Title
Alternative Energy Development
and China's Energy Future

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Alternative Energy Development and China's Energy Future

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Table of Contents

List of Tables

List of Figures

Executive Summary

In addition to promoting energy efficiency, China has actively pursued alternative energy development as a strategy to reduce its energy demand and carbon emissions. One area of particular focus has been to raise the share of alternative energy in China's rapidly growing electricity generation with a 2020 target of 15% share of total primary energy. Over the last ten years, China has established several major renewable energy regulations along with programs and subsidies to encourage the growth of non-fossil alternative energy including solar, wind, nuclear, hydro, geothermal and biomass power as well as biofuels and coal alternatives. This study thus seeks to examine China's alternative energy in terms of what has and will continue to drive alternative energy development in China as well as analyze in depth the growth potential and challenges facing each specific technology.

This study found that despite recent policies enabling extraordinary capacity and investment growth, alternative energy technologies face constraints and barriers to growth. For relatively new technologies that have not achieved commercialization such as concentrated solar thermal, geothermal and biomass power, China faces technological limitations to expanding the scale of installed capacity. While some alternative technologies such as hydropower and coal alternatives have been slowed by uneven and often changing market and policy support, others such as wind and solar PV have encountered physical and institutional barriers to grid integration. Lastly, all alternative energy technologies face constraints in human resources and raw material resources including land and water, with some facing supply limitations in critical elements such as uranium for nuclear, neodymium for wind and rare earth metals for advanced solar PV.

In light of China's potential for and barriers to growth, the resource and energy requirement for alternative energy technologies were modeled and scenario analysis used to evaluate the energy and emission impact of two pathways of alternative energy development. The results show that China can only meets its 2015 and 2020 targets for non-fossil penetration if it successfully achieves all of its capacity targets for 2020 with continued expansion through 2030. To achieve this level of alternative generation, significant amounts of raw materials including 235 Mt of concrete, 54 Mt of steel, 5 Mt of copper along with 3 billion tons of water and 64 thousand square kilometers of land are needed. China's alternative energy supply will likely have relatively high average energy output to fossil fuel input ratio of 42 declining to 26 over time, but this ratio is largely skewed by nuclear and hydropower capacity.

With successful alternative energy development, 32% of China's electricity and 21% of its total primary energy will be supplied by alternative energy by 2030. Compared to the counterfactual baseline in which alternative energy development stumbles and China does not meet its capacity targets until 2030, alternative energy development can displace 175 Mtce of coal inputs per year and 2080 Mtce cumulatively from power generation by 2030. In carbon terms, this translates into 5520 Mt of displaced CO_2 emissions over the twenty year period, with more than half coming from expanded nuclear and wind power generation. These results illustrate the critical role that alternative energy development can play alongside energy efficiency in reducing China's energy-related carbon emissions.

Introduction

The year 2010 marked an important transition point for China in its path of development as the end of the 11th Five Year Plan (FYP) period and the beginning of the 12th FYP period. Over the five year period between 2006 and 2010, China set out to reduce its energy intensity as defined by energy consumption per unit of GDP by 20% through energy efficiency policies and programs. In part due to the heavy infrastructure investments as part of China's US$586 billion stimulus program in 2008 and 2009, China fell short of meeting its 20% energy intensity reduction target with a 19.1% reduction by the end of 2010. Nevertheless, China has continued to pursue efforts to reduce both its energy and carbon intensities as it strives to meet the next set of targets, including a 40% to 45% reduction in CO_2 emission per unit GDP from 2005 levels by 2020. In March 2011, China also announced three key targets for the 12th FYP period including energy and carbon intensity reduction goals of 16% and 17%, respectively. Additionally, in line with previous goals announced for 2010 and 2020, an 11.4% goal for non-fossil penetration of total primary energy consumption was also announced for 2015.

Challenges in meeting the 11th FYP energy intensity reduction goal illustrate that China's efforts to reduce its energy consumption and CO_2 emissions will be complicated by its continued transition from an industrializing economy to developed economy. Despite a staggering three-fold jump in electricity demand over the last decade, rising demand is still expected as economic growth on the order of 7% annual growth has been set as a target for the 12th FYP period. To curb growth in energy demand while simultaneously reducing carbon emissions, an area where China has placed increasingly greater attention is alternative energy. Within this context, alternative energy includes not only traditional non-fossil energy such as renewable and nuclear energy, but also emerging coal alternative technologies. After becoming the world's leader in overall renewable energy finance and investment, China surpassed the U.S. as the country with the most installed renewable energy capacity in 2009 (Pew, 2011). China is also the world's largest producer of wind turbines and solar PV modules, driven by a record-breaking US$54.4 billion of private investment in the renewable energy sector in 2010. Likewise, the central government also invested US$32 billion in stimulus funds for the renewable energy and energy efficiency sectors in 2010. Outside of renewable energy technologies, China has also invested in exploring advanced coal-to-liquid, coal-to-chemicals, coal-to-gas conversion technologies while continuing to expand its nuclear generation fleet.

This study thus seeks to examine China's alternative energy developments both retrospectively and prospectively. From a retrospective point of view, this study examines what has and what will continue to drive alternative energy development in China, with a particular focus on policy drivers and technology developments. This study examines in-depth the major sources of non-fossil electricity generation including wind, solar, hydro, nuclear and geothermal, renewable energy utilization through the use of biomass, biofuel and solar water heaters, and fossil-based alternatives of coal-to-liquid, coal-to-chemicals and coal-to-gas. With accomplishments under the 11th FYP period as the basis, the potential of each major energy technology for growth in the next twenty years is evaluated. First, key categories of resource input requirements including basic construction materials (e.g., concrete, cement, steel, aluminum, copper), rare earth metals (neodymium, indium, selenium, gallium), energy and land requirements are evaluated from a life-cycle, cradle-to-grave perspective for each energy technology. For evaluating the energy requirements of alternative energy development, literature review and China-specific analysis in the case of nuclear is used to estimate an energy return on energy invested (EROEI), or the total lifetime energy output as a ratio of total lifecycle energy input, for each specific technology. Second, with the new 2015 and 2020 targets in mind, the recent enabling policies and their impacts in fostering the development of each technology are reviewed while the remaining technology-specific challenges for development are identified. Third, a comparison of the resource requirements, EROEIs as well as the total fossil energy input and power output of China's alternative energy technologies is conducted to better understand their limitations and potential in contributing to China's targets. Finally, scenario analysis is used to analyze the potential energy and emissions impact of different paces of alternative energy development and the likelihood of meeting China's 2015 and 2020 targets.

1. Recent Developments and Policy Drivers of China's Alternative Energy Expansion

1.1 Policy Drivers

1.1.1 Renewable Energy Law of China

The 2005 Renewable Energy Law of China marked the beginnings of policy-driven development of China's renewable energy industry once it went into effect on January 1, 2006. The first notable element of the law is the provision for a mandated market share as measured by medium- and long-term targets of the "total volume for the development and utilization of renewable energy (National People's Congress, 2005)." The law provided feed-in tariffs for technologies, including biomass power generation, and established grid feed-in requirements and standard procedures. With regards to grid integration, the law stipulates that:

> *"Grid enterprises shall enter into grid connection agreements with renewable power generation enterprises that have legally obtained administrative license…and buy all the grid-connected power produced with renewable energy within the coverage of their power grid, and provide grid-connection service for the generation of power with renewable energy (National People's Congress, 2005)."*

The subsequent implementing guidelines released in January also mandated that government-guided prices will be determined by the State Council for grid-connected renewable generation and established a cost-sharing mechanism where the incremental cost will be shared among utility customers (Martinot, 2005). The law further outlined financial support and economic incentives that the government may offer to renewable developers through a newly established renewable energy fund and through preferential loans and tax benefits.

1.1.2 2007 Medium and Long-term Development Plan for Renewable Energy

After the signaling of increasing government support for renewable energy development in the 2005 Renewable Energy Law, a goal of raising the overall share of renewable energy in total primary energy consumption to 10% by 2010 and 15% by 2020 was set for the first time in the 2007 Medium and Long-term Development Plan for Renewable Energy. The first official targets for priority renewable technology sectors including hydropower, biomass, wind, solar and others such as geothermal, tidal and biofuels were also announced for 2010 and 2020 (Table 1).

Table 1. Renewable Energy Targets set in the 2007 Medium and Long-term Plan

		2010 Target	**2020 Target**
Total Renewable Power		**200.8**	**361.9**
Hydropower	GW	190.0	300.0
Pumped Hydro (2011)	GW	2015 target: 41 GW	
Biomass	GW	5.5	30.0
Ag/Forestry Residues	*GW*	4.0	24.0
Biogas from org effluent	*GW*	1.0	3.0
Municipal Solid Waste	*GW*	0.5	3.0
Wind	GW	5.0	30.0
Off-shore	*GW*	0.2	1.0
On-shore	*GW*	4.9	29.0
Solar Power	GW	0.3	1.8
PV Total	GW	0.3	1.6
Remote PV	GW	0.2	0.3
Building Integrated PV	GW	0.1	1.0
PV	GW	0.0	0.2
Non-Grid Special Use of PV Tech	GW	0.0	0.1
Solar Thermal	*GW*	0.1	0.2
Tidal Power	GW	0.0	0.1
Other Renewable Energy Applications			
Solar Water Heater	mil m2	150	300
Geothermal energy	Mtce	4	12
Biomass Pellets	Mt consumption	1	50
Biogas and Biomass Gasification	mil rural households	40	80
Liquid Biofuels	Mt consumption	2.2	12
Bioethanol	Mt	2	10
Biodiesel	Mt	0	2

Source: NDRC 2007, "Medium and Long-term Development Plan for Renewable Energy in China."

In addition, the 2007 Plan also set guiding principles, policies and measures for accelerating the development of the renewable energy industries including:

1. Establishing sustainable and stable market demand through mandatory market share policies, such as setting specific non-hydro renewable generation and installed capacity targets
2. Improving the market environment through designating responsible parties in transmission and grid integration and setting solar integration standards development
3. Setting and improving renewable feed-in tariffs and cost-sharing policies
4. Increasing fiscal input to the renewable energy fund and tax incentives
5. Accelerating technology and industry development through continued research and development (R&D) support

1.1.3 Amendments to 2005 Renewable Energy Law

The unprecedented growth of renewable energy industries, particularly solar PV and turbine manufacturers, from 2005 to 2009 presented unexpected challenges and obstacles to provisions set forth in the Renewable Energy Law and the Medium and Long-term Plan. The wind industry, for example, has undergone such a rapid pace of growth in production with cumulative capacity doubling each year after 2005 that transmission planning and interconnection have not been able to keep pace. In 2010, total installed capacity of wind reached 44.7 GW but actual grid-connected wind capacity was only 31.1 GW, placing China second behind the U.S. in terms of total grid-connected wind capacity (NEA, 2011). In some wind farms in Gansu, there have been reports of grid-connections for only 20% of installed capacity of wind turbines due to grid connection challenges discussed in the wind section (Ma and Fu, 2011). At the same time, the revenue for supporting the renewable energy fund set up under the Ministry of Finance trails total expenditures with insufficient revenue stream from a surcharge of only 0.4 fen/kWh on national electricity sales (Martinot, 2011).

In response to these challenges to continuing the expansion of renewables, amendments to the 2005 Renewable Energy Law was adopted in December 2009 and went into effect on April 1, 2010. The 2009 amendments mandated more detailed planning and coordination on overall renewable and electric power sector development and transmission planning between the State Council, State Electricity Regulatory Council, grid companies, renewable energy developers and local governments. Additionally, the 2009 amendments also strengthened the requirements for electric utilities to purchase all generated renewable power by obligating them to guarantee the purchases of a minimum amount of electricity from renewable energy and mandating the use of economic penalties for non-compliance. However, the amendments did not include any guidelines on how this obligation will be implemented and the mandatory minimum amount of renewable generation for guaranteed purchase (Cheung, 2011). Lastly, the amendments recognized the need to raise the funding level for the renewable energy law by including a provision that allows the Ministry of Finance to supplement and raise the fund with general revenues.

In addition to these amendments to the 2005 Renewable Energy Law, other technology-specific policies were also ushered in over the last two years in response to the dynamic landscape of renewable energy sector in China. These policies are covered more in detail in the technology specific sections of the report.

1.2 11th FYP Achievements

As illustrated by the emergence of key policies for alternative energy development, the 11th FYP period has witnessed tremendous growth and expansion in China’s various alternative energy industries. By the end of 2010, China had met and in most cases, significantly exceeded all of its official renewable targets set under the 2007 Medium and Long-term Development Plan. As seen in Table 2 below, the 2010 installed capacity targets for wind, solar, biomass, hydro and utilization of solar hot waters and ethanol were all met by the end of 2010. The actual installed capacity of wind of 44 GW was more than 800% higher than the 2010 target of 5 GW, while actual solar capacity was nearly 300% higher, ethanol production was 220% higher, and hydro and solar water heater was 112% higher than their respective 2010 targets. This highlights that growth in renewable energy development in China over the last five years has surpassed initial expectations, propelling China to become the country with the fastest growth of 106% in renewable energy capacity from 2005 to 2010 (Pew, 2011).

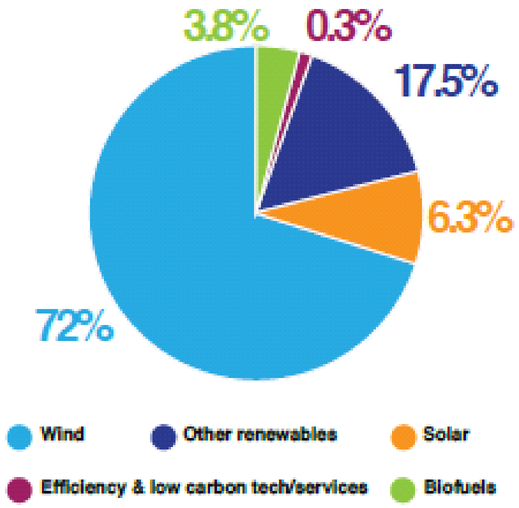
Table 2. China Installed Capacity for Alternative Energy Generation and Sources

	2005 Actual	2010 Target	2010 Actual	Target Met
Wind	1.26	5	44.7	✓
Solar	0.07	0.3	0.85	✓
Biomass	2	5.5	5.5	✓
Hydro	115	190	213	✓
Nuclear	6.9		10.8	
Geothermal	0.03		0.024	
Solar Hot Water (mil m2)	79.3	150	168	✓
Ethanol (mil tonnes)	1.02	0.8	1.8	✓

Sources: REN21 2006; BP 2010; CEC 2011.

In parallel to this rapid expansion in renewable generation capacity has been China's success in attracting record-setting levels of public and private investment in the renewable energy sector. Besides surpassing the U.S. as the leading investor in renewable energy, China also surpassed South Korea and the EU to become the country with the fifth highest growth in investment from 2005 to 2010, with an 88% growth in investment over the five year period. In 2010 alone, total investment underwent 39% increase with nearly 80% of the total invested in wind, 10% in solar and other renewables each, and a much smaller share in efficiency. As Figure 1 shows, the 2010 investment composition closely follows that of the past five years.

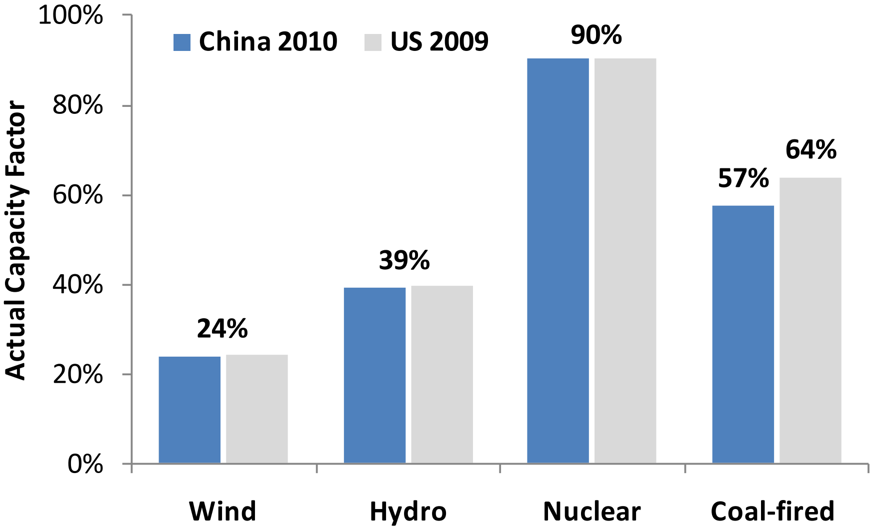
Figure 1. Distribution of Investments by Industry (2005 to 2010)



Source: Pew Charitable Trusts 2011, p. 34.

Another area of achievement during the 11th FYP period has been in the increased utilization of alternative energy generation as measured by rising capacity factors. In 2010, China was able to achieve the same capacity factors as the U.S. in 2009 for wind, hydro and nuclear power generation (Figure 2). Nuclear's high capacity factor of 90% in 2010 underscores its important role as a baseload generator. China's coal-fired power plants, however, have a notably lower capacity factor of 57% compared to 64% in the US in 2009, which was already lower than historical capacity factors of around 70%. The low capacity factors for China's coal generation results largely from the grid's reliance on coal-fired units for load following, peaking generation and other ancillary services needed to maintain grid stability (Kahrl et al., 2011).

Figure 2. Comparison of US and China Capacity Factors by Major Generation Sources



Sources: CEC 2011; EIA 2011.

In recognition of the weaknesses in the Chinese electricity grid for further penetration of renewables, particularly variable generation sources like solar and wind, China has also undertaken improvements in grid development and improvement. During the 11th FYP, China invested a cumulative total of 3.2 trillion RMB in power sector infrastructure development, with an annual average investment of 295 billion RMB in grid construction (GMEPA, 2011). To relieve transmission bottlenecks while increasing efficiency, China has started to invest heavily in ultra-high voltage alternating current (UHV AC) and high voltage direct current (HVDC) transmission which can transmit larger quantities of electricity over long distances with less power loss. In 2009, for instance, the State Grid Corporation of China and China Southern Grid Company put two high-voltage transmission lines into operation including a 1000 kV UHV DC from Shanxi to Hubei and 800kV direct current line from Yunnan to Guangdong. Three more new UHV AC transmission lines were also started in 2009 to connect Xiamen and Nanjing, Sichuan and Shanghai and western Inner Mongolia and Shandong, with completion slated for 2015 (Cheung, 2011). In 2010, grid development was also accelerated with a total of 440,000 km of 220V+ high voltage direct current (HVDC) transmission, an increase of 180,000 km from 2005, and completion of 2078 km of UHV transmission lines (GMEPA, 2011; Cheung, 2011). Besides new construction, China was also successful in continually lowering its grid’s overall transmission and distribution loss by 0.72 percentage points over the 11th FYP period to 6.49% loss by 2010 (GMEPA, 2011).

Thus, while China has very successfully expanded the scale and scope of its renewable energy technology manufacturing and installed generation capacity as well as raised its capacity factors to be on par with that of advanced countries, it faces concurrent challenges in maintaining grid stability as the demand for renewable integration accelerates.

1.3 China’s Path Forward

Following its 11th FYP accomplishments, China has announced plans and draft targets for the next five years with a next five years with a draft “Development Plan for Emerging Energy Technologies” released in March 2011. This March 2011. This draft plan focuses specifically on promoting new and emerging energy sectors including wind, including wind, solar and biomass with much higher capacity targets recommended for 2020 as well as annual well as annual growth targets for 2011 (Table 3. Revised 2020 Alternative Energy Capacity Targets and 2011 Annual Growth Targets

	2020 Installed Capacity (GW)	2011 Annual Growth Target
Wind	150	45%
Biomass	30	-
Solar	20	-
Nuclear	70	13.3%
Hydro	-	6.1%

Source: NDRC 2011.

). As part of the efforts to support renewable energy capacity development including hydro as well as nuclear energy development, a target of 5 trillion RMB in public and private investment from 2011 through 2020 was also announced. This is expected to include 2 to 3 trillion RMB for renewable sectors, with 1.5 trillion RMB for wind and 200 to 300 billion RMB for solar through 2020 (NDRC, 2010).

Table 3. Revised 2020 Alternative Energy Capacity Targets and 2011 Annual Growth Targets

	2020 Installed Capacity (GW)	2011 Annual Growth Target
Wind	150	45%
Biomass	30	-
Solar	20	-
Nuclear	70	13.3%
Hydro	-	6.1%

Source: NDRC 2011.

Wind, for instance, is expected to have 150 GW of installed capacity by 2020 with new industrial restructuring guidelines that emphasize the development of larger-capacity turbines (>2.5 MW) in effect on June 1, 2011. The 2020 capacity target for solar is 20 GW under the draft plan, but news reports have indicated that the solar target will likely be more than doubled to 50 GW by 2020 with 10 GW by 2015 under the 12th FYP blueprint for the solar power industry (Liu, 2011). The biomass target remains unchanged at 30 GW by 2020. There have also been indications that China's nuclear capacity target which had previously been expected to be 86 GW by 2020 has since been scaled back. The Nuclear Energy Administration announced an unofficial target of 70 GW by 2020 in late 2010, which was also recommended in the draft energy plan, but an official nuclear target has not yet been announced. Besides installed capacity targets for 2015 and 2020, China has also announced year-on-year growth targets for 2011 for the key alternative energy sectors. Specifically, these growth targets include 45% for grid-connected wind, 13% for nuclear and 6% for hydro (NDRC, 2011).

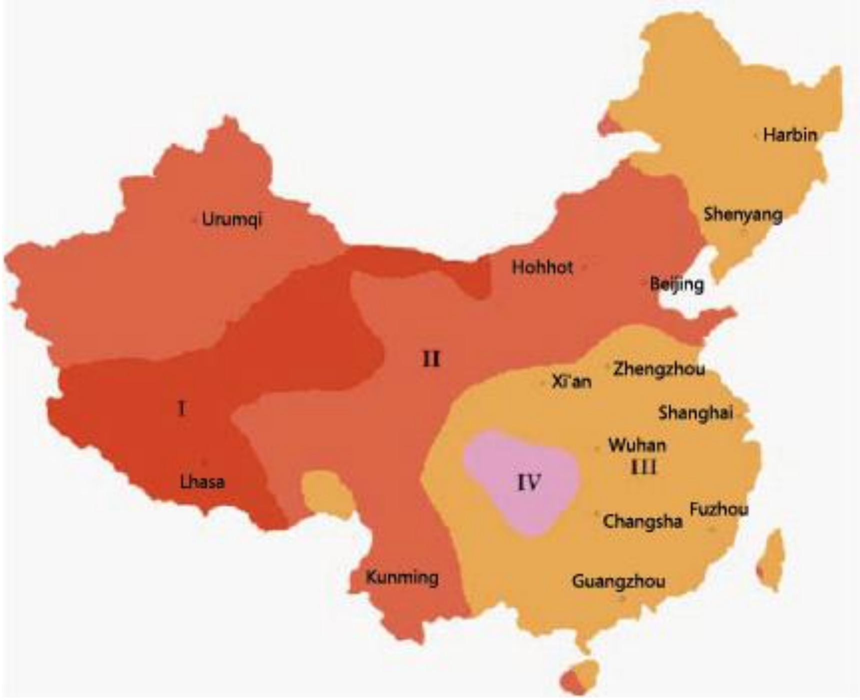
While China has continued to move forward with implementing its renewable energy development through updated targets for installed capacity, annual growth and investments, its actual progress in developing and utilizing alternative energy will be dependent on technological developments, policies and its ability to address existing implementation and expansion challenges. To better understand the unique physical and policy-related requirements and challenges that each alternative energy technology faces, an in-depth review and outlook on each of China's major alternative energy sources is presented in the next eight sections.

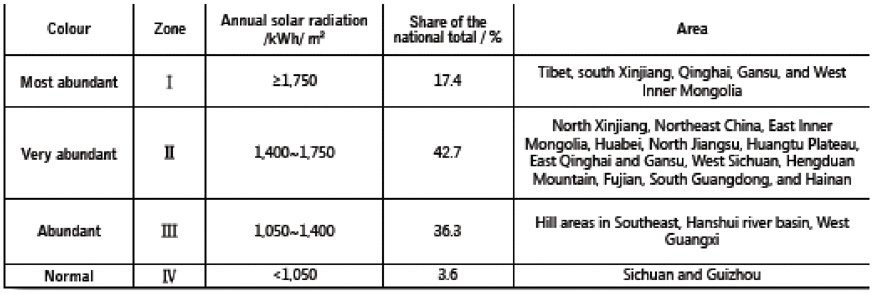
2. Solar Power Generation Technologies Outlook

2.1 Technology Overview: Current Status of Solar Technology Choices

As a relatively reliable renewable energy source and with abundant solar resources in China, particularly in the western regions, solar power generation has very high growth potential for the next two decades (Figure 3). During this time, the two major solar power generation technologies behind China's continued solar energy development will likely remain solar photovoltaic (PV) and concentrated solar thermal power (CSP). For CSP, although other countries including the U.S. and Spain have started using parabolic troughs and Australia have adopted dish stirling technology with a parabolic reflector, China has only recently started exploring small-scale solar tower demonstration project and is still conducting research on other CSP technologies. This study examines the potential of different solar PV technologies, including both crystal-silicon and thin-film PV cells, and CSP solar tower.

Figure 3. Map of China's Solar Resource Distribution





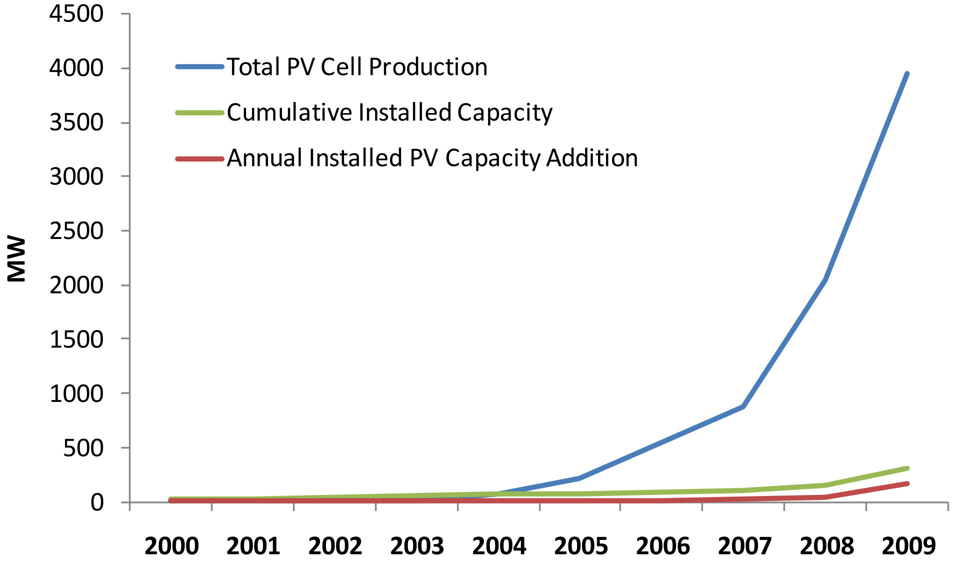
Colour	Zone	Annual solar radiation /kWh/ m^2	Share of the national total / %	Area
Most abundant	I	≥1,750	17.4	Tibet, south Xinjiang, Qinghai, Gansu, and West Inner Mongolia
Very abundant	II	1,400~1,750	42.7	North Xinjiang, Northeast China, East Inner Mongolia, Huabei, North Jiangsu, Huangtu Plateau, East Qinghai and Gansu, West Sichuan, Hengduan Mountain, Fujian, South Guangdong, and Hainan
Abundant	III	1,050~1,400	36.3	Hill areas in Southeast, Hanshui river basin, West Guangxi
Normal	IV	<1,050	3.6	Sichuan and Guizhou

Source: Li and Wang 2007, p. 28.

2.1.1 Status of Solar PV Technology

China has been an active producer of solar PV since the early 2000s, when initial industry development was driven by the Township Electrification Program for rural PV electrification in 2002. Beginning in 2004, strong demand from international PV market and influx of foreign investment helped significantly increase the production of crystalline silicon solar PV cells and modules, with domestic output of PV cells quadrupling from 100 MW in 2005 to 2 GW in 2008 (REN21, 2009). Although China's PV cell and module production capacity rose quickly after 2004, most of the production has been used to meet international rather than domestic demand. Due to high production costs and shortage of silicon material, more than 90% of China's solar PV products have historically been exported to Europe, US and other countries (Li and Wang, 2007). It is only within the last few years with a steady decline in the price of PV modules worldwide that Chinese PV products have been deployed in the domestic market with installed capacity more than tripling from 45 MW in 2008 to 160 MW in 2009 (Figure 4).

Figure 4. Solar PV Cell Production and Installed Capacity, 2000-2009



Sources: BP 2010, Zhao et. al. 2006, GreenTechMedia Research, 2010.

Solar PV technology applications in China can be divided into three main categories: off-grid remote solar PV and PV-wind hybrid systems for rural electrification, on-grid building integrated PV (BIPV) systems including rooftop PVs, and large-scale PV desert power plants. While rural PV have grown under the Township Electrification Program with 15 MW installed capacity by 2005, urban BIPV and rooftop PV generation is still relatively new in China as only a few developed cities have started pilot programs. Furthermore, rooftop PV growth will likely be capped to some extent due to competing demand for rooftop area from solar water heaters, which are already very popular amongst Chinese consumers. The largest growth potential is in large-scale PV power plants, which would also optimize the abundant solar resources in Western China.

Of the two main categories of solar PV cells, namely crystalline silicon and amorphous PV, mono-crystalline silicon (m-Si) and poly-crystalline silicon (poly-Si) have dominated Chinese production lines. M-Si cells are one of the oldest PV technologies and are made from single-crystal wafer cells and cut from cylindrical ingots which do not completely cover a square solar cell module. M-Si production tends to be more costly due to the waste of silicon and have averaged 160 RMB/kg under normal production conditions (DeBlock Consulting, 2011). Poly-Si, in contrast, is made from cast square ingots and tends to have lower production costs of around 60 RMB/kg (DeBlock Consulting, 2011). At the same time, poly-Si cells have lower conversion efficiencies of 14% to 17% when compared to m-Si, which can reach conversion efficiency of 18%. Recent studies have shown that the best m-Si cells can reach efficiencies of up to 24% in research, compared to 19% for poly-Si (NREL, 2011). In the past, mono-crystalline silicon has dominated solar PV production in China because of more mature technology with localized production, with 87% share of all silicon-based PV production in 2005 (Zhao et al, 2006). However, the m-Si share is expected to decrease over time due to the shortage of silicon and higher material requirements as it has already been the case for developed countries like the US. In fact, the share of poly-Si actually overtook mono-Si in 2008 and poly-Si comprised of 65% of total solar cell production in 2009 (Song, 2010).

Besides crystalline silicon, thin-film PV production is also becoming an increasingly important part of solar PV production in China and worldwide. In China, thin-film PV has mainly been in the form of amorphous silicon (a-Si), which has a higher light absorption rate than crystalline cells and thus results in lower production cost and energy requirement. For example, while 400-600 kWh/m^2 are needed to produce m-Si and poly-Si PV modules, only 120 kWh/m^2 is needed for a-Si PV modules. However, amorphous silicon has much lower conversion efficiencies compared to the silicon crystalline cells, with 2008 Chinese a-Si cells reaching efficiencies of only 6.9% and the best efficiencies reaching only 12% in research (Sherwani, et al., 2010; NREL, 2011). In China, amorphous silicon PV production accounted for 9% of total solar cell production in 2005 but quickly rose to account for 16% of global thin-film manufacturing capacity by 2009 (Song, 2010). Lastly, a newly emerging thin-film PV technology that will likely play an important role in China is copper indium gallium diselenide (CIGS), which is currently produced by five companies worldwide in Germany, Japan and the U.S. CIGS cells have much higher efficiencies than a-Si thin-film cells, with commercial efficiencies of 11-13% and best research efficiencies of nearly 20% (von Roedern, 2007). There is, however, no commercial production of CIGS cells in China yet.

2.1.2 Status of Concentrated Solar Power Tower Technology

Unlike solar PV, CSP is a relatively new area of solar power generation technology in China and development only recently began under the government’s push for renewable energy utilization. The extremely high upfront investment costs as well as lack of domestic technology have precluded the commercial development of CSP technologies such as solar towers and parabolic troughs. Thus far, China has only two small-scale solar tower pilot projects: a 70 kW plant in Nanjing completed in 2005 and a 1 MW solar tower project currently being implemented in suburban Beijing. Several companies are also working on developing larger commercial solar power tower plants in Northwestern China over the next five years, but large-scale commercial deployment will not likely occur until after 2015 (Wang, 2010). Nevertheless, CSP is expected to become an integral part of China’s solar power deployment given the abundant solar resources in the northwestern deserts and solar thermal targets of 100 MW and 200 MW by 2010 and 2020, respectively.

2.2 Overview of Solar Power Modeling Methodology

3.2.1 Solar PV Modeling Methodology

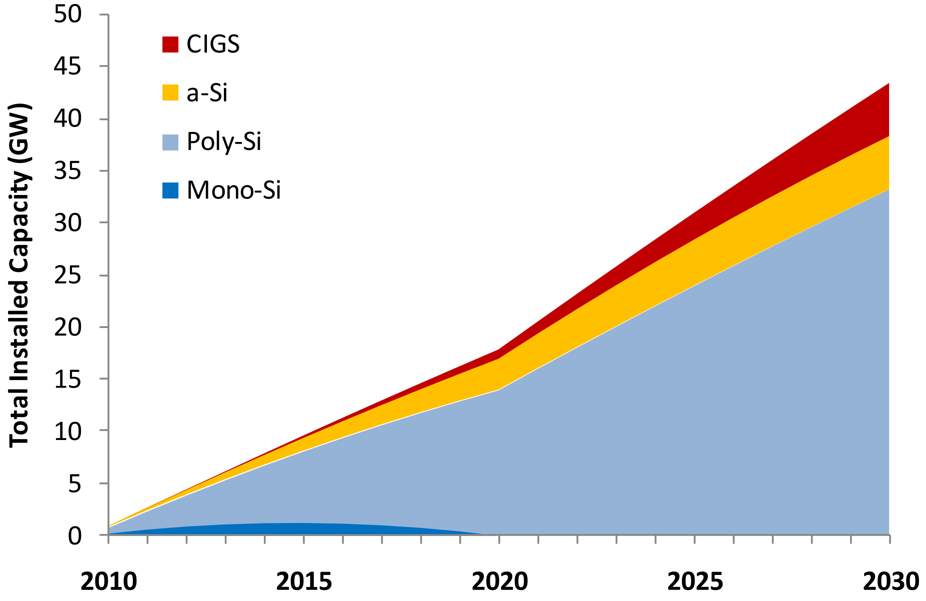
For solar PV, this study focuses on open-field solar PV power plant as the main PV technology for power generation over the next twenty years. Because there were no available studies or data on the performance of Chinese solar PV power plants, the average values of the three types of typical PV power plants (m-Si, poly-Si, a-Si) are used as the international proxy for estimating the overall system performance and land and water resource requirements for PV system in China (Sherwani, et al., 2010; Table 4). The performance values for CIGS plants are taken from another study of open-field PV power generation systems (Ito, et al., 2008). However, market developments China's PV cell production are taken into consideration in estimating the shares of different PV cells in solar PV generation through 2030 as the embodied energy and material requirements differ significantly amongst the different PV cell technologies (Figure 5). Data on the specific rare earth metal input per PV cell is taken from the Swiss Centre for Life Cycle Inventories' report on EcoInvent database (Jungbuth et. al., 2009). The material requirements for constructing the PV balance of systems (BOS) for all four types of plants is based on a study of a 3.5 MW open-field poly-Si PV plant in Arizona (Mason, et al, 2005). Lastly, different studies are reviewed to determine the EROEI as a ratio of the total energy output to energy output for each solar PV technology and an average value of international technologies is used as an international proxy for Chinese PV plants. As shown in the table below, poly-Si and a-Si PV technologies have the higher EROEIs which represent a more favorable return on energy invested to develop that technology.

Table 4. Study Assumptions on Solar PV Technical Parameters

	Mono-Si	Poly-Si	a-Si	CIS
Lifetime (yrs)	26	26	26	26
Efficiency (%)	11%	13%	7%	11%
Land Area (km2/MW)	0.023	0.023	0.044	0.028
Water (tonnes/MW)	464	494	615	25
EROEI	3.51	9.29	9.29	8.97

Sources: Sherwani, et al. 2010; Ito et. al. 2008; Jungbuth et al. 2009

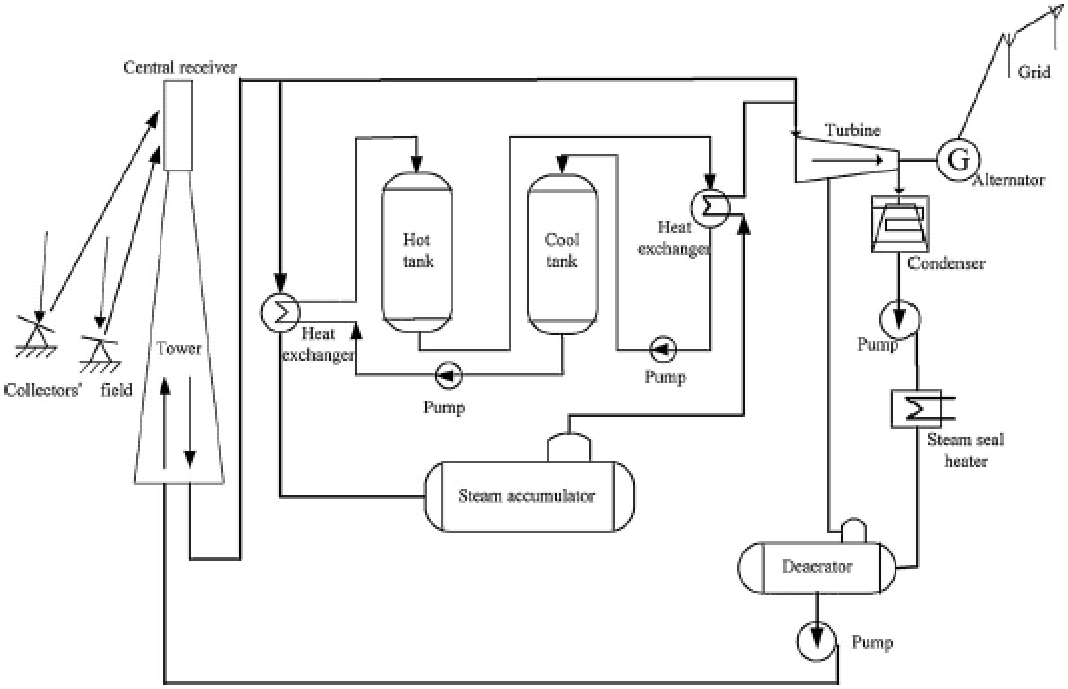
Figure 5. Projected Solar PV Capacity by Technology



3.2.2 CSP Tower Modeling Methodology

Although China currently does not have a commercial CSP tower plant in operation, a recent study conducted a life-cycle analysis of the planned 1.5 MW solar tower pilot in Beijing and provided sufficient China-specific data for evaluating the embodied energy and resource requirements for CSP tower to be used in this study (Chen, et al., 2011a). In particular, the Chen et. al. solar study involves an environmental extended input-output, hybrid life-cycle analysis of data inventory for the Beijing solar tower pilot project conducted by the project developers and sponsors. The 1.5 MW solar tower, designed by China Huadian Corporation and China Academy of Sciences and sponsored by the Ministry of Science and Technology and Beijing municipal government, was started in 2006 and could expand to 5 to 10 MW by 2015 if the pilot is successful. The CSP tower power plant consists of 100 curved heliostats which concentrate solar radiation onto a 100 meter tall receiver tower, where water is circulated as the heat transfer fluid to generate steam (Figure 6). The high pressure superheated steam is sent either to the solar energy storage system, which comprise of two oil tanks and a steam accumulator with one hour storage capacity, or the turbo-generator to generate power.

Figure 6. Components and Layout of Proposed CSP Tower in Beijing



Source: Chen et al. 2011a.

The study covers the manufacturing, operation and maintenance phases of the solar tower with an assumed lifetime of 20 years and load factor of 31%. Besides data from the Chinese study, a solar tower in Spain was also referenced in the analysis (Lechon, et. al., 2008) to ensure that the EROEI and net efficiency in the Chinese study is realistic.

2.3 Solar Power Resource and Material Requirements

2.3.1 Solar PV Requirements

Although the BOS is assumed to have the same material requirements for all four types of solar PV generation technologies, the material inputs to the PV modules differ significantly by technology (Table 5). While m-Si, poly-Si and a-Si all require silicon crystalline for the PV modules, CIGS is notably different in that it requires other rare earth metals including indium, gallium, and selenium for the PV cells and molybdenum and cadmium telluride for the back contact. Although the quantity of rare earth metal input to CIGS PV production appears lower on the order of kilograms per MW of capacity, these rare earth metals are very limited in production because they are all produced as by-products of other metals such as zinc, aluminum and lead.

Table 5. Assumed Material Intensity of PV Modules by Technology

	Mono-Si	Poly-Si	a-Si	CIGS
Si crystalline (tonnes/MW)	7.63	8.7	0.03	-
Copper (tonnes/MW)	-	-	-	0.4
Indium (kg/MW)	-	-	13.9	51.4
Gallium (kg/MW)	-	-	-	103.0
Selenium (kg/MW)	-	-	-	103.0
Molybdenum (kg/MW)	-	-	-	103.0
Cadmium telluride (kg/MW)	-	-	13.9	-

Source: Jungbuth et al. 2009; Ito et al. 2008

The total resource requirements for all four types of solar PV power generating technologies are presented in Table 6 below. In sum, solar PV would require over 1100 square kilometers of land area cumulatively through 2030. Of the raw material inputs, the largest requirements for solar PV is water at 20.2 million metric tons (Mt) cumulatively, followed by 2.5 Mt of steel, 2 Mt of concrete and nearly 1 Mt of aluminum.

Table 6. Total Resource Requirements for Solar PV Development

Unit: thousand tons unless noted otherwise	2010	2020	2030	Cumulative (Mt)
Land (thousand km2)	0.02	0.06	0.06	*1.16*
Water	398.9	975.9	945.6	*20.21*
Aluminum	16.9	43.1	51.7	*0.94*
Steel	44.7	113.9	136.6	*2.49*
Copper (BOS + Module)	6.0	15.4	18.6	*0.34*
Plastic	4.7	11.9	14.2	*0.26*
Concrete	37.9	96.6	115.8	*2.11*
Si crystalline	6.0	12.9	15.6	*0.30*

Rare Earth Metals (tons)				**(tons)**
Indium	1.1	13.9	30.6	*332.9*
Cadmium Telluride	1.1	5.4	1.0	*70.7*
Gallium	0.0	17.1	59.3	*525.5*
Selenium	0.0	17.1	59.3	*525.5*
Molybdenum	0.0	17.1	59.3	*525.5*

Of the rare earth metals, indium and gallium will most likely run into supply constraints due to limited resources and high demand from other applications. Indium virgin production has ranged from 400 to 500 tons per year, but reprocessed indium is becoming a large resource base with 1200 tons per year estimated for 2009 (Phipps, et al., 2008). Chinese smelters, in particular, are beginning to treat and process more of its tailings and slags with low Indium content (as low as 0.5% Indium concentration) to produce Indium as demand rises to meet the production of more Flat Panel Displays and other electronic applications. Gallium supply has also fluctuated in recent years, with virgin sources totaling 80 to 130 tons per year over the last five years and half of it used for wireless applications. However, there are potentially much more available resources as less than 10% of available resources are currently being extracted due to relatively low demand and prices (Phipps, et al., 2008). Selenium and cadmium telluride have higher resources with annual production of 4600 and 1200 tons per year, respectively, while molybdenum production exceeds 120,000 tons per year (Fthenakis, et al, 2009).

2.3.2 CSP Tower Requirements

Unlike solar PV power plants, CSP towers do not require special rare earth metals and most of the material and resource requirements are raw materials for various parts of the plant (Table 7).

Table 7. Material Intensity for CSP Tower

	Intensity (t/MW)	Applications
Steel	1933	Solar collectors, tower receiver, energy storage system foundation, turbo-generator system, control room
Concrete	7328	
Glass	67	Solar collectors (heliostats)
Copper	20	Transformer
Silica	0.4	Transformer

Source: Chen et al. 2011a

The solar tower is also noteworthy in that it is very water intensive with requirements of 486,667 tons of water per MW of capacity, or annual requirements of up to 127 million tons by 2030 (Table 8). This water is used as a heat transfer fluid, for cleaning the heliostat collectors, as chemical feed water, for the turbo-generator system and for circulating and auxiliary cooling water. The CSP tower also consumes auxiliary fuel for operation and maintenance, with the oil consumed comprising as much as 20% of total life-cycle energy demand (Chen et al., 2011a). As a result, the CSP tower has a relative low EROEI of only 1.05, which is comparable to the EROEI of 1.29 for a 17 MW solar tower in Spain (Lechon et al., 2008).

Table 8. Total Resource Requirements for Concentrated Solar Power Tower Development

Unit: thousand tonnes	**2010**	**2020**	**2030**	**Cumulative**
Land (thousand km2)	0.005	0.032	0.028	0.537
Water	24,333	147,559	127,555	2,482,000
Steel	97	586	507	9,858
Concrete	366	2,222	1,921	37,373
Glass	3.3	20.2	17.5	340
Copper	1.0	6.1	5.3	103
Silica	0.0	0.1	0.1	2.040

2.4 Enabling Policies for Solar Development

2.4.1 Solar PV Policies, Incentives and Programs

Over the last few years, the Chinese government has promoted solar PV manufacturing and domestic utilization through both national and provincial policies and financial mechanisms. The first major solar PV policy initiative was the Golden Sun Program launched by the Chinese Ministry of Finance and Ministry of Science and Technology (MOST) in July 2009. This program is funded by 100 billion RMB (US $15 billion) over an intended period of three years to support pilot PV projects. A total of 294 pilot projects have been funded through the program, with 50% of the investment for grid-connected PV projects and 70% of the investment for off-grid remote PV projects subsidized with government funds (Zhao et al., 2011). In 2009, China also launched the first 10 MW concession program for PV in the Gansu desert, with grid-connection prices of RMB1.09 per kWh and expectations of expanding the program to 100 MW in the surrounding regions. This has been followed with a second round of concessions, with the approval of four solar PV power stations ranging from 30 MW to 50 MW in Ningxia desert with approved prices of RMB1.15 per kWh. At the same time, subsidies of 20 RMB per Wp have also been provided to help drive the development and expansion for building integrated PV projects (REN21, 2009). Furthermore, NDRC has also invested directly in solar research and development with the approval of US$2.19 million to establish a national laboratory for silicon production in Henan province (Li, 2009). The national China Development Bank has also offered credit of up to US $19 billion to support a range of PV related projects from manufacturing polysilicon to solar panels.

In addition to the national policies, many provincial and local governments have also adopted policies and programs to promote the use of solar PV power. Shanghai municipal government launched one of the earliest programs to promote rooftop PV installations, with the initiation of the Shanghai 100,000 Rooftop program in late 2006. In February 2009, Qinghai province approved a plan to develop and expand the solar energy industry with 13 major programs under development. In May 2009, Jiangsu province also set goals of 50 MW for BIPV and rooftop PV for 2010, and 200 MW (including 180 MW for rooftop PV) for 2011 (Zhao et al, 2011).

2.4.2 CSP Policies

Enabling policies for future CSP development has primarily been in the form of direct government funding for demonstration projects, including the 1.5 MW solar tower pilot in Beijing. In addition, government funding for research and development is expected to continue through the 12th FYP period with preliminary commercialization targeted for 2015. For example, MOST is funding research on solar thermal power systems with lower boiling point working fluids and components such as trough concentrator absorber tubes, as well as examining the feasibility of other CSP technologies such as parabolic troughs, dish/stirling engines and line-focusing Fresnel reflect systems (Wang, 2010).

2.5 Remaining Challenges to Solar Power Deployment

2.5.1 Solar PV

In spite of the various supporting government policies and subsidies initiated in the last few years, China's solar PV industry still faces three major challenges for continued growth. First, the Chinese solar PV manufacturers face an unfavorable production market structure with a limited role in the supply chain where 90% of raw silicon materials are imported and 90% of products are exported (Li, 2009). The high dependence on foreign markets for both the supply of raw materials and the demand for finished products severely undermines Chinese firms' competitiveness. On one hand, domestic manufacturers' heavy reliance on imported silicon increases their vulnerability to international silicon prices shocks which could make up as much as 60% of the PV module's total production cost (Li, 2009). Although there have been government efforts to expand domestic silicon production, Chinese silicon manufacturers currently have very small production capacity and do not benefit from economies of scale. On the other hand, unless there is an uptake in domestic demand for solar PV systems, government supported growth of the PV industry will not translate into solar PV utilization.

Second, Chinese silicon and PV manufacturers also face a host of technical challenges that limit the future development of solar PV. Silicon producers are still using relatively outdated and energy-intensive production processes, which undermine their competitiveness with foreign silicon suppliers. For Chinese PV cell and module producers, production technology for advanced thin-film PV cells such as CIGS is controlled by US, Japanese and German companies and domestic technologies have not yet been developed in China (NREL, 2010).

Third, due to the relatively recent launch of many solar PV policies and programs and the lack of a strong foundation for program implementation, policy and institutional barriers have emerged to threaten their success. For solar PV power plant developers, a cumbersome approval process and persistent uncertainty over the feed-in tariff for grid-connected projects have slowed development. A new project is subjected to a lengthy multi-step, multi-level planning and approval process, including a feasibility study for NDRC, administrative licenses from urban planning bureaus, environmental protection bureaus, real estate bureaus and finally approval from the grid operator for grid connection (Li, 2009). As a result of this complex process, solar projects considered for the Golden Sun Program have been delayed or cancelled, with 39 projects cancelled in November of 2009 due to “inability to implement” (Bloomberg, 2011). Likewise, even after two years of planning, the Shanghai 100,000 Rooftop program achieved only one successful rooftop installation due to lack of subsidies for rooftop installations and even double charging residents for generating their own electricity (Shanghai Government, 2011).

2.5.2 CSP Tower

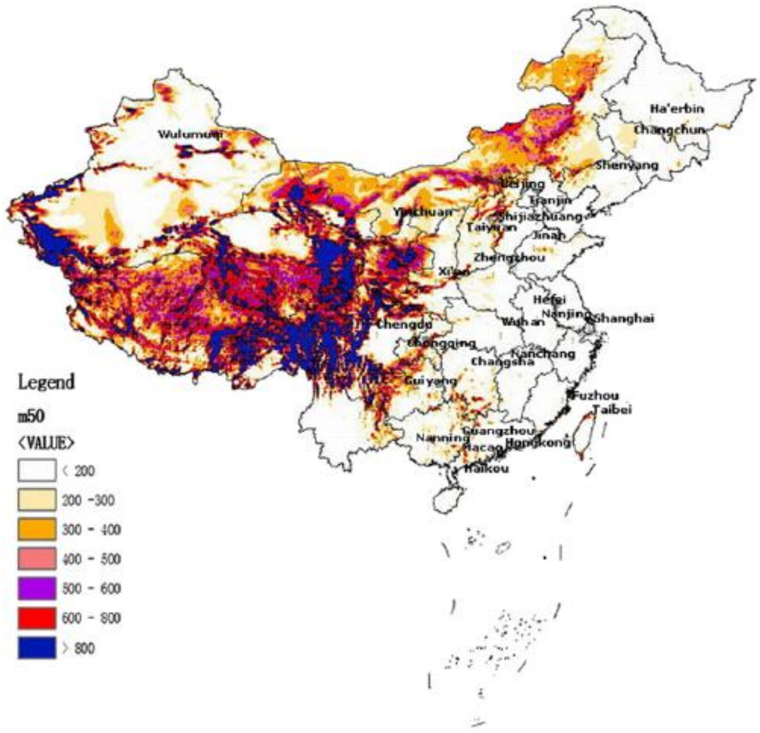
Similar to solar PV, the major challenges to CSP tower development are also multi-faceted and include technical, economic and policy challenges. For China, technical limitations have thwarted the large-scale deployment of CSP with only two small-scale solar tower pilot projects of less than 2 MW in Nanjing and Beijing. More specifically, China still need to develop and test key technologies such as large power rating receivers and high-temperature thermal storage systems before CSP tower generation can be expanded to the scale of 10 to 1000 MW needed for commercialization. Besides the technical limitations, CSP deployment also faces economic barriers in that current costs are prohibitively high and need to be reduced by over 50% before it can be considered competitive with coal-fired generation (Wang, 2010). Combined with the absence of any policies or subsidies for CSP development, commercialization and deployment of large-scale generation from CSP towers will not likely occur in the short-term.

3. Wind Power Generation Technologies Outlook

3.1 Technology Overview: Current Status of Wind Power Technologies

As the renewable industry that has undergone the fastest growth in the last ten years, China’s wind industry has grown significantly both in terms of production capacity and technological development. Wind turbines have actually been used in China for rural, off-grid electricity generation since the late 1970s with more than 170,000 small turbines of below 10 kW still in operation (Xu et al., 2010). By 2005, China had developed the capacity to manufacture wind turbines of over 600 kW and the government started actively promoting wind power development as a key renewable energy. As with solar, China’s wind resources are predominantly located in the northwestern and northeastern regions as well as off the southeastern and southwestern coast (Figure 7). In order to maximize the utilization of its wind resources, China will have to continue expanding its onshore wind power generation, which has grown rapidly since 2005, and develop its offshore wind power generation which has only started recently.

Figure 7. Annual Density of Wind Power at Height of 80 Meters

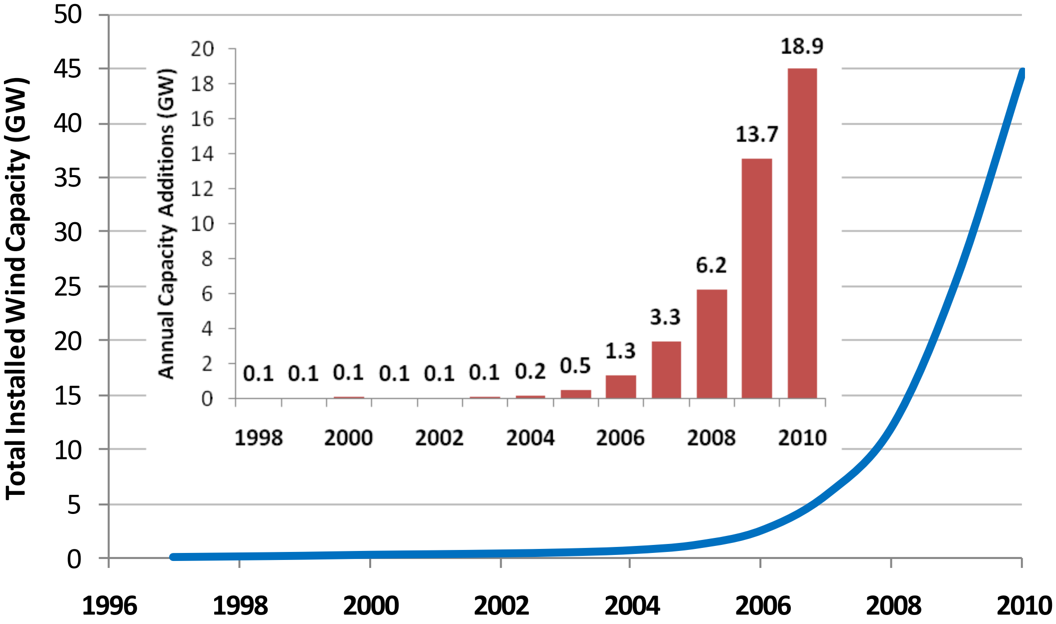


Source: Xu et al. 2010, p. 4440.

3.1.1 Onshore Wind Power Generation

Onshore wind power generation has been under development in China for the past 30 years, with a recent policy-driven boom in manufacturing and installed capacity. In particular, as described in the previous section, China's total onshore wind power capacity has more than doubled annually since 2005 with annual average growth rate of 104%. By 2010, total installed wind capacity in China totaled 44.73 GW with 18.93 GW added in 2010 alone (Figure 8).

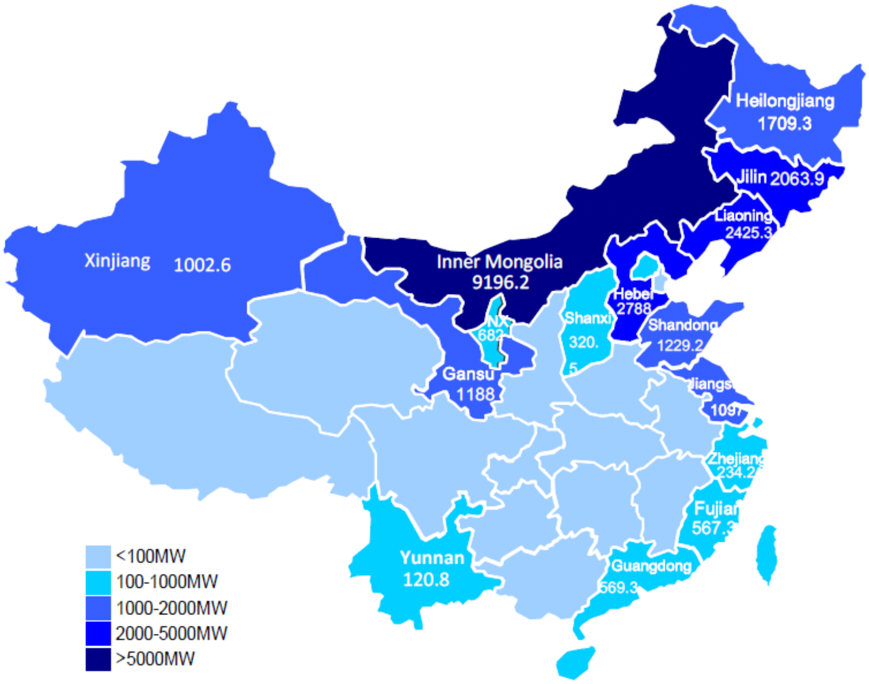
Figure 8. Total Installed Wind Capacity and Annual Capacity Additions, 1997-2010



Source: BP Statistical Review of World Energy 2010.

Most of China's current installed wind capacity is located in the northwestern regions of Xinjiang and Inner Mongolia with some installed capacity along the northeastern coast (Figure 9)

Figure 9. Installed Wind Capacity by Province in 2009



Source: Cheung 2011.

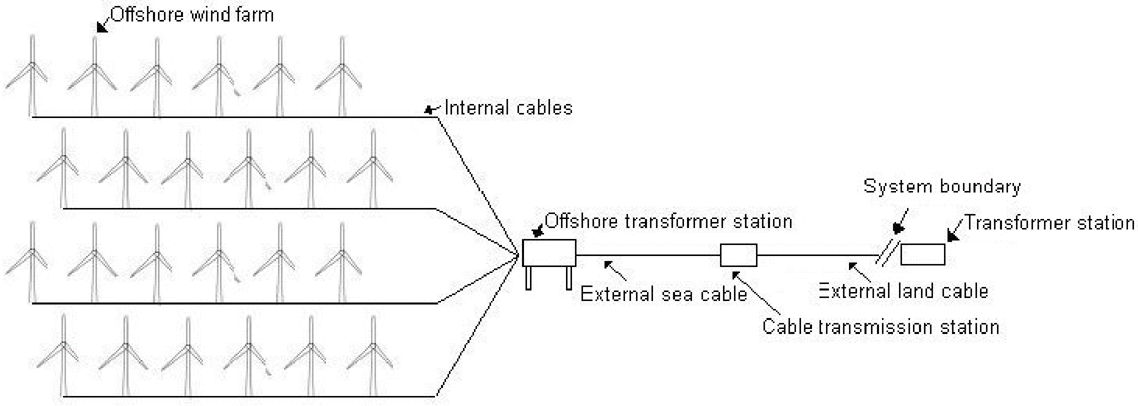
An onshore wind turbine consists of the rotor, which includes three blades made of resin and fiberglass and a nose cone; the nacelle which encloses the main shaft, gearbox, generator and transformer; the tower which supports the turbine assembly and the foundation for the entire turbine. A substation with an 110kV step-up transformer that helps decrease line loss and the wind farm control system are typically also located on an onshore wind farm. The size of commercial onshore wind turbines worldwide have been rising over time to maximize the utilization of wind resources, beginning with 500 kW turbines in 1990s and rising to 2 MW by the late 1990s and as large as 5 MW in 2005 (BWEA, 2005). In China, the evolution of wind turbine sizes have been slower but many of the leading domestic manufacturers including Sinovel and Goldwind, ranked second and fourth global wind manufacturers, have started producing large megawatt turbines on the order of 3 MW.

3.1.2 Offshore Wind Power Generation

Although countries such as Denmark and the United Kingdom already have offshore wind power generation facilities, China has only recently started to explore offshore wind with a total of only 63 MW of installed capacity in 2009. Nevertheless, offshore wind will become an increasingly important component of China's renewable portfolio with the China Meteorological Administration estimating total offshore wind potential of 200 GW (Cheung, 2011). Given that most of this offshore wind potential is located off China's eastern coast, where many of the largest cities and population centers are located, this technology has inherent advantages its close proximity to demand sources and access to better grid infrastructure. In recognition of these advantages, offshore wind shifted from a research and development phase to actual commercialization and grid integration in 2010 with Shanghai's 102 MW Donghaiqiao offshore wind farm becoming the first operating large-scale offshore wind farm. In October 2010, China announced plans to construct four offshore wind farms in Jiangsu province using Sinovel, Goldwind and Shanghai Electric turbines with a total expected capacity of 1 GW by 2015. As of May 2011, the Chinese Renewable Energy Industries Association expects that total offshore wind installed capacity will reach 5 GW by 2015 and 30 GW by 2020 (Xinhua, 2011a).

In terms of wind turbine technology, there are a few key design and technical differences between offshore and onshore generation. Because offshore wind tends to flow at higher speeds which translates into much higher production of electricity (with generation having a cubed proportional relationship to wind speed), larger wind turbines on the order of 2 to 5 MW capacity are commonly used for offshore wind farms. In actual size, offshore wind turbines typically have taller towers with heights of greater than 200 feet and longer blades (ANL, 2011). In addition, the foundation for offshore wind turbines are built on piles that are driven deep into the seabed and components such as the tower and nacelle need to be strengthened against wind-wave interactions and corrosion. Offshore wind farms also have a very different configuration for connecting to the grid, with undersea collection cables connecting multiple turbines, transporting the electricity to a transformer station where it is converted to high voltage for transmission to an external (on land) transformer station for distribution (Figure 10)

Figure 10. Sample Configuration for Electricity Transmission for Offshore Wind Generation

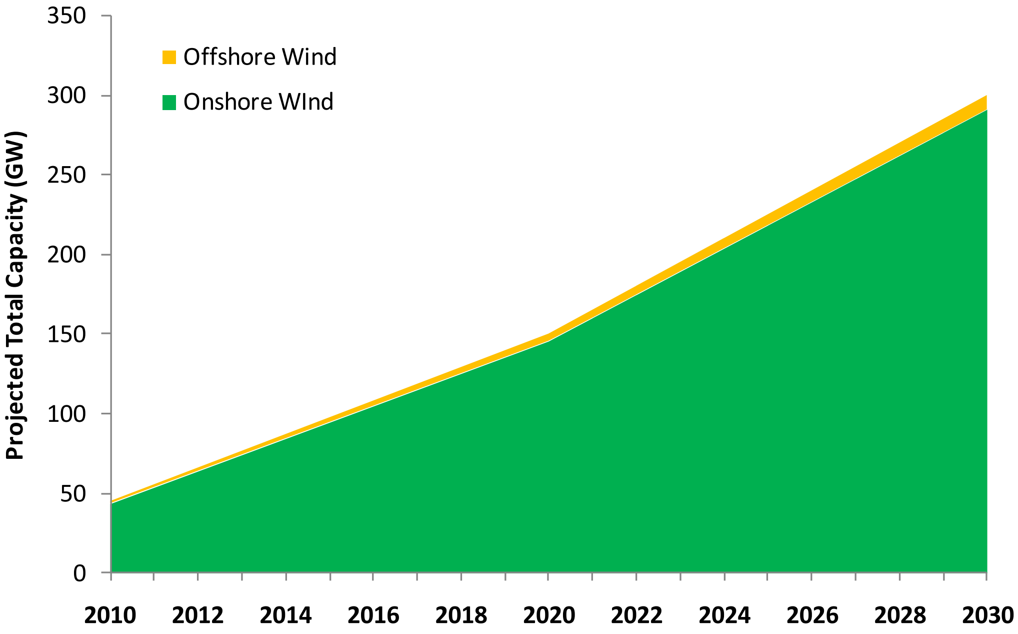


Source: Vestas 2006, p.13.

3.2 Modeling Methodology

In modeling the total resource and energy requirements of wind power generation, an implicit assumption is the technology shares between onshore and off-shore generation. For this study, the proportional split between offshore and onshore wind power targets stated in the Medium and Long-term Development Plan is used for 2010 through 2030 (Figure 11). This assumption appears reasonable given that offshore wind only started commercialization last year and there remains an overcapacity of onshore wind turbine production.

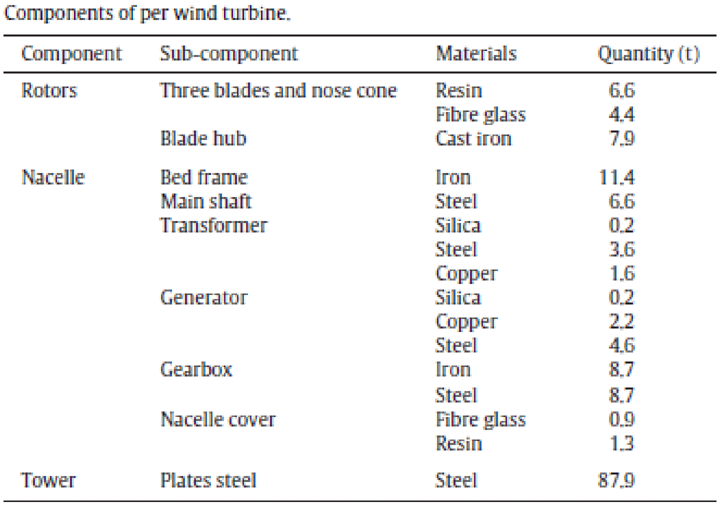
Figure 11. Projected Wind Capacity by Technology, 2010-2030



3.2.1 Onshore Wind Modeling Methodology

To model the expected performance and resource requirements for onshore wind power generation, a recent Chinese case study of a planned 30 MW onshore wind farm in Yulin city of Guangxi autonomous region was used as a proxy for future onshore wind farms (Chen et. al., 2011b). The specified onshore wind farm includes 24 wind turbines with 1.25 MW generating capacity connected to a 35 kW box-type transformer and substation. The Chen et. al. 2011 wind study has detailed suppliers' data on the total raw materials used to construct the wind turbines and the wind farm, from which material intensities per MW of capacity can be derived. The study also uses an extended environmental input-out analysis to analyze the life-cycle fossil fuel energy requirements and calculate an implicit EROEI for the wind farm over its 20 year lifecycle. The specific stages included in the analysis consist of: wind turbine and substation component manufacturing, transport of equipment to the wind farm site, construction of the tower foundation and substation, operation and maintenance including auxiliary power consumption and line loss, and decommissioning and disposal and partial recycling of key materials.

Table 9. Reported Material Input per 1.25 MW Onshore Wind Turbine



Components of per wind turbine.

Component	Sub-component	Materials	Quantity (t)
Rotors	Three blades and nose cone	Resin	6.6
		Fibre glass	4.4
	Blade hub	Cast iron	7.9
Nacelle	Bed frame	Iron	11.4
	Main shaft	Steel	6.6
	Transformer	Silica	0.2
		Steel	3.6
		Copper	1.6
	Generator	Silica	0.2
		Copper	2.2
		Steel	4.6
	Gearbox	Iron	8.7
		Steel	8.7
	Nacelle cover	Fibre glass	0.9
		Resin	1.3
Tower	Plates steel	Steel	87.9

Source: Chen, et al. 2011b, p.2324.

An additional area of modeling not included in the Chinese wind study but is included in this study is the use of neodymium, a rare earth metal, for the permanent magnets in the wind turbine generator. Based on information about the magnet use in existing 3.5 MW Scanwind turbines, it is assumed that 0.8 kilograms of neodymium-iron-boron magnetic material is needed per kW generated by the turbine, of which 25% of the magnet is pure neodymium by mass (Hatch, 2009; Lifton, 2009).

3.2.2 Offshore Wind Modeling Methodology

Since the first operational offshore wind farm was initiated only in mid-2010, China-specific data on offshore wind was not available for the resource requirement modeling in this study. Instead, a life-cycle analysis study of a 3 MW Vestas turbine designed for offshore wind farm is used as a proxy for Chinese offshore wind (Vestas, 2006). This Vestas study presents material inventory and life-cycle energy analysis of 3 MW offshore turbines sited approximately 14 km from the coast. However, due to different manufacturing designs and locations, there are differences in the material inventory of the Vestas offshore turbine and Chinese onshore turbine, including missing Vestas data on concrete, steel, resin, fiberglass and silica input to offshore turbines. To be consistent in modeling offshore and onshore wind turbine technologies, the derived material intensity from Chinese onshore turbines is applied to offshore turbines as it is assumed that the basic turbine structure is largely the same for both types and differs primarily in capacity. However, it should be noted that the lack of concrete and steel intensity data for offshore wind turbines likely result in an underestimated material requirement given that offshore turbines need piles and greater structural support than onshore wind turbines. The same neodymium material requirement as onshore wind turbines is also assumed for offshore wind turbines.

3.3 Wind Power Generation Resource Requirements

As discussed previously, the raw materials (concrete, steel, iron, etc.) and rare earth material input intensities to manufacturing wind turbines are very similar between onshore and offshore wind turbines (Table 10). There are some differences in the material intensity of iron for the foundations of offshore versus onshore turbines and in copper for transformer and generators.

Table 10. Assumed Material Intensity for Wind Turbines (tons/MW)

	Onshore	Offshore
Concrete	638.9	638.9
Steel	122.2	122.2
Iron	22.4	39.0
Resin	6.3	6.3
Fiber Glass	4.2	4.2
Silica	0.32	0.32
Copper	3.0	0.2
Aluminum	0.52	0.65
Water	1766.7	3766.7
Neodymium Magnet (Nd2Fe14B) of which:	0.80	0.80
Neodymium	0.20	0.20

Source: Vestas 2006; Chen et al. 2011b; Hatch 2009; Lifton 2009.

In addition, offshore wind turbines have higher water requirements than onshore turbines but are assumed to have no land footprint as it is located off the coast. For onshore wind farms, the land requirement of 0.27 square kilometers per MW of generation capacity from the Chinese study is much higher than international levels of only 0.17 square kilometers per MW found in Denmark (Fthenakis and Kim, 2009). Thus, we assume that the land requirements for China's onshore wind farms will decline over time to reach Danish levels by 2030 as a result of better wind farm configurations with minimized spacing between turbines. The estimated land footprint for wind farms does not preclude the use of unoccupied land between turbines for grazing, agriculture and recreation.

Table 11. Total Resource Requirements for Onshore and Offshore Wind Power Development

Unit: thousand tons unless noted	***2010***	***2020***	***2030***	***Cumulative***
Land (thousand km2)	4.9	2.2	2.5	57
Water	34,482	19,229	27,400	500,775
Concrete	12,061	6,726	9,584	175,155
Steel	2,307	1,286	1,833	33,497
Iron	432	241	343	6,277
Resin	119.3	66.5	94.8	1,733
Fibre Glass	80.0	44.6	63.6	1,162
Silica	6.0	3.4	4.8	88
Copper	55.8	31.1	44.3	810
Aluminum	9.8	5.5	7.8	142
Neodymium Magnet ($Nd_2Fe_{14}B$) of which:	15.1	8.4	12.0	219
Neodymium	3.7	2.1	2.9	54

The other main difference between onshore and offshore wind turbines is the EROEI of the two technologies. The China-specific onshore wind farm had an overall EROEI of 21.3, which is consistent with the average EROEI of 25.2 found in a survey of over 100 studies on wind generation (Kubiszewski, et al, 2010). The Vestas offshore wind power plant study, in contrast, had a higher EROEI of 35.3, which is used as a proxy for the Chinese offshore wind power plants.

3.4 Policies Enabling Rapid Wind Development

3.4.1 Policies Targeting Onshore Wind Development

Since the Chinese government first started supporting wind development with various policies, incentives and administrative programs, most of the initial focus has been on pushing forward onshore wind power generation. Specifically, China's wind policy started with the 2003 concession program for wind farms with greater than 100 MW capacity, where project developers were encouraged to submit bids for the concession. Only projects of over 50 MW requires approval from NDRC and projects with less than 50 MW of capacity only have to be approved by provincial governments (REN21, 2009). However, this resulted in bids that were below the actual project costs with the resulting prices set at as low as 0.4 RMB per kWh. By 2008, four more rounds of concession had been conducted with the setting of "government guided" prices through competitive bidding. Through these five concession rounds, a total of 49 wind farm projects were approved in six provinces. In 2009, however, NDRC recognized the need to refine concession bidding prices and thus issued the "Improvement of Wind Power Tariff Regulations." This announcement called for benchmarked feed-in tariffs based on regional wind resource availability. As a result, the current wind feed-in tariff system is divided into four regions for feed-in tariffs based on resource availability with the lowest tariff of 0.51 RMB per kWh in the regions of Inner Mongolia and parts of Xinjiang with the best available resources and the highest tariff of 0.61 RMB per kWh for regions with least favorable wind resources (Martinot, 2010).

Another policy that helped foster the development of China's wind turbine manufacturing industry is the 70% local content requirement issued by NDRC in 2005 to promote domestic production. Specifically, this policy required that 70% of the value content of wind turbines sold in China be manufactured domestically and resulted in major international manufacturers such as GE, Vestas, Gamesa and Siemens setting up joint ventures or factories in China. This policy has been so successful that it was rescinded in 2010 because it was no longer necessary.

Because the wind turbine manufacturing industry has grown so rapidly over the last five years, recent efforts have focused on increasing the scale of wind turbine production. In 2008, for instance, the Ministry of Finance offered financial incentives for the first fifty domestically manufactured and grid-connected wind turbines of over 1 MW with RMB 600 award per kW of capacity (REN21, 2009). The Ministry of Finance also set reinvested the revenue from taxes on imported large wind turbines of greater than 2.5 MW in technology development, innovation and capacity building. Most recently in 2011, the NDRC Guideline Catalogue for Industrial Restructuring mandated that preferential policies for encouraging wind development will only apply to manufacturers of wind turbines and related components for turbines of greater than 2.5 MW (Xinhua, 2011b).

3.4.2 Policies Targeting Offshore Wind Development

With a relatively mature onshore wind manufacturing industry that is beginning to experience overcapacity, China has shifted its wind policy to focus on advancing offshore wind energy development. After the completion of the first offshore wind project of 1.5 MW northeast of Bohai Sea in 2007, the first commercial offshore wind farm went into operation only last year. Offshore wind development has gained more attention and policy emphasis in the last few years, with the National Energy Administration asking each coastal province to develop an offshore wind development plan for 2020 with the guidance of National Energy Bureau and National Marine Bureau. In 2010, the first concession tendering process started with four projects sited in Jiangsu province and a total capacity of 1 GW. This included two projects of 300 MW each and two intertidal (i.e., depth of less than 5 meters) projects with 200 MW each. At the same time, major wind turbine manufacturers such as Goldwind began redirecting their investments away from onshore wind projects and towards offshore wind projects, with 145 million RMB shifted to a production base in Dafeng city in Jiangsu. This offshore production base is intended to focus on R&D for 3.6 MW and 6 MW offshore wind turbines with expected annual production capacity of 450 MW (Xinhua, 2011c).

3.5 Remaining Challenges for Wind Energy Development

In spite of the recent boom of China's wind industry following various supporting policies and programs, future development of wind energy – particularly to meet the 3% non-hydro fossil fuel goal – still faces many daunting challenges. The nature and geographic distribution of wind resources present obstacles for integration into China's power system. Wind's intermittent, variable and non-dispatchable nature combined with the need to continuously balance power supply and demand for maintaining system stability and power quality highlights the special considerations needed to accommodate wind integration.

3.5.1 Grid Connection and Integration Challenges

The unpredictability of wind and unclear cost-sharing arrangements for transmission and connection costs create disincentives for grid operators to integrate wind into the grid. Moreover, wind resources' geographic concentration in unpopulated areas like Inner Mongolia, where transmission and grid connections are limited, has created surplus wind generation capacity and developers face stiff competition for grid connections. This in turn has contributed to two major problems: a sizable share of installed wind capacity that is not connected to the grid and curtailment poses a persistent barrier to economic viability of wind farms even for grid-connected capacity. In western Inner Mongolia where local supply often exceeds demand from its small population, surplus wind power is a common problem. The disparate distribution of hydropower, concentrated throughout southern and eastern China, and lack of natural gas and pumped hydro resources as backup storage capacity leaves grid operators with only two options in addressing surplus wind power: export to neighboring grid or curtail to maintain balance (Li et al., 2010). But because the adjacent North regional grid only has two transmission lines to the independently operated Inner Mongolia grid, only small amounts of surplus wind electricity can be exported and the remaining surplus has to be curtailed. During the winter when combined heat and power plants have to remain operating, wind power may be curtailed to as low as only 20% in the region which severely undermines the profitability of wind projects even with feed-in tariffs (Cheung, 2011).

3.5.2 Technical Challenges to Wind Development

While the nature of wind power generation cannot be changed, technologies that can help mitigate variability and unpredictability have played a limited role in easing integration due to technological constraints. Despite having two of the world's top ten wind turbine manufacturers, much of China's wind industry still use imported technology for manufacturing key components such as gearboxes, converters and spindle bearings (Watson et al., 2011). This is particularly true for small wind power manufacturers, which do not have capabilities to produce turbines with capacity of 2.5 MW or greater and will not be able to contribute to offshore wind development. Furthermore, technical capabilities for preserving grid stability with high penetration of renewables such as low voltage ride-through, active power control systems, and reactive power compensation devices have not been utilized by China's grid-connected wind farms (Cheung, 2011). Likewise, China currently lacks a wind forecasting model with sufficient precision to help guide grid operators in scheduling the dispatch of ancillary units in part because shorter-term, site-specific resource data from developers is not shared with grid operators. Technological innovation in the wind industry in the near future will also be dependent on the human capital available in R&D both in industry and in basic research in university programs, research institutes and academies (REN21, 2009).

3.5.3 Policy and Institutional Barriers to Wind Development

The influx of wind enabling policies has contributed greatly to the growth of installed wind capacity but lack of clarity, implementation challenges, and unintended consequences have also hampered wind development. The wind project approval process set up for the concession program, where projects smaller than 50 MW can be approved through a faster process by the provincial government, have resulted in lack of coordination and imbalanced development between wind generation and grid development. Since only 10% of the 60 GW wind farm projects approved by provincial governments are examined and approved by NDRC, the vast majority of small wind farm projects is not considered in the national grid development plan and thus lack access to grid connections (Xinhua, 2011d). China has started to address this issue with the National Energy Bureau currently drafting regulations to standardize the approval process for small wind farm projects, but the policy impacts will be unclear in the short-run. Another major area of concern in wind policies is the continuing ambiguity over the integration and cost-sharing arrangement mandated in the Renewable Energy Law and its impact on grid connections for new wind farms. In spite of the clause requiring grid operators to purchase all grid-connected renewable energy, curtailment of wind has persisted both for technical reasons and for political reasons. Wind curtailment may persist even after 2010 revisions of the Renewable Energy Law that “obliges” grid operators to guarantee the purchase of minimum amount of renewable electricity generation because the specifics and implementation process is still unclear (Cheung, 2011). The continued burden of integration costs, not only for building new transmission lines but also for coal-plant cycling needed to accommodate wind generation on the grid, alone continue to discourage wind integration (Kahrl, et al., 2011).

3.5.4 Resource Constraints

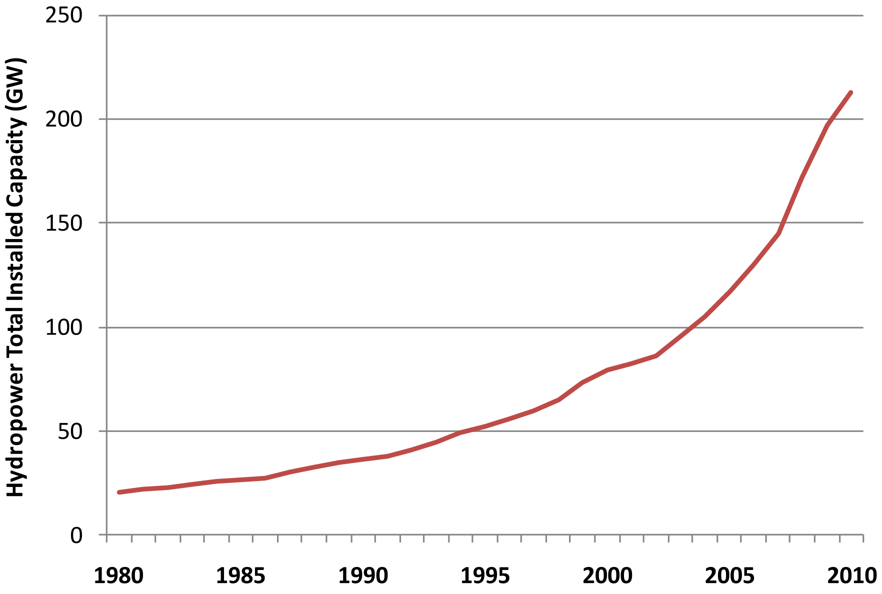
A potential resource constrain for wind power is in neodymium, a light rare earth element that forms the basis of high-strength permanent magnets with rising demand from in wind turbines as well as motors, generators, hybrid cars including the Toyota Prius and high efficiency appliances but increasingly short supply. Before the wind industry expansion, China was already a key producer in neodymium-iron-boron permanent magnets with nearly 50 thousand tons produced in 2007 and accounting for over 80% of the global supply (Shenzhen Juke Co., 2008). In 2010, the estimated global annual production of neodymium was 21,307 tons, of which 90% of extraction and processing is in China, with almost 10,000 more tons of production from non-China sources possible by 2015 (DOE, 2010). Although the estimated annual requirement of 3000 tons of neodymium for permanent magnets for China’s onshore and offshore wind turbines by 2030 is less than the expected production level, there will be competing demand for neodymium from hybrid vehicles which require 1.5 kilograms per vehicle (DOE, 2010). Moreover, neodymium extraction and processing has severe environmental consequences that are already being felt in villages in Inner Mongolia. In Baotou, for example, seven million tons of waste including radioactive tailings from neodymium processing is discharged annually into a local lake with toxic dust and airborne radiation (Parry, 2011). These environmental health problems will need to be addressed as China seeks to increase its neodymium output.

4. Hydropower Technologies Overview

4.1 Technology Overview: Current Status and Outlook

China started its hydropower development in the mid-1900s and has continued to rely on hydropower as an important alternative energy source to fossil fuels. Since 2000, hydropower growth has increased with most year-on-year growth rates exceeding 10%. By the end of 2004, China reached the number one ranked gross installed hydropower capacity in the world with 105 GW total after the 300 MW Gongboxia Hydropower Station went into operation. Over the last five years, China's total installed hydropower capacity has doubled to 213 GW by the end of 2010 (Figure 12). In part, this was due to the addition of the 26 generator sets in the Three Gorges Dam hydropower station with total capacity addition of 18.2 GW by the end of 2008. In addition to this reported conventional hydro installed capacity, China also had 13 GW of pumped hydro installed capacity in 2009 and over 40 GW of small hydropower that is not grid-connected and primarily for rural use[1] (Vermeer, 2011).

Figure 12. China's Hydropower Installed Capacity, 1980-2010



Source: NBS 2011.

There are two main types of hydropower installations including conventional reservoir dams, which use hydraulic head to control hydroelectricity generation, and run-of-river dams, which use the natural flow of water in streams and rivers to generate electricity. Given the large scale of China's hydroelectricity generation needs, most of the hydropower is from large reservoir dams constructed along major rivers including the Yellow River, Yangtze River, Wujiang River, and Hongshui River. More specifically, China has built a large number of concrete and earth-rock

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[1] The definition of small hydropower varies by country and has also changed over time in China. Prior to 1990, small hydro in China was defined hydro with capacity of up to 50MW but this definition has been revised over time and small hydro currently is defined as having capacity of up to 25 MW (Hicks, 2004).

dams with a height of greater than 100 meters and the Ertan Hydropower Station in Sichuan province marked the completion of the first concrete parabolic double-arch dam with a height of greater than 200 meters in China (Chang et al., 2010). China currently has 15 hydroelectric projects of over 1 GW under construction with all projects scheduled to be finished by 2015.

4.2 Hydropower Modeling Methodology

In light of the different types of hydropower generation, this study considers only conventional large hydroelectric generation and does not include small hydro, which are often not grid-connected, or pumped hydro, which is relatively small in scale compared to large hydro. Within the conventional reservoir hydro category, however, we do distinguish between three general types of dams in our analysis: medium dams with installed capacity between 25 MW and 50 MW, large dams with total installed capacity of up to 3.5 GW and extra-large dams with total installed capacity of greater than 3.5 GW. The distribution of China's conventional hydropower capacity by these dam types are based on the composition of the largest hydropower plants reported in the 2008 China Electric Power Yearbook as compared to the total installed capacity for 2007, including 28% extra-large dams and 70% large dams. The remaining 2% is assumed to be from medium dams and these shares are assumed to remain relatively constant through 2030 as it has been the case historically.

The three prototype dams examined are based on data and analysis in two publications, one Chinese LCA study on a medium and large dam and another Brazilian LCA study on an extra-large dam. More specifically, the Chinese LCA study uses an economic input-output lifecycle analysis (EIO-LCA) study of a medium 44 MW rock-filled dam built in China in the 1990s and a large 3.6 GW concrete arch dam built in the 2000s (Zhang et. al., 2007). This LCA study used detailed cost data from project-specific budgetary reports in conjunction with the Carnegie Mellon EIO-LCA model to derive the energy and greenhouse gas emissions through the two dams' lifecycle stages and is used as the basis for medium and large dams in our study. For extra-large dams, an international proxy based on a life-cycle inventory study of Brazil's 14 GW Itaipu dam is used as there are no studies or detailed data on China's recently constructed extra-large dams (Riberio and da Silva, 2010). The technical parameters of these three dams are shown in Table 12 below.

Table 12. Basic Parameters of Three Modeled Hydro Dam Types

		Medium Dam	Large Dam	Extra Large Dam
Actual Geographic Location:		Zhejiang, China	Southwest China	Brazil
Constructed in:		1993-1998	mid-2000s	1980s
Installed Capacity	*MW*	44	3,600	14,000
Lifetime	*yr*	50	100	100
Dam Type		Rockfill	Concrete arch	Concrete gravity
Height	*m*	88	305	196
Reservoir Area	*km2*	0.44	9.44	1350

Source: Zhang et al. 2007; Ribeiro and da Silva 2010.

Although two different studies were used for evaluating potential impact of hydroelectric technologies in China, both studies used similar boundaries in their life-cycle analysis with the inclusion of manufacturing of construction materials, dam construction and operation and maintenance. Since decommissioning of large dams are rare and reference data is not readily available, this last stage was excluded in both studies. Due to methodological differences in the use of EIO-LCA modeling where specific physical material intensities are not reported in the Chinese study, a similar sized rock-filled reservoir dam in Sweden was used as a proxy for estimating material intensities for the medium and large dam (IEA, 2002). However, the China-specific EROEI of 7.5 and 48.7 calculated from the Zhang et. al. study is used in the energy analysis of the medium and large dams.

4.3 Hydropower Resource Requirements

As large-scale projects with a much longer lifetime than most of the other power generation technologies, hydroelectric dams tend to be relatively material intensive. The construction of new medium, large and extra-large dams require sizable amount of raw materials such as iron, cement, steel and copper (Table 13). Hydroelectric dams also require significant amount of water for both construction and operation, but is much more difficult to quantify because of allocation and boundary issues. Over the next two decades, a total of 44 Mt of water along with 12 Mt of copper, nearly 8 Mt of cement, 4 Mt of steel and 3 Mt of copper may be needed to build and operate all of China’s dams.

Table 13. Total Resource Requirements for Hydropower Development

Unit: thousand tonnes unless noted	***2010***	***2020***	***2030***	***Cumulative***
Land (thousand km2)	0.5	0.3	0.2	5
Water	2,469	2,153	1,993	43,934
Lead	87	48	27	835
Iron	1,277	694	399	12,209
Copper	343	186	107	3,280
Steel	406	221	127	3,886
Cement	794	432	248	7,589

4.4 Policies Related to Hydropower Development

Unlike other renewable energy such as solar and wind, policy support for hydropower development in China have been uneven and some have actually hampered construction of additional dams. In enabling hydropower development, most of the government support has been in the form of target-setting including the targets set in the 2007 Mid and Long-term Development Plan for renewable energy. For hydropower specifically, targets include the 2020 goal of 300 GW of capacity announced in 2009, which was raised to 330 GW in a new proposed target announced in May 2010. Besides these targets, there have been very few direct policies promoting further hydropower development, particularly through the construction of mega dams. Despite its remaining potential as a renewable energy source and its economic competitiveness, severe criticism of Three Gorges Dam's environmental and social impacts and social unrest and protests by displaced residents have made the central government very wary of new large hydro projects.

In particular, new rules strengthening environmental management and resettlement planning for new hydro projects have been issued beginning with the 2005 NDRC and Environmental Protection Bureau circular mandating greater efforts to reduce the environmental impacts of hydropower construction (Vermeer, 2011). In 2006, NDRC also issued rules that required resettlement plans covering employment, education, environmental and other social provisions to be in place before starting hydropower projects. These rules essentially require developers to negotiate a resettlement compensation standard with local authorities, financing agency and the NDRC before their new hydropower project can be approved (Vermeer, 2011). Public participation of residents near proposed hydropower sites in the project approval process was also formalized through the 2006 Preliminary Rules for Mass Participation in Environmental Impact Evaluation. The political uncertainty surrounding large hydro development in China has affected the construction of new dams in the last few years, with delayed construction of many of the projects included in a 2008 NDRC list of new hydropower stations. In fact, only 17 GW of new hydropower projects were approved for construction from 2007 to 2009 (Vermeer, 2011). The political divisiveness over new hydropower construction has stalled short-term development as most of the supportive policies and programs have shifted towards wind and solar power.

4.5 Challenges to Hydropower Development

Besides an unfavorable political climate, hydropower development also faces resource challenges in China. The fast paced hydropower growth over the last three decades means China has already tapped into more than half of its technological potential of ~400 GW, compared to about 70% in developed countries. Although hydropower resources may still exist along some of China's rivers, utilization is limited as the severe droughts of 2009 and floods of 2010 have raised concerns about the actual availability of water for power generation (Vermeer, 2011). Large reservoir-based dams also face inherent challenges in the environmental impacts of inundation of large areas including cultural heritage sites, fragmentation of river ecosystems, and reservoir sedimentation upstream as well as ecological effects of erosion and water temperature changes downstream. The displacement of large human populations and subsequent negative impacts on land ownership, income and overall quality of life related to large hydro projects has become readily apparent in China within the last decade and will remain a major barrier to new projects.

As seen in the recent slowdown of new hydro projects, China also faces many institutional barriers to expanding its hydropower sites at the rapid pace that is needed to meet the 2020 target. The higher administrative standard that NDRC has set for large hydro project approvals has created new administrative burdens for both project developers and government agencies, with reports that 17 processes, 30 documents and 50 rounds of approval are needed before construction can begin (Vermeer, 2011). This has increased the time frame as well as human resources needed for the project approval process, with the approval time extended from days to at least one year. Furthermore, because the approval process is divided between various administrative agencies in different levels of the bureaucratic hierarchy and involves public participation in many cases, there are high transaction costs and uncertainties for project developers seeking approval for new sites. There are also crippling ambiguities surrounding the new resettlement compensation requirements for dams, which are exacerbated by the lack of a standardized compensation requirement and the need for a case-by-case negotiation on the total compensation cost. The total compensation could result in heavy financial burden for developers as recent compensation and resettlement costs have amounted to 130,000 RMB per displaced resident and totaling as much as half of the total project budget.

In addition to uncertain compensation requirements, Chinese hydropower developers are also confronted by various investment and market uncertainties including slow overall investment growth of only 2% from 2009 to 2010 compared to over 40% for wind (Vermeer, 2011). The absence of an integrated river planning framework and administration creates insecurities about water rights that could cost hydropower companies over the long-run, especially when the availability of water is limited. The unknown future of electricity market price trends, which are currently set very low and do not reflect the cost of generation, will also lower hydro developers' profit margins and their willingness to invest in new large projects. Finally, the dramatic fall of public acceptance as a result of social unrest and wavering government support all contribute to a negative investment climate for hydropower development.

5. Nuclear Technology Outlook

5.1 Nuclear Technology Overview: Current Status and Future Outlook

As one of the few non-fossil fuel generation sources that can be located near demand centers, nuclear power development has accelerated since 2000 with a five-fold increase in total installed capacity from 2.1 GW to 10.8 GW by the end of 2010 with the rise of new reactors along the eastern coast. Interest in expanding China's nuclear industry started as early as the late 1970s, and China began developing its own nuclear reactor designs along with imported technology from France, Canada and Russia. The 10th FYP period included plans for the construction of eight nuclear reactors, two of which did not start construction until the 11th FYP period. Both the 11th and 12th FYP included new reactors that are now or will soon be under construction and 25 GW of new capacity is planned to be in operation by the end of the 12th FYP period, with a total installed capacity of 43 GW possible by 2015.

Table 14. Active Nuclear Power Reactors and Sites in China

Reactors	Province	Reactor Net Capacity (MW)	Plant Total Capacity (MW)	Commercial Operation
Daya Bay 1 and 2	Guangdong	944	1,888	1994
Qinshan Phase I	Zhejiang	279	279	Apr-94
Qinshan Phase II, 1 -3	Zhejiang	610	1,830	2002, 2004, 2010
Qinshan Phase III, 1&2	Zhejiang	665	1,330	2002, 2003
Ling Ao Phase I, 1&2	Guangdong	935	1,870	2002, 2003
Tianwan 1&2	Jiangsu	1,000	2,000	2007, 2007
Ling Ao Phase II, 1&2	Guangdong	1,037	2,074	Sept 2010 (June 2011)
Total Reactors (14):			11,271	

Source: World Nuclear Association 2011a.

As seen in Figure 13 below, most of the reactors under construction and planned will be sited along China's densely populated coastal region in order to minimize the distance between generation and demand centers. This reflects a geographic advantage of nuclear power in that it is not limited to the remote Western regions where additional transmission and distribution networks will need to be built.

Figure 13. Existing and Planned Nuclear Reactors in China

Source: World Nuclear Association 2011a.

5.1.1 Existing Domestic Pressurized Water Reactor Designs

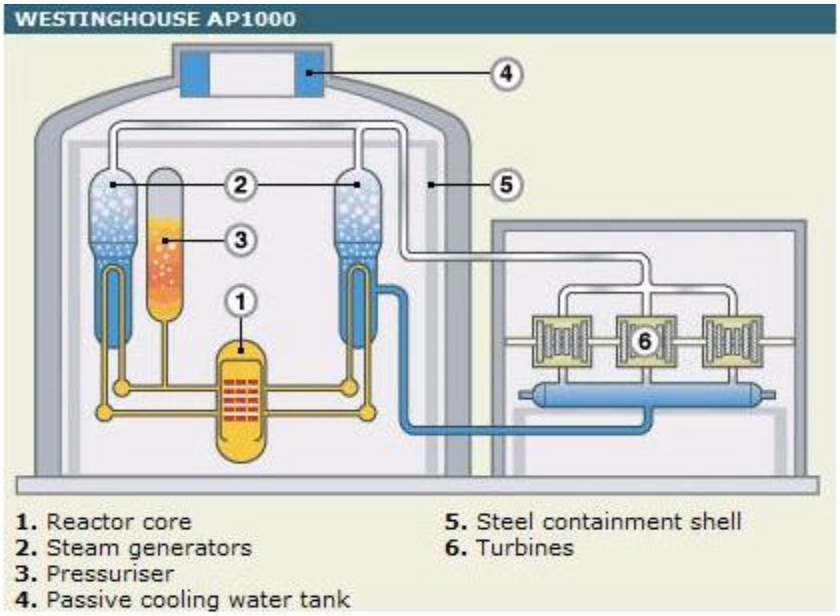
Since 2005, China has developed three domestic pressurized water reactor (PRW) designs, the CNP-300, CNP-600 and CNP-1000 and the CPR-1000. All four of these designs are based on the French pressurized water reactor designs, with the CNP-300 and CNP-600 as the earliest one- and two-loop PWR design and the CNP-1000 as the standard three-loop PWR design with a high burn-up rate of 60 GWd/t (WNA, 2011a). More recently, the CPR-1000 reactor design was developed by the Guangdong Nuclear Power Corporation for Ling Ao Phase II project with a gross capacity of 1090 MW. The CPR-1000 design is an updated version of the imported French three-loop technology and is considered a Generation II+ standard design with newly evolving CPR-1000+ designs being closer to Generation III standard.

Although China is still building Generation II units, particularly CPR-1000 units, for its near-term nuclear deployment, there has been growing shift towards foreign-based Generation III technology. Despite disagreements between China National Nuclear Corporation (CNNC), which favors domestic reactor designs, and the State Nuclear Power Technology Corp (SNPTC) favoring imported Generation III designs, an open bidding process was conducted in 2004 to select the basic design for China's Gen III technology development. After receiving bids from US Westinghouse, French AREVA and Russian companies, the Westinghouse AP1000 design was selected as the basis for China's Generation III reactor design development. With a technology transfer agreement in place for the first four AP1000 units, one of which began construction at the Sanmen site in 2009, domestic production of large number of reactors based on the AP1000 design is expected to begin by 2015.

5.1.2 Upcoming Generation III Designs

As the main basis for future Chinese Generation III reactors, the Westinghouse AP1000 reactor has 1250 MW gross installed capacity with two coolant loops and expected costs of $1600/kW for future production (WNA, 2011a). After the Fukushima accident in Japan, China has looked to the design of advanced reactors such as AP1000 for their safety features such as passive core and containment cooling systems (Figure 14). The construction of the first four reactors through the fuel loading stage currently takes 50 months, with six more months needed for grid connection, but the construction time is expected to decrease. In terms of manufacturing and construction, the reactors are built from modules fabricated near each site and nuclear fuel assemblies are also fabricated and supplied indigenously.

Figure 14. Simplified Diagram of AP1000 Nuclear Reactor Design



In addition to the conventional Generation III reactors, China is also exploring the feasibility of small Generation IV high-temperature gas-cooled reactor (HTR) with pebble bed fuels with a consortium set up to explore R&D for pilot HTR projects. Over the longer-term, fast neutron reactor technologies are also expected to become more common with plans to develop a domestic pilot demonstration project by the 2020s. In the short to medium-term, however, China's nuclear technologies will continue to be dominated by the domestic CPR-1000 and 1000+ Generation II PWR designs and the AP1000 Generation III PWR designs with the majority of planned and proposed projects over the next twenty years based on these designs.

5.2 Nuclear Modeling Methodology

The modeling methodology for nuclear power development differs from other major non-fossil generation technologies in that it is much more complex involving the multi-step nuclear fuel cycle with major uranium resource requirements and high energy demand. There have been many life-cycle studies on the resource and energy implications of nuclear power plants but the results and findings have differed significantly depending on analysis methodology, boundaries and technology assumptions. The methodology undertaken in this study, including assumptions for each major step of the fuel cycle as well as the underlying assumptions about installed capacity and technology choices, are presented below.

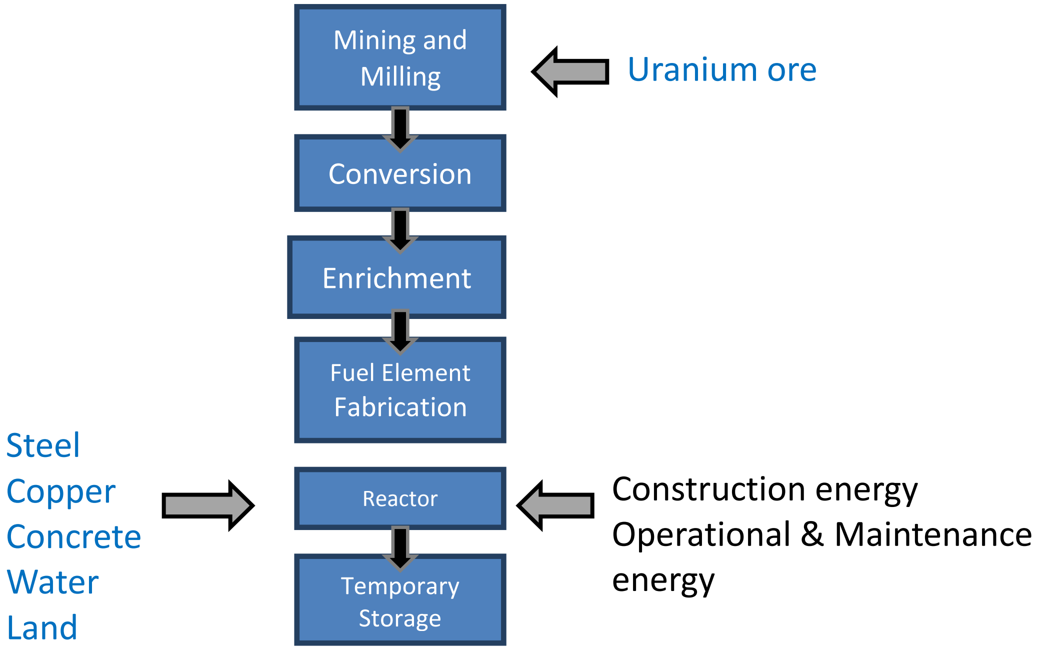
5.2.1 Technology and Capacity Assumptions

For this study, the projected nuclear installed capacity was based on the recently announced goal of 70 GW by 2020, an unofficial target recommended by the China Nuclear Energy Administration in November of 2010 and by the State Council Research Office in January 2011. Although the Japanese Fukushima nuclear accident in March 2011 has led the Chinese government to suspend its approval process pending safety reviews, this delay is expected to be short-term and officials have been quoted as saying that the official targets will not be lowered and that China is still on track to meet 70 GW by 2020 (Liu, 2011b). From 2020 to 2030, the same pace of capacity expansion is assumed with a total installed capacity of 130 GW by 2030.

5.2.2 Boundaries Overview

The boundary of analysis and specific scope of stages analyzed and key resource requirements is shown in Figure 15 below. The six key stages of the nuclear fuel cycle covered in this study include: mining and milling of the uranium ore; conversion of the uranium ore into gaseous uranium fluoride (UF6); enrichment; fuel rod fabrication of enriched uranium oxide; reactor construction, operation and maintenance; and temporary storage of high-level radioactive waste. Since China only has a very small pilot reprocessing plant with capacity of only 100 tons per year and construction and operation of a commercial reprocessing plant using advanced French technology is not expected until 2020, reprocessing is not considered in this study and analysis is based on a once-through fuel cycle (WNA, 2011b). The nuclear analysis was separated into three main areas: total uranium resource requirements at each stage of the nuclear fuel cycle and its associated thermal and electrical energy demand, raw material and resource requirements for the nuclear reactor plant, and construction and operational energy of the nuclear reactor.

Figure 15. Scope of Nuclear Power Generation Analysis and Major Resource Requirements



5.2.3 Uranium requirements

For new nuclear reactors expected to come online in the next twenty years, Generation III designs based on AP1000 is assumed to dominate along with continuation of the CPR-1000 design. As a result, an average 600 tons of natural enriched uranium is needed for the initial core of a new 1000 MW PWR and an average burn-up fuel rate of 45 GWd/t or 179.58 tons of enriched natural uranium per year is needed based on China-specific studies (Yang and Huang, 2010). By calculating the annual capacity additions and excluding the 1.45 GW of existing CANDU reactor capacity, the enriched natural uranium needed for new capacity addition's first core and for reloading can be calculated separately for each year from 2010 to 2030 using the assumed uranium intensity. The sum of the first core and reloading enriched uranium requirements are then used as inputs in an online nuclear fuel material balance calculator in order to calculate the specific uranium compounds and pure uranium needed at each stage of the nuclear fuel cycle (WISE Uranium Project, 2009). The calculations and results from this calculator were tested and validated by using the same technical parameters as a reference reactor in another study and comparing the calculator outputs with that study's material balance results. (Storm van Leeuwen, 2007). To calibrate the calculation to Chinese technologies and processes, China-specific technical parameters from literature review and the LEAP model on nuclear power plant efficiency are also entered into the calculator (Table 15).

Table 15. Assumed Technical Parameters for China's Nuclear Fuel Cycle

	First Core	Reloading
Uranium Ore Grade	0.15%	0.15%
Fuel Burn-up (GW d/t U)	45	45
Enrichment Product Assay (% U-235 in enriched product)	3.3%	4.2%
Enrichment Tailings Assay (% U-235 in depleted uranium tailings)	0.30%	0.30%
U-235 Concentration in UF6	0.71%	0.71%
Losses (conversion, fuel fabrication)	0.50%	0.50%
Separative Work Units (kg SWU/kg U enriched)	4.97	4.97
Power Plant Efficiency:	32.3%	32.3%
Power Plant Capacity Factor:	85%	85%

Sources: Zhou and Zhang 2010; Beerten et al. 2009; Yang and Huang 2010; LBNL China 2050 Energy End-Use Model.

5.2.4 Nuclear fuel cycle energy requirements

Through the first five front-end stages of the nuclear fuel cycle, uranium ore is converted from raw ore into enriched natural uranium that forms the basis of the fuel rods used by nuclear reactor to generate power. China-specific data and information is used to evaluate the uranium requirements and related processing energy needs at each stage of the cycle.

Uranium Mining and Milling

China has 100,000 tons of known uranium resources with production of 840 tons per year and relies on imports for more than half of its uranium ores (WNA, 2011b). China has eight operating uranium ores as seen in Table 16 below and have launched recent acquisitions to secure more imported uranium ore from Kazakhstan, Namibia, Niger, Australia, Uzbekistan, and Mongolia.

Table 16. Operational Uranium Mines in China

Mine	*Province*	*Type*	*Nominal capacity (tonnes U per year)*	*Started*
Fuzhou	Jiangxi	Underground & open pit	300	1966
Chongyi	Jiangxi	Underground & open pit	120 expanding to 270	1979
Yining	Xinjiang	In-situ leach (ISL)	300	1993
Lantian	Shaanxi	Underground	100	1993
Benxi	Liaoning	Underground	120	1996
Quinglong	Liaoning	Underground	100	2007
Shaoguan	Guangdong	Underground	160	2008

Source: WNA 2011b.

There are three basic types of uranium ore mining techniques: underground excavation, open-pit mining and in situ leaching mining. Based on the domestic mines currently in operation in China, the specific shares of the three main types of mining techniques is derived and assumed to be static for calculating a weighted average mining and milling energy requirements.

During the milling stage, the raw uranium ore is crushed and ground to facilitate the dissolution and precipitation of uranium in acid or alkaline solutions (Lenzen, 2008). Milling is usually performed close to the mining site and results in a dry uranium ore concentrate known as yellowcake. Because in-situ leaching is a relatively new technique where uranium is already dissolved, milling is not required and there is a lower energy requirement compared to underground and open-pit mining. The energy intensity for mining and milling are taken from a review of nuclear life-cycle studies and weighted by the China-specific shares of mining with a final average intensity of 0.854 MJ per kilogram of ore (Beerten et al., 2009).

Table 17. Uranium Ore Mining and Milling Energy Intensity Assumptions

Unit: MJ thermal/kg ore	**Production Share**	**Mining Energy Intensity**	**Milling Energy Intensity**	**Mining & Milling Energy Intensity**
Underground	36%	0.512	0.61	1.122
In-situ Leaching	22%	0.388	-	0.388
Mixed Mining	42%	0.264	0.61	0.874
Weighted Average				***0.854***

Source: energy intensities taken from Beerten et al. 2009.

Uranium Conversion

After the uranium ore has been milled, the uranium oxide can be converted either using a dry kiln process, which is the case for the U.S., or a wet process using nitric acid, which is used in most other countries including China. After the conversion process, impurities from the uranium oxide are removed and the resulting gaseous uranium hexafluoride (UF6) can be liquefied at lower temperature and under moderate pressure. The liquid UF6 solidifies when it is stored within steel shipping cylinders for transport to the enrichment plant. The wet process uses less energy than the dry kiln, and an average of reported thermal energy intensity and electrical energy intensity from a 1998 study based on European data and a 2001 Australian study are used as an international proxy for China, with 629 MJ thermal per kg uranium and 56.3 MJ electricity per kg uranium (Beerten et al., 2009; Lenzen, 2008).

Uranium Enrichment

Because the natural concentration of U-235 isotopes in UF6 feedstock is only 0.7%, uranium enrichment is needed to reach the U-235 concentration of 3.3% needed for a nuclear reactor's first core and the 4.2% concentration needed for reloading cores. During the enrichment process, which is typically done using gaseous diffusion or gas centrifuge, the mass differences between different uranium isotopes are used to separate them into enriched product for fuel and tailings also known as depleted uranium which have much lower concentrations.

Of the two enrichment processes, the gas centrifuge process was first introduced in the 1940s but was replaced by the simpler diffusion process in the 1960s, when centrifuge process was redeveloped as a smaller-scale second-generation enrichment technology. The centrifuge process is much more energy-efficient than diffusion and requires some heat and very little electrical energy of about 100 kWh/SWU[2] to rotate the centrifugal cylinders and accounts for 65% of global enrichment processes in 2010 (WNA, 2011c). At the end of the enrichment process, the enriched UF6 is turned into uranium oxide, the feedstock for fuel fabrication. With the exception of the US and France, most countries no longer use gaseous diffusion for enrichment on a large commercial scale because it is very energy-intensive and requires significant amounts of electricity on the order of 2400 kWh/SWU as well as thermal energy (Beerten et al., 2009).

China currently has only two small centrifuge plants imported from Russia, both with capacities of 0.5 million SWU per year with expansion underway (WNA, 2011c). Nevertheless, much of China's enriched uranium supply is imported from Europe and Russia, where the centrifuge process is also used for commercial enrichment. In this study, most of China's uranium ore is assumed to have 0.15% ore grade and is assumed to require 4.97 SWU per kilogram of enriched uranium as reported in a European study for ores with the same ore grade (Beerten et al., 2009). In addition, the centrifuge process is also assumed to be the predominant method of enrichment with an average direct and indirect energy intensity of 187 kWh per SWU (Lenzen, 2008).

Fuel Fabrication

In the fuel fabrication stage, the enriched uranium oxide is sintered, baked and pressed into ceramic pellets which can then be stacked and encased in zirconium alloy fuel rods. China has a main fuel fabrication plant in Yibin in Sichuan province but the capacity is only about 600 tons of enriched uranium per year with capacity expansion planned for the near future (WNA, 2011b). A second fabrication plant in Baotou, Inner Mongolia, was also established in 1998 and currently supplies the two CANDU reactors as well as some PWR reactors. In the short-term, France and the Westinghouse are supplying fabricated fuel assemblies to China. Efforts are also underway to build pilot mixed oxide fuel fabrication plants but are not considered in this study because it is expected to take more than ten years to become operational. This study uses the average values of the 1998 European and 2001 Australian study for fuel fabrication, namely 99 MJ of thermal energy per kilogram of enriched uranium and 135 MJ electrical energy per kilogram of enriched uranium (Beerten et al, 2009; Lenzen, 2008).

Temporary Storage of Spent Fuel

At the backend of the nuclear fuel cycle, the spent fuel elements leaving a nuclear reactor is transferred to nearby temporary storage site and stored for a period of time for radioactive decay to lower the activity of fission products. The energy associated with temporary storage of spent fuel is applied to only high-level waste and an average value from the 2001 Australia study and a 1995 study of a 1000 PWR is used (Beerten et al., 2009). The specific energy intensity assumed for temporary storage is 500 MWh thermal and 80 MWh electricity per ton of high-level waste. In determining the proportion of spent fuel that may be high-level waste,

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[2] SWU, or a separation work unit in kilograms, is the standard unit used to measure the capacity of enrichment plants. SWUs are a function of the amount of uranium processed and the enrichment concentration and measures the quantity of separative work performed to enrich a given amount of uranium to a certain concentration.

international data on the high-level, intermediate and low-level shares of waste is used as a proxy for China (Lenzen, 2008).

5.2.5 Reactor resource and energy requirements

Another major source of energy demand in the nuclear fuel cycle is the energy used for constructing the nuclear reactor and power plant. General findings from various nuclear plant construction lifecycle analysis studies have shown that both economic input-output and process-based LCA have problems in estimating the total construction energy (Beerten et al., 2009). Specifically, input-out LCA tends to overestimate total construction energy because components for nuclear power plants are very expensive due to extra safety-related precautions but have much smaller incremental increase in energy. At the same time, process-based LCA often underestimates total construction energy because nuclear power plant materials require higher energy use than other products in the sector. Thus, because input-output overestimates and process-based LCA underestimates, the average of results from three studies for each of these processes are used to determine a mid-range value that may serve as a reasonable estimate for construction energy. From two LCA studies and a LCA meta-review study, the construction energy intensity in GWh per GW capacity from input-output LCA ranges from 3500 to 4100 while the process-based LCA values range from 1177 to 1500. The average of results from both types of studies is determined to be 2602 GWh per GW and is used as an international proxy for the construction of Chinese nuclear power plants. For raw material inputs to reactor construction, material intensities per MW of capacity are calculated from the total material requirements of a 1000 MW PWR reactor in a 2008 meta-review of nuclear LCA studies (Sovacool, 2008). Both assumed energy and material intensities may be an underestimate for China as construction tends to be more energy and material intensive given the dominance and structure of China's heavy industries.

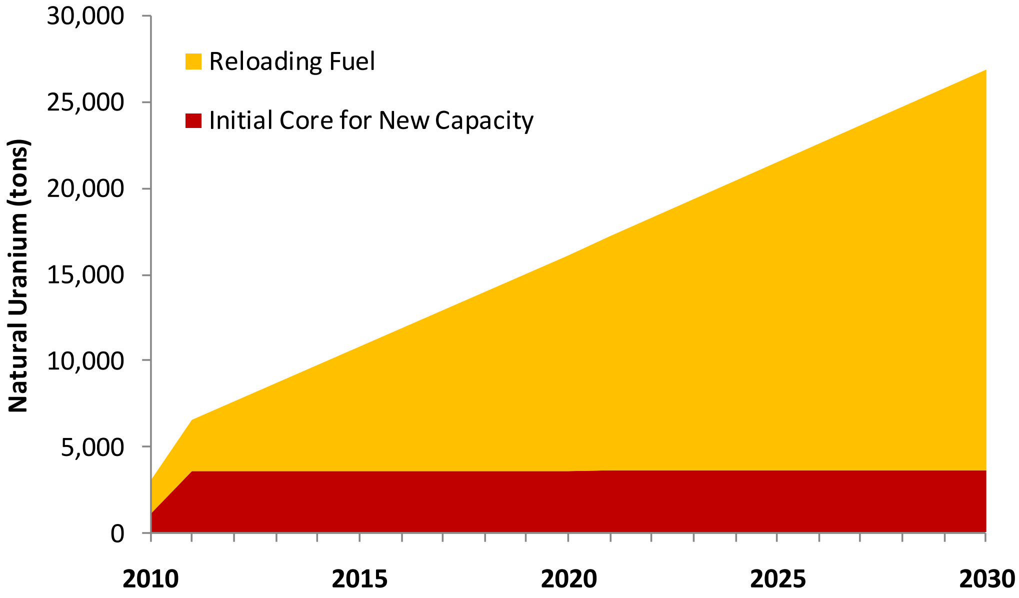
For operation, maintenance and refurbishment, values from previous LCA studies also range widely for both thermal and electrical energy requirements. The average values of 270 GWh thermal and 10 GWh electrical per year for a 1000 MW PWR from a meta-review study is used as an international proxy for China in this study.

5.3 Nuclear Power Resource and Energy Input Requirements

5.3.1 Nuclear fuel cycle's uranium and other resource demand

The total uranium resource, raw material and energy input to constructing China's future nuclear generation fleet is modeled based on the methodologies detailed above. Based on the projected nuclear capacity, annual demand of nearly 27,000 tons of natural uranium will be needed to power China's nuclear reactors by 2030 (Figure 16). Most of this natural uranium fuel will be for supplying the reloading fuel rods for the reactors, with only 3600 tons needed for the first cores for new reactors. Cumulatively from 2010 to 2030, a total of 337,000 tons of natural uranium is needed for China's nuclear power generation fleet.

Figure 16. Projected Natural Uranium Demand for Nuclear Reactors by End-Use, 2010--2030



Of the natural uranium needed for supplying the nuclear reactor's fuel, a larger amount of natural uranium needs to be mined and milled from uranium ores due to losses in the mining and milling and conversion processes. In particular, Table 18 shows that a significant amount of uranium ore would have to be mined to provide the required uranium equivalent for supply uranium fuel to reactors because China's uranium ore has a relatively low ore grade of only 0.15%. In 2030, this translates into an annual mining of over 19 million tons of ore and conversion of nearly 32,000 tons of U3O8 yellowcake.

Table 18. Uranium Mass Balance for China's Nuclear Fuel Cycle

	2010	*2020*	*2030*	*Cumulative*
Mining & Milling Input				
Uranium Ore (tons)	2,101,378	11,440,755	19,126,513	239,355,938
Uranium equivalent (tons)	3,152	17,161	28,690	359,047
Conversion Input				
U3O8 (tons)	3,507	19,093	31,920	399,467
Uranium equivalent (tons)	2,974	16,191	27,068	338,749
Enrichment Input				
UF6 (tons)	4,376	23,825	39,830	498,468
Uranium equivalent (tons)	2,959	16,110	26,933	337,054
SWU	1,709,777	9,417,762	15,866,396	197,130,670
Fuel Fabrication Input				
Enriched UF6 (tons)	509	2,677	4,366	55,923
Enriched Uranium equivalent (tons)	344	1,810	2,952	37,814

Reactor Input				
Uranium Oxide UO2 (tons)	389	2,043	3,332	42,683
Enriched Uranium equivalent (tons)	343	1,801	2,937	37,625
Spent Fuel (tons)	389	2,043	3,332	42,683
High-level Radioactive Waste (tons)	27	143	233	2,988

In terms of raw material input to the actual construction of the reactor and power plant, the highest demand is for concrete with over 1 Mt per year after 2020 and a cumulative demand of 20.5 Mt over the next twenty years (Table 19). Demand for steel, another important structural material for construction, will also continue to grow to nearly 200,000 tons per year by 2030 with a cumulative total of 3.9 Mt. Copper, although demanded on a smaller scale, also have important implications given its limited supplies and rising prices in recent years.

Table 19. Total Material Resource Requirements for Nuclear Development

Unit: thousand tons	**2010**	**2020**	**2030**	**Cumulative**
Concrete	292	1,006	1,020	20,556
Steel	55	189	192	3,869
Copper	2.34	8.07	8.18	164.8

5.3.2 Uranium Fuel Cycle Energy Demand

Because there is an extensive range in the EROEI of nuclear power generation, an EROEI specific to China's nuclear generation is determined by applying energy intensity assumptions to the uranium resource input to each step of China's nuclear fuel cycle to estimate the total energy input for nuclear generation. The assumed energy requirements for each step of the fuel cycle based on the literature review are shown in Table 20 below. For 2010, the EROEI is calculated to be 19.4 for nuclear generation.

Table 20. Energy Intensity for Nuclear Fuel Cycle Processes

		Thermal Energy Intensity	Electricity Intensity
Mining and Milling	*MJ/kg ore*	0.854	-
Conversion	*MJ/kg U*	629	56.3
Enrichment	*kWh/SWU*	187	-
Fuel Fabrication	*MJ/kg U*	99	135
Construction	*GWh/GW*	2602	-
Operation and Maintenance	*GWh/GW/year*	270	10
High-level waste Temporary Storage	*MJ/kg waste*	1.8	0.29

5.4 Policies Fostering China's Nuclear Development

Prior to 2005, nuclear power played a relatively minor role in China's power sector due to the lack of financial support and incentives from the government and the overall absence of a long-term strategic plan, including technology development strategy in terms of nuclear reactor design options (Zhou et al, 2011). This trend shifted in 2005 with the 11th FYP's greater emphasis on clean energy generation and renewed government focus on nuclear power development was formalized through the State Council's approval of the "Medium and Long-term Nuclear Development Plan (2005-2010)" in March of 2006. Under this plan, China adopted its official goal of goal of increasing nuclear capacity to 40 GW by 2020 and nuclear power was also officially recognized as an important energy source during the 11th FYP period. In March 2008, the central government's nuclear energy division was also relocated to the National Energy Bureau under NDRC, a further signaling of the rise of nuclear as an important energy source in China.

Over the last five years, there have also been growing focus and emphasis on formulating a coherent and comprehensive nuclear technology development strategy for China with efforts taken to standardize nuclear energy design and manufacturing system. From 2005 to 2006, a 22-month bidding process was held for selecting the design for China's new nuclear reactors. In selecting the winning design that would serve as a fundamental Generation III reactor design for China's future fleet, important factors included whether it conformed with accumulated Chinese experience in PWR designs and international trends toward Generation III reactors as well as cost effectiveness and safety (Zhou et al., 2011). The $5 billion contract was ultimately awarded to Westinghouse for construction of four new AP1000 reactors and a technology transfer agreement was signed. In addition to these efforts to standardize Chinese nuclear reactor designs, the government has also invested 300 billion RMB in four key nuclear manufacturing companies in order to advance domestic manufacturing capabilities (Zhou et al., 2011).

Another major policy area that has helped strengthen China's nuclear development is the expansion of value-added tax waivers to the entire nuclear industry and the introduction of other preferential tax policies to mitigate the high initial upfront investment needs for nuclear power plants. In 2008, a fifteen year tax rebate scheme was developed for new reactors with an annual 75% tax rebate offered for the first five years of a new reactor operation, decreasing to 70% for the following five years and to 55% for the tenth to fifteenth years of operation (Zhou et al., 2011). The nuclear industry also benefits from tax waivers on imported nuclear energy equipment and materials that are not available domestically, land-use tax rebates and income tax rebates including a lower 15% income tax rate, permission for reduced tax base and other possible tax waivers.

5.5 Challenges to China's Nuclear Expansion

China's nuclear development has taken off rapidly in recent years and with an ambitious (unofficial) target of 70 GW by 2020, continuation and possibly acceleration of the current pace of capacity expansion will face several major obstacles.

5.5.1 Resource Constraints

Unlike other countries that have expanded their nuclear power industry since the 1970s, China's plans for unprecedented scale and speed of expanding its nuclear reactors suggest that resources constraints could be a limiting factor. One of the largest resource constraints will be in China's uranium supply, with total domestic uranium resources estimated to be between 88,000 to 100,000 tons of uranium and annual production of only 770 to 840 tons of uranium per year (Yan et al., 2010; WNA, 2011b). In contrast, our estimates in Table 18 show that the uranium demand for China's expanding fleet of nuclear reactors total nearly 3000 tons in 2010 and could grow to 26,900 tons by 2030. Although the assumed uranium demand for initial cores and reloading cores might be an overestimate as other studies have used lower values for newer reactors, domestic supply would nevertheless still be short by as much as 1000 tons in 2010 (Yan et al., 2010). In fact, the cumulatively uranium demand from 2010 to 2030 equals more than three times China's entire resource base in our analysis. China has recognized its uranium resource constraints and has pursued uranium exploration in Xinjiang and Guangdong and exploring alternatives sources such as leaching uranium from coal ash (WNA, 2011b). At the same time, China has also taken steps to secure foreign supply of uranium with the signing of various contracts and agreements with Areva and Cameco and mines proposed and initiated in throughout Africa, Australia and Central Asia.

Besides natural uranium resource constraints, China's nuclear development will also face a diminishing nuclear workforce and shortage of nuclear research and development personnel. The next generation of the nuclear workforce is faced with limited options for nuclear engineering program with only a few offered by universities. For these programs, student retention is difficult as only a third of admitted students actually remain in the field (Zhou et al., 2011). Universities and industry have recognized this growing imbalance and have launched new nuclear engineering programs, one year professional training programs and recruitment programs to accelerate workforce development but inadequate high-level research and development personnel will remain a major weakness in China's nuclear industry. Furthermore, China's nuclear safety and inspection capacity may also be outpaced by rise of new reactors, with only 100 staff members in regional nuclear safety inspection offices and 200 staff members in the technical support center of the National Nuclear Safety Administration (NNSA) (Zhou et al., 2011).

Another limitation to China's rapid nuclear expansion will be nuclear waste treatment options, which is particularly important given that reprocessing is not expected to play a major role in the short-term. China currently only has one intermediate-level waste storage facility for spent fuel in central Gansu province with a storage capacity of 550 tons and industrial scale disposal sites in northwest Gansu and Guangdong provinces (WNA, 2011b). These capacities will clearly have to be expanded to meet the projected rise in spent fuel, which could reach over 3000 tons annually by 2030. China is also still in the process of selecting sites and building a high-level waste repository, which is not expected to be completed until 2020 so temporary storage capacity of high-level waste will also continue to be in high demand.

5.5.2 Safety

Besides inadequate personnel for inspecting and enforcing nuclear reactor safety, China's nuclear industry also faces reactor safety concerns particularly for its older reactors which are diverse in technology design and origin. China's 14 operating nuclear reactors include 6 different nuclear reactor designs and imported technology from France, Canada and Russia. This diversity in technology design, which China is currently addressing through its move to a standardized Generation III reactor design, makes safety inspections and problem diagnosis more difficult and time consuming. The construction quality of domestically built nuclear reactors has also been an area of concern, especially given the rapid pace of construction needed to build new reactors to meet the 2020 target. In 1998, for instance, a reported welding problem shut down the Qinshan I reactor for more than a year. Other potential construction quality issues include poor planning, poor quality control, unqualified construction workers, corruption and bribes and material theft (Zhou et al, 2011). Safety concerns could cripple China's nuclear development if public acceptance drops, as concerns have risen after the Japanese Fukushima nuclear accident. In response, expert review groups have been inspecting existing nuclear power plant since late March and a nuclear safety plan is being developed for new nuclear power project approvals (Liu, 2011c). China nevertheless will need to strengthen not only its nuclear safety regulatory enforcement, but will also need to foster safety culture and awareness in the nuclear industry to ensure that safety will not be compromised in future development.

5.5.3 Regulatory and Institutional Barriers

China's nuclear legal and regulatory framework needs to be strengthened and updated to sufficiently meet the needs of its fast-paced nuclear development. From the legal perspective, China currently lacks a comprehensive major law that governs the use of nuclear energy and related activities, particularly as it relates to nuclear power safety and operation. Although the State Council is currently developing a nuclear safety plan, it is unclear if this will be enforced as a law and how comprehensive the plan will be. Moreover, the three existing regulations and rules that relate to the nuclear energy were all adopted prior to 1994 and do not address any of the concerns or issues arising from the current boom (Zhou et al., 2011). From the institutional perspective, there is an imbalance between the regulatory and supervisory agency and the state-owned nuclear companies as China's NNSA lacks independence and power as a subdivision within the Ministry of Environmental Protection while the state-owned companies have more power being directly under the State Council (Zhou et al., 2011). As mentioned previously, the NNSA has limited staffing capacities and lacks a research and development branch for helping develop technical standards and analyze the adequacy of existing regulations and rules.

6. Geothermal and Biomass co-fired Generation Technologies Outlook

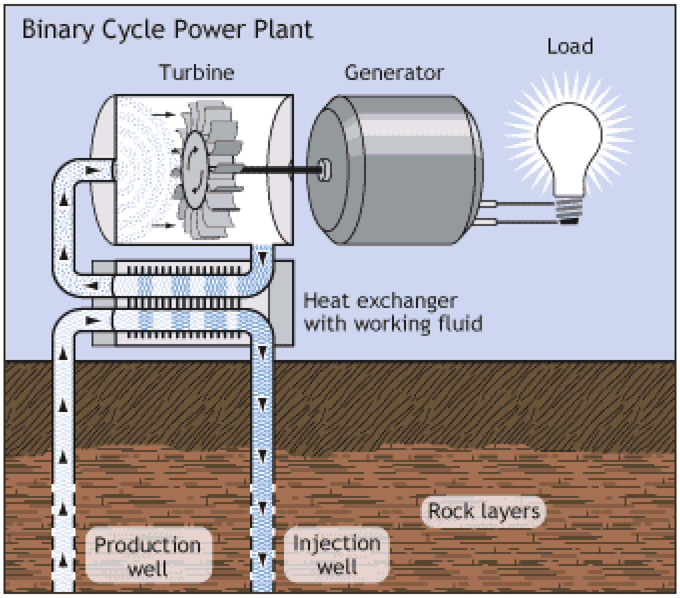
In addition to the main non-fossil generation technologies of solar, wind, hydro and nuclear, geothermal and biomass power generation are two other renewable generation technologies that can contribute – albeit on a much smaller scale – to China's alternative energy development.

6.1 Geothermal Power Technology Overview

China has become an increasingly important geothermal energy user in the last few years as the global leader in direct use of geothermal energy through ground source heat pumps and conventional geothermal space heating. In 2005, China used 12.6 $TWh_{thermal}$ of geothermal energy with 55% of energy used for bathing and swimming, 14% for conventional district heating and 14% for geothermal heat pump (Bertani, 2009). This follows a rapid expansion of ground source heat pump installation from 8 million m^2 in 2004 to 30 million m^2 in 2007, and district space heating from 13 million m^2 in 2004 to 17 million m^2 in 2006 (Bertani, 2009). In terms of power generation, however, geothermal energy plays a negligible role with virtually no increase in installed capacity but rather, a decrease from 30 MW to only 24 MW in 2009.

One of the reasons for the very limited application of geothermal energy to power generation is that most of the geothermal resources in China are shallow-lying, low-temperature reservoirs and better suited for direct use. In order to expand the utilization of low-temperature geothermal resources for power generation, foreign technologies and geothermal binary cycle power plants are needed to exploit China's geothermal resources. The geothermal binary cycle differs in that it uses hot geothermal fluid as well as a secondary fluid with a lower boiling point than water because direct use of the low-temperature geothermal fluid is ineffective in driving the thermal power conversion process. After the hot geothermal fluid is transferred to the surface through injection wells, it is passed through the heat exchanger where it causes the secondary fluid to flash to vapor and drive the turbine to generate electricity (Figure 17). The geothermal binary power plant can also provide heat by transferring some of the geothermal heat to a district heating system. Since low to moderate temperature geothermal resources are prevalent throughout China, the binary cycle geothermal power plant is assumed to be the main technology for power generation.

Figure 17. Diagram of Geothermal Binary Cycle Power Plant



Source: US DOE Geothermal Technologies Program 2010.

6.2 Modeling Geothermal Power Generation Technology

To evaluate the life-cycle resource and energy impact of geothermal binary plants' role in China's power sector, a 2010 life-cycle assessment study on typical European plants serves as the international proxy for China (Frick et al., 2010) as there are virtually no known lifecycle studies on geothermal generation technologies in China. This study uses a simplified plant layout and inventory data from experts and literature review to evaluate the environmental impacts of a 1.75 MW reference plant at two sites under base case (Table 21). The scope of the study includes construction, operation and decommissioning of the plant and includes inventory data on material input to the plant and performance-related data for calculating the implied EROEI. For our study, the average values of the assumed technical parameters of the Site A and Site B base case plants are calculated and used for calculating EROEI, which is relatively low at 4.56 due to the low conversion efficiency of only 10.5%.

Table 21. Technical Parameters of Geothermal Binary Power Plants

		Site A	Site B	Average
Reservoir depth	km	3.8	4.7	4.25
Design flow rate	m3/h	250	155	202.5
Lifetime	yrs	30	30	30
Conversion efficiency	%	9.70%	11.20%	10.5%
Capacity	MWel	1.75	1.75	1.75
Full Load Hours	hrs	7000	7000	7000
Auxiliary power for feed-pump (10% capacity)	MWel	0.18	0.18	0.18
Auxiliary power for recooling	MWel	0.33	0.28	0.305

Source: Frick et al. 2010.

For material and resource input, the material intensities are calculated or taken from the Frick et al. 2010 study including 147.2 tons of steel per MW for the cooling tower, plant building and other components, 2.1 tons of copper per MW for the transformer and 38.4 tons of concrete per MW. The land footprint is calculated to be 1634 m^2 per MW based on data presented in a 2007 Geothermal Energy Association report (Kagel et al., 2007). For geothermal binary plants, water is not quantified as a resource input because of boundary issues with recirculating fluids and evaporation. Based on these assumed intensities, the total resource requirements for China's geothermal binary cycle plants are calculated and shown in Table 22 below.

Table 22. Total Resource Requirements for Geothermal Power Development

Unit: thousand tons unless noted	2010	2020	2030	Cumulative
Land (thousand m2)	0	159.5	163.4	3,229
Steel	0	14.4	14.7	291
Concrete	0	3.75	3.84	75.9
Copper	0	0.20	0.21	4.15

Note: no geothermal generation capacity addition has been reported for 2010 and is assumed to be zero.

6.3 Geothermal Policies and Challenges

Unlike geothermal heating and heat pump industries, the geothermal power industry has not received any government policy support despite the need for significant preliminary investment. The policy focus on geothermal power began in April 2011, when the Ministry of Land and Resources announced that geothermal power will provide 1.7% of total energy demand in 2015 (He, 2011). At the same time, the central government is allocating 164 million RMB to explore and evaluate shallow-lying geothermal reservoirs in 29 provincial capitals. However, this small scale of funding and very late start compared to other renewable energy policies illustrate that geothermal power development in China will be faced with many challenges.

From a technical perspective, China will likely have to continue relying on foreign technology for the binary power plants needed to generate electricity from its geothermal resources. China's low to moderate temperature geothermal resources presents challenges to technology development because there are very limited applications that can effectively utilize geothermal heat of below 150°C. High temperature resources for geothermal power are also geographically disperse and concentrated only in Tibet and Yunnan. There are also great resource uncertainties since China's geographic resource base is not well known due to the lack resource exploration and development efforts in the past.

At the same time, technological development related to geothermal power generation in China faces additional barriers. On one hand, China currently lacks the capacity to develop binary cycle power plants with a national R&D community of only a hundred and insufficient funding and public support. On the other hand, even from a global perspective, technical development is a challenge as the advanced low to moderate temperature geothermal technologies are held exclusively by United Technologies Corporation in the US. The high upfront investments needed to explore the development of uncertain technologies, particularly in an increasingly market-oriented economy focused on profits, will also hinder geothermal development in China.

6.4 Biomass Resources and Power Generation Technologies

As a major agricultural producer, China produces over 800 million tons of crop residues annually which make up more than half of China's total biomass resources. In addition to crop residues, other biomass resources in China include animal dung (23%), municipal solid waste (14%), industrial wastes (10%) and firewood (2%) (CAS and GIEC, 2005). Rice, corn and wheat are the three main crops from which crop residues are derived and production is heavily concentrated in southeastern regions along the fertile Yangtze River valley. Crop residues are currently used primarily to meet rural household energy demand or as fodder, industrial fertilizer and discarded or incinerated in the field. The 200 million tons of crop residues discarded or incinerated annually has an energy content equivalent of 100 million tons of coal equivalent (Mtce) and can be redirected to support 33 GW of biomass generation capacity in China (Chen and Li, 2010). China also has 300 million tons of wood waste from timber mills that could theoretically support 100 GW of biomass power generation (Zhao, 2011). In reality, however, China's installed capacity of biomass power in 2006 was only 2.2 GW, with 1.7 GW from stalk residue and the remaining from rice hulls and municipal waste (REN21, 2009). Although installed capacity has grown to 3.1 GW in 2008 and over 5 GW in 2010, a gap still exists between existing capacity and the 30 GW target set in the Medium and Long-term Plan for Renewable Energy Development for 2020.

There are three main types of biomass power generation technologies, including biomass combustion, biomass gasification and biomass co-fired coal power generation. Of these three technology types, biomass gasification is the most common and involves gasifying biomass where the resulting fuel gas is burned in a gas turbine or engine to generate power. In China and other developing countries, small biomass gasification systems known as fixed bed gasifier are used for generating power. These fixed bed gasifiers are very small in scale with generation capacity of less than 200 kW but have environmental benefits in very low SO_2, NO and N_2O emissions. In addition, there is also medium and large-scale biomass gasification systems known as fluidized bed gasifier with generation capacity of 400 kW to 3 MW but these are used primarily in Europe. China have also developed small biomass gasification technologies with capacity ranging from 2.5 kW to 200 kW as well as a series of circulating fluidized bed biomass gasification systems with capacities from 200 kW to 4 MW (CAS and GIEC, 2005). Because most of the biomass gasification plants have small capacities below 30 MW, the average efficiency of power generation is only 15%.

Biomass combustion, which involves directly burning biomass in a specialized boiler to produce steam for electricity generation, is less common in China but biomass boiler systems that use timber, stalk residue and rice hulls as feedstock have been manufactured and tested. In particularly, companies in Shanghai and Hangzhou have manufactured rice hull boilers for combustion plants that are increasingly used by rice mills to reduce environmental pollution and its electricity consumption and cost (CAS and GIEC, 2005). However, the scale of these plants remains very small and cannot be centralized into large biomass combustion generation systems. Demonstration biomass combustion projects using foreign technologies are being implemented in Hebei and Shandong province to utilize other crop residue resources.

Lastly, co-firing or co-combustion of biomass waste in coal-fired power plants is another type of biomass power generation with over 228 existing plants worldwide, including over 70 plants in Finland and 40 plants in the U.S. (Al Mansour and Zuwala, 2010). Three subcategories of biomass co-firing technologies exist, including direct co-firing where biomass and coal are both burned in the coal boiler furnace, indirect co-firing where a biomass gasifier is installed to the coal boiler and parallel co-firing with two separate boilers. Biomass co-firing typically involves substituting 1% to 20% of coal input with biomass, and can be applied to a combination of fuels and boiler types ranging from 50 to 700 MW (Al Mansour and Zuwala, 2010). In China, there is only one biomass co-firing demonstration project for a 300 MW pulverized coal-fired furnace plant and large-scale deployment is not expected in the near future due to transport constraints, prohibitively high costs and lack of technological capabilities in biomass pulverization (Wang et al., 2011).

6.5 Modeling Biomass Power Generation in China

In this study, biomass power generation is thus modeled as primarily from biomass gasification with an average efficiency of 15%. In addition, based on Chinese articles and reports, a capacity factor of 50% is used to account for availability and the actual proportion of installed capacity used (Chen and Li, 2010). Due to the lack of China-specific information on biomass feedstock and performance, biomass is only considered as an energy transformation technology and resource requirement analysis and lifecycle energy analysis were not conducted. Rather, biomass power generation is also incorporated into our China energy end-use model's transformation module with the designated parameters for efficiency and capacity factor.

Scenario analysis is used to evaluate the energy and emissions impact of biomass power development in China with two scenarios of installed capacity growth modeled. Under the reference scenario, China will meet its 2020 target of 30 GW and continue expanding to utilize wood waste with a total installed capacity of 40 GW by 2030. Under the Alternative Stumbles scenario, we assume that installed capacity will not reach the target of 30 GW until 2030 as a result of challenges to expanding the scale of biomass power generation.

6.6 Policies and Challenges for Biomass Power Generation

The primary supporting policy for biomass power development is a feed-in tariff on par with coal-fired electricity cost of 0.25 RMB per kWh for all biomass power projects, which has been in place since the 1990s. In 2008, the subsidy was raised to 0.35 RMB per kWh but was still far below the national average biomass electricity price of 0.63 RMB per kWh (REN21, 2009). In July of 2010, NDRC approved a new biomass electricity price of 0.75 RMB per kWh to make biomass power generation more economically viable (Zhao, 2011). In the short and mid-term, feed-in tariffs are expected to remain the main policy mechanisms for supporting the development of biomass power generation given the higher cost but lower thermal efficiency of crop stalks when compared to coal. At the same time, with clusters of development including 17 plants under construction in Jiangsu province, the NDRC has also issued guidelines in August 2010 mandating at least 100 kilometer distance between two biomass power plants in order to prevent regionalized overinvestment and subsequent inflation of local crop prices.

As a relatively young and not yet widely commercialized technology, biomass power plants still face many challenges in playing a greater role in China’s power sector. From a technological perspective, China still lacks capabilities in biomass combustion and biomass co-firing and thus faces limits in expanding the applications, scale and utilization of biomass resources. Technological development in biomass power generation has been further hampered by shortages in basic research funding and weak research and development capabilities in private industry (CAS and GEIC, 2005). With limited options in domestic technology, import of foreign technology and possibly technology transfer is also difficult because differences in biomass resources between China and other countries result in different equipment requirements and generation conditions. The availability of biomass resources, particularly in the arable land needed to cultivate these resources, and the related costs of transport and processing are also barriers to further biomass power development. Despite recent increases in the feed-in tariff, relatively high generating costs, lack of financing options and low capital availability have deterred large companies from investing in large-scale biomass power generation projects. Finally, unclear policies and the lack of standardized project initiation and approval processes have resulted in imbalanced development of biomass plants as in the case of Jiangsu province.

7. Outlook of Solar Water Heaters in the Residential Sector

In addition to power generation, China has also been pushing forward the use of alternative energy sources in meeting residential energy needs. A major alternative energy technology is solar water heaters, which have environmental benefits in displacing traditional water heaters fueled by electricity, LPG and natural gas. Besides solar water heaters, biogas is another alternative energy source that has been promoted for replacing biomass and fossil fuels for cooking in rural households.

7.1 Solar Water Heating Technologies Overview

Solar water heater utilization started in China as early as the 1970s, and has been advocated and promoted for residential use within the last decade. China has since become the world's largest producer of solar water heaters with annual sales of 13 million m^2 in 2004 and production value of US$1.4 billion (Li and Hu, 2005). China has also become the leading consumer of solar water heaters, with over 70% of global installed capacity in 2008 and accumulated installed area of 168 million m^2 in 2010 (REN21, 2010). Domestic demand for solar water heaters is primarily from residential households in suburban areas in large cities, small and medium-sized cities and towns with 90% combined market share. Within urban households, the solar water heater is used to provide hot water for showers, cleaning, washing, drinking and cooking. The annual installed area of solar water heaters exceeded 25 million m^2 in 2009 with total installed area surpassing the 2010 target of 150 million m^2 putting China well on its way to meet its 2020 target of 300 million m^2.

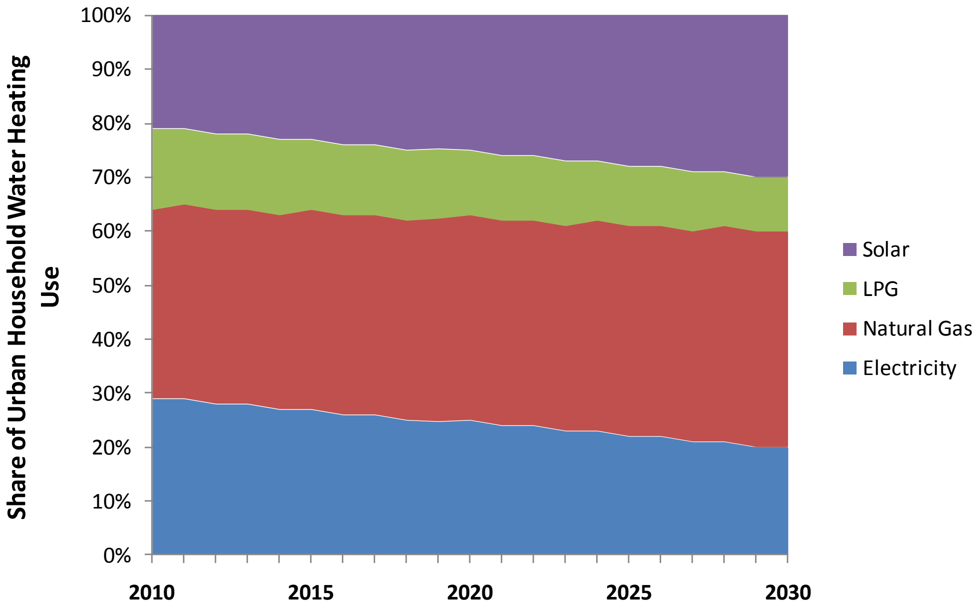
There are three main types of solar water heating technologies: flat plate collectors, evacuated tube collectors and combined storage collectors. As the oldest and most simple technology, combined storage collectors are also known as integrated water heaters and use a water tank that acts as both storage and solar collector and uses gravity flow to deliver the heated water. The integrated solar water heaters have negligible market share in China with only 1% in 2004 and are used primarily in frost-free southern regions (Li, 2005). Of the two types of split solar water heaters, the Chinese market has been increasingly dominated by evacuated or vacuum tube system water heaters with a 35% market share in 1997 rising to a 95.4% market share in 2007 (Li and Hu, 2005; Han et al., 2010). China thus differs from the EU and other countries where flat plate collector systems dominate the solar water heating market with an 86% share in the EU. Compared to flat plate collectors, the evacuated vacuum tube system is more efficient in minimizing heat loss to the environment through a vacuum created between the two glass collector tubes.

The vacuum tube solar water heating systems used in China include solar reflecting plate and glass vacuum tubes, a supporting system and the water tank, all of which are usually installed on the roof. Cold water is pumped upward from a residence's kitchen or bathroom to the roof and the heated hot water is then transported downward through the insulated pipes (Han et al., 2010). The solar collector area ranges from 2 to 3 m^2 with typical water tanks having a total capacity of 150 to 200 liters and has a designed lifetime of 10 to 15 years.

7.2 Modeling Solar Water Heaters in China

In projecting the total installed capacity of solar water heaters from 2010 to 2030, China is assumed to meet its 2020 target and continue rising at a slower pace to reach a total of 150 million urban households or 450 million m^2 in 2030.

Figure 18. Urban Household Water Heating Technology Shares, 2010 - 2030



In light of the continued dominance of vacuum tube systems in the Chinese solar water heating market, only vacuum tube solar water heating technology is considered in modeling solar water heaters. Based on China-specific study of solar water heaters in Zhejiang province, a major manufacturing base with 20% of national production share, the vacuum tube system in this study is assumed to have an average collector area of 3 m^2 and lifetime of 12.5 years (Han et al., 2010). Resource requirements for the vacuum tube solar water heaters are not considered in this study for two main reasons: international life-cycle studies have only analyzed the material intensity of flat plate collectors in Greece and the small scale of material input to the solar water heaters (Kalogirou, 2009).

In modeling the energy and emissions impact of China's solar water heater development, the primary focus is on the displacement of water heating energy from electric, natural gas and LPG water heaters. Since our China Energy End-use Model already have a very detailed urban water heating module with China-specific water heater stock turnover model, water heating intensities for each type of fuel, and total water heating energy demand, scenario analysis in our LEAP model is used to calculate the displaced fossil fuel (Figure 18). More specifically, an Alternative Stumbles scenario is created to assess a potential case in which China fails to meet its 2020 target for solar water heating and does not reach 300 million m^2 of installed capacity until 2030. This serves as the counterfactual baseline for the reference case of alternative energy development, when the target is met in 2020, and the gap is considered the additional solar water heaters induced by policy-driven solar water heating development. The fuel displacement can then be calculated by the fossil-fuel market-weighted share of natural gas, electric and LPG water heaters and each water heater's calculated average primary energy intensity. Thus, for a given year, the natural gas for water heating displaced by solar water heaters can be calculated as:

$$Displaced\ Fuel_{(NG)} = \Delta\ SWH \times NGWH\ Market\ Share \times EI_{NG}$$

Where:

$Displaced\ Fuel_{(NG)}$ = total natural gas fuel in primary energy terms displaced in Mtce

Δ SWH = total additional solar water heater installation per year in units

NG WH Share = market share (%) of natural gas out of all fossil fuel water heaters

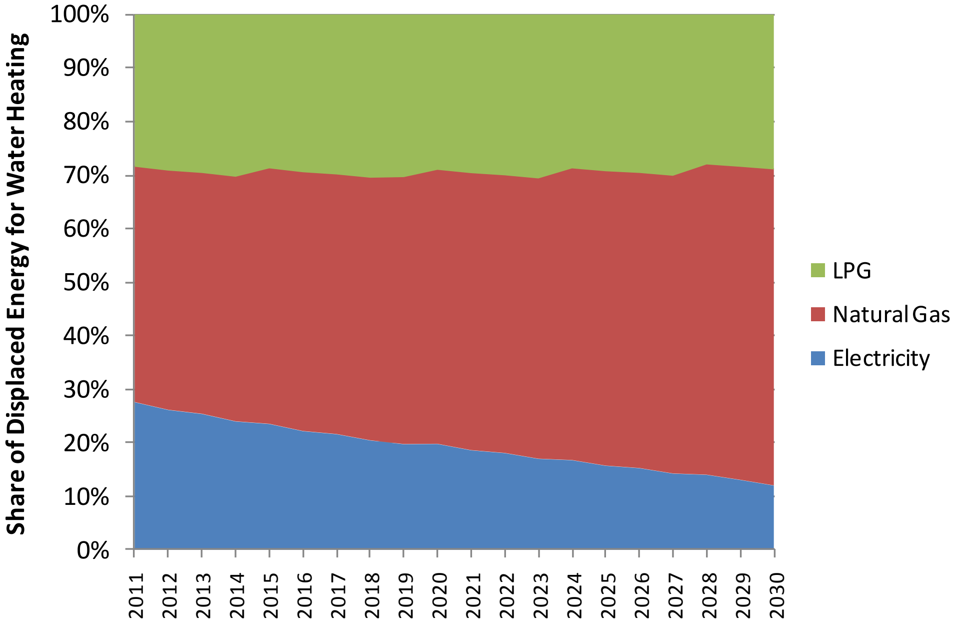
EI_{NG} = the primary energy intensity (Mtce/unit) of natural gas water heaters

The electricity and LPG fuel displaced by solar water heaters can be calculated using the same method. The CO_2 emissions impact can then be calculated using China-specific energy content and IPCC emissions factor for natural gas and LPG, and the grid average carbon emission intensity for electricity.

7.3 Energy and Emissions Impact of Solar Water Heaters

With continued expansion of solar water heaters for urban households, a cumulative total of 85 Mtce of fossil fuels and electricity will be displaced by the 50 million additional solar water heaters. Of the energy displaced, the dominant and increasingly growing share will be from natural gas, with 5.4 Mtce (or 60% share of total) displaced in 2030, followed by electricity with 1.1 Mtce (Figure 19). An additional 2.61 Mtce of LPG will also be displaced in 2030, or a total of 24.9 Mtce cumulatively.

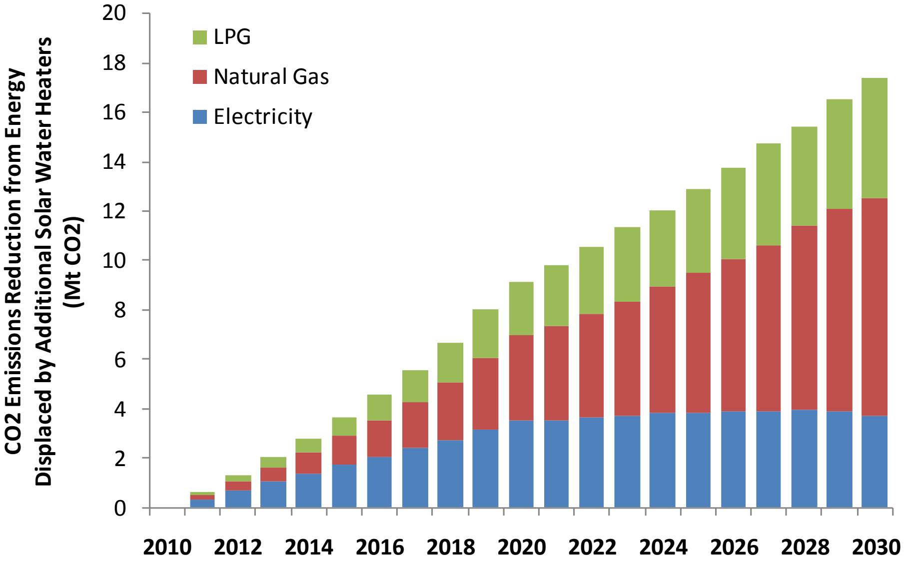
Figure 19. Share of Energy Displaced by Additional Solar Water Heaters, 2010-2030



Note: 2010 is not depicted in the graph because there was no energy displacement in 2010.

In terms of CO_2 emissions, the energy displaced will result in an annual reduction of 17.4 Mt CO_2 by 2030 and a cumulative total of 179 Mt CO_2 over the twenty year period (Figure 20). In the earlier years, most of the CO_2 emissions reduction will be from electricity but this share will decrease over time as electricity's share of total displaced energy and its carbon intensity (kg CO_2 per kWh) both decrease. By 2030, displaced natural gas will contribute to half of the total emission reduction with the remaining portion from LPG and electricity.

Figure 20. CO_2 Emissions Reduction from Fuel Displaced by Solar Water Heaters



7.4 Policies for Promoting Solar Water Heaters

Besides its inclusion in the Medium and Long-term Renewable Energy Development Plan, solar water heaters were also included in an Implementation Plan on Promoting Solar Thermal Utilization approved by NDRC in April 2007. Under this implementation plan, the installation of SWH systems has priority for major hot water consumers such as hospitals, schools, restaurants and swimming pools (Han et al., 2010). China also has 12 national standards related to testing and solar water heating evaluation, products, and management as well as national industry standards to standardize the development of the solar water heating industry (Li and Hu, 2005). The NDRC and Ministry of Construction have also issued specifications for building-integrated solar water heating systems and organized a national conference to encourage local governments to issue local regulations mandating solar hot water adoption and provide financial support (REN21, 2009). Most recently in 2010, solar water heaters were added to the national "Home Appliances to the Countryside" subsidy program for rural household appliances with 243 producers approved for the subsidy scheme (Xinhua, 2011e).

On the provincial level, both mandatory push and voluntary incentive-based pull policies have emerged to expand the domestic market for solar water heaters. In the major solar water heating production base of Zhejiang, the 2007 Management Measures on Building Energy Saving issued by the local government mandated compulsory installation of solar water heaters in new villas and houses and strongly recommended installations in apartment buildings with less than 12 stories. Zhejiang province has also issued technical standards to control the quality and safety of solar water heaters, including requirements for manufacturing, installation, adjustments and evaluation (Han et al., 2010). Additionally, Zhejiang and other provinces and cities have also offered financial subsidies on household solar water heater installation, with the actual subsidy amount varying from 300 RMB to 500 RMB depending on the county or city compared to average market prices of 1,800 RMB for a 200L solar water heater (Han et al., 2010).

As a result of these various national and local policies promoting and even mandating residential use of solar water heaters, a recent survey shows that 73% of consumers are aware of solar water heaters (compared to only 26% for PV) and that 85% of respondents living in high rise buildings have installed solar water heaters (Yuan et al., 2011). Solar water heaters are common in high rise buildings with more than seven floors because they are relatively new and building integration of solar water heaters including reserving roof space for collectors and wall space for pipes were taken into consideration during building design and construction. While the initial technology shift has been facilitated by recent national and provincial policies, there are still technical aspects that pose barriers to continued expansion of solar water heater utilization.

7.5 Challenges to Solar Water Heaters Expansion

The fast adoption of solar water heaters for residential use in China has revealed persistent barriers facing the emerging industry including product reliability, technical performance and institutional barriers to implementing policies supporting solar water heater utilization. As with the solar PV industry, the young solar water heater manufacturing industry also faces unfavorable production structures and subsequent reliability issues. With over five thousand domestic manufacturers competing for a relatively small market, most manufacturers have very limited production capacity and do not benefit from production economies of scale. Rather, the intense competition drives prices down and leads manufacturers to use low-quality material that in turn leads to unreliable solar water heaters with poor quality. A recent news report revealed that small workshops in Haning city of Zhejiang province sold counterfeit brand solar water heaters and that only 30 producers have passed China General Certification Center quality standards over the last five years (Xinhua, 2011e). Furthermore, recent market surveys have also shown that the actual lifetime of solar water heaters is only 6.5 years, rather than the 10 to 15 year design lifetime (Han et al., 2010). Consumers surveyed in Shandong province, another major production region, have also identified stability and durability as major issues with solar water heater implementation and utilization (Yuan et al., 2011).

Related to product reliability and durability concerns is the fact that current Chinese solar water heating technologies still face performance issues that need to be addressed by technological development and the consideration of other technology choices. In Northern China where winter temperatures drop to sub-zero temperatures, the water tanks and pipes of solar water heaters installed outside on building roofs can freeze and crack (Yuan et al., 2011). The solar collectors of the dominating solar water heating technology in China, namely the vacuum tube solar water heater, also require more roof space than flat plate collectors and poses installation difficulties in high-rise apartment buildings with over 12 stories. The performance of split solar water heaters such as the vacuum tube systems may also raise concerns in water scarce regions since the water in the pipes between the water tank and the place of use cannot be heated and 1.7 liters of water has been estimated to be wasted per use of the water heater (Han et al., 2010).

Institutional challenges to provincial solar water heater policies have also limited the growth of solar water heater installations in China. On one hand, visual pollution, limited roof space and the extra costs required for installing pipes in the walls all pose logistical difficulties for integrating solar water heaters into existing residential buildings. On the other hand, ambiguous language such as “strongly recommended” and “encouraged” and the absence of specific implementation guidelines have deterred estate management and developers from complying with mandatory solar water heater installation requirements (Han et al., 2010). In some cases, estate developers and managers have even found legal loopholes to charge residents solar water heating maintenance fees. Lastly, installations of water heaters on existing rooftops may actually be prohibited in some cities because compulsory solar water heater installation policies conflict with existing local policies mandating building and city aesthetics (Li and Hu, 2005).

8. Outlook of Biofuels Development in China

8.1 Biodiesel

China has been focused on biofuel development since the late 1990s, with the first large-scale application of fuel ethanol in 1999 and continued expansion under the 11th FYP period. During the 11th FYP period, China’s total biodiesel production capacity reached three million tons per year with six producers with an annual production capacity of greater than 100,000 tons (Table 23). However, total biodiesel output was only 200,000 tons in 2010. The feedstock for biodiesel production in China is primarily waste cooking and vegetable oil and animal fats, which have inherent reuse advantages in reducing the cost and burden of disposal and sewage treatment. Biodiesel is sold to consumers as an industrial fuel oil and is currently not used as a transport fuel through biodiesel and diesel blending. The Ministry of Finance has recently sought to expand the production scale of biodiesel by enacting a retroactive tax exemption on biodiesel production from waste animal fats or vegetable oils in December of 2010. This policy exempts biodiesel production from consumption tax, including backdated tax refunds to January 1, 2009, with equivalent savings of 900 RMB per ton of biodiesel (Blanchard and Niu, 2010). Nevertheless, biodiesel production faces problems with feedstock’s unstable quality and the lack of a national quality standard.

Table 23. Biodiesel Producers by Production Capacity

Annual Production Capacity	Producers
< 10,000 tons	26
< 50,000 tons	13
< 100,000 tons	7
> 100,000 tons	6

Source: Hui Market Research Reports 2010

Besides the financial incentives for biodiesel production, China is also considering expanding the feedstock for biodiesel to rapeseed and jatropha given that restaurant waste oil capacity is limited to two million tons per year. China is currently the world's largest producer of rapeseed with over one-fifth of global production but short-term development of biodiesel from rapeseed will likely be limited by the heavy energy costs of production due to low yield and high fertilizer use. In fact, a recent lifecycle study of rapeseed-based biodiesel in China found a total energy input of 27,918 MJ, which is 1.1 times higher than the biodiesel energy content of 25,443 MJ or an EROEI of 0.79 (Chen and Chen, 2011). Another potential feedstock for expansion of biodiesel production is jatropha, which is available in Sichuan, Guizhou and Yunnan provinces. Jatropha has advantages in that it can be grown on marginal lands and demonstration projects with capacities of greater than 10,000 tons per year are under construction in Guizhou and Yunnan (Wu et al., 2010). However, jatropha-based biodiesel production faces problems in reaching mass production scale, mechanized collection of crops and effective utilization of residues.

8.2 Bioethanol

Since 1999, China's bioethanol production has grown to a total production capacity of 1.8 million tons per year with five major bioethanol producers, including four grain-based biofuel producers. Unlike biodiesel, bioethanol is blended with gasoline to produce E10 for use as a transport fuel and ethanol gasoline accounts for as much as 20% of total gasoline consumption in China (Leng et al., 2008). Ethanol is distributed by 27 cities in 9 provinces. As seen in Table 24 below, most of China's bioethanol production use grains as a feedstock and have only launched two demonstration cassava-based bioethanol plants, including the Guangxi plant. Cassava-based bioethanol plants have two major advantages, its ability to be cultivated in marginal land and the fact that it is not a staple starch food for the Chinese population.

Table 24. Five Major Bioethanol Producers in China

Producers	Feedstock	Annual Capacity (tons/yr)
Jilin Biofuel	Corn	600,000
Heilongjiang Huarun Ethanol	Corn	250,000
Anhui Fengyuan	Corn	440,000
Henan Tianguan	Wheat	300,000
Guangxi Zhongliang	Cassava	200,000
Total		1,790,000

Source: Green Energy Information Network 2011.

Due to China's reliance on grain-based fuel ethanol and its competition with food production on limited arable land, recent policies have limited the expansion of existing bioethanol production and halted new project approvals. In particular, new grain-based fuel ethanol plant project approvals were stopped indefinitely in 2006 (Wu et al., 2010). In addition, the government is also limiting corn starch based bioethanol projects with processing capacity of less than 300,000 tons per year and has eliminated projects with annual capacity of less than 100,000 tons per year (Agra Europe, 2011). Instead, the government is encouraging non-grain based bioethanol and especially those that can be cultivated on alkaline land and wasteland.

Potential feedstock for bioethanol production that have received growing attention in China include sweet sorghum and lignocelluloses. For sweet sorghum, China currently has over 125 resources registered and a 5000 ton per year demonstration project was established with support from the National High Tech program (Wu et al., 2010). Lignocelluloses, which include crop residue, grass, sawdust, wood chips, solid animal waste and industrial waste are being explored in research and development projects at several major universities including Tsinghua University. However, both feedstock face challenges in the storage and pretreatment of feedstock and low conversion rate and high energy consumption of production processes, with efficiencies ranging from 12% to 14% for fresh cassava and 15% to 25% for dilute acid and enzyme hydrolysis (Wu et al., 2010).

8.3 Modeling the Development of Biofuels

Life-cycle analysis studies of bioethanol and biodiesel from different feedstock have shown very low energy returns, with only sweet sorghum-derived ethanol and biodiesel derived from waste cooking oil, soybeans and jatropha having an energy return that is greater than the energy input. As a result of these relatively low EROEIs as well as the multiple challenges facing development of biofuels derived from non-grain feedstocks that are unlikely to be resolved in the short-term, only direct use of E10 bioethanol is considered in the modeling analysis for this study. Specifically, bioethanol is incorporated into our LEAP end-use model as a transport fuel.

Table 25. Lifecycle Energy Input to Biofuels in China

Per MJ Fuel Output	Petroleum Input MJ	Coal Input MJ	Total Energy Input MJ	EROEI (Output/Input)
Corn-derived ethanol	0.17	0.9	1.07	0.93
Sweet sorghum-derived ethanol	0.12	0.57	0.69	1.45
Cassava-derived ethanol	0.07	1.19	1.26	0.79
Conventional diesel	1.12	0.16	1.28	0.78
Waste cooking oil-derived biodiesel	0.36	0.61	0.97	1.03
Soybean-derived biodiesel	0.29	0.34	0.63	1.59
Jatropha-derived biodiesel	0.09	0.41	0.5	2.00

Source: Ou and Zhang 2010.

9. Outlook of Advanced Coal Alternative Technologies Development

China's abundant coal resources and its limited supply of oil, gas and chemical products have made the exploration of coal alternatives development of coal-to-liquids (CTL), coal-to-chemicals and coal-to-gas technologies very appealing and urgent. While demonstration projects were launched in all three areas of coal alternatives and production has started, challenges have also emerged that question the role of coal alternatives in supplying China's shortfall in energy resources and chemicals.

9.1 Coal to Liquids

9.1.1 Current Status of Coal Liquefaction

In exploring the development of coal-to-liquids in China, pilot demonstration projects in both the direct coal liquefaction (DCL) and indirect coal liquefaction (ICL) processes were undertaken in Inner Mongolia. The investments in these new projects have been driven by an economic advantage where oil is four times more expensive than coal and energy security concerns of heavy reliance on imported oil (Zhang, 2010). For example, Shenhua group, a stated-owned mining and energy company and the largest coal producer in China and the world invested 50 billion RMB during the 11th FYP period. Several other companies also started DCL and ICL demonstration projects but NDRC project approval was suspended in September 2008 due to concerns about water requirements and overinvestment in a technology that was not commercialized at that time.

Currently, Shenhua Group has the only operational DCL plant in China which was constructed and started in Inner Mongolia in December 2008. This plant converts coal into gasoline, diesel and other oil products through direct coal liquefaction in which hydrogen is added to the organic structure of coal with coal broken down by high temperature and pressure into distillable liquids. The coal-derived liquids are then further hydrocracked to produce synthetic crude oil and refined and hydrotreated to produce transport fuels. The plant design was developed with help from West Virginia University and has a production capacity of one million tons per year with a daily output of 25,000 barrels of oil. On an annual basis, 3.45 Mt of raw coal is used to produce 1.1 Mt of fuel and oil products, including 715,000 tons of diesel, 250,000 tons of naphtha and 102,000 tons of LPG (Wu, 2010). Shenhua is planning on expanding its CTL capacity target to 3 million tons per year by 2015 with another CTL plant in Ningxia awaiting NDRC approval. Shenhua further expects its total CTL capacity to reach 30 million tons of oil products per year by 2020, with annual production of 11 Mt of oil and oil products and 18.3 bcm of gas possible (Pew, 2010; China Daily, 2010).

There is also only one ICL demonstration plant in China, namely the Yitai Group project started in Inner Mongolia in March 2009. This is China's first industrial-scale CTL plant using ICL technology and has an annual production capacity of 160,000 tons with diesel and naphtha as the main outputs. Under ICL, the coal structure is completely broken down by gasification with steam and the composition of gasification products are then adjusted to produce synthesis gas, which is reacted over a catalyst at relatively low pressures and temperatures. The Yitai group expects that total annual production capacity will expand to 600,000 tons with plant upgrades (Cox, 2009).

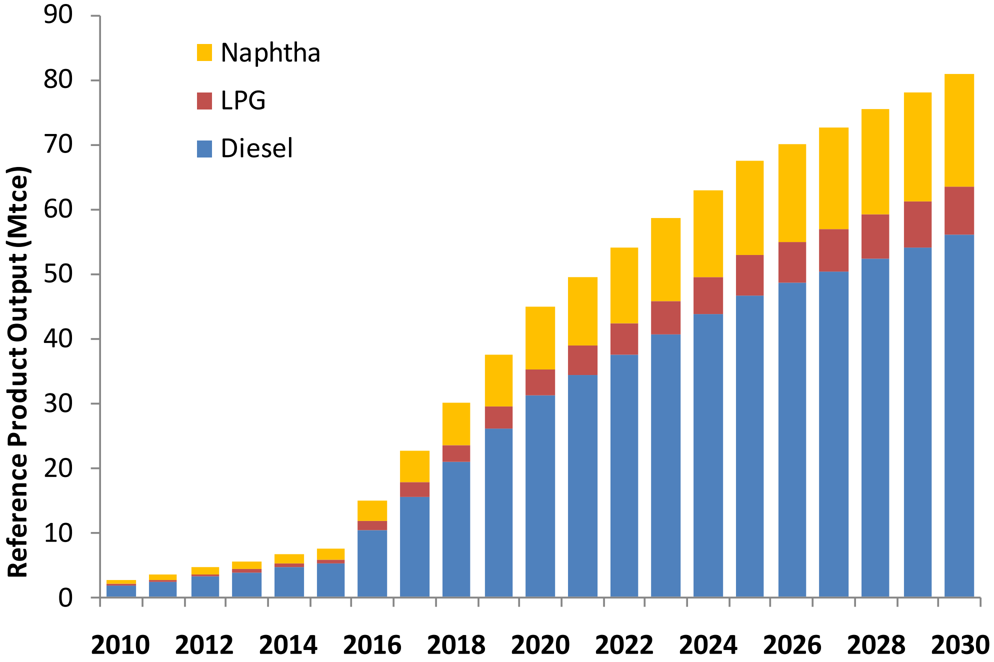
In the near future, coal to liquids projects in China will continue to be driven by high oil prices and the recently implemented local use requirements by NDRC in mid-2010 that require value to be added locally to a proportion of production and encourages the development of advanced coal alternative technologies in resource-rich regions in western China (Zhang, 2010). However, continued CTL development also faces challenges in the high water requirements for DCL and ICL technologies with 6 to 12 tons of water needed to produce a ton of fuel and the Shenhua plant consuming 10 Mt of water annually in a water-scarce region (Schneider, 2010).

9.1.2 Modeling Coal Liquefaction

In this study, CTL is modeled as an energy transformation process and is included in the transformation module of our LEAP model. Two scenarios were used to analyze the potential impacts of CTL on China's energy pathway. The reference scenario assumes that China will reach the forecasted target capacity of 30 Mt/yr by 2020 and continue to grow to 60 Mt by 2030. This is contrasted with the counterfactual baseline of the Alternatives Stumble Scenario, in which water constraints and other barriers delay China from reaching 30 Mt/yr until 2030.

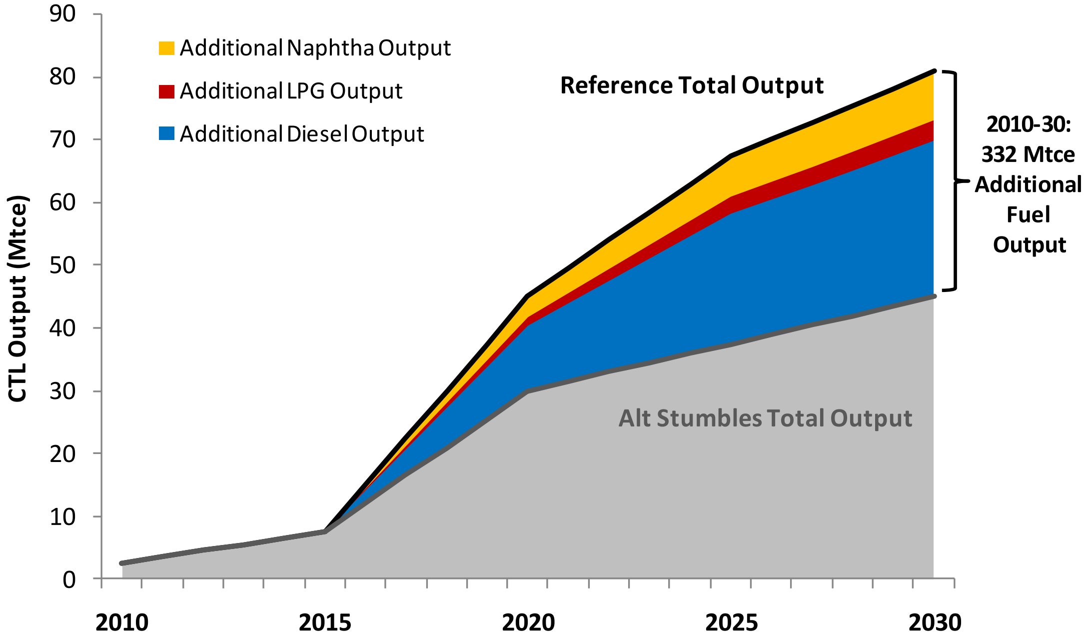
The total outputs for the reference scenario is shown in Figure 21 below. As China's demonstration CTL plants achieve the necessary scale for commercialization, CTL is expected to take off rapidly after 2015 and reach annual production of 56 Mtce of diesel, 7.4 Mtce of LPG and 17.5 Mtce of naphtha by 2030. Most of the coal liquefaction output will be in the form of diesel, a major transport fuel that with rising demand.

Figure 21. CTL Output by Product Type under Reference Scenario, 2010-2030



Under the Alternative Stumbles scenario, however, water and technological constraints could reduce CTL outputs by a cumulative total of 332 Mtce. In other words, the reference scenario would produce additional 230 Mtce of diesel, 30 Mtce of LPG and 72 Mtce of naphtha when compared with the Alternatives Stumble scenario (Figure 22).

Figure 22. Difference in CTL Output Products by Scenario, 2010-2030

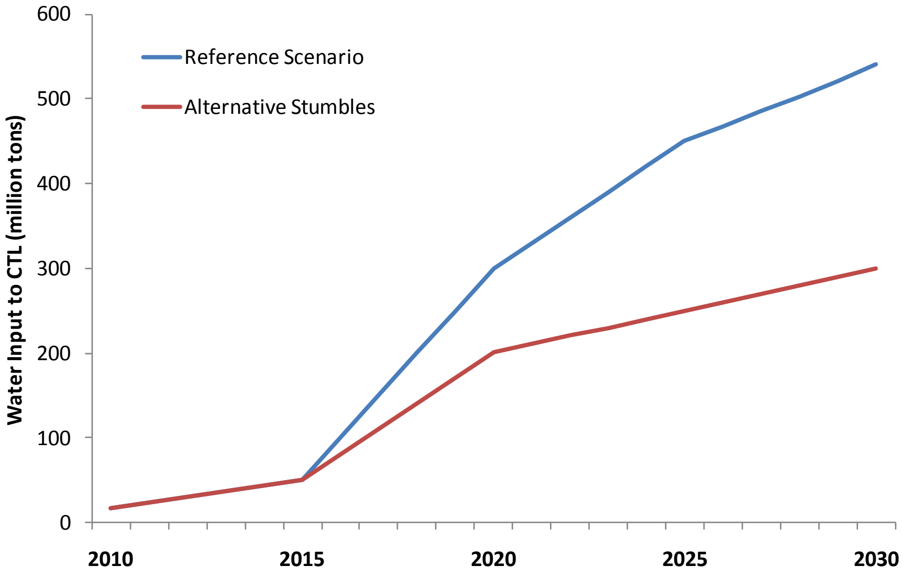


This in turn leads to lower net energy input in the form of coal and electricity (Table 26) as well as nearly half of the water requirement as the reference case of CTL development (Figure 23). Nevertheless, even the slower pace of CTL development would still require 300 million tons of water annually by 2030 and nearly 3.5 billion tons of water from 2010 to 2030.

Table 26. Comparison of Energy Input to CTL by Fuel Type and Scenario for Key Years

	2010	2015	2020	2025	2030	Cumulative
Reference Scenario						
Coal Input	4.7	14.0	84.1	126.1	151.4	1588.1
Electricity Input	0.1	0.3	1.9	2.8	3.3	34.9
Alternative Stumbles						
Coal Input	4.7	14.0	56.1	70.1	84.1	967.0
Electricity Input	0.1	0.3	1.2	1.5	1.9	21.3
Additional Energy Input under Reference						
Coal Input	0.0	0.0	28.0	56.1	67.3	621.0
Electricity Input	0.0	0.0	0.6	1.2	1.5	13.7
Total	*0.0*	*0.0*	*28.7*	*57.3*	*68.8*	*634.7*

Figure 23. Water Requirements for CTL Development by Scenario, 2010-2030



9.2 Coal-to-Chemical

Another area of alternative coal technologies that China has started exploring with growing demand for synthetic chemicals but limited natural gas and oil feedstock is coal-to-chemicals technologies. These include coal-methanol, coal-dimethylether (DME), coal-glycol and coal-olefin.

9.2.1 Coal-to-methanol

For methanol production from alternative fuels, coal or natural gas can be used as a feedstock with coal-to-methanol having a 67% share of total output in 2009. With coal as a feedstock, coal gasification produces syngas which is used to produce methanol through methanol synthesis. Coal methanol production requires an input of 2.4 tons of standard coal per ton of output. The conversion efficiencies of gasification and synthesis for each stage and for the overall process are shown in Table 27 below. In 2010, the annual coal-to-chemical capacity was 42.3 Mt but actual utilization was much lower at 46% with only 19.3 Mt of output (Aibida, 2011). Shenhua group has one of the newest and largest coal-to-methanol plants in Baotou, with capacity to produce 600,000 Mt of methanol and olefin once it begins commercial operation in late 2011 (Schneider, 2011). Methanol is used primarily as a chemical in China, with only 18% or 3.45 Mt of methanol used as fuel. However, methanol for fuel use is likely to increase as China enacted the national “Methanol Vehicle Fuel Standard” (GB/T23510-2009) in December 2010 with an 85% blending ratio. Coal-methanol thus has potential to grow in China with forecasts of 66 Mt/yr production possible by 2020 and 130 Mt/yr by 2030 (Yikai Data, 2011). The major limiting factor for coal-methanol development is the high water requirement for coal-to-methanol production, with 10 to 20 tons of water needed to produce one ton of methanol. In recognition of the overcapacity of methanol production and current low utilization rate, NDRC also began tightening control over coal-to-chemical projects by setting minimum scale targets and removing approval authority from local governments in April 2011 (Zhang, 2011). For new coal-to-methanol projects, a minimum 1 Mt/year production capacity is required for approval.

Table 27. Coal to Methanol and Coal to DME Process Efficiency

Process	Stage Efficiency %	Overall Process Efficiency
Coal to Methanol Gasification	45%	43%
Coal to Synthetic Methanol	95%	
Coal to DME Gasification	41%	39%
Coal to Synthetic DME	95%	

Source: Constructive analysis on energy consumption and life cycle of main pollutants of various new energy buses, *Vehicles*, 2009.

9.2.2 Coal-to-DME

Related to coal-to-methanol is the newer technology of coal-to-DME, which is produced by dehydration of methanol with an input of 1.5 ton of methanol per ton of DME and has similar efficiencies as coal to methanol production (Table 27). China’s coal-DME capacity was 8 Mt/yr in 2010, but utilization rate was also quite low at 30%, and capacity is projected to grow to 20 Mt/yr by 2020 and 40 Mt/yr by 2030 (Yikai, 2011). There are currently two operational large-scale coal-DME demonstration projects in Inner Mongolia, with production capacities of 3 Mt/yr and 0.4 Mt/yr. DME is used primarily as a substitute fuel for LPG in China, but is currently not permitted to be blended with LPG as a fuel.

9.2.3 Coal-to-Glycol and Coal-to-Olefin

Two other emerging coal-to-chemicals technologies are coal-glycol and coal-olefin production, with two ongoing demonstration projects in Inner Mongolia. The coal-glycol demonstration plant has an annual capacity of 200,000 tons per year while the Shenhua coal-olefin plant has a planned capacity of 600,000 tons per year but is not yet operational (Zhang, 2011). As a precursor to plastics production, methanol and synthetic gas, olefin has been in demand and three additional coal-olefin plants are expected to open in 2011. However, because coal-olefin technologies are still very new and not yet commercialized, NDRC has also set a minimum production capacity scale requirement of 500,000 t/yr for new projects (Zhang, 2011).

Due to the relatively small scale of coal-methanol production and the coal-DME plants, coal-to-chemicals are not modeled explicitly in this study. However, the resource requirements for coal-to-chemicals conversion technologies from a recent Chinese study are shown in Table 28 below.

Table 28. Total Resource Requirements for Coal-to-Chemicals Development

	Coal-Methanol		**Coal-DME**	
	GJ Input per GJ Output	Conversion Efficiency	GJ Input per GJ Output	Conversion Efficiency
Coal	1.75	55%	1.79	54%
Electricity	0.07		0.08	
Total Energy	1.83		1.86	
Water (tons/GJ)	0.74		0.78	

Source: Zhang, et al. 2006.

9.3 Coal-to-Gas

As a country with sparse natural gas resources, China is currently in the exploratory and R&D stage of coal-to-synthetic natural gas (SNG) development with NDRC having permitted the construction of four coal-to-SNG demonstration projects. These four projects include two plants in Inner Mongolia with 3 bcm and 1.6 bcm of annual capacity, one in Liaoning province with 4 bcm/yr and one in Xinjiang province with 6 bcm/yr capacity. The Datang 4 bcm/yr coal-to-gas plant in Inner Mongolia is expected to be completed by 2012, with the first production line of 1.3 bcm operating in 2010. There are a total of 25 coal-to-synthetic natural gas projects planned with total potential capacity of over 25 bcm. The current demonstration projects use domestic two-step conversion process based on high pressure pulverizing coal gas technology but NDRC has also encouraged joint-venture projects using foreign technology such as the one step coal-to-gas technology used in the US. The future development of synthetic natural gas from coal will require supporting gas pipeline infrastructure, such as the 359 kilometer pipeline being built to connect the Datang plant with consumers in Beijing (Zhou, 2010). Coal-to-SNG is also not modeled in this study in the absence of a commercialized production line.

10.Comparative Analysis of Alternative Energy Technologies Potential

Based on the literature review and resource input assessment for each alternative energy technology, a comparative analysis of the material resources and energy input requirements can be conducted. On the resource input side, this includes the cumulative raw material input for all of China's 2010 to 2030 installed generation capacity for alternative energy including solar, wind, hydro, nuclear, and geothermal as well as the average intensity per kWh generated. On the energy input side, the analytical results are presented in terms of the average energy output to fossil fuel input which takes into consideration the fossil fuel requirements for manufacturing, operating and maintaining, and decommissioning of each technology.

10.1 Natural Resources and Material requirements

In supporting China's alternative energy development, water and concrete are two major resources that will be demanded on a significant scale. As seen in Table 29, hydroelectric and CSP have the two highest concrete material intensities per MW of installed capacity while geothermal and solar PV have concrete intensities that are below traditional natural gas combined cycle and coal-fired power plants.

Table 29. Comparison of Concrete Intensity for Alternative and Fossil Energy Technologies (tons/MW)

	Estimated Concrete Intensity (tons/MW)
Geothermal	38
Solar PV (balance of sytems)	47
Natural Gas	*60*
Coal	*100*
Biomass	160
Nuclear	170
Wind	639
Hydroelectric	5,000
CSP: solar tower	7,328

Note: Natural gas and coal concrete intensities taken from Sullivan et al, 2010.

In terms of water, there is a surprisingly large variation in the water intensity for different types of PV power plants with CIS having the lowest water intensity of all alternative energy technologies and amorphous silicon having the highest intensity of all PV technologies (Table 30). CSP also has the highest water intensity that exceeds off-shore wind by two orders of magnitude, illustrating the potential water constraints to expanding CSP solar tower development. Nuclear and geothermal are not included due to complex boundary issues.

Table 30. Comparison of Water Intensity for Alternative Energy Technologies (tons/MW)

	Estimated Water Intensity (tons/MW)
Hydro	154
Solar PV	
CIS	25
Poly-Si	494
Mono-Si	464
Amorphous-Si	615
Wind	
On-shore	1,767
Off-shore	3,767
CSP: solar tower	486,667

Based on the material input intensities per MW of capacity reviewed in each technology sections and our reference projected installed capacity and modeled electricity generation output for each energy type (discussed more in Section 12), the average material intensity for each technology type can be calculated using a kWh of electricity generated as the functional unit. By using kWh, rather than MW or GW of installed capacity, as a functional unit, the variance in availability and capacity factors between the energy technologies are taken into consideration and the results are normalized. The average material intensity per kWh for key resources is thus calculated by dividing a specific energy type's cumulative resource input from 2010 to 2030 by its cumulative generation output and the results are shown in Table 31.

Table 31. Summary of Key Lifecycle Material and Resource Intensity per kWh of Generation by Technology

	Land	Water	Steel	Cement	Concrete	Aluminum	Copper
	m2/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh
Wind	0.01	61.4	4.11	-	21.5	0.02	0.10
Nuclear	-	-	0.33	-	1.78	-	0.01
Hydro	0.0003	2.15	0.19	0.37	-	-	0.16
Solar PV	0.002	28.0	3.45	-	2.92	1.30	0.47
CSP	0.01	30,379	120.7	-	457.4	-	1.26
Geothermal	0.00	-	3.34	-	0.87	-	0.05

Note: Solar PV and CSP Solar Tower are distinguished as separate energy types because their material input requirements vary due to different technical and performance requirements, rather than capacity scale such as offshore and onshore wind and different sizes of hydro.

As illustrated by the table above, all alternative energy technologies require steel, cement or concrete, and copper as major material inputs. While all energy technologies use water and land during their lifetime, water intensities are not shown for nuclear and geothermal technologies due to lack of sufficient data, high uncertainty and complex boundaries and definitions. Due to the same data limitations and given different boundary issues surrounding uranium mining, the land intensity for nuclear power is also not presented. Of all the technology types, solar CSP tower appears to be most material-intensive in terms of steel, concrete and copper as well as water-intensive, with an average per kWh intensity that exceeds the other technology types by one to three orders of magnitude. In terms of land, however, wind and CSP power generation has the largest footprint with 0.01 m^2 per kWh generated. This large land requirement for solar and wind is not likely a serious limitation as most of the abundant solar and wind resources are located in remote regions with low competition for land use.

From an aggregate perspective, the annual as well as cumulative total material and resource requirements of all of China's alternative energy generation capacity for selected years is shown in Table 32 below.

Table 32. Annual and Cumulative Material and Resource Requirements for China's Alternative Energy Development

Unit: thousand metric tons	**2010**	**2020**	**2030**	**Cumulative (Mt)**
Land (thousand km2)	5.5	2.6	2.7	64.2
Water	61,683	169,917	157,894	3,047
Concrete	12,757	10,054	12,644	235
Cement	794	432	248	7.6
Steel	2,909	2,411	2,810	53.9
Aluminum	27	49	59	1.1
Lead	87	48	27	0.8
Iron	1,709	935	742	18.5
Copper	408	247	184	4.7
Glass	3	20	17	0.34
Silica	6	3	5	0.09
Resin	119	67	95	1.7
Fiber Glass	80	45	64	1.2
Plastics	5	12	14	0.26

From 2010 to 2030, the cumulative land needed to site all of China's power plants from non-fossil, alternative energy is 64,200 km^2, or the equivalent size of West Virginia and ten times the total land area of Shanghai. On an annual basis, the total additional land needed for China's new alternative energy technologies range from two to over five thousand square kilometers, similar to the size of Rhode Island. For some generation technologies such as solar PV and wind where the resource availability is concentrated in remote regions, land availability will unlikely be limiting factor. However, these generation technologies will require new transmission lines and expanded power grids for exporting electricity to the demand centers and thus have additional land and material requirements not captured by the technology itself.

As illustrated earlier, another major resource requirement for China's alternative energy pathway is water. Cumulative demand for water could reach 3.05 billion tons by 2030, or nearly the total annual national water consumption in 2009, and annual demand of between 61 and 185 million tons of water. Combined with CTL water requirements (not included in table above), water demand for China's alternative energy development would total 700 million tons annually by 2030. The cumulative total of 8.8 billion tons is even more staggering as the equivalent of nearly three years of the entire country's annual water consumption. More importantly, as with land, regional variations in resource availability will determine the extent to which water will be a limiting factor for alternative energy development. Although the technology is too nascent for water to be a constraining factor now, the development of large-scale, water-intensive solar CSP tower in the western solar-rich regions of China will intensify the demand for water in an already water-scarce region.

To provide the basic foundation of power plant structures and plant control buildings, significant quantity of building materials such as steel, aluminum, concrete and cement are needed in China's alternative energy development. For example, cumulative total of 235 Mt concrete and 7.6 Mt cement, 18.5 Mt iron and 54 Mt steel will be needed by 2030. The cumulative iron and steel demand is equivalent to 3% and 9% of total production in 2009, respectively. More significantly, the cumulative demand of 4.7 Mt copper exceeds the 2009 total domestic production 4.14 Mt, with the 2010 annual copper demand for alternative energy development requiring up to 10% of total domestic production. Smaller but nevertheless sizable amounts of aluminum, fiber glass, resin and lead are also needed for China's alternative energy development.

10.2 Rare Earth Element Input Requirement

A summary of China's alternative energy development's total requirements of silicon and rare earth metals for key selected years and on a cumulative basis is presented in Table 33. As the basic technical requirement for solar PV cells and wind turbines, silicon and neodymium will be demanded in the highest amount with a cumulative total of nearly 300,000 tons and 54,000 tons, respectively. However, the demand for indium, gallium, selenium, and molybdenum are also significant given their limited production volume as secondary by-products of mining and processing of other metals such as zinc and copper. Since each of these metals are used primarily for one type of technology (solar PV or wind), discussion of these rare earth element requirements have already been covered in the technology-specific sections (Section 2.3.1 and 3.3) and not included here.

Table 33. Silicon and Rare Earth Metal Requirements for China's Alternative Energy Development

Unit: tons	2010	2020	2030	Cumulative
Silicon	6,000	12,900	15,600	297,000
Neodymium Magnet	15,102	8,422	12,000	219,318
Neodymium	3,706	2,067	2,945	53,820
Indium	1.1	13.9	30.6	333
Cadmium Telluride	1.1	5.4	1.0	70.7
Gallium	0.00	17.1	59.3	526
Selenium	0.00	17.1	59.3	526
Molybdenum	0.00	17.1	59.3	526

10.3 Fossil Fuel Input Requirements

10.3.1 Defining Energy Return on Energy Investment

Besides the raw material and natural resource requirements, another important input to alternative energy technologies over their lifetime is the energy used during manufacturing of materials, construction, operations, maintenance and refurbishment and in some cases, decommissioning of the plant. In order to compare the energy input requirements of each alternative energy technology type, an energy return on energy invested (EROEI) or average ratio of energy output to energy input is selected or developed for each alternative energy technology. Specifically, EROEI can be defined as:

$$EROEI = \frac{Usable\ Acquired\ Energy\ (Energy\ Output)}{Energy\ Expended\ (Energy\ Input)} = \frac{\sum(Net\ Annual\ Generation\ Output \times Lifetime)}{\sum(Manuf + Constr + O\&M + Decom)Energy}$$

In this study, the EROEIs are either taken directly from international or China-specific studies (for solar PVs, CSP, onshore and offshore wind) or calculated using the given total lifecycle energy input in MJ/kWh output basis from the studies and converting the kWh output to calorific equivalent of 3.6 MJ/kWh (hydro, geothermal).

For nuclear, a different calculation is used to determine the ratio between energy output and energy input but with a very similar implication and meaning as EROEI. In the absence of a Chinese lifecycle study on nuclear power plant and given our methodology of tailoring the nuclear fuel cycle to Chinese plants, an EROEI or average lifecycle energy demand was not readily available. Thus, we calculated the total energy demand for the nuclear fuel cycle, construction and operation and maintenance by multiplying international energy intensities as proxy with projected capacity installations. The energy output to energy input ratio for a given year is calculated as:

$$Energy\ Output\ to\ Energy\ Input\ Ratio = \frac{Generation\ Output}{\sum(EI \times Capacity\ Addition)}$$

Thus, in our calculation of energy output to energy input ratio, the lifetime element is less clear and not directly included in our calculation because the lifecycle energy consumption is attributed to the first year rather than over the lifetime when the new capacity is installed for simplicity in modeling. This is a reasonable assumption since the only repeating and lifetime-dependent energy input to a nuclear power plant is the energy for operation and maintenance, which is less than 10% of the total lifecycle energy consumption.

10.3.2 EROEIs of Alternative Energy

The EROEI for all the alternative energy technologies and the 2030 installed capacity of each technology is shown in Figure 24 along with some benchmark EROEI values for conventional fossil fuels in the U.S.[3] In terms of energy return on energy invested, there appears to be three main clusters of technologies: a cluster with very low EROEIs (<10, shown in red and magnified in the graphic subset), a cluster with relatively favorable EROEIs (between 10 and 50, shown in blue) and one extremely high EROEI (400+, shown in green). Interestingly, the figures shows that those technologies with significant amount of installed capacity (i.e., greater than 100 GW) have relatively favorable EROEIs including 130 GW of nuclear with an average output to input ratio of 19, 245 GW of large hydro with EROEI of 245, 291 GW of on-shore wind with EROEI of 21 and 98 GW of extra-large hydro with the highest EROEI of 405. Likewise, there is very low installed capacity of below 10 GW for the emerging technologies that have very low EROEI of below 10. This suggests that the Chinese capacity targets have taken the technological performance and resource requirements into consideration in the development of their alternative energy targets.

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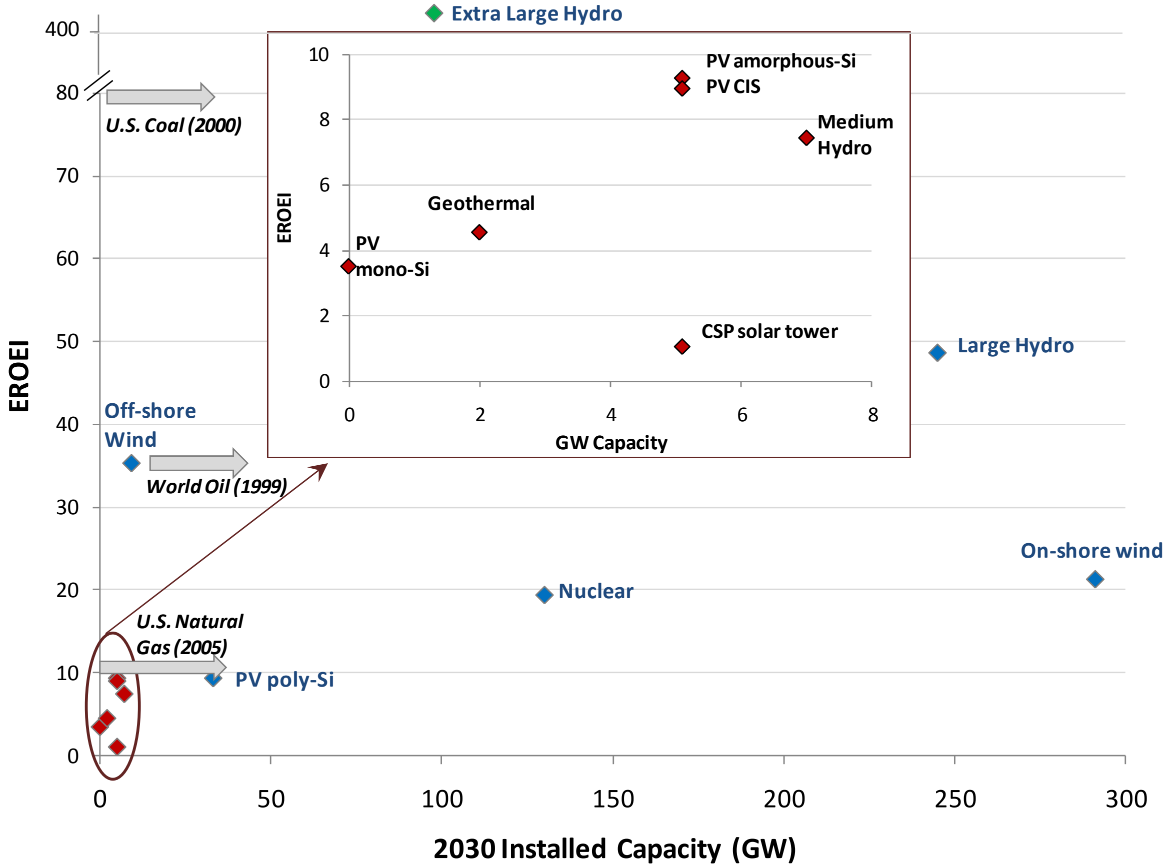
[3] EROEI for biomass power generation is not considered because feedstock and technology choices are relatively unique to China and no China-specific data is available.

Figure 24. EROEIs and 2030 Installed Capacity by Alternative Energy Technology



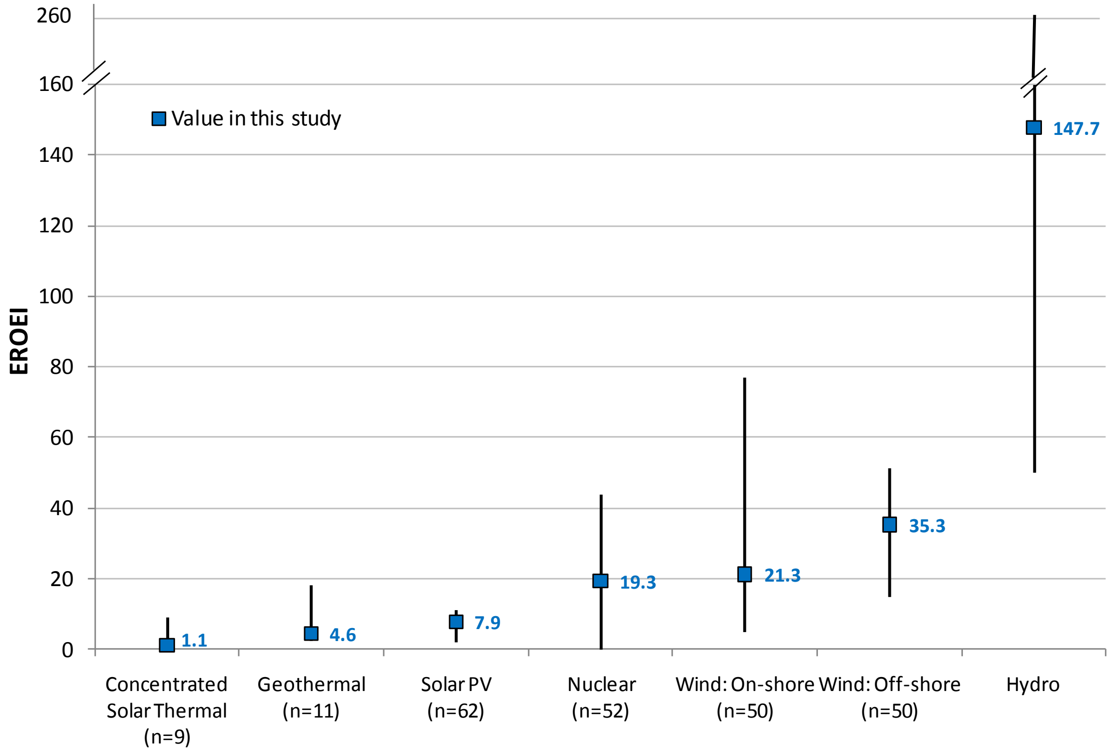
Note: The value shown for nuclear is not an EROEI per se, but is the annual average energy output to energy input ratio. EROEI for conventional fossil fuels for the US and world oil production is from Murphy and Hall 2010.

At the same time, Figure 24 illustrate that alternative energy technologies do require significant amounts of fossil fuel input and there are few energy sources with EROEIs on par with the dominant fossil fuel currently in use in China. For instance, offshore wind and large hydro are the only two energy technologies that have an EROEI equal to or above oil, but still fall below U.S. coal in 2000. In fact, extra-large hydro is the only alternative energy technology with an EROEI that exceeds coal's EROEI but its total installed capacity is constrained.

10.3.3 Contextualizing EROEIs

Although attempts have been made to use the most appropriate and China-specific EROEIs in the analysis for this study, it is important to consider variations in the range of EROEI for each technology type in existing international literature. Because there are few technology specific LCA studies for the four different types of solar PV and three different sizes of hydro dams, an weighted-average EROEI by 2030 technology shares is calculated for PV and hydro and compared to other studies. The comparison of EROEIs used in this study with the range in existing international literature is shown in Figure 25.

Figure 25. Range in Alternative Energy EROEIs in Existing Literature



Note: solar PV and hydro EROEI values used in this study are the weighted average EROEI by 2030 technology shares. "n" is the number of studies or analyses included in meta-reviews of international literature and are based on analysis in Burkhardt et al. 2011 (concentrated solar thermal), Gagnon, et al. 2002 (hydro) and Kubiszewski et al. 2010 (all other technologies). The number of studies reviewed was not given for the range in hydro reservoir EROEI.

As illustrated above, the range in EROEIs differ considerably across technology types with the widest range in the EROEI for onshore wind and hydro and the smallest range in EROEI for solar PV and concentrated solar. The difference in EROEI ranges may reflect the different development stages of the energy technologies as concentrated solar power is a very new technology, as reflected by the few studies that exist, and has limited design configurations including primarily solar tower and parabolic trough. Hydro reservoir dams, in contrast, have an extensive range in their installed capacity size, dam type, and lifetimes and have been used in various countries for decades. Lifetime in particular is an important influencing factor on EROEI as the very high EROEI of 405 calculated for extra-large hydro is closely related to its very long lifetime of 100 years. Geothermal, interestingly, is also not a common generation technology with few existing lifecycle studies but has a surprisingly wide range in EROEI. On-shore and off-shore wind generation also have a relatively wide range in EROEIs but this could be due to the rapid development and evolution of wind turbines.

Besides the range in EROEIs, it is also interesting to note where the EROEI used in this study falls in the range of EROEIs found in existing literature. For nuclear, on-shore wind and hydro, the EROEI used in this study appears to fall in the middle range of existing values. For CSP and on-shore wind, the China-specific EROEI values used in this study are in the bottom or lower end of

EROEIs found in international literature. Geothermal is also in the bottom end of its range of EROEI, which could result from having used an advanced and more energy-intensive enhanced recovery binary geothermal power plant as a proxy. Since international data points were used as proxies for solar PV and off-shore wind, their EROEIs from this study fall in the upper range of existing literature.

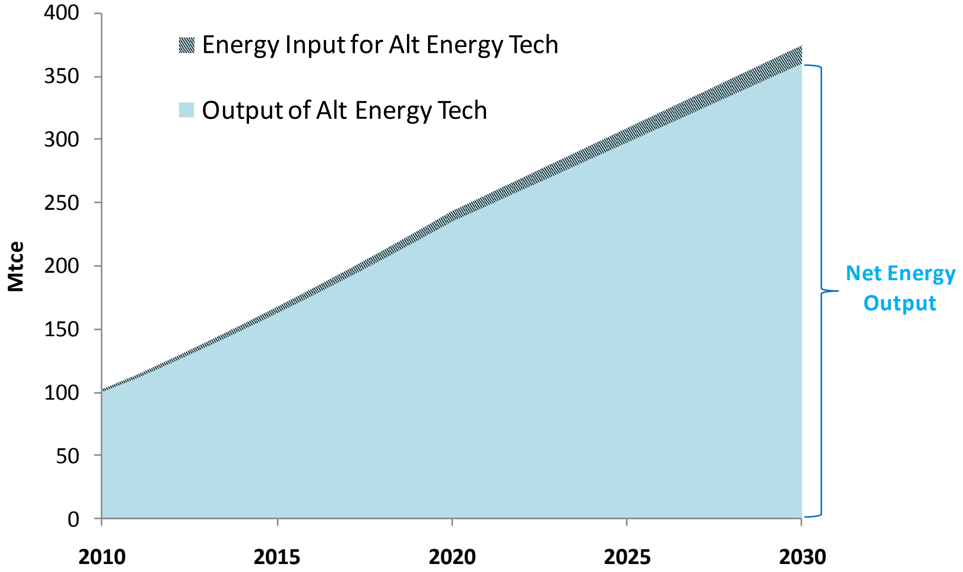
10.3.4 Fossil Fuel Dependency Ratio of Alternative Energy Development

In addition to using EROEI as an indicator of the net energy return for alternative energy technologies, another indicator evaluates the annualized energy input of all alternative energy technology development and compares it to the total electricity generated by these technologies. This indicator, the fossil fuel dependency ratio (FFDR), highlights the dependency on fossil fuels for development of alternative non-fossil and alternative energy technologies and provides a rough annual measure of net energy production. Annual electricity generation output by each alternative energy type from 2010 to 2030 is taken from our China end-use energy model and converted to calorific equivalent at 0.1226 kilograms of coal equivalent (kgce) per kWh for all energy sources. The total annual energy output in Mtce is then multiplied by the projected technology shares to calculate output per technology (solar PV, CSP, on-shore wind, etc.) since EROEIs are technology-specific. The implied energy input for a given technology and year is then calculated by dividing that year's annual energy output by the technology-specific EROEI. Using on-shore wind as an example, the formula for calculating the implied 2030 annual energy input is given below:

$$Implied\ Energy\ Input_{(\text{On-shore wind, 2030})} = TWh_{2030,wind} \times Tech\ Share_{on-shore} \times 0.1226 \times \frac{1}{EROEI\ (on-shore\ wind)}$$

The total implied energy input for all alternative technologies is shown as a portion of total energy output with the unshaded blue area representing the net energy output of China's alternative energy technologies. As seen in Figure 26, the energy input is a very small portion (3-4%) of total energy output and suggests that China's alternative energy development does have large net energy return. In particular, China's net energy return (total output minus input) will rise from 100 Mtce in 2010 to 235 Mtce in 2020 and 360 Mtce in 2030.

Figure 26. Energy Input as Share of Energy Output for Alternative Energy Development, 2010-2030

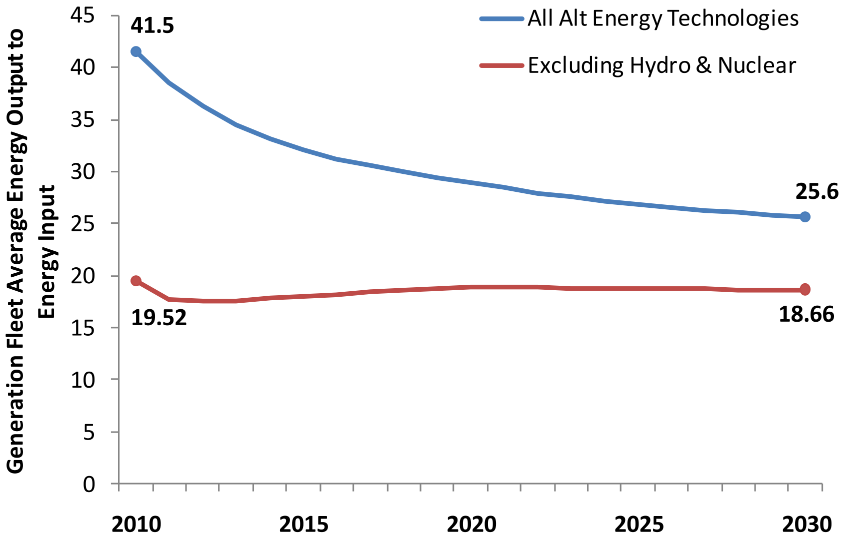


From the point of view of the FFDR, the relationship between the annualized fossil fuel energy input to the annual energy output for all alternative technologies for a given year is represented as:

$$\text{FFDR}, \textit{for year } i = \frac{\Sigma\,(TWh\ Output)i}{\Sigma\,(Implied\ Energy\ Input)i}$$

As the formula suggests, a higher FFDR indicates that less fossil fuel energy input is needed for alternative energy development and implies that there is greater energy return per unit of fossil fuel invested in developing the technology. The average FFDR of China's alternative energy generation fleet is actually quite high but declines from 41 to 26 over the next twenty years, reflecting declining energy return for each unit of fossil fuel input (Figure 27). This ratio declines over time as newer technologies with lower (current) EROEIs such as solar PV, solar CSP towers and geothermal are integrated into the power sector with rising installed capacities over time. Although technological improvements may increase the EROEI of these technologies over time, the unquantifiable uncertainty of pace of technological development prevents us from using dynamic EROEIs and our results over the long-term may be an underestimate.

Figure 27. Alternative Power Generation Fleet Average Fossil Fuel Dependency Ratio

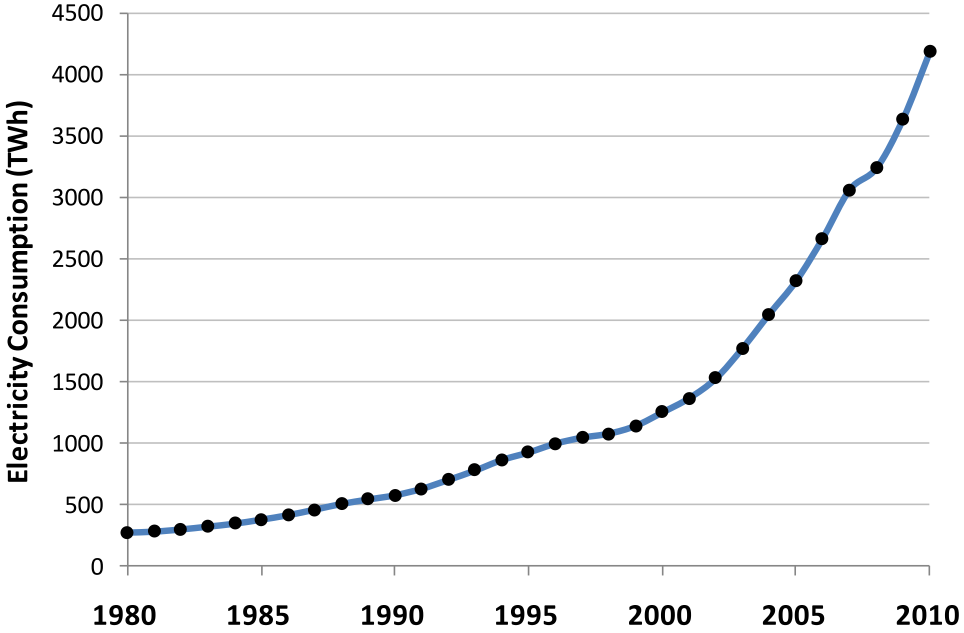


It is also important to note the large impact that large-scale alternative energy technologies with relatively high EROEIs, namely hydro and nuclear power generation, have on the fleet average FFDR. If hydro and nuclear energy inputs and outputs were excluded, the subsequent fleet FFDR would decrease to only 19 in 2020 and remain relatively flat thereafter. The net energy return on energy invested is still relatively high because after excluding hydro and nuclear, wind (on-shore wind in particular) is responsible for the bulk of electricity generation with much lower generation output from solar and geothermal. This illustrates the importance of large hydro and nuclear power generation to China's alternative energy development, as the net energy return of energy invested would be much lower in the absence of continued nuclear and hydropower development.

11. Energy and CO_2 Emissions Impact of China's Alternative Energy Development

Historically, China's electricity consumption has grown at an astounding rate with rapid economic growth, urbanization and industrialization as the major energy drivers. From 1980 to 2010, China's total electricity consumption grew at an average rate of 9.5%, with faster annual growth of over 13% over the last decade (Figure 28).

Figure 28. Historical Electricity Consumption, 1980-2010



Source: NBS, 2011.

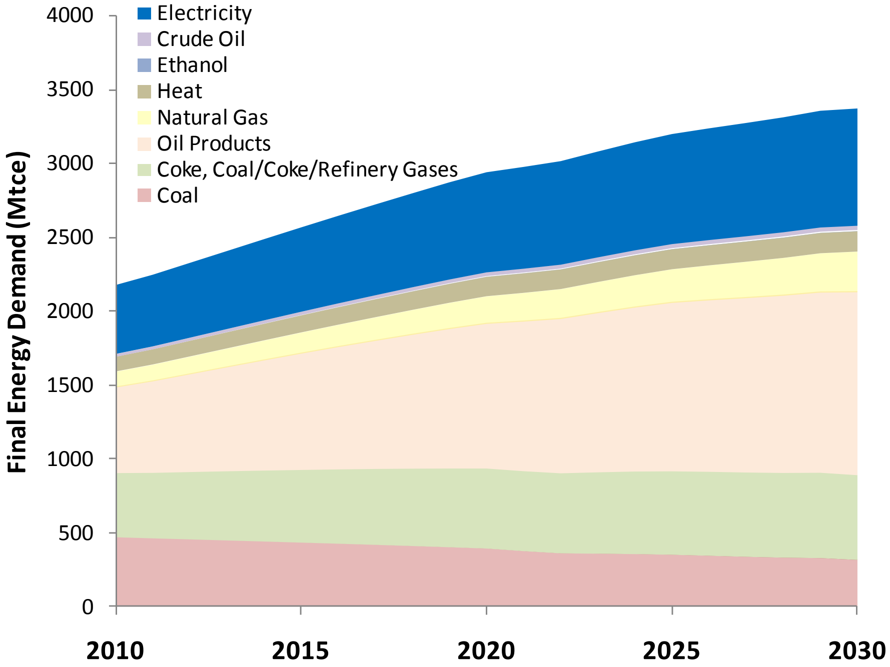
11.1 China's Energy Outlook to 2030

Given the unprecedented growth in electricity demand and China's continuing transition from a rapidly developing economy to an industrialized nation, a bottom-up energy model is needed to provide the basis for understanding future growth in the power sector. Thus, to evaluate the role of the power sector in providing China's future energy consumption, an energy outlook to 2030 was developed using the China End-Use Energy Model. This bottom-up model consists of both the energy consumption sector and the energy production sector (transformation sector) including: residential buildings, commercial buildings, industry, transportation, agriculture, and transformation. Within the energy consumption sector, key drivers of energy use include activity drivers (total population growth, urbanization, building and vehicle stock, commodity production), economic drivers (total GDP, income), energy intensity trends (energy intensity of energy-using equipment and appliances). These factors are in turn driven by changes in consumer preferences, energy costs, settlement and infrastructure patterns, technical change, and overall economic conditions.

For this study, the final energy demand is assumed to be the same under both scenarios but the primary energy demand will change slightly as a result of different mix of power generation technologies and capacities (see section 12.3). In particular, China's final energy demand will continued to grow at over 2% per year from 2175 Mtce in 2010 to 3367 Mtce in 2030. While most of this growth will be in the oil products needed to support China's burgeoning transport sector and other industrial uses, growth in demand for electricity is also expected to continue.

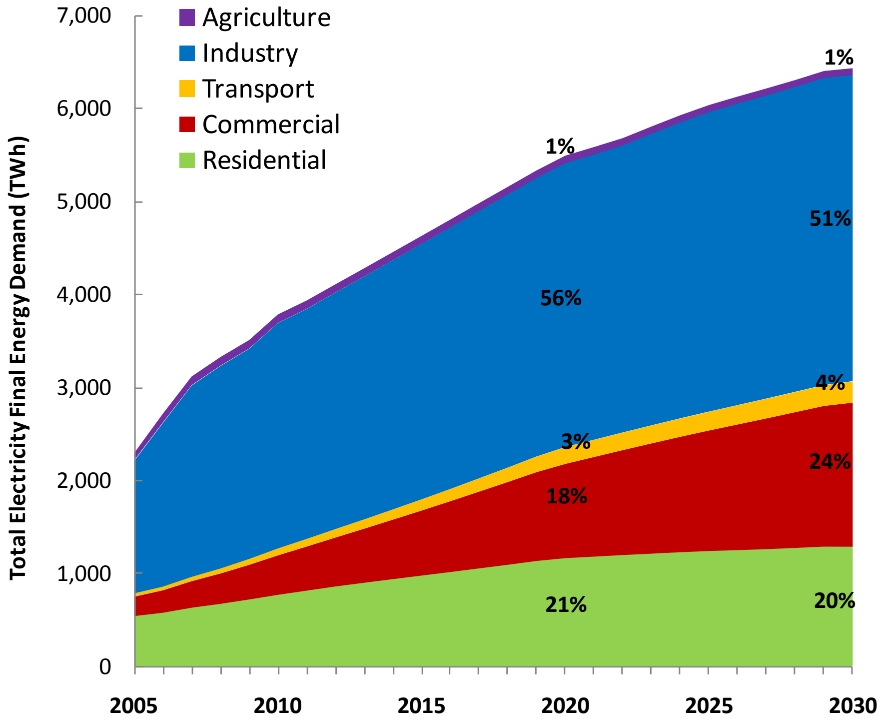
By 2030, electricity will make up nearly one-quarter of China's total final energy demand, up from its current share of 21%.

Figure 29. China's Final Energy Demand by Fuel, 2010-2030



In particular, electricity demand over the next twenty years will be increasingly driven by the commercial sector as China shifts away from heavy industrialization and urbanization begins to slow down after 2020. From 2020 to 2030, the commercial sector's share of electricity consumption will grow from 18% to nearly a quarter of the total while the industrial share declines from 56% to 51% (Figure 30). Transport sector will also see a slight increase in its share of total electricity demand between 2020 and 2030 as more electric vehicles enter the market and rail electrification continues.

Figure 30. Electricity Demand by Sector, 2010-2030



11.2 Power Sector Modeling and Scenario Analysis

In light of this expected growth in demand for electricity, the power sector is modeled as a module within the transformation sector of the China End-Use Energy Model. This power sector module is adapted to reflect changes in installed capacity by generation type and the overall generation mix, dispatch algorithms, and specific efficiency levels by generation type. For example, given the dominance of coal-fired power in China's electricity generation, six different categories of coal-fired generation ranging from small plants of less than 100 MW to subcritical and ultra-supercritical plants with greater than 1 GW of capacity are modeled using different heat rates and technology switching through 2030. Following specified power sector module parameters, the model also uses algorithms to calculate the amount and type of capacity required to be dispatched to meet the final demand from the energy consumption sector. The model currently uses an environmental dispatch order that favors dispatching all available non-fossil generation first to meet demand with coal dispatched last to meet any remaining demand. In this study, two different scenarios for power sector development are created by using different parameters in the installed capacity of alternative energy sources from 2010 to 2030 to evaluate the direct energy and CO_2 emissions impact of China's alternative energy development.

In line with the scenario analysis used for biomass, CTL and solar water heaters, the two power sector scenarios are based on a reference path of alternative energy development and an Alternatives Stumble scenario of slower development. The reference path represents continued rapid development of alternative energy at a pace consistent with meeting all stated targets for 2015 and 2020 as a result of coordinated and effective policies and successful technological development to address existing challenges and constraints. The Alternative Stumbles scenario, in contrast, represents a counterfactual baseline where China is not able to overcome the existing barriers to continued alternative energy development and thus may not reach its 2020 capacity targets until 2030. Rather, it is expected that the pace of alternative energy capacity expansion with be slower and at a pace more consistent with the older targets set in 2007. The specific capacity assumptions for both scenarios are shown in Table 34.

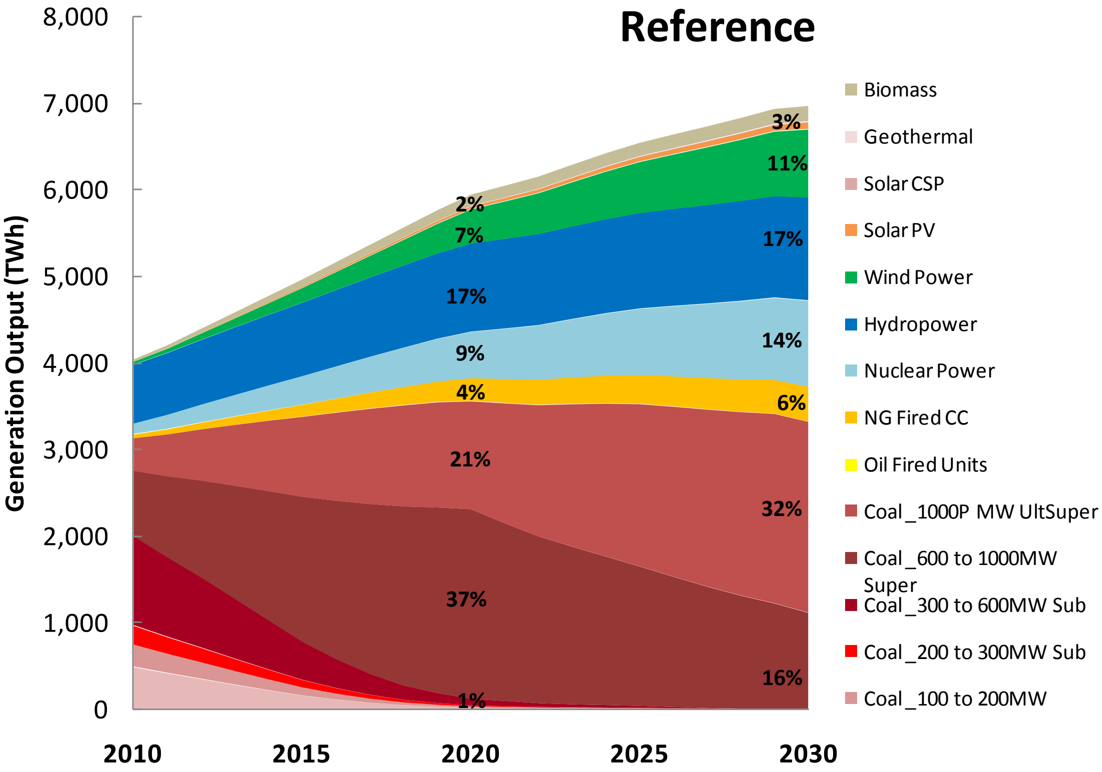
Table 34. Installed Capacity by Power Generation Technology and Scenario

	Reference Scenario			**Alternatives Stumble Scenario**		
Installed Capacity (GW)	**2010**	**2020**	**2030**	**2010**	**2020**	**2030**
Solar PV	0.5	17.8	45.9	0.5	4.5	18
Solar CSP	0	2.2	5.1	0	0.5	2
Wind Power	22	150	300	22	104	244
Hydropower	200	300	350	200	270	315
Geothermal	0.1	1	2	0.1	1	2
Biomass	5.5	30	40	5.5	17.8	30
Nuclear Power	16	70	130	16	63	103
NG Fired CC	16.3	65	100	16.3	65	100
Coal <100MW	160.4	51.6	0	160.4	51.6	0
Coal: 100 to 200MW	86.7	51.6	22.5	86.7	51.6	22.5
Coal: 200 to 300MW Subcritical	72.1	51.6	56.2	72.1	51.6	56.2
Coal: 300 to 600MW Subcritical	341.1	309.7	202.5	341.1	309.7	202.5
Coal: 600 to 1000MW Supercritical	96.5	361.3	281.2	96.5	361.3	281.2
Coal: >1000MW Ultra Supercritical	48.3	206.5	562.4	48.3	206.5	562.4

11.3 Energy Implications of China's Alternative Energy Development

As a result of the different installed capacities for alternative energy technologies through 2030, particularly for solar, wind, biomass and nuclear power, China's electricity generation mix will differ. Under the reference scenario of alternative energy development, renewable energy will supply 27% and 32% of China's electricity by 2020 and 2030, respectively, up from only 18% in 2010 (Figure 31). With the addition of nuclear power generation, nearly half of China's electricity supply will be from non-fossil, alternative energy sources, including 17% from hydro, 14% from nuclear and 11% from wind. While the relative share of coal generation decreases significantly from current level of 78% to 48% by 2030, the absolute electricity generation output from coal is actually relatively flat over this twenty year period. This suggests that alternative energy development is crucial to stabilizing the power sector's demand for coal as electricity demand rises, and that more aggressive deployment of alternative energy is needed to reduce coal input to the power sector from current levels.

Figure 31. China's Electricity Generation Output by Fuel under Reference Scenario, 2010-2030



The importance of rapid deployment of alternative energy in moving China away from coal is illustrated in the Alternatives Stumble scenario, where slower expansion of alternative energy technologies results in rising coal-fired generation with 750 more TWh from coal-fired generation per year in 2030. In terms of coal input for electricity generation, this translates into additional annual input of 175 Mtce for the power sector in 2030. In other words, successful achievement of China’s alternative energy targets can save 2080 Mtce of coal cumulatively from the power sector from 2010 to 2030 (Figure 32). However, if China is unsuccessful in its alternative energy deployment, then renewable energy will only supply 27% of electricity generation by 2030 with only 38% from all non-fossil energy including nuclear (Figure 33).

Figure 32. Potential Coal Savings in Power Sector due to Alternative Energy Deployment

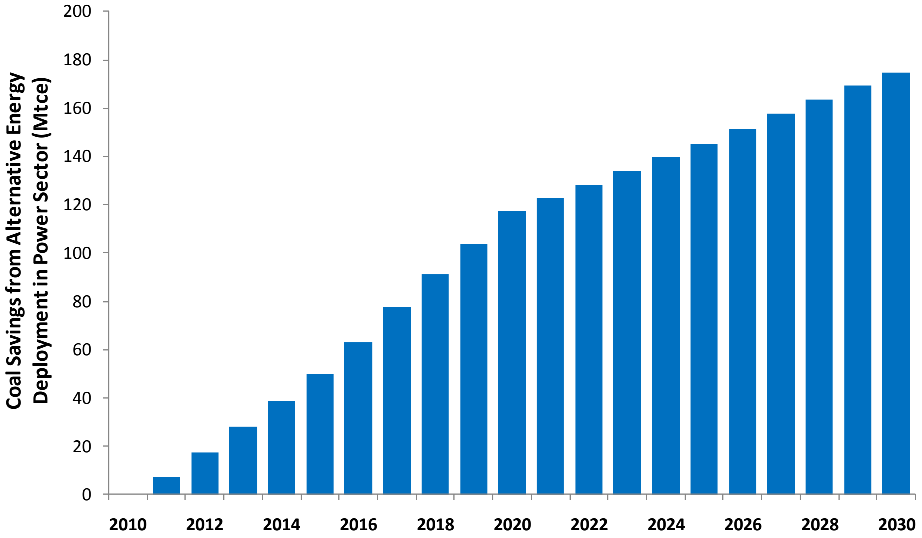
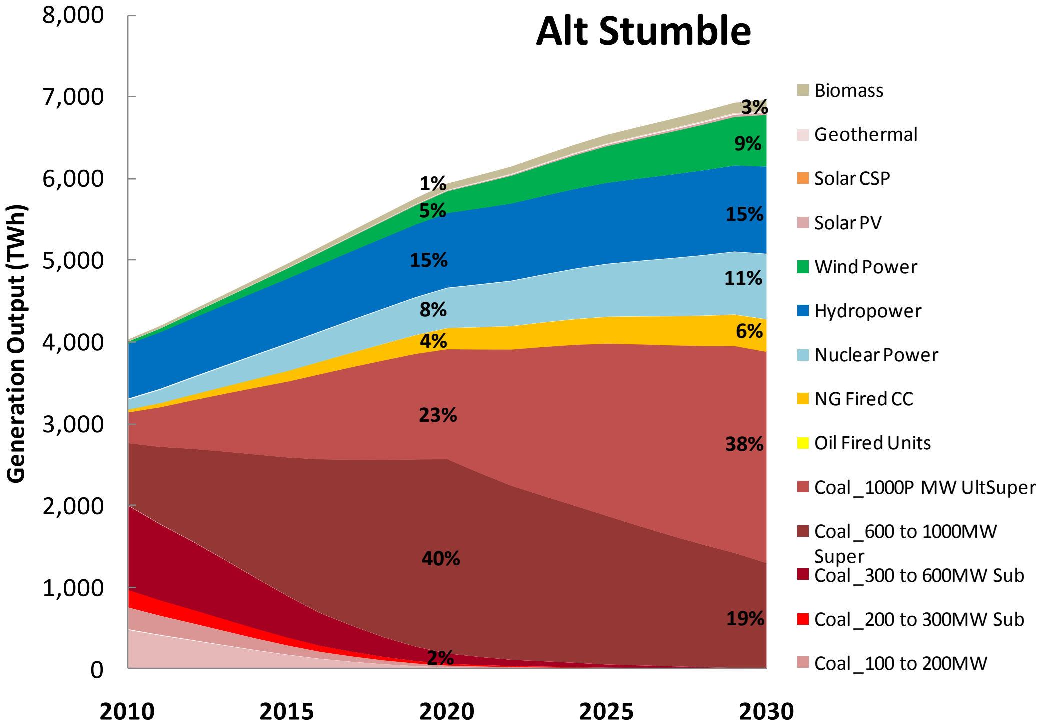
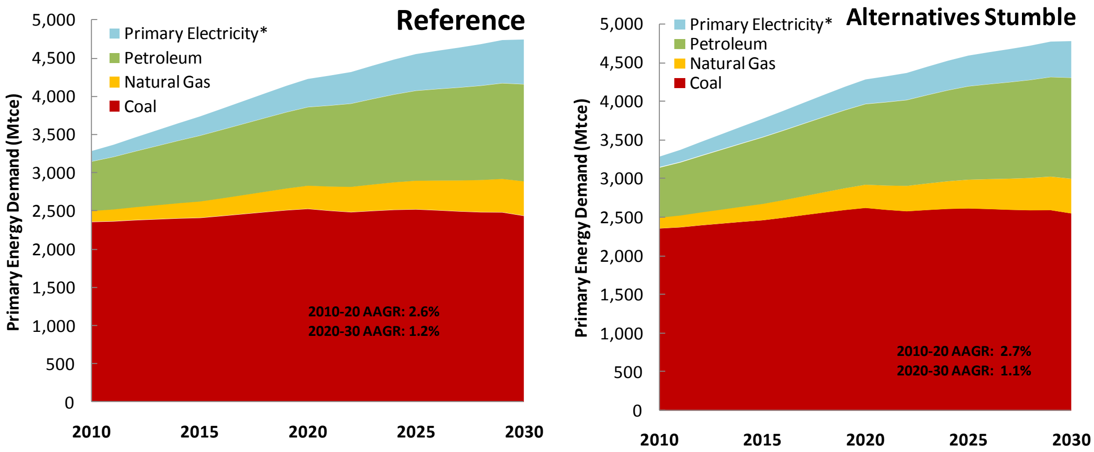


Figure 33. China's Electricity Generation Output by Fuel under Alternatives Stumble Scenario, 2010-2030



In total primary energy terms, a successful pathway of alternative energy development will result in higher share of primary electricity and smaller share of coal in total primary energy consumption as well as slightly lower total primary energy consumption due to higher energy conversion process efficiency (Figure 34).

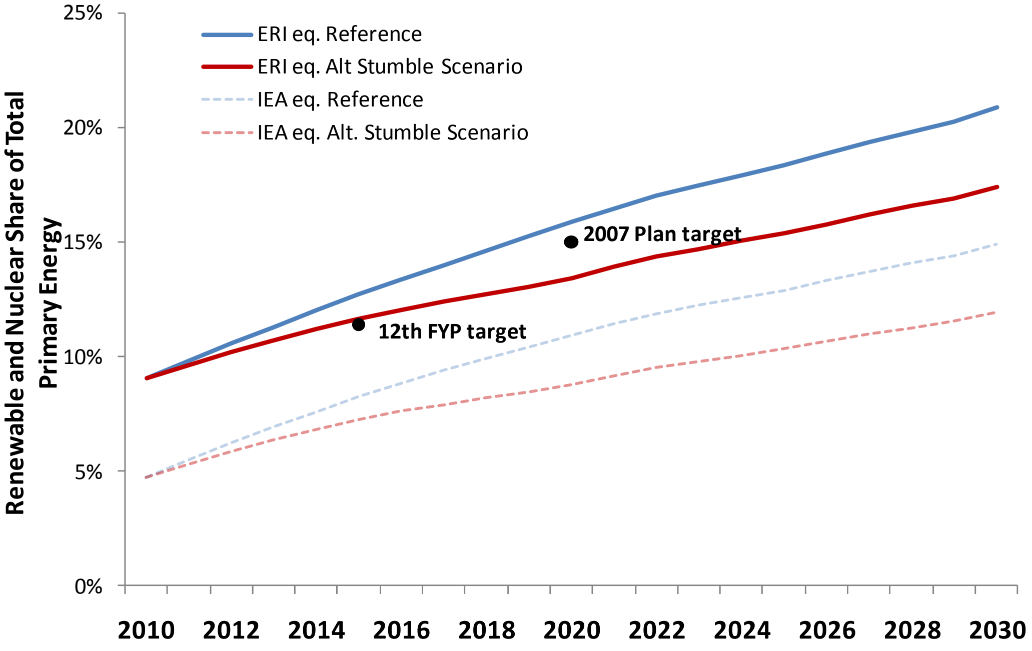
Figure 34. Total Primary Energy by Fuel, Reference and Alternatives Stumble Scenario



Note: primary electricity includes all renewable power following IEA and LBNL convention of using calorific equivalent for converting to primary energy terms.

From a broader perspective, one of the key implications of China's progress in alternative energy development is whether it can meet the 12th FYP (2015) target of 11.4% of alternative energy in supplying total primary energy demand and the 2020 target of 15%. Following the Chinese convention of using power generation equivalent (0.37 kgce per kWh with 33% process conversion efficiency) for converting renewable electricity to primary energy terms, the total non-fossil share of primary energy consumption is determined. At the same time, the IEA and LBNL convention of using calorific equivalent for electricity to primary energy conversion is also applied with the results compared against ERI method of conversion (Figure 35).

Figure 35. Comparison of Non-fossil Share of Total Primary Energy with Chinese Targets, 2010 - 2030

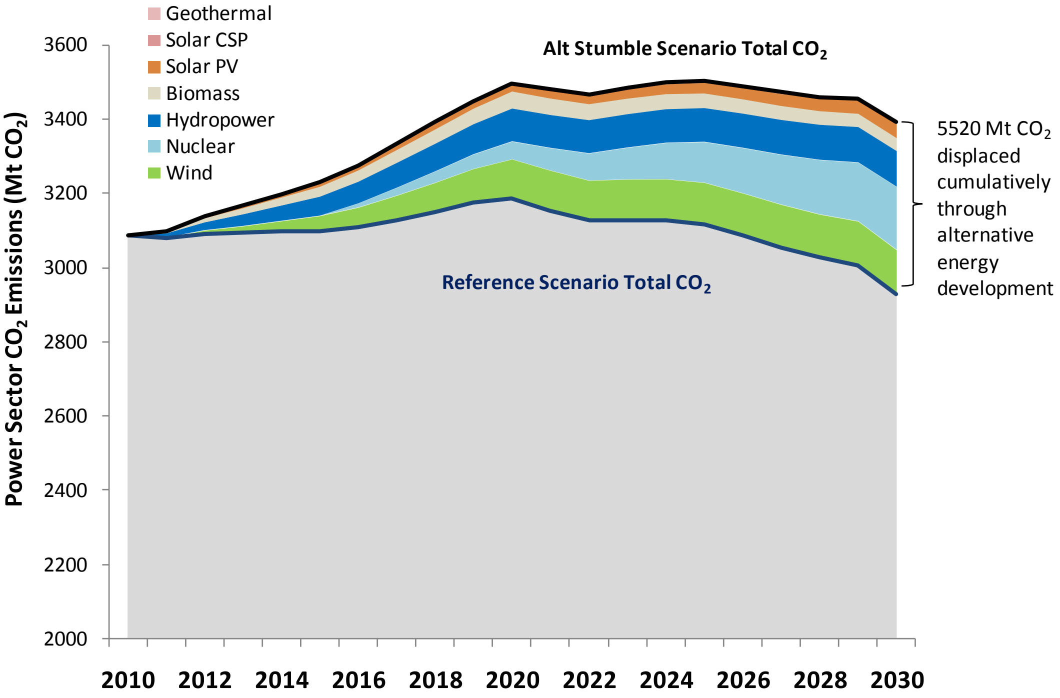


As seen in Figure 35, China will achieve its 12th FYP target of 11.4% of non-fossil energy consumption before 2015 if it is successful in its alternative energy development as represented by the reference scenario. Furthermore, continued expansion of alternative energy technologies after 2015 will be needed for China to achieve its 2020 target of 15% non-fossil energy as it will only achieve 16% share in 2020 under the reference scenario. If existing challenges such as grid integration, resource constraints and technological limitations cannot be effectively addressed and alternative energy development occurs at a slower pace than planned, then China will barely make the 12th FYP target with 11.7% share of non-fossil energy in 2015. Under this scenario where alternative development stumbles, China will miss its target of 15% non-fossil energy by 2020 with a non-fossil share of only 13.4% by 2020 and will not reach a 15% share until 2024. By 2030, the non-fossil share of total primary energy demand will reach 21% under the reference scenario of alternative energy development but only 17% under the Alternatives Stumble scenario.

11.4 CO_2 Emissions Impact of China's Alternative Energy Development

By reducing the input of coal to power generation, successful implementation of China's alternative energy development plan can result in significant displacement of CO_2 emissions over time. As seen in Figure 36, up to 463 million tons of CO_2 emissions or about 5% of total CO_2 emissions can be displaced annually by 2030 if China achieves its alternative energy capacity targets at a faster pace consistent with the reference scenario. Most of the 2030 emissions displacement will be from the faster expansion of nuclear and wind power, which accounts for 37% and 26% of the displaced CO_2 in 2030. Hydropower accounts for another 21% of the displaced CO_2 in 2030 while biomass and solar each accounts for 8% share. A cumulative displacement total of 5.5 billion tons of CO_2 emissions, or half of the total annual CO_2 emissions in 2030, could be achieved under the reference pathway of alternative energy development.

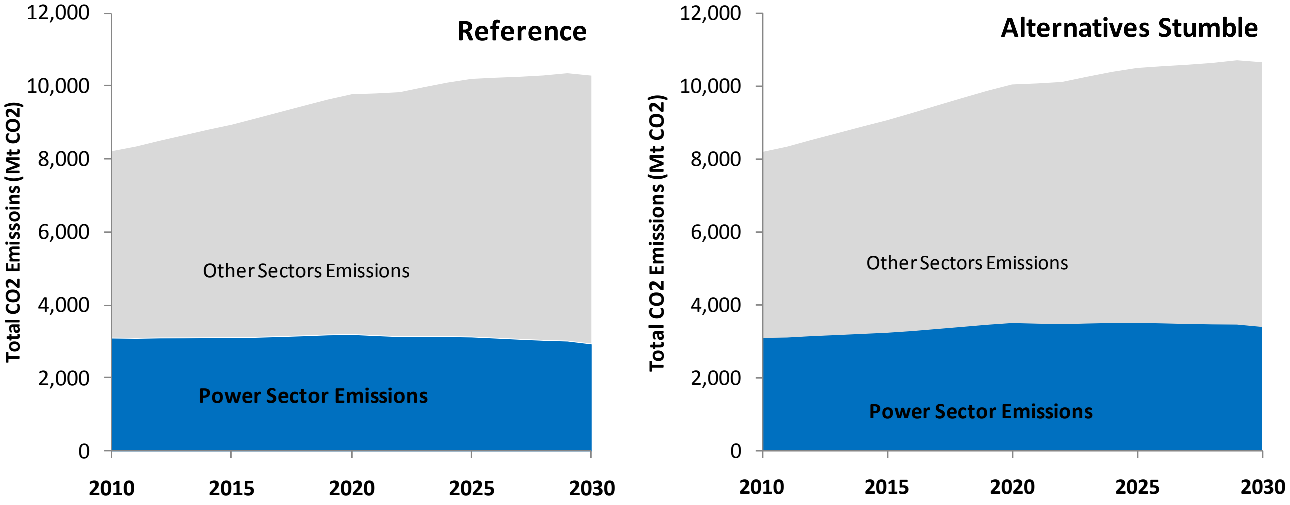
Figure 36. CO_2 Displaced by Expanded Alternative Energy Deployment, 2010 - 2030



Note: Y-axis not scaled to zero.

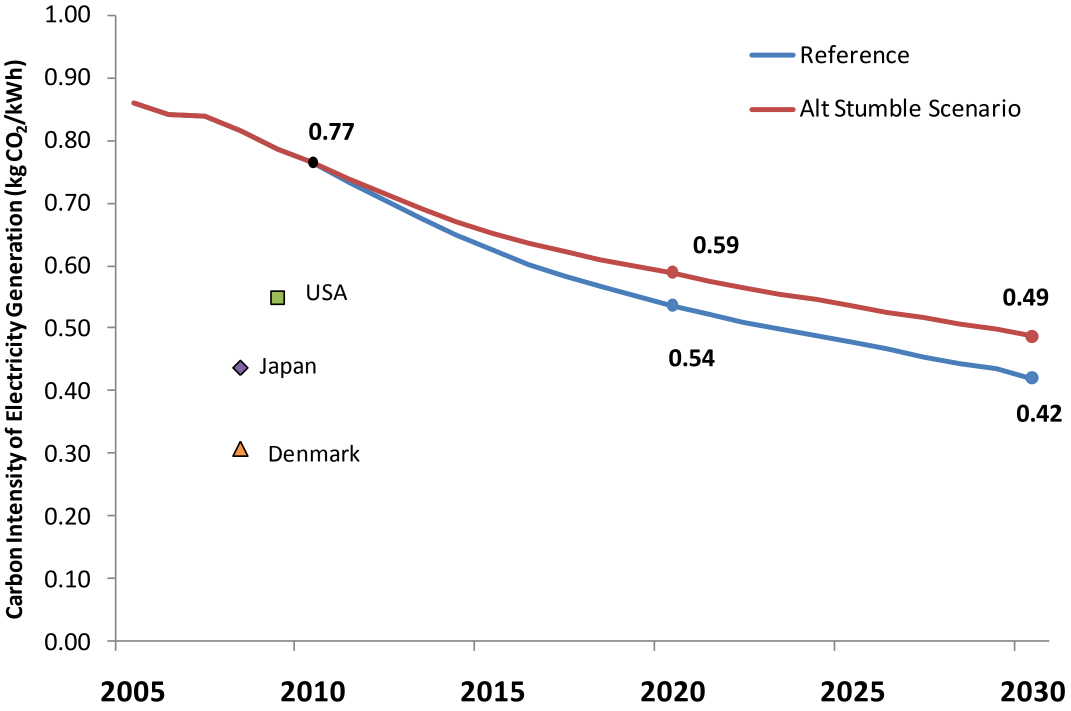
The displaced CO_2 emissions from expanding electricity generation from alternative energy sources are important as the power sector contributes at least a third of the total CO_2 emissions in China (Figure 37). Figure 37 also illustrates that without successful deployment of the alternative energy technologies, China's power sector emissions will not peak until around 2025 with 3500 Mt CO_2, compared to a lower peak of 3190 Mt CO_2 by 2020 under the reference scenario.

Figure 37. Power Sector Share of Total Emissions under Reference and Alternatives Stumble Scenario, 2010 - 2030



Successful alternative energy development will also have an important impact in reducing the overall carbon intensity of China's electricity supply. In particular, on a per kWh basis, China's carbon intensity will decrease rapidly from 0.77 kg CO_2 in 2010 to only 0.42 kg CO_2 by 2030 under the reference scenario of alternative development (Figure 38). Moreover, by 2020, China's electricity generation will actually be less carbon intensive than the current U.S. electricity supply with a carbon intensity of 0.54 kg CO2 per kWh. By 2030, continued integration of alternative energy will make China's power supply slightly less carbon intensive than the current Japanese electricity supply.

Figure 38. Carbon Intensity of China's Electricity Generation under Reference and Alternatives Stumble Scenarios, 2005 - 2010



Under the less successful Alternatives Stumble scenario, China's electricity supply will reduce carbon intensity to 0.59 kg CO_2 per kWh in 2020 and 0.49 kg CO_2 per kWh in 2030. By 2030, China will thus have an electricity supply that is less carbon-intensive than the US currently, but will still be slightly more carbon-intensive than Japan. Given the relatively late start of alternative energy development in China, the rapid reduction in carbon intensity of the electricity supply under both scenarios underscore the crucial impact of alternative energy technologies in decarbonizing China's growing power sector.

12. Conclusions

After years of rapid growth in electricity demand and similar paces of growth in coal-fired electricity generation output, China has started to focus on developing and expanding its supply of alternative energy as it seeks to rein in energy consumption related CO_2 emissions growth. Along with continued emphasis on energy efficiency improvements, including the successful reduction of 19.1% in energy intensity between 2006 and 2010, China has concurrently focused on alternative energy development as another necessary step in achieving its 2020 carbon intensity reduction goals.

Renewable and alternative energy development have received regulatory and financial support under a flurry of laws and regulations passed within the last decade, including the 2005 Renewable Energy Law and its 2009 amendments, the 2007 Medium and Long-term Development Plan for Renewable Energy and the 2010 Draft Development Plan for Emerging Energy Technologies. As a result, China met all of its 2010 renewable targets and also became the world leader in total installed clean energy capacity with unprecedented investment in grid construction and expansion. In the short to medium-term, China aims to achieve 11.4% and 15% of its total primary energy consumption in 2015 and 2020, respectively, from non-fossil energy and has set specific 2020 installed capacity targets for solar PV and concentrated solar thermal, on-shore and off-shore wind, nuclear, hydro, geothermal and biomass power. In addition, solar water heaters, biofuels and advanced coal alternatives are also expected to play a bigger role in China's clean energy development.

However, despite recent policies that have enabled extraordinary capacity and investment growth over a short period of time, alternative energy technologies face persistent as well as emerging constraints and barriers to growth. For relatively new technologies that have not achieved commercialization, China faces many technical limitations to expanding the scale of installed capacity. This includes the lack of domestic technologies for enhanced recovery geothermal power generation and inadequate capabilities to produce the high power rating components and high temperature thermal storage needed for large-scale concentrated solar towers. For even newer emerging technologies such as coal-to-liquids, coal-to-gas, coal-to-chemicals as well as biomass combustion and co-firing for power generation, there is limited research and development capacity and technological obstacles are even greater.

Another major area of concern for the alternative energy industries is the uneven and often changing market and policy support for development, such as the dramatic decline in investment and major shifts in policymakers' attitudes for hydropower expansion. For coal alternatives, biofuels and geothermal power technologies, financial support and investor interest have been extremely limited due to ambiguous market signals and changing policy support (e.g., halting of CTL approvals). Furthermore, the majority of alternative energy technologies also face resource constraints both in terms of human resources and material availability. On one hand, workforce development have not caught up with the extraordinary speed of growth in nuclear power capacity, with shortages in trained nuclear workers, research and development staff and safety inspectors. Similarly, although it has not yet undergone expansion, geothermal development faces limited research and development capacity. On the other hand, expanded production scale of many alternative energy technologies have also revealed constraints in raw materials and rare earth elements including uranium for nuclear, silicon for solar PV and neodymium for wind. There is also an overarching shortage in water resources for all alternative energy technologies, particularly those that are more water-intensive such as coal alternatives and those with resources concentrated in the water scarce western regions of China.

Lastly, for solar PV and wind power, physical and institutional barriers to integration with the power grid are major challenges to expanding their roles in China's electricity supply. An inherently inflexible grid with transmission bottlenecks, few balancing load options besides coal-fired generation, ambiguous cost-sharing requirements and underpriced electricity have all discouraged renewables integration and exacerbated curtailment of wind by power grid companies. Moreover, the wind industry itself has also faced intense competition for grid connections due to a flawed approval system that have led to regional overheating and industry-wide overcapacity.

In light of China's potential for and barriers to growth, two scenarios of alternative energy development were used to evaluate the extent to which challenges and constraints may cripple the growth of alternative energy utilization and the overall energy and emissions impact. The results show that China can only meets its 2015 and 2020 targets for non-fossil penetration if it successfully achieves all of its alternative energy capacity targets for 2020 with continued capacity expansion through 2030. To achieve this level of alternative energy utilization in the power sector, significant amounts of raw materials including 235 Mt of concrete, 54 Mt of steel, 5 Mt of copper along with 3 billion tons of water and 64 thousand square kilometers of land are needed. In terms of the energy return on fossil fuel invested for alternative energy development, China's alternative energy supply will likely have relatively high system-wide average fossil fuel dependency ratio of 42 declining to 26 over time, but will have a much lower ratio of only 19 if nuclear and hydropower are excluded.

With successful alternative energy development, 32% of China's electricity and 21% of its total primary energy will be supplied by alternative energy by 2030 with the 2030 electricity supply being less carbon-intensive than the current US and Japanese electricity supply. Compared to the counterfactual baseline in which alternative energy development stumbles and China does not meet its capacity targets until 2030, alternative energy development can displace 175 Mtce of coal inputs per year from power generation in 2030 and 2080 Mtce cumulatively from 2010 to 2030. In carbon terms, this translates into 5520 Mt of displaced CO_2 emissions over the twenty year period, with more than half coming from expanded nuclear and wind power generation. In sum, if China is able to mitigate and address the existing and emerging challenges to alternative energy development, it can significantly decarbonize its power sector and achieve impressive energy and emission reductions.

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