come without costs. A World Bank study estimates 750,000 people die in China every year, as a result of burning coal.[7] Recent cases of Chinese cities shrouded in dangerous levels of air quality, appropriately deemed the "airpocalypse" have been a key driving force behind the domestic push for GHG emission mitigation. On April 24, 2014, the Standing Committee of China's National People's Congress (NPC) voted to approve amendments to China's Environmental Protection Law (EPL). The 20 new articles have three major implications: 1) China will add a new penalty system that fines municipalities based on days accumulated of pollution (compared to the current one-off fine); 2) China will implement a performance-based assessment system on officials' environment protection track record (compared to the current system based on economic growth); and 3) China will allow nongovernmental organizations to take legal action against polluters on behalf of the public.[8] The amendments provided the Ministry of Environmental Protection (MEP) with greater legal

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[1] Chow, 2013.
[2] McKinsey and Company, 2009b.
[3] Burnett, Fletcher and Zhao, 2013.
[4] McKinsey Climate Desk and Company, 2009b.
[5] Leggett, 2011.
[6] Hamlin and Li, 2010.
[7] Goldenberg, 2014.
[8] Finamore, 2014.

authority in regulating and issuing fines. The new EPL will take effect on January 1, 2015 – promising greater transparency and incentives for change; the amendment is an encouraging exhibition of political willingness for change.

Reducing GHG emissions is now a priority for Chinese policymakers, a pursuit that it sees as serving its own national interest. China's leaders are "increasingly acknowledging that climate change is real … and that it poses a significant threat to the country's long-term prosperity in terms of already observable droughts, declining crop yields, damage from rising sea levels, floods, and increased extreme weather events."[9] In a meeting with US secretary of State John Kerry, President Xi Jinping pointed out "China is making progress not at the others' demand but [because of] our own will."[10]

Public health is emerging as the top driver for China's growing willingness on climate action. On March 5th, 2014, to mark the beginning of China's National People's Congress, the Prime Minister, Li Keqiang, declared the central government's commitment to reduce levels of air pollution. He advocated for a "war on pollution" that would "fight pollution with the same determination" with which the government fought poverty.[11] While he omitted the fact that China's coal consumption continues to grow, he did reference the components of the State Council's ten-point plan as an indication of dedication towards improving air quality. The Ten-Point Plan, or the "The State Council Action Plan on Prevention and Control of Air Pollution" presents a set of state-led and market-driven mechanisms for reducing particulate levels 10% from 2012-2017.[12] While much of the language is vague and details of the plans remain undefined, the plan represents a significant step of the Central Government towards dealing with air pollution in China. In its specifics, the plan also demonstrates the challenges that the Central Government will face achieving its goals. The plan's includes the following components relevant to climate:

1. *Reduce multi-pollutant emissions*. This includes heavy industry, energy production, and transport and aims to reduce sulfur and nitrogen emissions. This component includes solutions ranging from reducing the number of inefficient coal power plants to dealing with urban traffic pollution through better transport systems and higher quality fuels.
2. *Modify industrial structure*. This component includes reducing overcapacity as well as reducing the level of "backwards" and inefficient production in high-polluting industries. This also includes limiting new investment projects to higher levels of efficiency in both capacity and emissions and terminating illegal investment projects that violate current laws. This will require coordination and cooperation from local governments.
3. *Encourage enterprise transformation and technological innovation*. The government will encourage scientific and technological research in both mitigating air pollution as well as monitoring pollution levels. Policies will encourage industry best practices to reduce inefficiencies and reduce pollution levels as well as spur further innovation into lowering industrial pollution.

[9] Schoen, 2013.
[10] Tiezzi, 2014.
[11] The Economist, 2014.
[12] MEP, 2013.

4. *Speed the shift towards a cleaner energy mix.* This requires reducing total coal consumption through raising external transmission by shifting to natural gas and other non-fossil fuel energy sources as well as limiting the emissions from coal-generation.
5. *Improve legal and supervisory standards to enforce existing laws.* This includes periodic provincial-level reporting of both the ten worst and ten best air quality levels through public disclosure.
6. *Establish regional policy mechanisms for environmental governance.* These policy bodies will work at the regional level to coordinate solutions to major environmental problems, enforcement of environmental laws, information sharing, and pollution control and early warning systems.
7. *Establish an early warning system to help the management of extreme pollution conditions.* This warning system should establish a threshold based on weather conditions for contingency plans to guide public behavior to limit the health effects of the pollution.

Given the level of pollution in many urban areas around China and the growing demand for action among the people of China, circumstances may force the leadership's hands into meaningful action.

In addition to these salient issues of air pollution and human health, China also sees other co-benefits to climate action, including:

1. **Economic Competitiveness:** Developing the clean energy industry presents great opportunities for economic competitiveness. Great strides in both wind and solar energy technology in recent years illustrate their competitiveness in the global market. A study on green jobs in China projects the solar and wind energy industries will create 6,680 and 34,000 jobs annually between 2011 and 2020.[13]

2. **Economic Rebalancing:** Focusing on the environment as a priority aligns with the shift from manufacturing to service-oriented industries.

3. **Energy Security:** Developing clean energy provides greater energy security and less reliance on finite resources or imports. Under current consumption patterns, China's oil import requirements are projected to double from 2014 levels, account for 75% of demand and surpass peak US import levels by 2029.[14]

4. **Political Legitimacy:** The political leadership views environmental considerations as an opportunity to increase the legitimacy of the Chinese Communist Party.

5. **International Leadership:** China has long desired to be seen as a leader among developing nations, environmental issues provide this opportunity to be seen as a leader in the international community.

Understanding these co-benefits to reducing GHG emissions can help open dialogue and create greater incentives to adopt mitigation strategies.

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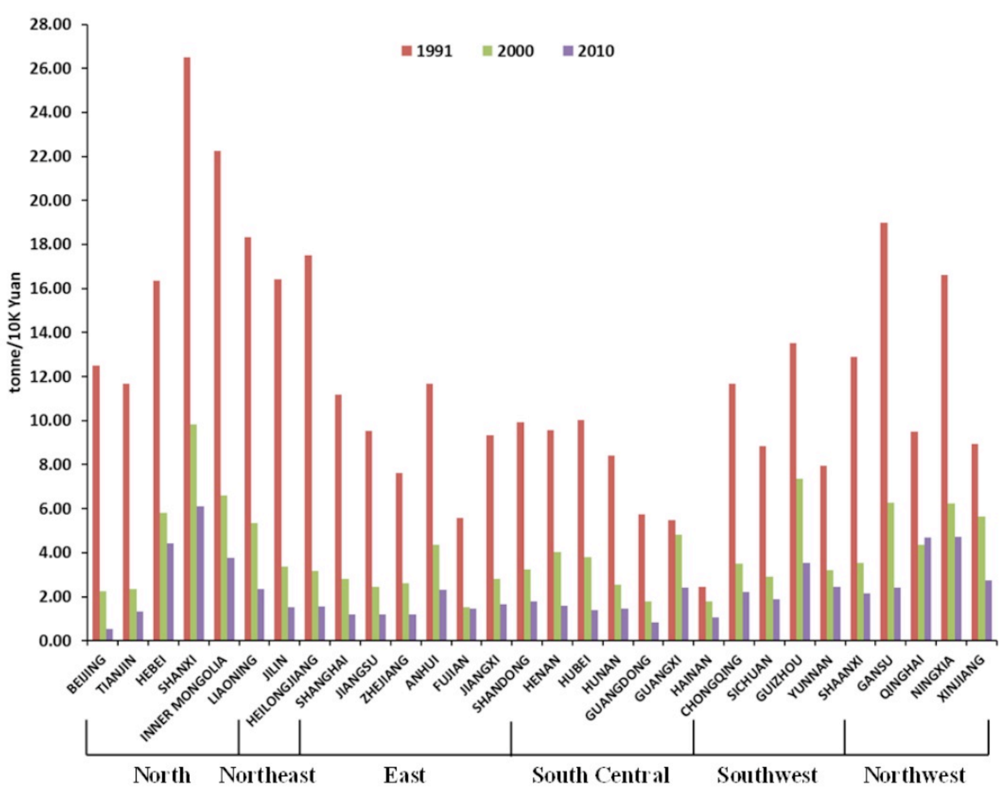
[13] Pan et al., 2011.
[14] BP, 2014.

The income gap between eastern and western provinces poses a significant challenge for abating future greenhouse gas emissions. In recent years, development has largely centered on the eastern border, with wealth levels lowering as one moves to the central and western provinces.[15] As policies are being implemented to shift industries to the west and raise standards of living, China could face a surge in GHG emissions. By 2030, *The Economist* projects 1 billion Chinese, or 70 percent of the population, will live in urban centers compared to 50 percent in 2014. This presents a great challenge to the cause. In an effort to spread out the growth, Beijing has plans to move upwards of 5 million residents to neighboring Hebei Province, aiming to cap population to 18 million by 2020.[16]

As Figure 2 illustrates, northern and northeastern provinces have the highest share of GHG emissions. However, time series analysis reveals that the gap is closing. While in 1991 the difference was significant, we are now seeing some northwestern provinces; particularly Gansu, Liaoning, Ningxia and Xinjiang emission levels are on par with Shaanxi province (the historically highest emitter of GHG).

Any plans to reduce GHG emissions must take these trends into consideration. Opportunities lie in learning from the experiences from the east and establishing less polluting plants, more efficient buildings and greater public education to counter the potentially disastrous effects of emissions potential.

Figure 1: Time Lapse of GHG Emissions, by Province, 1991-2010



Source: Paper for Agricultural & Applied Economics Association, 2013[17]

[15] Schiavenza, 2013.
[16] Stanway, 2014.
[17] Burnett, Fletcher and Zhao, 2013.

PROGRESS AND IMPACT OF THE 12TH FIVE-YEAR PLAN[18]

Chinese policy centers on its five-year plans (FYP), which detail economic development guidelines for all provinces. Devised during the Communist Party's plenary sessions of the Central Committee and the National People's Congress, the FYPs detail the social and economic initiatives to shape the economy. While the last few FYPs emphasis was put on investment-driven growth, the most recent iteration, the 12th FYP (2011 – 2015), shifts emphasis to sustainable growth, industrial upgrading and the promotion of domestic consumption. Priority sectors include energy, automotive, IT infrastructure and biotechnology. It is also the first FYP to introduce binding emission targets to reduce carbon intensity to 17% below 2010 levels by 2015.

Progress to meeting targets has been mixed. Greater strides are being made in providing for energy supply than in reducing energy consumption and raising efficiency. Emphasis has been placed on diversifying energy production through investments in solar, wind, coal, oil and hydropower generation. The most promising appears to be wind power; China is set to meet and perhaps exceed its installation targets. Fuel switching targets are also included in the 12th FYP; details of developments in natural gas and shale gas are discussed in the following energy sector discussion. Recent events have also prompted the government to add additional targets, including reducing average levels of PM2.5 particulates in 47 cities by five percent based on 2010 levels before 2015.

However, more must be done to meet efficiency standards, focusing on demand-related targets. Reports reveal that under current consumption behavior, "it seems likely that without draconian measures – such as planned blackouts in peak summer months,"[19] energy intensity targets will not be met. As China is a "cross the river by feeling the stones" country, often employing pilot programs to test new strategies and policies before deciding whether to scale-up, such drastic measures are unlikely in the short term.

RATIONALE

Despite already possessing a high proportion of global anthropogenic carbon emissions, China's greenhouse gas emissions are expected to rise dramatically in the next twenty years, until at least 2030 while other more developed countries' emissions are expected to decline.[20]

[18] China Greentech Initiative, 2013.
[19] Ibid.
[20] Leggett, 2011.

Figure 2: GHG Emission Projections ($GtCO_2e$)

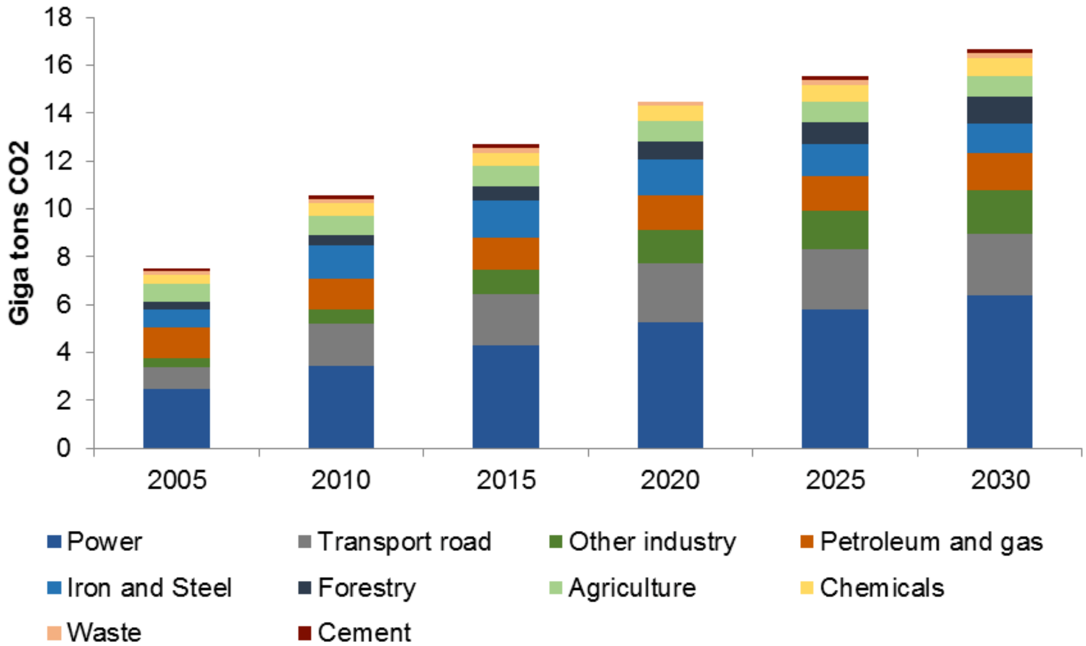
	2005	2010	2015	2020	2025	2030
Business as Usual	7.519	10.55	12.700	14.686	15.560	16.664
Full Technical Potential	7.519	10.55	10.684	11.039	9.647	7.523
Abatement ($GtCO_2e$)			2.016	3.647	5.913	9.141

Source: McKinsey Climate Desk, 2009[21]

Slicing BAU projections by sector reveals that the source of these greenhouse gas emissions increases will continue to be dominated by the energy, industry (particularly iron and steel) and transport road sectors, accounting for 48 percent, 18 percent and 15 percent of BAU projections in 2030 (refer to Figure 4 below). As such, the following analysis will focus on these three sectors as well as some mention of the building sector.[22] However, it is important to note that while our analysis focuses on these sectors, China must continue to approach mitigation with a multi-pronged approach and continue efforts in all sectors to cut down CO_2 emissions.

[21] McKinsey and Company, 2009b.
[22] An important sector to consider in wake of growing population and urbanization trends.

Figure 3: Sector Breakdown of GHG Emissions



Source: McKinsey Climate Desk, 2009[23]

[23] McKinsey and Company, 2009b.

SECTORS OF IMPORTANCE

ENERGY PRODUCTION

According to the US Energy Information Administration (EIA), energy demand within non-OECD countries, mainly led by China and India, will rise 112 percent between 2010 and 2040. Moreover, non-OECD energy demand growth will outpace OECD demand growth 20% by 2010, 50% by 2020, and 90% by 2040 at the margin. Countries outside of the OECD will account for 94% of total emissions growth from 2010-2040, and Asian countries in this group could represent 71% of the total increase. China's projected contribution could account for 69% of non-OECD Asia emissions growth and 49% of total world increases in carbon dioxide emissions.[24] Although the bulk of GHGs in the atmosphere have been emitted by developed countries, these trends still suggest that significant emission reductions will need to occur in non-OECD countries.

The sheer size of emissions growth across Asia makes it important to consider the source of these current emissions. Based on this team's energy production sector analysis, policymakers in China must incorporate a variety of reforms in this sector to reduce the level of CO_2 emissions. With nearly 70% of China's energy needs coming from coal and 51% of worldwide emissions coming from coal combustion in China alone,[25] changing China's trajectory on coal quickly is both a high priority but is exceedingly difficult.

China continues to develop at a substantial pace, and coal continues to provide a reliable source of inexpensive energy production; China's share of worldwide emissions will likely continue to grow. In 2011, coal prices dropped due to overcapacity in production and an increase in imports, further exacerbating coal use.[26] The International Energy Agency (IEA) estimates that the total energy supply will remain roughly the same until 2020, and this includes coal as a source for 30% of total worldwide energy. To achieve lower CO_2 emissions by 2050 in line with a 2 degrees Celsius warming scenario, total coal demand would need to fall 45% from its 2009 levels.[27] Understanding this reality is important to develop policies that curtail GHGs in the near term. This coal dependence is creating major problems for both the Chinese people and the central government.

In this analysis, renewables technologies, greater efficiency in coal-power generation, and encouraging the development of China's shale gas reserves yield the greatest potential in terms of reducing the energy sector's contributions to CO_2 emissions.

BARRIERS: RENEWABLES TECHNOLOGIES & GRID INFRASTRUCTURE

China does not have a unified electricity grid. It has six independent regional power grid clusters, including the Northeast, North, East, Central, South, Northwest, Xinjiang, and Tibet. Three companies manage these clusters: State Grid Corporation of China manages four (the

[24] IEA and ETP, 2012.
[25] IEA, 2012.
[26] Wang, 2014.
[27] IEA and OECD, 2012.

East, Central, Northwest, Northeast, and part of the North grid); the Western Inner Mongolia Corporation manages the remainder of the North Grid, and the China Southern Grid Company manages the Southern grid.[28] In each regional grid cluster, balancing of supply and demand take place at the provincial level. Trading of power takes place at both the provincial and regional level, although cross-regional trade is minimal.[29]

Figure 4: Map of Chinese Electric Grids

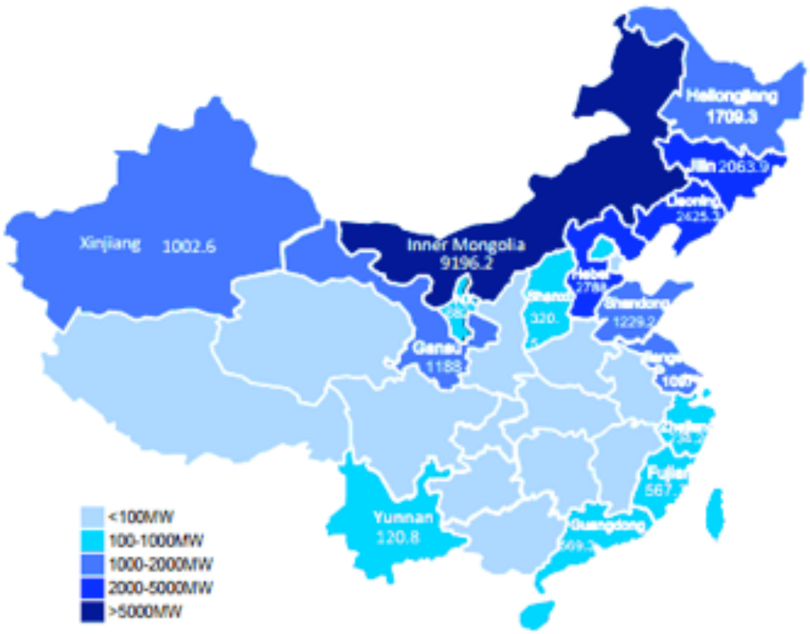
Source: NDRC Energy Research Institute, 2009[30]

TECHNICAL: INFRASTRUCTURE LIMITATIONS

The three grid companies apply a three-step process toward integrating variable power from renewable sources into the grid. The companies first aim to accommodate the variable supply, and then curtail surplus generation. The final option, transmitting the surplus to other regional power systems, is not feasible given the lack of connections between power grids.[31] Moreover, the three companies are each responsible for losses as well as profits; as such, very little inter-company cooperation occurs. Renewable technologies are not equitably distributed across all regions and all provinces: for example, hydropower is disproportionately located in south and central China and does not contribute substantial power to the grid to meet demand in other regions. Wind power, which is mostly located in the north, faces the same obstacle.[32]

[28] Cheung, 2011.
[29] Ibid.
[30] Wang, 2009.
[31] Ibid.
[32] Ibid.

Figure 5: Installed Wind Capacity by Province (MW)



Source: China Wind Energy Association, 2010[33]

MARKET: STRUCTURE OF CONTRACTS

Electricity trading practices are also a challenge to realizing the full potential of renewable technologies in China. Even if new capacity additions improve prospects for inter-regional electricity trading, rigid market structures will dampen China's ability to realize the full potential of renewable technologies. Long-term contracts govern around 80 percent of the trading that occurs between provinces and regions. Regions and provinces set their trading quantities and prices based on multi-year forecasts.[34] Because the electricity market is so rigid, and because long-term contracts form the basis of the market, even if electricity-importing provinces have developed enough generation capacity over the year to meet demand, they must still receive electricity because of a prior agreement. As a result, the province must sell the surplus capacity to another region by significantly lowering its export prices, thus creating large inefficiencies within the electricity market.[35]

FINANCIAL: COSTS OF INTEGRATING RENEWABLES TO GRID

Overcapacity in solar generation has eased after a number of policy shifts towards industry consolidation. These policies have helped reduce the number of players in the solar industry, but overcapacity is still an issue in 2014. The government is aware of this and working

[33] China Wind Energy Association, 2010a.
[34] Ibid.
[35] Ibid.

to address the issue. The biggest barrier to increasing the level of renewables generation countrywide is the investment required to connect electricity grids across provinces and the costs of connecting renewables to the grid. This process will continue to require step-by-step policy changes. The government has implemented policies to simplify the approval process, and this will facilitate the construction of better grid infrastructure and ultrahigh voltage lines to better transmit this generation across China. [36]

BARRIERS: COAL DEPENDENCE AND MITIGATING COAL-BASED EMISSIONS

For many developing economies, including China, coal and other fossil fuel energy sources will remain the primary method for electricity generation in the near future. Following the Fukushima nuclear accident in Japan, many developed nations have shifted their own generation towards coal.[37] This shift away from nuclear power, particularly among European nations, coupled with the low price of coal, could increase fossil fuel dependence worldwide. Debates led by the NDRC to implement coal-use caps by region have proven difficult due to varying regional interests. As of yet, there appears to be no unified national mapping of coal cap reductions.[38]

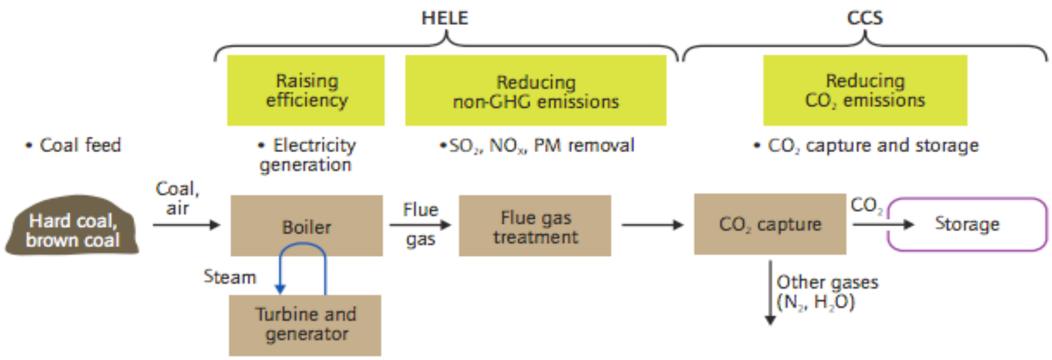
Given the level of worldwide emissions from coal today, and the projected growth in energy demand over the next few decades, a technology that could allow for its continued use while mitigating its emissions contribution has a significant place in future climate policy. This is known as Carbon Capture and Sequestration Technology (CCS). Although it has not reached full development or commercial feasibility, CCS has significant potential for reducing the GHG impact of coal for much of the developing world. The continued use of coal in power generation presents a significant challenge to overall emissions reductions commitments. An emissions reduction portfolio that does not address coal, as CCS aims to do, will not make a significant impact on global CO_2 emissions.

TECHNICAL: HIGH EFFICIENCY, LOW EMISSION COAL GENERATION

[36] Wang, 2014.
[37] The Economist, 2013.
[38] Wang, 2014.

In the medium-term, plants employing high-efficiency and low-emission technology (HELE) will provide a vital link between conventional coal-generated electricity and CCS-generated electricity. Today 50% of new coal-generating plants use HELE technologies including supercritical and ultra-supercritical generation.[39]

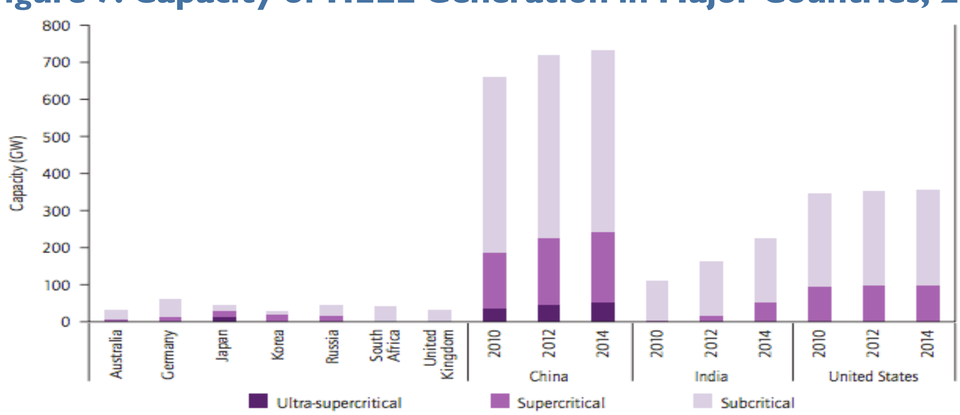
Figure 6: HELE and CCS in Coal Electricity Generation Process



Source: OECD/ IEA, 2012

While this is promising in terms of reducing the emissions impact of coal-generation, roughly 75% of all coal-generation today do not employ HELE technology, and about half of current coal-generating capacity is over 25 years old.[40] Implementing supercritical generation will provide a link to even more efficient ultra-super critical technology that will further reduce the emissions associated with coal-generation.

Figure 7: Capacity of HELE Generation in Major Countries, 2010



Source: OECD/ IEA, 2012

HELE technology includes three tiers of carbon-intensity and coal-consumption intensity: supercritical, ultra-supercritical, and advanced ultra-supercritical technology.[41] Non-HELE technology, or subcritical generation, is most common in coal-generated electricity today. Plants combust pulverized coal in a boiler to produce steam that powers a generator. Subcritical

[39] IEA, 2013b.
[40] Ibid.
[41] Ibid.

generation both requires more coal and higher carbon emissions than its more efficient descendants. Supercritical generation produces steam at higher pressures and allows for greater efficiencies in coal consumption that help offset its higher costs.[42] Ultra-supercritical technology operates at greater pressure levels and higher temperatures to improve the efficiency of generation. While both of these technologies are in production, the final HELE technology, advanced ultra-supercritical technology requires substantial capital costs due to the extreme pressure and temperature of generation. The requirement for super alloys that can withstand the higher pressures is a major challenge to implementation today.

China's efforts to implement more efficient coal-powered power plants began in 2006 when the first 1 GW ultra-supercritical coal-fired unit began operating. Demand has increased since 2006 to over 100 on order, and as of July 2012, 46 units are in operation. China has since become the world leader in the number of large-scale ultra-supercritical coal plants on order and in production.[43]

FINANCIAL AND TECHNICAL: DEVELOPMENT AND FEASIBILITY OF CCS

CCS targets large sources of emissions such as fossil fuel dependent power plants. There are three main methods for capturing (scrubbing) emissions. In *post-combustion* capture, the technology targets the carbon dioxide within the flue gases that the combustion process releases. This technology originated with industrial uses, but its use at a power plant level scale has potential to significantly reduce the levels of carbon dioxide that these plants emit into the atmosphere.

In *pre-combustion* capture, producers partially oxidize the fossil fuels and can separate out component gases, such as carbon monoxide, carbon dioxide, and hydrogen. At this point, the producers separate the streams of gases and can capture the carbon gases while allowing the hydrogen to continue through the process for combustion and the generation of electricity.

The final method is *oxy-fuel combustion* where producers burn fuel in an environment of pure oxygen, rather than normal air. At this point flue gases (primarily water vapor and carbon dioxide) are re-circulated into the chamber, cooled, and the result is a stream of carbon dioxide and a byproduct of condensed water. Each of these methods has its own drawbacks and limitations, and there is no question that each of these will require significant investment to come to fruition as a viable technology for reducing greenhouse gas emissions.[44] All ultimately require underground disposal in geologic formations.

While the commercial potential of this technology will take more time and investment to determine, it is clear that the potential for reducing emissions while still using fossil fuels in the global energy mix is worth further development. CCS technology will not serve as a panacea, but rather as an integral part of both overall energy efficiency promotion and the increased adoption of renewable and low-carbon energy sources. There are obvious uncertainties relating to the technology, given its level of development. The technology, while capital intensive, seems to offer a glimpse into a future where countries can find a way for employing worldwide coal

[42] Ibid.
[43] Qili, 2013.
[44] IPCC, 2005.

resources without undermining the 2 degrees Celsius warming scenario.

MARKET: DEPENDENCE ON COAL

The development of CCS in China is of particular relevance today given the dependence on coal as an energy source. China's headlong push for economic growth led to an over-reliance on energy-intensive heavy industry like steel, cement, and glass production, both to serve burgeoning domestic demand in China and for international markets. While most of China's new coal builds are set to conform to HELE technology, the challenge is the sheer volume of plants being considered. After the 2013 "airpocalypse" episode that left much of northern China blanketed in dense smog, China restricted the construction of about fifteen new coal plants in and around Beijing and neighboring provinces. However, China was still set to build about 350 new coal plants all across the country.[45]

The government's acknowledgment of the air quality problems associated with coal dates to the 11th Five-Year Plan (2006-2010), which required the closing of 85 Gigawatts (GW) of generating coal plants that did not meet efficiency standards. The current 12th Five-Year Plan (2011-2015) sets a cap on total production of coal by 2015 and requires large coal plants (600 Megawatts or greater) to employ supercritical or ultra-supercritical technology. The overall goal of the increased efficiency standards for coal plants is to reduce the carbon intensity of power generation no less than 17 percent (from 2010) by 2015 and 40-45 percent by 2020.[46] This level of air pollution poses a threat to internal security and threatens sustainable economic growth, which is changing the government's calculations with respect to investment in CCS and other alternatives to coal. Nonetheless, amidst concerns over safety and water quality, the Chinese government is careful in pushing for CCS, approving only 100 pilot programs and being stringent with subsidies, asking mostly for companies to pay for technology development.[47]

Even as China struggles to reduce its dependence on coal through diversification of fuel sources, efficiency, and economic rebalancing, it is also investing heavily in CCS technology. As of February 2014, China has 12 large-scale CCS pilots, up from 6 in 2011.[48] However, none of them are connected to major coal-fired power plants but are rather connected to natural gas wells and refineries.[49] Beyond the sheer scale of the problem, the main barriers in China may be technical and economic. Can CCS be deployed in power plants incorporating the latest technology from around the world and drive down costs of deployment? Here, China would benefit from outside expertise and be able to quickly incorporate new intellectual property into practice.

SOCIAL: AIR POLLUTION AND ENERGY PENALTY

While CCS is promising in its potential as a bridge technology towards a lower-carbon economy, it yields additional challenges for emissions reductions through its "energy penalty." The energy penalty refers to the 15-20% extra fuel that the CO_2 capture process requires. This additional consumption of fuel can yield additional emissions (those associated with the

[45] Yang and Cui, 2013.
[46] IEA, 2013a.
[47] Wang, 2014.
[48] Global CCS Institute, 2014.
[49] Mann, 2014.

immediate CCS process) as well as indirect emissions (those originating in the fuel production and transportation) that reduce the magnitude of emissions reductions from CCS. The worry is not the additional CO_2 emissions, but rather the level of additional sulfur dioxide (SO_2), particulate matter and nitrogen oxide (NO), and ammonia (NH_3) resulting from additional coal consumption, with its attendant negative effects on public health.

According to a 2011 study from the European Environment Agency, the energy penalty has the following direct effects for the three main sub-level emissions. Particulate matter and nitrogen oxide levels increase according to the amount of the energy penalty. That is, as coal consumption increases, the level of these pollutants correspondingly increases. Sulfur dioxide emissions decrease because their removal is a requirement of the overall CCS process. Ammonia emissions increase substantially due to the degradation of amine-based solvents used in the CCS process. This level of increase, however, is still small relative to the overall level of ammonia emissions originating in agriculture (94% in Europe).[50]

The indirect increases in emissions originate in the extraction and transport of the 15-20% more coal that the process requires. This includes any additional emissions that arise from the mining and excavating process to the process of transporting the extra fuel to the plant. Advocates for lower carbon energy point to these indirect costs as falling outside of the spectrum of the CCS process and will persist regardless of the efficiency and effectiveness of CCS. The same report issues a caveat with respect to the impact of the energy penalty on air pollution, and it suggests that a more fully mature CCS process could deal with these other pollutants to increase the appeal of CCS. The report offers no absolute assessment, but it does temper enthusiasm for CCS's prescription as a panacea for the climate ills of coal-dependence.

The report states that while CCS "is considered to be generally beneficial both in terms of air quality and climate change…" the increase in emissions of ammonia, nitrogen oxide, and particulate matter "means that CCS would not be ranked very high on the beneficial for air quality' axis." These mixed emissions reductions diminish the potential for CCS in China in the present. Thus, paradoxically, a focus on public health as a major co-benefit may disincentivize the adoption of CCS in China.

REGULATORY: LEGAL FRAMEWORK FOR CCS[51]

According to a white paper from the Center for Climate Change Law, the National Development Reform Commission in China published a "Circular on Promoting the Trials of Carbon Capture, Use, and Storage." The document puts emphasis on the NDRC's efforts to promote CCS projects throughout China. It formally established the "Technology Innovation Union of Carbon Capture, Use, and Storage," that incorporates 40 distinct organizations ranging from businesses to universities. While this is a significant step towards strengthening the policy environment surrounding CCS in China, many reforms are needed to encourage CCS investment over the near-term.

The National 12th Five-Year Specialized Plan on CCS development (March 11, 2013) projected that CCS will provide a significant aid to China's road towards a less carbon-intense economy.[52]

[50] European Environment Agency, 2011.
[51] Gu, 2013; NDRC, 2013.

It cited the challenges associated with CCS, including the elevated costs of the technology, but the plan also identified detailed approaches that had not been addressed in previous policy documents on both technology development and the establishment of relevant policy and law.

There are seventeen national departments coordinating China's national climate change policies, so this level of policy fragmentation is not a new phenomenon. Despite the efforts to better coordinate policies relating to CCS at the national level, gaps still remain in China's regulatory framework with respect to the codifying of CO_2 as formally regulated air pollution, the laws regarding the regulation of utility pricing in China for plants deploying CCS technology, and the environmental and land-use regulations needed for transport and eventual storage or usage of captured CO_2.

Existing national regulations concerning the environment and air quality do not specifically list greenhouse gases as air pollutants that yield climate change. While air pollution regulations limit sulfur dioxide (SO_2) emissions in power plants, they do not limit emissions of CO_2. This law, however, if amended to include CO_2, could provide the regulatory conditions for limiting CO_2 and thus spurring additional development of CCS technology. CCS's state of technological immaturity, however, poses problems for leaders to carry out this regulatory step. Without commercially feasible options for limiting CO_2, there is little appetite for adding it to the list of regulated air pollutants. A preemptive law at the national level to better regulate CO_2 without a commercially feasible technology to do so could prompt entrenchment and resistance at the provincial level and thus undermine the national policy.

The regulations across the coal and electric power industries also provide a vehicle for further incorporating CCS into China's legal framework. While these regulations do not reference the technology specifically, they deal with many issues related to CCS. From pricing structures for electric power to the environmental standards of production and construction of power plants, specific amendments to these laws could allow a CCS power plant operator, for example, to charge a higher price to reflect its increased production costs. Without allowing a plant to cover the increased costs associated with CCS, there is little incentive for the additional investment required to implement the technology. However, passing on all or most of the costs to the consumers conflicts with energy security, a high Chinese priority.

The lack of adequate regulation in China hinders the potential wide scale adoption of CCS projects in China. Additional regulations should outline requirements for CO_2 pipeline construction, land management for potential storage sites, standards for monitoring sites after injection, and the liability provisions for the underground storage of CO_2. Site selection also requires further clarification. Given that CCS requires substantial geological work to determine potential sites for effectively storing the captured carbon, the environmental regulations, site monitoring, and land management regulations require revision to clarify standards for further CCS development. Setting a firmer regulatory environment around CCS in place will remove a level of uncertainty that could hinder future investment in CCS. The international community could aid China in propagating best practices that might have been developed in the advanced economies in all of these.

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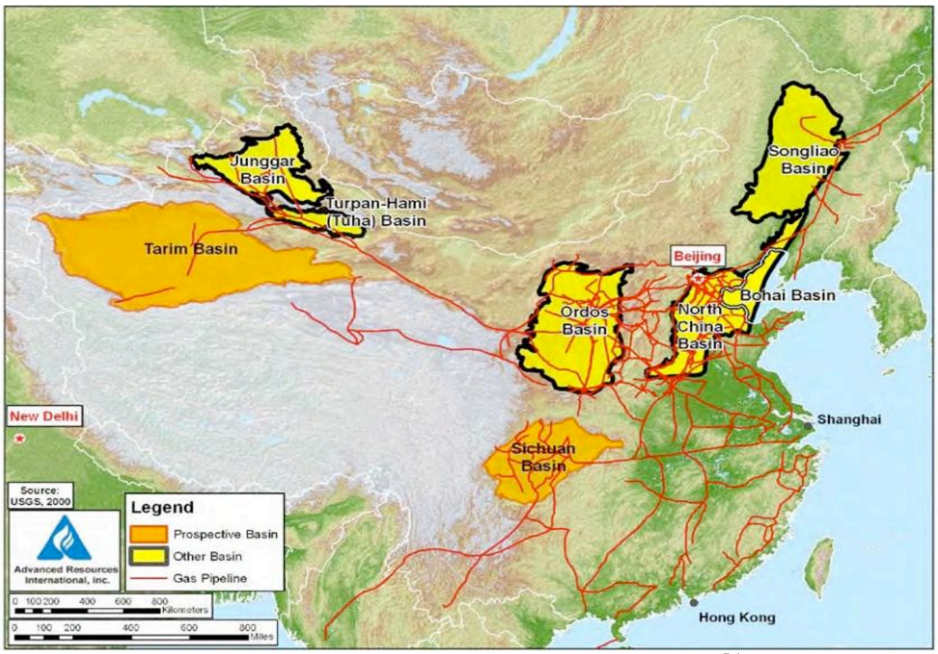
[52] Gu, 2013.

CCS projects require investment decisions over a long time horizon, and firms make investments based on their projections of the regulatory and market environment upon completion of the project. Further reforms must set clear standards, to establish the legal liability for investors, and to allow producers to set a higher price for CCS-generated electricity in order to spur further investment and development of CCS in China.

BARRIERS: FUEL SWITCHING TO NATURAL GAS[53]

Fuel switching is the term used for the trend in North America of shifting from coal-based power to natural gas, facilitated by low gas prices due to the shale gas revolution. China possesses among the largest shale gas reserves in the world, making it an excellent candidate to pursue fuel switching as a strategy that satisfies both climate mitigation and energy security. However, several barriers exist to achieve this goal.

Figure 8: Shale Gas Basins and Pipeline Infrastructure in China



Source: Advanced Resources International, 2009[54]

REGULATORY: LEGAL FRAMEWORK AND PROPERTY RIGHTS

Chinese shale gas reserves are underdeveloped and the country has invested much more heavily into its coal, nuclear, and renewables generation sectors. One of the biggest unknowns in fossil fuel switching is the effect it will have on the Chinese power grid. The unique system of mineral rights ownership in the United States and Canada is often attributed as the cause for the rapid expansion of unconventional drilling in North America. Because China has a very different system of land tenure, it is almost impossible to say at this point what the future holds for unconventional fossil fuel extraction in China.

GEOPOLITICAL: POTENTIAL FOR US EXPORTS OF LIQUIFIED NATURAL GAS

Could China emulate this decline in coal reliance and reduction in emissions? A seemingly simple solution would entail US export of excess natural gas in the form of liquefied natural gas (LNG) to China to allow the increased adoption of natural gas in electricity production. Exports

[53] Jones, 2013.
[54] Advanced Resources International, 2011.

of US LNG could both allow US exporters to take advantage of significant world price differentials and affect the geopolitical balance in Europe and Asia. According to the Federal Energy Regulatory Committee (FERC), there are 13 proposed LNG export terminals with many more potential sites for LNG export. The Obama administration has already allowed the approval of four LNG export terminals in 2014, and the Department of Energy seems poised to approve ten more.

However, some US industrial interests advocate restricting liquefied natural gas exports (LNG) as they could threaten the US competitive advantage of low domestic gas prices, which averaged $2.75/ million British thermal unit (MMBTU) in 2012.[55] According to the American Petroleum Institute, a trade organization, the impact of sustained LNG exports would only increase prices from $0.32 to $1.02 mm BTU on average from 2016-2035.[56] This suggests that the slight increase in price in the domestic market could allow significant near-term emissions reductions.

MARKET: PRICING OF LNG IMPORTS

LNG exports imports or exports could encourage the shift from coal-generated to natural gas-generated electricity worldwide. This shift would assuredly affect US coal exports and further shift investment from coal to natural gas extraction. LNG imports from the United States are not, however, a panacea for China's coal dependency. The process of liquefying natural gas is costly and typically adds between $5 and $8 per MMBTU.[57] These costs narrow the competitiveness of US LNG exports in Chinese energy markets. LNG exports could provide a boost for the US economy, but given the costs of exporting natural gas abroad, the US likely will not be able to match Chinese future demand for natural gas.

TECHNICAL: INFRASTRUCTURE

China possesses incredible potential for natural gas development but currently lacks the infrastructure and regulatory framework to take advantage of it. The IEA's estimated emissions reductions from fuel switching for China are 3 $GtCO_2$ but not until 2030; therefore there is incredible uncertainty about the prospects for fuel switching there. Japan currently relies heavily on LNG imports from Southwest Asia, and would most likely benefit the most from American natural gas exports.

CONCLUSION

China's energy production sector emissions reductions will greatly contribute to the recommended 2 degrees Celsius warming scenario by 2050. While the long-term prospects of the industry require a shift away from fossil fuel energy, in the near term adoption of more efficient coal generation technology along with further development of CCS technology will prove vital to China's future economic growth. China's policy makers can speed this process through specifically targeting CO_2 as an air pollutant and strengthening the regulatory environment around the CCS process. A number of barriers challenge China's shift to a lower-

[55] US EIA, 2013.
[56] ICF International, May 15, 2013.
[57] Holland, June 25, 2013.

carbon economy, and policymakers should consider them carefully when enacting further climate policy related to energy production.

ENERGY EFFICIENCY: INDUSTRIAL EMISSIONS FROM IRON AND STEEL

Within China's industrial sector there exist many opportunities for GHG emissions reductions. The following table outlines the estimated emissions and abatement potential of the top three emitting industries in China: iron and steel, cement, and chemicals.

Figure 10: Emissions from Industry, 2009

	2005	2010	2015	2020	2025	2030
BAU	2.6	4.418	5.354	5.844	5.954	6.274
Full Technical Potential	2.6	4.418	4.644	4.695	4.109	3.574
Abatement (GtCO$_2$e)			0.710	1.149	1.845	2.700

Source: McKinsey Climate Desk[58]

Under the BAU scenario, Chinese industrial emissions[59] are expected to increase by 1.856 GtCO$_2$e (42% increase) from 2010 emission levels, 4.418 GtCO$_2$e, reaching 6.274 GtCO$_2$e by 2030.

In more detail, the McKinsey Climate Desk program measures the iron and steel industry as the leading industrial emitter in China, at 2.015 GtCO$_2$e in 2010 and estimates its BAU emissions to grow to 2.940 GtCO$_2$e (46% increase) by 2030. BAU emissions from the chemicals industry will grow the most among China's industries, from 0.84 GtCO2e in 2010 to 1.899 GtCO$_2$e by 2030 (126% increase). Finally, BAU emissions from the cement industry will rise from 1.563 GtCO2e in 2010 to 1.735 GtCO2e in 2015 and then will fall to 1.435 GtCO2e in 2030 (a combined 8% decrease) as China's demand for cement is expected to decline starting in 2015.[60]

Additionally, abatement potential by 2030 is largest in the iron and steel sector at 1.516 GtCO$_2$e. The chemicals industry has the second largest abatement potential, at 0.784 GtCO$_2$e. The cement industry has the smallest abatement potential, at 0.399 GtCO$_2$e.

Figure 11: Emissions from Iron and Steel, 2009

	2005	2010	2015	2020	2025	2030
BAU	1.092	2.015	2.534	2.825	2.883	2.940
Full Technical Potential	1.092	2.015	2.260	2.293	1.891	1.424
Abatement (GtCO$_2$e)			0.274	0.532	0.992	1.516

Source: McKinsey Climate Desk[61]

[58] McKinsey and Company, 2009b.
[59] For the Iron, Steel and Cement industries.
[60] IEA, 2009.
[61] McKinsey and Company, 2009b.

Figure 12: Emissions from Chemicals, 2009

	2005	2010	2015	2020	2025	2030
BAU	0.635	0.84	1.086	1.293	1.559	1.899
Full Technical Potential	0.635	0.84	0.943	1.015	1.047	1.115
Abatement ($GtCO_2e$)			0.143	0.278	0.512	0.784

Source: McKinsey Climate Desk[62]

Figure 13: Emissions from Cement, 2009

	2005	2010	2015	2020	2025	2030
BAU	0.874	1.563	1.735	1.726	1.513	1.435
Full Technical Potential	0.874	1.563	1.441	1.387	1.17	1.036
Abatement ($GtCO_2e$)			0.294	0.339	0.343	0.399

Source: McKinsey Climate Desk[63]

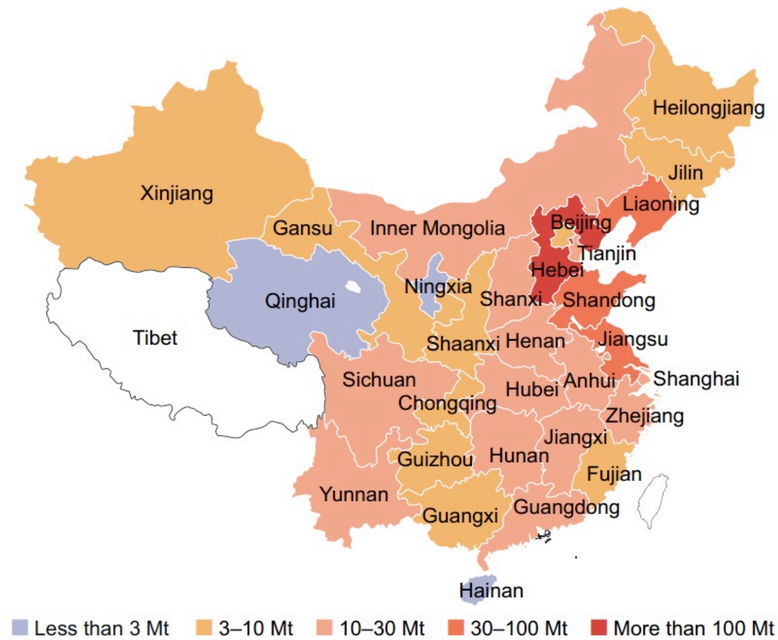
The abatement potential associated with these statistics are based upon the application of energy efficiency improvements, fuel and feedstock switching, combined heat and power, recycling and recovery, and carbon capture and sequestration within China's industries.

The case of China's iron and steel industry provides a clear, obtainable instance of GHG emissions abatement and also serves as a guide for the similar situations in China's cement and chemicals industries. China's steel emissions abatement potential dwarfs the combined abatement potential from the cement and chemical industries, representing 17% of China's total abatement potential. Additionally, China's iron and steel emissions abatement potential is three times that of China's buildings emissions abatement potential, 0.618 $GtCO_2e$. Due to the iron and steel industry's relative weight in GHG abatement potential, this energy efficiency section will focus on analyzing China's iron and steel industry's structure and barriers.

According to the World Steel Association, China is the world's largest steel producer, manufacturing 716.5 million tonnes of crude steel in 2012, dwarfing the second largest producer, Japan, which manufactures 107.2 million tonnes.[64] When segregated by provincial production, China's iron and steel output is largely located along its North Eastern seacoast, in Hebei, Liaoning, Shandong, and Jiangsu provinces, and with additional production farther inland.[65]

[62] Ibid.
[63] Ibid.
[64] World Steel Association, 2013.
[65] Holloway et al., 2010.

Figure 9: Chinese Steel Production, by Province



Source: Reserve Bank of Australia, 2009[66]

GHG emissions within the iron and steel industry are linked directly to the traditional iron reduction process, which releases CO_2 as a byproduct of iron ore and coking coal inputs, and indirectly through the localized energy production used to attain the high levels of heat required for iron reduction and other industrial processes. Specifying emissions related to an individual Chinese steel plant requires the analysis of several elements, including furnace type, production scale, and the quality of raw materials.

Among furnace types, two main technologies are employed in China. The average Basic Oxygen Furnace (BOF) technology has a carbon dioxide intensity of 1.6 tCO_2/tonne of crude steel, while the Electric Arc Furnace (EAF) technology has a carbon dioxide intensity of 0.7 tCO_2/tonne of crude steel.[67] BOF steel production relies on the traditional iron reduction process, producing emissions onsite through iron reduction and offsite through energy production. EAF technology, on the other hand, relies on scrap steel (steel obtained from end-of-life transportation, utilities, equipment, and buildings), and recycles it into a new product through melting, resulting in only offsite emissions through energy production. In aggregate, BOF constituted 90% of China's crude steel production in 2010, with only 10% of steel production attributable to EAF. In comparison, steel production among developed countries relies much less on BOF, 38%, and has a much higher adoption rate of the EAF process, 61%.[68] Currently, the low adoption rate of EAF in China can be attributable to low supplies of scrap steel and limited scrap collection and processing systems. However, as China's stock of steel increases with urbanization and ages, future scrap steel supplies will aid the adoption of the EAF process.[69]

[66] Ibid.
[67] Zhu, 2008.
[68] Lee et al., 2012.
[69] Ibid.

Another important factor in the case of Chinese iron and steel industry emissions is the furnace scale. A larger furnace has a lower surface to volume ratio, resulting in lower heat losses during steel production and thus is more energy efficient.[70] In addition, the use of a larger furnace makes the installation of energy-efficient equipment more economical. As seen in the following table, most of China's blast furnaces have a volume in the 300-999 m^3 range, while very few operate at the least CO_2 intensive level.

Figure 10: Chinese Blast Furnace Emissions, 2004

	CO_2 Intensity tCO_2/yr	Number of Installations	Production Capacity Mt/yr	Share%	Annual Production Mt/yr	Annual CO_2 Mt/yr
Total	1.25	395	230.9	100	251.9	314.9
>3000 m^3	1.09	6	16.6	7.1	17.8	19.4
2000 - 2999 m^3	1.17	28	50.9	22	55.5	65
1000 - 1999 m^3	1.21	39	38.3	16.6	41.8	50.6
300 - 999 m^3	1.31	231	107.8	46.7	117.6	154.1
101 - 299 m^3	1.33	82	16.5	7.1	18	23.9
<100m^3	1.37	9	0.9	0.4	1	1.3

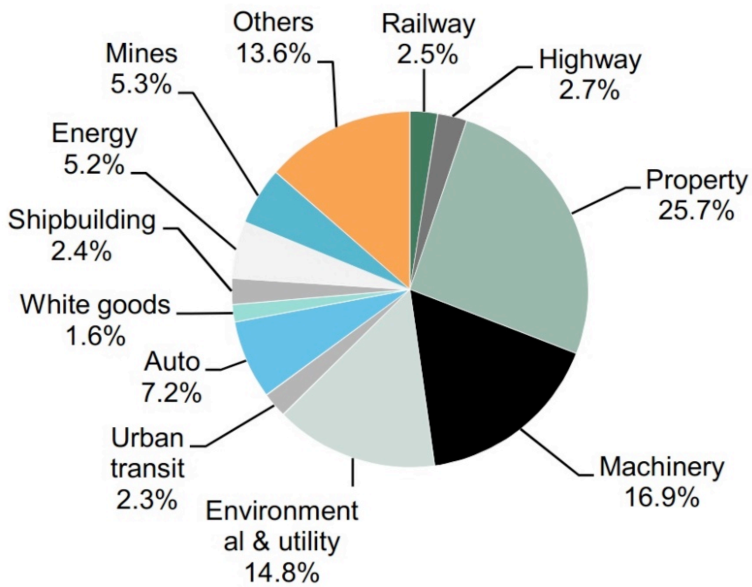
Source: Chatham House, 2008[71]

China's current supplies of iron ore and coke also factor into the iron and steel industry's GHG emissions data. While China is a major producer of iron ore, much of its reserves have low iron content of only 33%, compared to 62% in Australia and 65% in Brazil and India.[72] This lower iron content makes it more expensive and less energy efficient for steel mills to process Chinese iron ore. Additionally, China's iron ore reserves are located in the Chinese north and west while China's steel mills are situated in the northeast, closer to shipping lanes. This has resulted in more than 80% of China's iron ore being imported from Australia, Brazil, and India, adding to GHG emissions associated with China's shipping sector.[73] At the same time, China's high demand for coking coal has caused a similar inflow of coke from abroad.

In the case of China, increased steel demand has been driven by high rates of urbanization as the government is investing more in infrastructure, transport, and businesses while the private sector has established more industries and residences. China's current plan is to raise its urbanization rate from 47% in 2009 to 67% by 2030 – a significant shift of 280 million people to its cities.[74]

[70] Zhu, 2008.
[71] Ibid.
[72] Holloway et al., 2010.
[73] Ibid.
[74] Kwan, 2010.

Figure 11: China's Demand for Steel



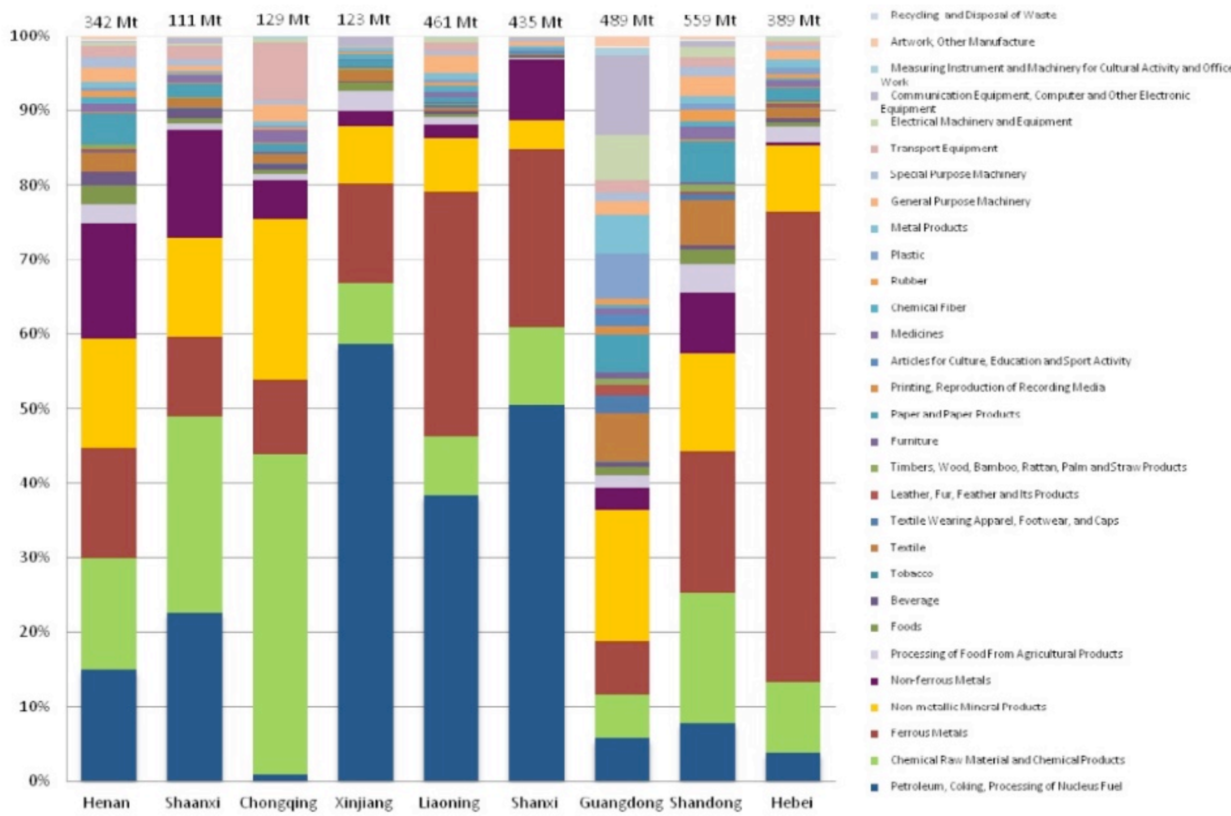
Source: BNP Paribas, 2014[75]

PROVINCIAL EMISSIONS

While GHG emissions data is available at the country level in China, not all of the provinces provide energy data at the industrial sub-sectoral level, making iron and steel-related GHG emissions forecasting difficult within individual provinces. Only Chongqing, Guangdong, Hebei, Henan, Liaoning, Shaanxi, Shandong, Shanxi, and Xinjiang province provide GHG emissions data at the iron and steel level, revealing the high quantity of iron and steel emissions in Hebei (246 Mt CO_2e), Shandong (106 Mt CO_2e), Liaoning (151 Mt CO_2e), and Shanxi (103 Mt CO_2e).[76]

[75] Cheung, 2014.
[76] Lu and Price, 2012.

Figure 12: CO_2 Emissions of Industrial Subsectors, by Province, 2008



Source: Ernest Orlando Lawrence Berkeley National Laboratory, 2012[77]

STRUCTURE OF INDUSTRY

China's iron and steel industry, which was decentralized in the 1990's, still operates under influence by the Chinese central and local governments. Most mills are small or medium scale and are privately run, while a few large scale mills are state-owned enterprises (SOEs).[78] Both SOEs and private mills are specified in Beijing's 12th Five Year Plan to increase their value-added output by 18% and must contribute to the Plan's overall goals of a 16% reduction in energy intensity and a 17% reduction in carbon intensity.[79] Additionally, the Chinese government has proposed a 40 to 45% CO_2 emissions intensity reduction target by 2020 and has designated the iron and steel industry as a "strategic emerging industry" for national security, stressing the roles of research and development within the sector.[80] However, the iron and steel industrial efficiency programs vary throughout the country because each province and municipality creates their own energy efficiency initiatives to achieve Beijing's Five-Year Plan goals. The Chinese government has taken further steps to discourage small inefficient mills through changes to the iron ore import regime and through environmental licenses. Furthermore, the State Council has targeted steel overcapacity as a means of controlling environmental problems, announcing orders for the shutdown of blast furnaces under 400 m^3 in volume, and the

[77] Ibid.
[78] Murray et al., 2010.
[79] Industrial Efficiency Policy Database, 2012.
[80] The Central People's Government of the People's Republic of China, 2010.

consolidation of the top 10 iron and steel producers.[81] However, China's speed of elimination, a 15 million ton target, does not compare to the addition of new capacity, 30 million tons a year resulting from high demand.[82]

BARRIERS

POLITICAL

Despite Premier Li Keqiang announcement in 2014 of a war against pollution, China's current environmental political structure poses significant challenges to the successful development and implementation of iron and steel industry emissions programs.[83] Historically, regulations for pollution and environmental impact set by the Ministry of Environmental Protection have been neglected by local authorities and industries due to lack of enforcement and sanction powers. For example, in 2013, 71 out of 74 cities monitored failed to meet the Ministry's air quality standards.[84] Not only have fines been seen as negotiable, but the practice of "quiet days" (when enforcement officials rely on the honor system for reporting rather than inspecting factories) has worsened the situation.[85] Whether the recent announcement of a nationwide monitoring system for industrial emissions and the classification of emission levels misreporting as a crime will result in higher rates of compliance remains to be seen.[86] Additionally, the Ministry of Environmental Protection's staff size is too low and diffuse to monitor effectively. Although the Ministry of Environmental Protection employees more staff (300 in its Beijing headquarters, 30 in each of 5 regional offices, 60,000 at the provincial and township level, and 2,600 at affiliate agencies and institutes) than its counterpart in the U.S., the EPA (17,000 employees total), the ratio of environmental agency employees to population size is much higher in the U.S (57 employees per 100,000 population) than in China (5 employees per 100,000 population). Furthermore, China's current regulatory system over the iron and steel industry includes multiple agencies: Ministry of Environmental Protection, National Development and Reform Commission, Ministry of Land and Resources, and Ministry of Industry and Information Technology. The existence of such a large bureaucracy with supervision of overlapping slivers of the iron and steel industry has resulted in serious coordination problems both horizontally and vertically. Policies addressing energy efficiency might be stymied due to these conflicting regulatory regimes.

MARKET

China's role in the global iron and steel industry market structure influences the potential from Chinese emissions abatement actions. Significantly, China's growing import of iron ore and coking coal from abroad has resulted in a predicament of overreliance on a few exporters: Australia, Brazil, and India. While China has recently produced investments in Africa, South America, Central Asia, Canada, and Russia, to diversify iron ore exploration and mining, a setback

[81] Bi et al., 2013.
[82] Yap, 2014.
[83] Blanchard and Stanway, 2014.
[84] Li, 2014.
[85] China Greentech Initiative, 2013.
[86] Lim and Stanway, 2014.

in ore or coke imports due to international issues could force China's iron and steel industry to rely on less efficient domestic supplies in steel production, resulting in higher GHG emissions.[87]

Furthermore, lack of open firm, local, and provincial level technical data on iron and steel energy use for the public makes it more difficult to perform accurate analysis of the Chinese iron and steel market. As a result, possible foreign joint ventures and investment in the Chinese market are at a disadvantage in contrast to state-led investment which has better access to this information.

CULTURAL/SOCIAL

Historically, the iron and steel industry has been portrayed in China as a measure of economic development. Thus, infringement upon the current iron and steel industry could be seen as doing harm to China's international competitiveness, resulting in policymakers choosing to not pass long-term emissions legislation in order to maintain short-term production capacity. Furthermore, steel mills in China serve the state in maintaining high levels of social stability by providing jobs to locals. An unexpected shift in the iron and steel industry due to regulation or market instability could result in a high level of social discontent. With a total employment of 3.2 million workers in 2011, and most steel plants located in economically vital provinces, social instability among steel workers is a serious concern for the Chinese regime.[88]

FINANCIAL/TECHNICAL

Among the smaller holding iron and steel producers with fewer financial resources, short investment payback thresholds, risk, and limited access to capital could prevent possible investment planning. Additionally, their lack of access to skilled labor and small furnace size could reduce the abatement potential associated with technological development. However, among larger iron and steel firms with access to private and state capital, skilled labor, and large furnace structures, many GHG emission reduction technologies are available with payback periods of less than five years.

[87] Holloway et al., 2010.
[88] Bi et al., 2013.

Figure 13: Key Abatement Technologies in Iron and Steel Industry

Key Technology	Potential energy saving or GHG reduction per installation	Typical Cost (RMB per installation)	Average payback period
BOF/converter waste gas recovery	Up to 9.1 kWh/tonne of steel energy saving	About 100 million RMB	3 years
CDQ	0.1 to 0.2 million tonnes of CO_2e	400 million RMB	2-3 years
High temperature combustion technology (HTAC)	Up to 30% of energy consumed to generate heat in blast furnace	40 million RMB	1.5 years
Inverters or VSD for motor systems	10-30% energy savings in motor system	Medium voltage frequency converter for pump 600,000 RMB	1.5 years
Recycling of blast furnace gas and power generation	0.3 to 1 million tonnes of CO_2e depending on size of plant	10 million RMB	0.8 years
Sintering cogeneration technology	Energy saving per unit may reach 12 kWh/tonne of sinter	170 million RMB	2.5 years
TRT	0.1 million of CO_2e per year	20 to 150 million RMB	2 years
Waste gas power generation (CCGT/CCPP)	0.1 to 2.5 million tonnes of CO_2e depending on the size of plant	0.1 to 1 billion RMB	3-5 years

Source: Camco China, 2010[89]

However, in the case of carbon capture and sequestration, which has high capital costs, positive CO_2 abatement costs, and is still in a developmental stage, other incentives will have to be implemented to promote China's iron and steel industry in the adoption of this technology.

RECOMMENDATIONS

Because energy efficient payoffs from the iron and steel industry's technological improvements can be unclear to the sector, Chinese government assistance can help provide incentives and information for emissions abatement practices. Therefore, in order to capitalize on these technological opportunities, the following initiatives are recommended for implementation or maintenance by China:

1. **Adopt Scrap Steel Collection Programs and EAF subsidies:** Local and national programs which incentivize the collection and recycling of scrap steel within

[89] Murray et al., 2010.

China can increase the relative profitability of EAF compared to BOF. Further adoption of EAF through project subsidization can produce a new market in China as EAF plants are less capital intensive, take less time to build, and can be more responsive to demand than BOF plants due to EAF's flexible production cycles.[90]

2. **Create Domestic Energy Efficiency Programs:** Chinese adoption of an energy efficiency program which assists the iron and steel industry in energy efficient management, evaluating performance, and electricity demand forecasting can help smaller sized steel plants plan and carry out energy efficient upgrades with private capital. Alongside China's developing cap and trade programs, this could help the iron and steel industry eventually produce a price of carbon within China.
3. **Expand the Availability of Emissions Data:** Access to emissions data on the firm, local, and provincial levels can help foreign firms join Chinese firms in choosing partners for appropriate projects. Currently, only 25% to 30% of Chinese steel firms are members in the World Steel Association, and 70% are members of the China Iron and Steel Association - both organizations geared towards providing private inside information between firms.[91]
4. **Develop Local Natural Gas Resources:** Iron reduction can be done through natural gas instead of coke through Direct Reduced Iron furnace technology. While China's conventional natural gas resources are quite limited, vast shale gas reserves exist. Much will depend on Chinese ability to extract these reserves within the needed time frames and with minimal environmental damage.
5. **Engage in Multilateral and Bilateral Technology Programs:** China should maintain and expand its current participation in technical assistance programs. Japan's assistance through the JICA Energy Efficiency Training program[92], Green Aid Plan End-Use Energy Efficiency Program, and the Asian Development Bank's Shandong Energy Efficiency and Emissions Reduction Project have proven that China can transform foreign aid into iron and steel emissions reduction projects while maintaining current levels of employment and stability. Additionally, dialogues such as the U.S. – China Strategic and Economic Dialogue and the ASEAN+3 meetings can promote cooperation on developing energy efficient iron and steel technologies between China and other actors.

OTHER INDUSTRIES

Although analysis focused on the power and the iron and steel industries, it is important to highlight two other sectors that will play a pivotal role in the reduction of GHG emissions in China, they are: transport and buildings. Both sectors relate heavily to end-user and consumer behavior and benefit from more stringent industry standards as well as greater incentives and education of the general public.

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[90] Lee et al., 2012.
[91] IEA, 2009.
[92] Japan International Cooperation Agency, 2014.

TRANSPORT

In 2009, China's transport sector emissions climbed to over 470 $MtCO_2e$, more than double China's transport emissions a decade before.

Figure 14: Emissions from Transport

	2005	2010	2015	2020	2025	2030
BAU	0.343	0.583	0.98	1.387	1.59	1.81
Full Technical Potential	0.343	0.583	0.916	1.202	1.28	1.349
Abatement ($GtCO_2e$)			0.064	0.185	0.31	0.46

Source: McKinsey Climate Desk, 2009[93]

However, great strides in policy have been made to address transport emissions. In September 2013, the State Council released the "Action Plan for Air Pollution Prevention and Control" in response to the dangerous levels of smog.[94] As part of the action plan, fuel standards were set by region, with the strictest standards for Shanghai and Beijing. Additionally, subsidies have been provided for the adoption of hybrid vehicles or to incentivize the use of public transportation, while some regions have promoted the use of liquefied natural gas (LNG) vehicles.[95]

Urbanization and spatial geography will play a key role in the transport sector. "You can almost see the end game," states McKinsey China Director Jonathan Woetzel. According to Woetzel, the Chinese population will gravitate towards existing urban centers such that current cities will become bigger hubs with populations ranging between 10-50 million people, akin to Western Europe. As a result, rail transportation will become increasingly important, with emphasis on the 35 major cities in the next 10 years.[96]

Within urban centers, in addition to growing existing municipal policy to curb personal vehicle use and increased fuel efficiency, investing in public transportation infrastructure will be key to GHG mitigation action. This is something we see happening in Beijing and Shanghai. But in anticipation of these growing hubs, public transportation will be increasingly important in growing second and third-tier cities. While historically policies have been reactionary (such as Beijing limiting the number of cars on the road during danger levels of air pollution[97]), China could become more forward thinking. The costs of damage control are beginning to greatly outweigh preventative measures.

A three-pronged approach to reducing GHG emissions in China has been recommended in a companion paper[98] in this project. This involves:

[93] McKinsey and Company, 2009b.
[94] Clean Air Portal, 2013.
[95] Wang, 2014.
[96] Woetzel, 2013.
[97] BBC, 2013.
[98] Bartlett et al., 2014.

- Determining more sustainable and equitable ways to limit demand for light-duty vehicle travel, such as distance fees.
- Continuing to explore using fiscal incentives, like tax breaks, to promote the use of electric vehicles and alternative fuel technology and plug-in infrastructure.
- Encouraging partnerships between domestic and international vehicle manufacturers, to accelerate diffusion of clean technology.[99]

BUILDINGS

As rural regions develop, the building sector will become increasingly important in the abatement of GHG emissions. China is the "single biggest build out of infrastructure in the history of mankind… spending more as a share of GDP (approximately 8.5% annually) in the last 15 years and in absolute numbers; the market is clearly still going."[100] Urbanization will be the key issue in the coming decades. Infrastructure productivity is still lacking in China; experts liken it to western standards of the 1940s and 1950s. Anticipating cities to grow and greater densification of clusters, "China still has 40-50 years of infrastructure productivity to catch up."[101] With the majority of the population slated to live in these mega urban centers, the challenge will be to strike the balance between productivity, improved urban quality of life and environmental soundness.[102]

Although building emissions fell in the early 1990's due to improvements in heating infrastructure, since then, building emissions have been on the rise. Current Chinese building sector emissions stand at 1.343 $GtCO_2e$ and are expected to rise to 2.443 $GtCO_2$ by 2030 without abatement measures. As of 2009, commercial and public service buildings accounted for 70% of sector emissions while residential buildings accounted for 30%.[103]

Figure 15: Emissions from Buildings

	2005	2010	2015	2020	2025	2030
BAU	0.906	1.343	1.649	2.004	2.213	2.443
Full Technical Potential	0.906	1.343	1.56	1.755	1.776	1.825
Abatement ($GtCO_2e$)			0.089	0.249	0.437	0.618

Source: McKinsey Climate Desk, 2009[104]

[99] Bartlett et al., 2014.
[100] Woetzel, 2013.
[101] Ibid.
[102] Ibid.
[103] The Policy Climate Interactive, 2013.
[104] McKinsey and Company, 2009b.

Chinese policymakers are aware of this potential problem and are addressing it with a variety of policies ranging from heating restrictions, labeling of energy efficient household electronics to building standards for both residential and commercial properties. In Beijing, local communities are encouraging change in user behavior by providing free energy-saving light bulbs to allow users to experience the cost-savings from the simple switch.

One challenge China faces in this sector is in the accurate measurement of achievements. Despite having commissioned several research firms to develop citywide emissions inventories, the industry lacks a common methodology – an issue that resonates worldwide.[105] A greater push for standardization of measurements will be the first step towards methodical abatement in this sector.

Tackling emissions in the buildings sector will require more stringent industry-wide standards and will also require changing consumer behavior. This will necessitate tremendous amounts of public education, similar to what the US has been experiencing since the 1980s.

[105] Cities Today, 2013.

CONCLUSION

Although a multi-pronged approach to reducing greenhouse gas emissions will yield the best results, China's emissions story still revolves around energy production and industries. Despite China's growing dependence on its service sector over its more energy intense manufacturing sector, China still maintains 50% higher energy intensity than the US. Additionally, China's share of world GHG emissions is expected to rise dramatically (China's proportion of global GHG emissions is projected to rise from 17% in 2005 to 26% in 2030) necessitating industry leaders and policy makers to consider Chinese abatement potentials.

China's energy industry holds the most significant abatement potential, 9.1 $GtCO_2e$ by 2030. Emissions abatement planning in China's energy industry must accept that coal will remain China's primary fuel source. China's long-term goal should be the implementation of carbon capture and sequestration (CCS), which could be structured under a new regulatory framework. In the medium-term, China can rely on high-efficiency low-emission (HELE) coal plant technology alongside natural gas resources. Chinese policymakers can ease this transition through clearer regulatory guidelines, investments in HELE and CCS, and relaxing the electricity market structure to encourage swifter deployment of renewables.

China's second highest source of abatement potential is industry, with 2.7 $GtCO_2e$ by 2030. Of industries, the iron and steel industry has the largest abatement potential, and can serve as a guide for the cement and chemicals industries. The steep rise in iron and steel emissions can be linked to China's high rate of urbanization and high international demand. Chinese iron and steel firms can reduce their GHG emissions through the adoption of more efficient furnace technologies, employing economies of scale, and monitoring raw materials quality. In order to ensure the success of these abatement measures, policymakers can employ scrap steel programs, Electric Arc Furnace subsidies, energy efficiency programs, provide emissions data, stimulate fuel switching, and engage in international technological programs.

Finally, other less emitting industries such as the transport sector and buildings must also be prioritized for China to achieve its abatement potential. As a direct result of smog produced by the transport sector, China has initiated a move towards subsidizing less carbon emitting vehicles and promoting public transportation. Furthermore, China can achieve greater values of abatement in the transport sector by following the avoid, shift, and improve model. China's buildings sector has experienced greater emissions in the past decade due to urbanization. Action in the buildings sector will require both more stringent standards and education programs aimed at changing consumer behavior.

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