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AVOID – providing key advice to the UK Government on avoiding dangerous climate change

AVOID – Avoiding dangerous climate change

DECC: GA0215 / GASRF123 2009 – 2012

ANNEXES

(Supplement to the AVOID report on "China's energy technology options to 2050")

Authors: Ajay Gambhir, Neil Hirst, Tamaryn Brown, Mark Faist, Sam Foster, Mark Jennings, Luis Munuera, Danlu Tong, and Lawrence K C Tse

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Delivered from author(s): Ajay Gambhir Date 06/06/2011
Institute(s): Grantham Institute for Climate Change, Imperial College London

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Annex A: Comparison of key assumptions in recent China 2050 studies

Modelling group Year of study	**IEA** 2010	**SPRU/Tyndall** 2009	**ERI** 2009	**IIASA** 2011	**LBNL** 2011
Scenario	BLUE Map (ETP 2010)	Range (S1-S4)	Low growth, low carbon	Mix and Efficiency	Accelerated Improvement scenario
Key mitigation assumptions					
Global aim					
ppm	450ppm CO_2e	550ppm CO_2e	not specified	450ppm CO_2e	not specified
^oC	2	2.9		2	
China 2050 CO_2 target					
Absolute / $GtCO_2$	4.3 Gt	1.5-4.5$GtCO_2$^	5.0$GtCO_2$	2.2-4.5+	7.4
tCO_2/capita	3.1*	1.1-3.2	3.5	1.5-3.2	5.2
China peak year	2020	2020-2030	2020-2030	2020-2030	2027
Effort-share	Least cost	C&C**	n/a	Least cost	n/a
Key socio-economic assumptions					
GDP growth (2010-2050)	not specified	650-990%	750%	520%	730%
Population (2050) / billion	not specified	1.40	1.46	1.42	1.41
Urbanisation (2050) / % of population	not specified	not specified	79%	79%	79%

Notes: ^SRPU/Tyndall range results from the specific form of Contraction and Convergence (whether per capita or per unit GDP)
+Total emissions in 2050 are for the Central and Planned Asia region of which China is ~90% by population and GDP
*Per Capita figures for IEA derived from absolute figures using UN central assumption of China population of 1.4billion by 2050
**C&C = Contraction and Convergence (by 2050)

Annex B: IIASA's Global Energy Assessment (GEA) scenarios

The GEA scenario comprises essentially one scenario, describing alternative energy system transformations (pathways) towards a more sustainable future. These sustainable futures are defined by normative objectives related to environmental impacts of energy conversion and use, energy security, and energy access. All pathways fulfil these objectives by reaching specific and clear targets. For example, the pathways all stabilize future global mean temperature increase to 2 degrees Celsius above preindustrial levels, and they all lead to (almost) universal access to energy services throughout the world by 2030. Another common feature to all pathways is economic and demographic changes that are consistent with the GEA aspirational goals toward sustainable development. One of the salient reasons is that the objective of the GEA scenarios is to tell the energy story of this transformative change rather than to focus on uncertainties or variations of other essential driving forces such as the demographic or economic changes. The focus is on energy-related transformations toward more sustainable futures. For the AVOID project two stabilization pathways titled “GEA Mix” and “GEA Efficiency” have been compared in detail, with focus on the China (centrally planned Asia) region.

The main aim of the GEA pathways is thus to provide a better understanding of what combination of measures, over which time-frames, and at what costs are needed to deliver the necessary solutions. A critical factor is to which extent changes in the level of demand for energy services together with demand-side efficiency measures can reduce energy consumed to provide mobility, housing and industrial services and thus help to fulfil the goals across virtually the whole range of sustainability objectives. At low energy demand, many alternative supply-side configurations might be possible to fulfil the aspirational goals of the GEA. By contrast, less emphasis on energy demand will require a much more rapid expansion of a broader portfolio of supply-side options. Hence, the successful implementation of demand-side policies increases the flexibility of supply-side options (and vice versa).

Figure B.1 gives an illustration of this concept, which is used as the scenario logic of the GEA pathways. Three GEA pathway groups, simply labelled GEA-Efficiency, GEA-Mix, and GEA-Supply, are constructed to represent different emphases in terms of demand-side and supply-side changes. Each group varies in particular with respect to assumptions about the comprehensiveness of demand-side policies to enhance efficiency, leading to pathways of comparatively low energy demand (GEA-Efficiency), intermediate demand (GEA-Mix), and high demand (GEA-Supply). Within each group, a range of alternative pathways for the supply-side transformation are explored.

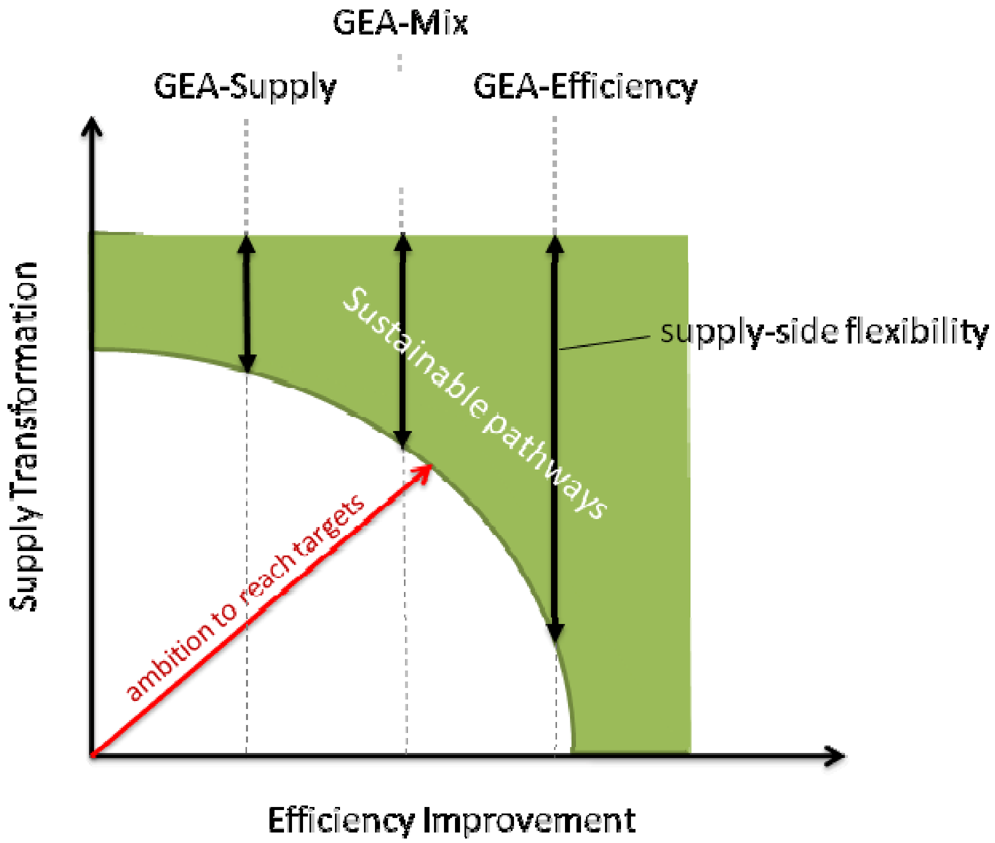


Figure B.1: Schematic illustration of the GEA pathways (Supply, Mix, and Efficiency), exploring alternative combinations of efficiency improvements and supply-side transformations to achieve ambitious targets for sustainable development. The ambition of the sustainability targets defines the necessary combination of supply and efficiency measures. High levels of efficiency improvements, as depicted by the GEA-Efficiency pathways, increase the supply-side flexibility to reach the targets (and vice versa).

Many alternative GEA pathways fulfil the normative objectives set out for the global energy system. Moving from these objectives to a specific pathway entails three critical choices or “branching points”. The first branching point describes alternative levels of energy demand and efficiency improvements, and leads to distinct pathway groups of low, high and intermediate demand (GEA-Efficiency, GEA-Supply and GEA-Mix respectively). Another branching point explores alternative transformations on the supply-side with the main aim to test the flexibility of different supply-side configurations to fulfil the GEA sustainability objectives given the levels of energy demand resulting from the first branching point. One aim was specifically to understand whether any of the supply options were mandatory. This was explored by constraining the portfolio of supply-side options by either prohibiting or limiting the availability of a particular technology, including nuclear, carbon capture and storage, biomass, and renewables. A further branching point, whose importance was revealed by this supply-side analysis, concerns changes in the transportation system. A “conventional” transportation system relying on liquid fuels has substantively different implications for supply-flexibility compared to an “advanced” transportation system dominated by electric or hydrogen-powered vehicles. Although any major transformation in an end use sector that entails fuel switching will impact the energy supply, the magnitude of impact from transformations in the transportation systems warranted its inclusion as an explicit branching point.

Branching point (1): *what is the level of energy demand?*	**Branching point (2):** *what are the dominant transportation fuels and technologies?*	**Branching point (3):** *how diverse is the portfolio of supply-side options?*
GEA-Efficiency (low demand) GEA-Supply (high demand) GEA-Mix (intermediate demand)	Conventional Transportation (liquid fuels) Advanced Transportation (electricity / hydrogen)	Full Portfolio (all options) Restricted Portfolio (excludes or limits particular options): - No CCS - No BioCCS (CCS + Bio-energy) - No Sinks - No Nuclear - No Nuclear & CCS - Limited Renewables - Limited Biomass - Limited Biomass & Renewables - Limited Biomass, No BioCCS & No Sinks

Table B.1: Branching points and GEA pathways.

The GEA pathways share a common median demographic projection whereby the global population increases from almost 7 billion today to about 9 billon by the 2050s before declining toward the end of the century. Figure B.2 illustrates this population projection in the context of the full range of global demographic developments from a very low to an unlikely high number of people by 2100. This median development path is a challenging one as the global population will be aging rapidly thought the century and concentrating ever more in urban areas. The GEA pathways also share a median economic development path so as to allow for significant development in the 50 or so of the poorest countries in the world while at the same time reflecting increased resource productivity and demand growth in the richest countries dampened by changing consumption patterns and lifestyles. This central economic development path common to all three GEA scenarios is illustrated in Figure B.3 that shows the full range of economic trajectories for the global energy scenarios in the literature.

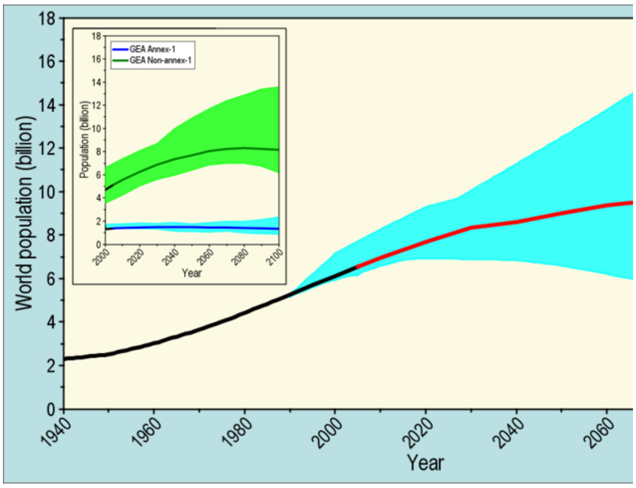


Figure B.2: Global population projections highlighting the median GEA development pathway in comparison with the range of population projections from the literature. The top insert shows the development of the Industrialized and Developing regions.

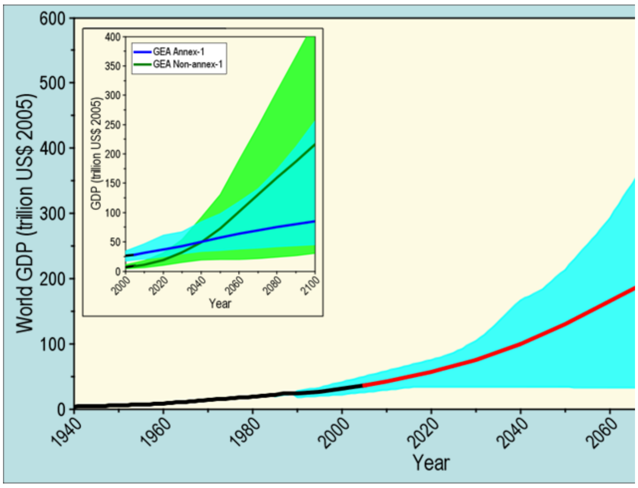


Figure B.3: Global economic development projection highlighting the median GEA development pathway in comparison with the range of economic projections from the literature. The top insert shows the economic development of the Industrialized and Developing regions.

Annex C: End-use Modelling Methodology

Data for end-use modelling was, amongst others, taken from the following key sources. These will be referred to using the abbreviations below:

- IEA Energy balances - IEA En. Balances
- IEA Energy Technology perspectives 2008 – ETP2008
- IEA Energy Technology perspectives 2008 – ETP2010
- Lawrence Berkley National Laboratories – LBNL2050
- Stockholm Environment Institute – SEI2009
- Energy Research Institute – ERI2009

C.1. INDUSTRY

- Due to the complexity of the industrial sector, even in developed countries it is difficult to estimate the energy demand. Table C.1. compares the historical industrial energy use by sector for China in 2005. The wide range of reported values highlights uncertainty in these numbers.
- The value reported by ERI2009 is 45% higher than the number stated by IEA in its energy balances. Our bottom-up model estimates a value similar to the ETP2008.
- Estimations are particularly difficult for the chemical industry (given the wide range of products) and for the less energy-intensive industries such as manufacturing of machinery and end-user products. Moreover, the definition of sectors in industry differs from country to country. This makes it difficult to estimate future consumption in China by comparing its 2050 economy to other countries (e.g. South Korea in 2005). Therefore, we estimate that our uncertainties for 2050 are at least as large as discrepancies in the 2005 data.

Table C.1. Comparison of reported energy use by sector in 2005

Final Energy use, 2005	**IEA En. Balances**	**IEA ETP2008**	**ERI2009**	**IIASA (CPA)**	**Imperial**
Iron and Steel	5.5	8.7	8.6		8.5
Chemical and Petrochemical	3.1	4.9	3.7		3.3
Non Ferrous Metals	1.0	1.0	1.2		1.4
Non Metallic Minerals	4.5	4.6	8.2		5.3
Machinery and transport	1.6	1.5	3.0		*1.6*
Food and Tobacco	0.8	0.8	0.0		0.8
Paper Pulp and Print and wood	0.8	0.8	0.0		1.0
Other (incl. construction, textile)	2.5	2.2	4.2		2.5
TOTAL	**19.9**	**24.6**	**28.9**	**24.5**	25.4

Modelling methodology:

- The industry model assesses the abatement potential across the whole of the secondary industry sector. The sector was divided into the following manufacturing categories: Iron and steel, chemical and petrochemical, non-ferrous metals, non-metallic minerals, machinery and transport, food and tobacco, pulp and paper and other (incl. construction, textiles).
- The model determines both the overall energy requirements and the total CO_2 emissions of industry by sector and fuel type.
- The total energy required is the sum of the energy required per sector. This is the product of the production rate in tons of sector (i) and the energy intensity of sector (i) in GJ/ton. i.e.

$$Total\ energy\ required = \sum_i (Production\ rate_i \times Energy\ Intensity_i)$$

- The total emissions from industry is found by calculating the fuel requirements of each sector by multiplying the energy required by sector (i) by the % Share of fuel (j) and the multiplying these by the emissions factor of each fuel (kg CO2 per GJ). Finally, emissions per sector are summed to determine the overall emissions in the industry sector.

$$Total\ CO_2\ emissions = \sum_i \sum_j (Total\ energy\ required_i \times \%Share\ of\ fuel_j \times Emissions\ factor\ of\ fuel_j)$$

- CCS was addressed by increasing the overall energy intensity of the iron and steel and cement sectors. Based on conversations with academics, the extra energy requirement was taken to be 110 kJ/mol of CO_2 captured. Using IEA estimates, it was assumed that 75% of all iron and steel and cement plants would be equipped with CCS by 2050 and that these would capture 90% of their CO_2 emissions.
- Key sensitivities in the model, which would require more detailed research and analysis include:
  - Improved projections of production rates – current estimates vary considerably. The sensitivity of demand to GDP should also be assed
  - Better consistency in the grouping of different industrial sectors. There is little transparency in how different sources have grouped different manufacturing processes.
  - Improved estimate of China's fuel mix: It is very uncertain how China will move away from coal. Most other industrial countries have substituted coal with gas and oil however this is unlikely owing to China's low domestic reserves of these fossil fuels.
  - Improved understanding of how China's industrial sector is likely to change over time and the degree to which it will shift to high value products and the service sector.
- The main assumptions of the model are given in the tables below:
  - **Economic assumptions:** The IIASA GDP and population projections were used for the both the baseline and abatement scenarios. However, most demand projections in literature do not include sensitivity on GDP growth.
  - **Production rate, energy intensity and fuel share** assumption are given in tables A.2 - 4 below.

Table C.2. Assumptions and sources of production rates for each sector

Sector	2005 Source	Projection assumption
Iron and steel	ERI2009	Comparison of projected demands (LBNL2050, ERI2009, ETP2010)
Chemical and petrochemical	Estimation based on ERI2009	Own estimation, based on ERI2009 and combined with projections of High Value Chemicals demand from IEA analysis, adjusted for imports.
Non ferrous metals	Estimation based on ERI2009	Estimation from per-capita consumption (LBNL2050, ETP2008)
Non metallic minerals	ERI2009	ERI2009
Machinery and transport	Own estimation	Assumed to scale with industry GDP
Food and tobacco	Own estimation	Own top-down estimates based on population growth
Pulp, paper and print	LBNL2050	ERI2009
Other (incl. construction and textile)	Own estimation	Own top-down estimates

Table C.3. Assumptions and sources of energy intensity for each sector

<table>
<tr><th>Sector</th><th>2005 Source</th><th>Baseline assumption</th><th>Abatement assumption</th></tr>
<tr><td>Iron and steel</td><td colspan="3">Detailed bottom-up modelling (Wang [1], Worrell [2], ETP2010)
• Four main process routes investigated: BF/BOF, Smelt/BOF, DRI/EAF, Scrap/EAF
• Aggressive shift away from smaller inefficient plants towards larger advanced plants.
• Increased share of electric arc furnaces (33% by 2050)
• Increased share of continuous and thin slab casting (phasing out of ingots).</td></tr>
<tr><td>Chemical and petrochemical</td><td>ERI09</td><td>20% of LC savings</td><td>ERI2009</td></tr>
<tr><td>Non ferrous metals</td><td>ERI09, LBNL2050</td><td>20% of LC savings</td><td>LBNL2050</td></tr>
<tr><td>Non metallic minerals</td><td colspan="3">Detailed bottom-up modelling (Hasanbeigi et al. [3], Tsinghua [4], Murray [5])
• Phasing out of inefficient vertical shaft kiln and shift towards efficient dry kilns with pre-calciner and pre-heater.
• Decreased Clinker-cement ratio through blended cements (71% in 2050).</td></tr>
<tr><td>Machinery and transport</td><td>Own estimation</td><td>20% of LC savings</td><td>UNIDO motor systems value, Brazil values, 50% penetration</td></tr>
<tr><td>Food and tobacco</td><td>Own estimation</td><td>20% of LC savings</td><td>Assumed no improvement</td></tr>
<tr><td>Pulp, paper and print</td><td>LBNL2050</td><td>20% of LC savings</td><td>LBNL2050</td></tr>
<tr><td>Other (incl. construction and textile)</td><td>Own estimation</td><td>Same as LC</td><td>No abatement measures</td></tr>
</table>

Table C.4. Assumptions and sources of fuel share for each sector

Sector	**2005 Source**	**Baseline assumption**	**Abatement assumption**
Iron and steel	IEA En. Balances	Constant fuel share	Higher electricity use due to increased penetration of electric arc furnaces
Chemical and petrochemical			Estimation based on Korea in 2005 with oil replaced by coal and some biomass
Non ferrous metals			Estimation based on Germany in 2005 with some gas replaced by heat
Non metallic minerals			Assumed biomass reaching 38% (same as Germany in 2007), decreasing coal by the same amount
Machinery and transport			Estimation based on Germany with some gas replaced by amount of coal and heat
Food and tobacco			Estimation based on the US with gas replaced by coal and biomass
Pulp, paper and print			Estimation based on Korea with oil replaced by coal and some heat
Other (incl. construction and textile)			Constant fuel share

C.2. TRANSPORT

- The transport sector model assesses all the major transport modes including road, air (including domestic and international flights), rail, and water. The model assesses both passenger transport and freight transport. The road transport sector is modelled through vehicle stocks in each year with a detailed vintage (i.e. vehicle types, fuel types, vehicle age in the annual stock). Non-road transport sectors are modelled separately, as described below.

- The non-road transport sectors are based on the 'ASIF' approach:
  - A = activity levels, projected with an assumed annual growth rate from current levels;
  - S = modal splits of the transport modes
  - I = fuel intensity for these transport modes
  - F = the fuel split used within transport modes

- Table C5 summaries activity levels for passenger and freight transport in 2050, once the overall travel activity level ("A") and modal split ("S") have been taken into account.

Table C.5. Activity levels projection in 2050 from various studies

	Imperial Baseline	Imperial Abatement	Source
Passenger (billion passenger-km)			
Rail	1308	1901	Baseline from SEI2009*, abatement from IIASA
Air	1962	1407	Baseline from SEI2009, abatement from IIASA
Freight (billion tonne-km)			
Rail	8525	8525	Own judgment based on SEI2009 and IIASA
Water	21278	21278	Baseline and abatement from SEI2009

* Using a model based on the Long-Range Energy Alternatives Planning (LEAP) tool developed by the Stockholm Environment Institute (SEI) for China in 2009

Fuel intensity for these transport modes is projected based on current levels and estimated future improvement rates. In the abatement scenario, energy intensity for rail passenger travel, rail freight and water freight are assumed to fall by about one third by 2050, compared to 2005 levels. Air passenger energy intensity is assumed to fall by about one fifth by 2050 on 2005 levels. The energy intensity estimates were arrived at by following assumptions made by SEI2009 for the non-transport sectors from Stockholm Environment Institute's LEAP. These are high-level estimates and further research would be required to produce more precise projections.

Projections of the fuel mix in each transport mode were also developed by following SEI2009's assumptions. In the abatement scenario, the penetration of electricity in rail is 100% by 2050; whilst biofuels reach 20% of air fuel in 2050, and 30% of water in 2050. Whilst the ETP2010 assumes a 30% displacement of fossil fuels in the marine and aircraft sectors by 2050, reviewers at

Tsinghua University have indicated this may be too optimistic, which is why the sensitivity analysis in Section 7: Total emissions comparisons, of the main report assesses the impact of a lower (10%) biofuel penetration in these sectors.

The Energy demand for the non-transport sector based on the 'ASIF' approach can be calculated from the following formulae:

$$\mathit{Energy\ Demand\ (by\ transport\ mode, by\ fuel\ type)} = \sum_{\mathit{Fuel\ type}} \mathit{Activity} \times \mathit{Modal\ Split} \times \mathit{Fuel\ Intensity} \times \mathit{Fuel\ Share}$$

CO_2 emissions can be derived by specifying the carbon content of the fuel types used.

$$\mathit{CO2\ Emission} = \mathit{Activity} \times \mathit{Modal\ Split} \times \mathit{Fuel\ Intensity} \times \mathit{Carbon\ Content\ in\ Fuels}$$

The emissions factor for electricity is taken from the IIASA Mix scenario, with a sensitivity examined in Section 7: Total emissions comparisons, using the (higher) electricity CO_2 intensity from the IIASA Efficiency scenario.

- The model for the road transport sector is based on the road transport model reported in Ou et al (2010). This model has considerable detail of road vehicle types, with vehicles divided into 9 categories including: heavy duty trucks (HDTs), medium duty trucks (MDTs), light duty trucks (LDTs), mini-trucks (MTs), heavy duty buses (HDBs), light duty buses (LDBs), cars, minivans (MVs), and motorcycles (MCs). The sales for these vehicles are projected with consideration of the penetration rates of mild hybrids, full hybrids, plug-in hybrid electric vehicles and pure electric vehicles. The vehicle stock in each year can be obtained from the sales projection and the survival rates for different types of vehicles.

- There is a large range of projections on the future vehicle population in China by 2050. For example, Argonne National Laboratories [6] give a range of about 500-650 million vehicles by 2050, And ERI2009 gives a figure of about 550 million (in its low carbon, low growth scenario). Ou et al [7], on which this work is based, estimate 500 million vehicles by 2050. The Imperial central scenario is much lower than this, based on discussions with Professor Shigeki Kobayashi at Toyota Central R&D Laboratories (whose work fed into the IIASA GEA scenarios), based on the assumption that China will have more limited vehicle ownership by 2050, following more Japanese patterns of growth. This is discussed in the main report, with a sensitivity analysis in Section 7: Total emissions comparisons.

According to Ou et al. [7], the penetration rate of EVs and other advanced vehicles are assumed to be as shown in Table C.6:

Table C.6. Share of EV and HEV application rate in future

a) Baseline scenario

Year	EV shares in Sales (%)		HEV application rate in conventional vehicle Sales (%)		
	For LDT, MT, HDB, LDB, PC and MV	For HDT and MDT	Mild-	Full-	Plug in-
2010	0	0	0	0	0
2020	0.6	0	0.6	0.3	0.3
2030	2.5	0	2.5	1.3	1.3
2040	5.6	0	5.6	2.8	2.8
2050	10	0	10	5	5

b) Abatement scenario

Year	EV shares in Sales (%)		HEV application rate in conventional vehicle Sales (%)		
	For LDT, MT, HDB, LDB, PC and MV	For HDT and MDT	Mild-	Full-	Plug in-
2010	0	0	0	0	0
2020	2.5	0	3.1	1.6	1.6
2030	10	0	12.5	6.3	6.3
2040	22.5	0	28.1	14.1	14.1
2050	40	0	50	25	25

This model does not consider hydrogen fuel cell vehicles (as hydrogen demand in the IIASA transport abatement scenarios is also not considered), but the combined sales of hydrogen fuel cell and electric vehicles by 2050 in the ETP2010 is about 40%, which compares reasonably closely with the assumption here of 40% sales of electric vehicles by 2050.

The fuel demand (DE – direct energy demand) for each year is calculated with the vehicle population (VP - split into vehicle vintages), vehicle shares of different fuels (i.e. electricity, gasoline, diesel, CNG, LPG), annual vehicle distance travelled (VDT), and fuel economy (FE) for different types of vehicles (in terms of category, fuel type and technology type – e.g. conventional, hybrids etc.), using the following equation:

$$DE_y = \sum_{i,j} VP_{i,j,y} \times VDT_{i,j,y} \times FE_{i,j,y}^{-1}$$

Where:

- DE is the direct energy demand in year y;
- $VP_{i,j,y}$ is vehicle population for vehicle type i with fuel type j in year y;
- $VDT_{i,j,y}$ is the fleet average annual vehicle distance travelled for vehicle type i with fuel type j in year y;
- $FE_{i,j,y}$ is the fleet average on-road fuel economy of the for vehicle type i with fuel type j in the y.

- Biofuels (including bioethanol and biodiesel) and CtL (coal-to-liquid) are projected based on Ou et al. [7] but scaled proportionally with the total oil consumptions (due to different vehicle populations). In the low vehicle growth scenario, biofuels consumption in 2050 is 68 million tonnes of oil equivalent (TOE), and CtL is 61 million TOE. In the high vehicle growth scenario, biofuels will reach 89 million TOE, and CTL will be 80 million TOE.

As with the non-road transport sectors, CO_2 emissions from the road transport sector are calculated by applying emission factors for the different fuels. Again, the emissions factor for electricity is taken from the IIASA Mix scenario, with a sensitivity examined in Section 7: Total emissions comparisons, using the (higher) electricity CO_2 intensity from the IIASA Efficiency scenario.

C.3. BUILDINGS

- The buildings model assesses the abatement potential in the main energy end-use categories in both residential and commercial buildings (water heating, space heating, cooking, lighting, cooling and appliances).
- The model first projects the number of households and commercial buildings in urban and rural areas based on saturation curves that correlate, respectively, household habitation and commercial office space with income levels and service sector GDP. The structure is also split into northern, transition and southern zones to account for the different climatic conditions and heating requirements. This population split is based on the UN population model, and an extrapolation of LBNL (Lawrence Berkeley National Laboratories) [8]. The heating requirement for each zone is derived from useful energy estimates in industrialised countries with similar heating degree days and GDP per capita. The residential model is also segmented by urban and rural households.
- The model projects the appliance and cooling usage in buildings, based on household income/ownership saturation curves. Where ownership data is lacking, Japan at similar levels of GDP/capita was chosen as a template model for urban areas, while rural areas take after present-day China. Lighting is projected based on the number of lighting points and daily usage levels in ERI2009, which correlate well with GDP/capita in the UK. The model then projects for a baseline and abatement scenario the different levels of building insulation and associated heating demands, as well as the usage of different cooking technologies, and different efficiencies of lighting technologies and appliances. The main assumptions are as follows:

Space heating:

- Space heating demand is projected using estimates of **useful energy** requirement for heating in the heated zones. It is assumed that this requirement (building envelope efficiency) in the baseline develops as an extrapolation of LBL, 2008, reaching levels similar to those of the UK at the same level of GDP/capita in heated zones. In the abatement scenario envelope efficiency is doubled, whereby the stock in heated zones reaches levels comparable to the Royal Institute of British Architects' Silver Standard.
- China is divided into three regions according to LBL 2008: One heating Northern region where District heating is the main heating technology, one transition region with a larger penetration of electric heating and cooling demand, and a cooling only Southern region. The resulting useful energy demands are presented in Table C.7.

Table C.7: heating intensity in different Chinese heating areas in the Imperial buildings model

Baseline		2010	2020	2030	2040	2050
North						
Heating intensity, urban	MJ/m2/yr	256	259	263	266	270
Heating intensity, rural	MJ/m2/yr	48	104	159	215	270
Transition						
Heating intensity, urban	MJ/m2/yr	105	115	125	134	144
Heating intensity, rural	MJ/m2/yr	25	55	84	114	144
Abatement						
North						
Heating intensity, urban	MJ/m2/yr	256	232	207	183	158
Heating intensity, rural	MJ/m2/yr	48	76	103	131	158
Transition						
Heating intensity, urban	MJ/m2/yr	105	108	110	113	115
Heating intensity, rural	MJ/m2/yr	25	48	70	93	115

- The model estimates the **share** of heating demand and efficiencies provided by heat pumps, CHP, traditional and commercial biomass, gas condensing boilers, solar water heaters, etc. For the baseline scenario these are produced from historical projections and literature (e.g. Letschert 2007, ASHRAE 2010), while the technology mix in the abatement scenario is sourced from IEA (2010).

Table C.8: Share of heating demand provided by different means in different regions

Baseline	Urban		Rural	
	North	Transition	North	Transition
Electric	6%	6%		3%
Gas Boiler	25%	20%	17%	7%
Coal	2%	4%	2%	2%
Biomass	4%	1%	20%	20%
DH	28%	14%	8%	4%
Heat pumps	21%	38%	17%	32%
Solar Thermal	12%	14%	16%	20%
Oil/LPG	2%	3%	8%	12%

Abatement	Urban		Rural	
	North	Transition	North	Transition
Electric	0,06	0,06	0,12	0,03
Gas Boiler	0,25	0,2	0,17	0,07
Coal	0,02	0,04	0,02	0,02
Biomass	0,04	0,01	0,2	0,2
DH	0,28	0,14	0,08	0,04
Heat pumps	0,21	0,38	0,17	0,32
Solar Thermal	0,12	0,14	0,16	0,2
Oil/LPG	0,02	0,03	0,08	0,12

Lighting:

- The number of lighting points is kept constant, as the number of households and floor space are carried on across scenarios. The efficiencies for LEDs, CFLs, fluorescent tubes and incandescent lamps have been extracted from IEA (2008), whereas the mix of lighting technologies is derived from ETP2010 in the baseline and abatement scenarios.

Appliances:

- The model projects the appliance and cooling usage in buildings, based on household income/ownership saturation curves. Where ownership data is lacking, Japan at similar levels of GDP/capita was chosen as a template model for urban areas, while rural areas take after present-day China.
- Appliance efficiencies are derived from various sources (IEA2009, [8], ERI2009, [9], among others). In the baseline, the efficiency of the appliances stock generally reaches current Chinese Minimum Energy Performance. In the abatement scenario, appliance efficiency in 2050 reaches the average levels of Japanese equipment in the early 2000s.

Table C.9: Penetration of key appliances and their efficiency in the Imperial abatement scenario

		2010	2030	2050
Refrigerators				
Per 100 household		106	147	150
UEC* Urban	kWh/yr/unit	441	369	338
UEC Rural	kWh/yr/unit	440	373	341
Room Air Conditioners				
Per 100 household		99	139	217
Households cooled		32	40	50
Clothes Washer				
Per 100 urban household		101	138	181
Per 100 rural household		56	73	73
UEC Urban	kWh/yr/unit	55	36	22
UEC Rural	kWh/yr/unit	41	38	35
Colour TV Sets				
Per 100 household		154	206	210
UEC Urban	kWh/yr/unit	125	99	63
UEC Rural	kWh/yr/unit	243	174	99

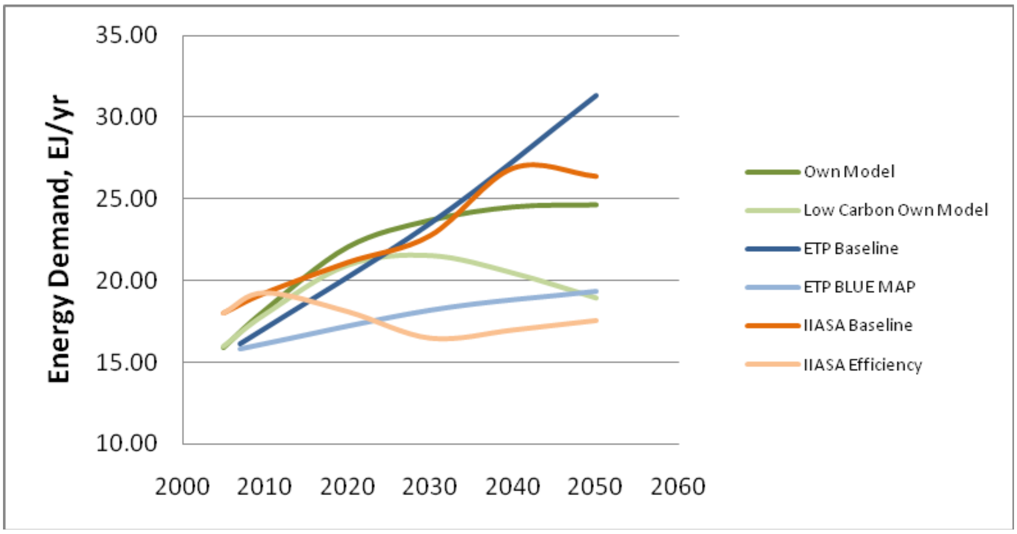
Water heating:

- Due to the lack of data the modelling follows ETP2010 assumptions on water heating energy demand by energy carrier type for both scenarios.

Cooking:

- Due to the lack of data the modelling follows ETP2010 assumptions on cooking energy demand by energy carrier type for both scenarios.

- From these estimates the model calculates the energy demand in each major category of usage, split by major energy carrier.
- As a result of these relatively high levels of assumed efficiency of building envelope and white goods, and saturation of appliance penetration, the final energy demand begins to saturate in the Baseline before 2050 – in contrast with other ‘frozen technology’ scenarios where growth is more linear. The low carbon scenario aligns well with other literature sources, and reflects the strong potential for deep carbon cuts in the sector.



- CO_2 emissions are calculated using emissions rates derived from IIASA scenarios, using the IIASA Mix electricity emissions factor. The emissions impact of using the higher electricity emissions factor in the IIASA Efficiency scenario is explored in the sensitivity analysis in Section 7: Total emissions comparisons.

- Key sensitivities in the model which would require more detailed research and analysis include:
  - Stock turnover rates would allow for an appreciation of the level of retrofitting required, as most Chinese policies apply only to new build.
  - Better data on the technologies used in water heating and cooking in the different areas (currently rely on IEA assumptions)
  - Better data on biomass use by end-use and the conversion efficiencies of technologies used in rural areas – an area of unavoidable uncertainty.
  - The commercial sector is highly sensitive to the assumption around m2/tertiary sector GDP. LBNL2050 claims this driver might not be realistic for long-term projections; further analysis around this assumption would be necessary.

Annex D: Detailed assessment of low-carbon technologies in China

D.1. POWER SECTOR

Coal-fired power generation

Installed capacity in IIASA abatement scenarios by 2050: 680 GW (Mix) and 400 GW (Efficiency)

Current state of the technology and future development and commercialisation challenges	- The coal power sector in China is highly disaggregated. The largest five power companies make up 42% of capacity and the remainder is made up of local smaller enterprises (which have a higher energy intensity and less capability for innovation and R&D). - China has required (since 2005) that all new coal-fired power plants greater than 600 MW be build with USC technology. China closed down 14 GW of small coal-fired plants in 2007 alone [10]. - China is desperately trying to meet its growing electricity demand. The Chinese still experience electricity shortages and blackouts at peak times. In order to meet this demand, China is likely to continue its rapid expansion of the coal-fired power sector.
Current/historic maximum deployment rates	- Currently, sub critical pulverised coal plants make up the main balance of China's coal fired power generation. However, the penetration of SC and USC technology is increasing. SC plants make up about half of new orders [11]. As of 2007, there were about eighteen 1000 MW USC plants (12 of which are now in operation) and ten 600 MW USC plants on order or under construction in China [12]. According to the IEA, current (2007) SC capacity is about 50 GW and current USC is about 10 GW [13].
Current costs and how they are likely to develop over time	- The cost of construction of power plants in China is increasing. Between 2005 and 2007 the cost of construction doubled. This is attributed to the rise in commodity prices, labour and safety standards as a result of China's economic growth. - Cost of coal is rising, however electricity prices are not in line with these rises - a large number of coal-fired power stations are currently running at a deficit and do not have surplus for investment in new equipment and advanced technologies [10]. - Closure of plants has enormous social cost. The coal-fired power sector plays an important role in the Chinese economy. Closing down smaller plants has resulted in high unemployment. In 2007, 152000 people were impacted by the closure of power plants. Furthermore, smaller plants are more labour intensive than larger, efficient plants so the impact is greater.
R&D, IP and skills (scientific, engineering, monitoring, regulatory) requirements to support this degree of technical rollout	- China has considerable experience in the operation of SC power plants. The first domestically manufactured SC units were put in operation in 2004 (2x 600MW plants). - In 2007, China has become the largest Thermal power equipment manufacturer in the world ([14], [15]). The three main manufacturers are: Shanghai Electric Group, Harbin Electric Corporation and Dongfang Electric Corporation. All three of these companies have the capability to design and manufacture SC and USC equipment - The boilers and turbines are typically domestically manufactured using internationally supported technology ([12], [15]). China has also begun exporting SC and USC technology to other countries (e.g. Turkey and India) [15]. - China does however rely on imports of alloys required to build the high pressure and high temperature USC boiler. - Owing to China's interest in improving energy security through increased efficiency, there is strong government support for the roll out of SC and USC technologies. The

	NDRC has shown clear focus and strategy, beginning with the development of domestic manufacturing expertise and followed by a combination of ' front-end R&D support' and 'back end policy-pull measures' (See [15] for more details)
Resources required to support the technology to the level deployed, and feasibility of China obtaining/producing these resources	- A possible bottleneck for China is the supply of specialised alloys for the manufacture of high pressure and high temperature USC and SC boilers. (As mentioned above) - Additional production processes such as CCS, coal grinding and pollution control increase coal consumption. Coal fired power plants are highly water intensive. There is the potential for air-cooled units however these typically have a lower efficiency.
The infrastructure requirements and system integration challenges	- China does not have a merit system for power plants. All plants, independent of their efficiency or pollution controls receive the same priority and plants are allocated a generating allowance according to their capacity. China is starting to transfer generation allowances from small to larger plants, giving preference to more efficient plants.

Integrated Gasification Combined Cycle (IGCC)

Installed capacity in IIASA abatement scenarios by 2050: 110 GW (Mix) and 9.2 GW (Efficiency)

Current state of the technology and future development and commercialisation challenges	- Globally, IGCC is a well-known technology. The first IGCC plant was tested in Germany in the 1970's and following this IGCC came online in the 1980s in the US. Since then, however, deployment of IGCC globally has been relatively limited and there are currently only 6 plants in operation in the world. - There are mixed opinions regarding maturity of IGCC. Significant experience has been gathered from IGCC in the chemical process industry and so some consider the technology to be reasonably mature. However, system reliability is typically lower than conventional coal-based power plants leading some to still consider the technology as unproven. - Current IGCC power plants in operation have a capacity ranging from 100 - 300 MW and a net efficiency of 43-45% [16]. Efficiency can theoretically reach as high as 55%. Some larger (500 MW) IGCC units exist in the refinery industry, which run on refinery bottom residue. These are based in Italy and Japan. - China has a number of proposed IGCC demo projects: 1) China Yantai IGCC demo plant (300-400 MW) - this was supposed to come online in 2010 but is currently on hold; 2) GreenGen stage I plan is a 250 MW IGCC plant, increasing to 400 MW with CO2 separation in stage II (by 2015); 3) China Datang Group and China Electric Investment Group to build three to five 300-400MW IGCC units. Progress in the first phase has been slower than expected but is apparently nearing completion.
Current/historic maximum deployment rates	- General Electric has proposed a 10+10 IGCC demonstration project between the US and China, where each country builds 10 demonstration plants. If this were completed, it is expected that this would help to reduce the uncertainty surrounding construction costs and would allow IGCC to reach cost parity with SC. - There are 12 units waiting for approval by the NDRC [11]. - The IEA projects that IGCC capacity could reach 170 GW by 2030.
Current costs and how they are likely to	- The investment cost of IGCC is high. Around 1100-1400 US$/kW. Some literature estimates that costs could be as high as 2000 US$/kW [17]. - There is high uncertainty in the costs of IGCC and what the potential for decrease is. This remains one of the main barriers for IGCC development.

develop over time	- IGCC without CCS is more expensive than either USC or PC plants. However, IGCC with CCS is much cheaper than PC or USC with CCS. The additional cost of CCS to a 500 MW IGCC plant is a 32% cost increase compared to 74%, 61% and 54% for sub-, super- and ultra-super-critical plants respectively. - Interestingly, with increased coal prices the difference in the levelised cost of an IGCC plant compared to a USC plant becomes less [18]. This implies that as China's economy matures and coal becomes more expensive, IGCC technology will become more economically attractive.
R&D, IP and skills (scientific, engineering, monitoring, regulatory) requirements to support this degree of technical rollout	- China still imports some of the key technologies for IGCC construction including: the gasifier, advanced gas turbine blades, blade passage technologies and advanced sealing techniques in the gas turbine [10]. - Aside from this, China does have the technical capability to produce IGCC plants domestically. Gas turbines contribute only a small amount to the cost of IGCC (<2%) and so China should be able to develop a domestic supply chain for IGCC construction, which would bring down construction costs. This is a stated objective of the NDRC. - IGCC is quite a complex technology and ensuring operational reliability, adaptability and control is not straightforward and requires experience. This is a limitation for the uptake of IGCC since China has not yet acquired this domestic knowledge - Key areas which China needs to develop expertise in include: large scale gasification, gas clean-up and air separation technologies; gas turbine technologies and system integration and control technologies - China has designed its own two stage entrained flow gasifier [16]. The performance of this gasifier is in line with and in some areas better than international designs. - China has expertise in manufacturing conventional cryogenic air separation units. China is developing expertise in advanced air separation processes such as membrane separation. Pilot scale testing was carried out in 2006 [16].
The resources required to support the technology to the level deployed, and feasibility of China obtaining/producing these resources	- IGCC plants use much less water compared to other coal fired power plants. This fact is currently not being recognised due to the under-pricing of water. - China's coal reserves typically have a high ash content which can reduce the efficiency of water slurry gasifiers. More expensive, dry-feed gasifiers, however, are able to run on high ash coal without any efficiency reductions. In general, it has been demonstrated that IGCC plants are more flexible to variations in coal quality and type compared to SC and USC technology. The Wabash IGCC switch from using bituminous coal to petroleum coke with only a minor change in operating conditions.
Major policies, targets and supporting measures	- In general, China is doubtful that there will be a legally binding carbon price within the next ten years and so its focus has been on maximising energy security and minimising energy costs. For this reason it has chosen to focus on USC plants, which is a highly efficient, well-known and cost effective technology. The economic advantage of IGCC with CCS has received only limited interest.
Potential role of international community	- Experience in operation of IGCC plants has been acquired in the US, Netherlands and Spain. This knowledge needs to be transferred to China for China to be able to quickly implement IGCC technology. - A clear signal to China that developed countries are serious about mitigating climate change and that a global deal is likely would place pressure on China to invest in low carbon technologies such as IGCC+CCS.

Gas-fired power generation

Installed capacity in IIASA abatement scenarios by 2050: 305 GW (Mix) and 190 GW (Efficiency)

Current state of the technology and future development and commercialisation challenges	- Despite China's limited domestic gas reserves gas fired power generation is attractive as a power generation technology since the CO_2 emissions factor is lower compared to coal. In addition China is already heavily reliant on imports of oil - Currently, gas makes up around 2 % of China's total power generation mix.
Current/historic maximum deployment rates	- The IEA projects that gas-fired and oil-fired power generation could make up around 200 GW of China's power generation capacity by 2030. This is an increase from around 40 GW in 2007.
Current costs and how they are likely to develop over time	- China imports most of its high efficiency gas-fired equipment. This translates to higher capital costs - Gas fired power plants are around 3385 Yuan/kW ($500/kW) while larger ones (300 - 390 MW) are around 4354 Yuan/kW ($700/kW)
R&D, IP and skills (scientific, engineering, monitoring, regulatory) requirements to support this degree of technical rollout	- China currently relies largely on imports for its gas turbine technology.
The resources required to support the technology to the level deployed, and feasibility of China obtaining/producing these resources	- Gas supply in China is limited.
The infrastructure requirements and system integration challenges	- Gas will play a key role in China in managing peak electricity supply with a large amount of intermittent renewable capacity. Modern combined cycle gas turbines have the advantage of being able to ramp up electricity production quickly and can cycle between low and high production frequently without affecting the economics of the plant. This is not possible with coal. - Gas infrastructure for transport of gas is limited. - Gas could be particularly relevant in the Eastern and Southern coastal regions in China. These areas have seen high economic growth in recent years yet
Major policies, targets and supporting measures	- Current energy pricing policies in China are limiting the deployment of gas-fired generation in China. Gas fired power plants have to conform to the Power Sector Reform measures as well as the international practise of take-or-pay gas purchase.

Solar (solar photovoltaics and concentrated solar)

Installed capacity in IIASA abatement scenarios by 2050: Solar PV 1080 GW (Mix), 680 (Efficiency), Solar CSP 94 GW (Mix), 94 GW (Efficiency) by 2050.

Current state of the technology and future development and commercialisation challenges	- As of the end of 2010, an estimated 35GW installed capacity worldwide (mostly silicon solar PV, which is the most mature technology, with a significant and growing share of various thin-film technologies); - In most cases cost is still much higher than grid price, except where insolation high and electricity prices high; - Incentives such as Feed in Tariffs have helped drive down cost and some countries will see grid parity in a few years; - Various thin-film technologies are currently competing with silicon, and organic PV and concentrator PV may be commercialised; - Solar CSP is a mature technology. In China, there have been demonstration plants in Inner Mongolia, Gansu, Qinghai, Xinjiang and Tibet.
Current/historic maximum deployment rates	- Highest rollout rate of solar PV to date was in Italy in 2010 – reportedly 5 GW; - Unlikely to be specific limits to roll out several GW per year if it is economic.
Current costs and how they are likely to develop over time	- Current cost estimates range from $2800/kW (IIASA GEA) - to $5600/kW (IEA ETP, for the US) in 2010; - The cost consists of the PV module and the mounting, cables, converters, buildings alterations (the Balance of Systems); - 2050 unit cost estimates are of the order $1000/kW (Greenpeace/EPIA, IEA, IIASA), with reductions driven by process improvements, economies of scale and alternative technologies (thin-film PV, organic PV); - However, there could be a floor cost of $1600-2600/kW ([19]; [20]) most likely due to limits to the Balance of Systems cost reductions; - Unit cost of solar CSP initially lower than that of solar PV, hence CSP offers a plausible alternative in the short term. However, the potential for cost reduction is lower - in the IIASA scenarios the unit costs decrease to $1600/kW in the Baseline and Mix scenarios, and to $2150/kW in the Efficiency scenario.
R&D, IP and skills (scientific, engineering, monitoring, regulatory) requirements to support this degree of technical rollout	- China is the world’s largest producer of silicon solar cells, and around half of the approximately 15 GW added globally in 2010 was produced in China; - Chinese modules are widely recognised as the world’s best value in terms of cost per unit of electricity supplied. This is largely due to the cheaper labour costs in China, economies of scale and improvements in process made as the industry has grown; - Chinese manufacturers have been reliant on imported production lines, though at least one company has begun its own production line and this may change rapidly; - Poly-silicon wafer manufacture has been a high entry barrier segment for China. The largest domestic manufacturer, GLC Poly, has relied heavily on imported poly-silicon, but has recently announced an investment programme of $2.3bn, which, if projections are met, would make it the number one poly-silicon producer in the world by 2012. The government also plans to consolidate the industry, closing smaller, inefficient manufacturers to meet its energy intensity goals, and offering support to large solar companies wishing to become vertically integrated. A key challenge will be to use newer, more efficient manufacturing processes to move away from the current reliance on scaling up existing processes.
The resources required to support	- An estimate of the space required for 1200 GW of solar PV is 8 billion m^2. A rough estimate of available roof space (~500 million households) is around 5 billion m^2. This suggests that a

the technology to the level deployed, and the feasibility of China obtaining/producing these resources	significant proportion of the capacity in the IIASA abatement scenarios would need to be in the form of solar farms (and this is certainly feasible); - The raw material for silicon solar cells is sufficient, though large-scale production could be restricted by silver availability. Any bottleneck would be further downstream. - The raw material resource for newer thin film technologies (particularly tellurium and indium) could be limited; - CSP is a highly water-consuming technology, so sites must be chosen with regard to water resources.
The infrastructure requirements and systems integration challenges	- China's richest solar resources are in the North and West of the country, compared to dense population centres in the South and East. Hence a long distance high capacity power network is required; - Intermittent sources such as solar will also require sufficient systems balancing (e.g. fossil fuel generation) plant to ensure supply meets variable demand loads; - CSP power can be stored for around 7 hours, and possible to co-run with a gas turbine at night to generate a constant output.
Major policies, targets and supporting measures	- The 2006 Renewable Energy Law (REL) put in place many policies such as feed-in tariffs, power pricing and subsidies for wind, solar and biomass technologies, plus mandatory grid access for all renewables; - The Medium and Long-term Development Plan for Renewable Energy of 2007 (MLTDP) built on the REL with an aim to speed up the development of renewable energy. This set a target of 1.8 GW of solar installed by 2020; - The 2009 Golden Sun project, looking to boost the domestic solar market to 20GW installed capacity, will subsidise 50% of the cost of solar projects over 500 MW, and up to 70% for smaller independent projects, until 2011. - Continued R&D to help bring costs down will be critical.
Potential role of international community	China is looking to develop capabilities in the upstream (poly-silicon wafer) manufacturing processes. Companies in Germany, Norway, Japan, Korea and the U.S have been key players up to now, although China is catching up rapidly. In at least one instance, that of Poly Plant Project Inc. and LTST Co. Ltd, Chinese companies have imported new polysilicon technology and equipment.

Nuclear

Installed capacity in IIASA abatement scenarios by 2050: 290 GW (Mix), 120 GW (Efficiency) by 2050

Current state of the technology and future development and commercialisation challenges	- Chinese domestic technology is Generation II and II+, with the incumbent domestic technology CPR1000 PWR. - China is importing a number of foreign Generation III technologies, including Westinghouse's AP1000 and AREVA's EPR, and potentially Korea's APR-1400. It has bought the rights to the AP1000. By analogy with Korea's nuclear development, it is likely that within 10 years China will be able to develop its own Generation III reactor.
Current/historic maximum deployment rates	- The highest rates of build-out were seen in the US and France in the late '70s / early '80s, peaking at around 10 GW per year. China is still in the early stages of its rapid nuclear acceleration, but given its size, and its central planning, the implied build-out rates for the IIASA scenarios, at less than 10 GW per year until the 2040s, look plausible.
Current costs and how they are likely to develop over time	- The cost of nuclear power stations, and nuclear electricity, has risen steadily in the OECD. This has been due to increasing safety standards, leading to safety upgrades and retrofits, as well as rising labour costs, dominating cost reductions through learning. Whilst newer technologies aim to build-in safety so that retrofits and upgrades will not be necessary, the cost of nuclear in China in the IIASA scenarios rises for the same reasons; - The lifetime of a nuclear plant has a significant impact on the cost of nuclear electricity. The current benchmark is 60 years, but this can be extended if the case for safety is made; - The IIASA scenarios show the unit cost of nuclear power rising from $2200/kW in 2005 to $3350-4950/kW in the Baseline and Mix scenarios in 2050, and to $3800-6180/kW in the Efficiency scenario. For comparison, the IEA gives the estimated unit cost at $2700-3300/kW in 2050, although some sources give a higher cost (e.g. IAEA - $6000/kW)
R&D, IP and skills (scientific, engineering, monitoring, regulatory) requirements to support this degree of technical rollout	- With China having bought the rights to the AP1000, the diffusion and reproduction of this technology will enable China to build up the expertise to develop its own Generation III reactor; - Safety design and monitoring will be of great importance. There have been concerns over the safety of the domestic CPR technology, which would not meet current OECD standards. However, with the adoption of the AP1000 technology, which has high safety levels designed-in, China should be able to adopt higher levels of safety; - The manufacturing bottleneck is currently the pressure vessel, made by a relatively small number of manufacturers worldwide. China has three state-owned manufacturers with the capacity to produce around 7 sets per year currently, but the NDRC has authorised investment for this to increase to around 20 sets per year by 2015, which would allow China to keep pace with domestic demand. However, certain other components, such as the large pumps and valves for the AP1000, are made exclusively by UK Sheffield Forgemasters International. China may look to develop capability in this area to avoid this becoming a bottleneck.
The resources required to support the technology to the level deployed, and the feasibility of China obtaining/producing these resources	- The most common feedstock is uranium, used in PWRs such as the CPR1000, the AP1000 and the EPR. However, thorium is an alternative for fast-breeder reactors, and has been used extensively in e.g. India for decades; - Uranium is produced in only a small number of countries - in 2007 60% of uranium produced came from Canada, Australia and Kazakhstan, with 97% coming from just 11 countries. China's known recoverable uranium resource was estimated in 2007 as 100 ktU, and the world's as 5.4 MtU. If the nuclear projected in the IIASA scenarios were uranium-based, China would need approx. 1-2 MtU up to 2050, implying heavy reliance on imports. The sufficiency or otherwise of the world's resource is not fully known. However, the rate at which Kazakhstan was able to ramp up production may indicate that there is more available than is currently thought; - Uranium-based fast-breeder reactors, with fuel reprocessing, can lead to a 50 times more

	efficient use of uranium (Imperial College analysis). - Alternatively, China could credibly develop thorium-based reactors. The global thorium resource is estimated to be 4 times larger than its uranium resource; - PWRs consume more water than coal power stations; hence this will be a major consideration in plant location.
The infrastructure requirements and systems integration challenges	- Nuclear is normally a base load technology. However, France has shown that light water reactors can load-follow reasonably well. Other PWRs such as the EPR also have the capability to vary their output. How cost-effective this could be is not very clear. Further, non-water-cooled reactors, such as fast-breeder reactors, are currently not able to load-follow. This may be another reason for some form of nuclear technology mix.
Major policies, targets and supporting measures	- China has a clear and ambitious nuclear power programme, with a target of 40GW of installed capacity by 2015, and 70GW by 2020; - Chinese nuclear technology is being developed through international collaboration; - A possible risk to the nuclear development is safety. An incident of medium significance anywhere in the world is likely to lead to a reconsideration of OECD nuclear programs, but is unlikely to slow China's program. A very significant incident, however, may lead to show-stopping unpopularity.
Potential role of international community	- AMEC and EDF have been awarded the new UK contract, and could offer knowledge transfer to China in the planning and infrastructure building aspects of the projects. - The international community may offer knowledge transfer on uranium enrichment, and perhaps most interestingly in reprocessing. Sellafield has experience in fuel reprocessing. This could become an important area of capability for China given their likely uranium import reliance. - China is developing its capabilities in pressure vessel manufacture, but this could be accelerated with collaboration. Some components such as the large pumps and valves for the AP1000 are made exclusively at UK-based Sheffield Forgemasters International. Knowledge transfer in this area could relieve any manufacturing bottlenecks.

Hydro

Installed capacity in IIASA abatement scenarios by 2050: 250 GW in both Mix and Efficiency by 2050

Current state of the technology and future development and commercialisation challenges	- Hydropower is a well-developed, mature and competitive technology. Many countries, including Japan, the US, France and Switzerland, have already exploited over 80% of their hydropower resource; - Techno-economic factors do not strongly limit the installation of additional hydropower, though policies such as fixed tariffs for small hydro and technology improvements could accelerate the growth of small hydro; - China had by 2008 exploited only 27% of its estimated 540 GW (other sources say 400 GW) economic resource, with around 145 GW of hydropower installed, which is projected by Chang et al. [21] to have reached around 194 GW in 2010. This has been achieved with the construction of many multiple-GW units and the further growth of small hydro plant, mainly to serve un-electrified rural households. Over the longer term, the bulk of the new capacity is expected to be large hydro, in which China is becoming the world leader, having recently completed the largest hydro plant in the world, the 18.2 GW [possibly 22.5 GW by 2012] Three Gorges Dam.
Current/historic maximum deployment	- The present deployment rate in China, estimated to be up to 50 GW between 2008 and 2010, is the largest historic rate of hydropower build-out (approximately the total hydro capacity of Norway every year). China has been installing at least 5 GW per year since the mid-1990s and

rates	between 2006 and 2007 alone 20 GW was installed.
Current costs and how they are likely to develop over time	- The unit costs, and hence electricity costs, of hydropower are expected to rise over time. Since the technology is mature, there is little learning to be done, and rising labour costs, and potentially the rising cost of environmental precautions, mean an upward trend; - The IIASA scenarios show the average unit cost of hydropower (aggregated small and large) increasing from $1760-2460/kW in 2005 to $2270-3180/kW in 2050, constant across all scenarios including the Baseline. - For comparison, the IEA assumes unit costs for the US of $2000/kW and $3000/kW for large and small hydro respectively, constant across the period 2010-2050. Estimated unit costs from large hydro projects in China can be as low as $760/kW, and as high as $1583/kW [22]. McKinsey [23] assume a cost of $1560/kW in 2005 in developing countries. Chang et al. [21] suggest that the 18.3 GW Three Gorges project was completed for $22bn, giving a unit cost of around $1200/kW. - Even at the higher end, hydro electricity is very competitive with the grid, and it is fully expected that technology cost will not be a limiting factor in the deployment of hydropower; - One factor of uncertainty around hydro is the potential cost of unforeseen environmental side-effects, including relocations, flooding of arable land and population centres, and geological disasters. Minimisation of the risk of these side-effects will be very important for the optimal development of hydropower.
R&D, IP and skills (scientific, engineering, monitoring, regulatory) requirements to support this degree of technical rollout	- The main barriers to implementation of the targeted large hydropower are issues around delays and external costs related to environmental risks and displacement of population. For example, the construction of the Xiluodu dam has already been delayed once due to the absence of an environmental impact study. Achieving the target of 300 GW will require careful planning to ensure that no external costs are incurred, and further that the benefits of the project outweigh the risks to the environment and population. - Despite the environmental issues, hydro power is fully expected to be exploited close to the total resource by 2050. This is applicable even in 'baseline' cases, reflecting the fact that it is part of China's electrification policy, regardless of carbon considerations ([24], [17], [25]). An explicit low carbon push for hydro may mean that some of the less economic resource is exploited, but this will amount to a small additional fraction.
The resources required to support the technology to the level deployed, and the feasibility of China obtaining/producing these resources	- Estimates of the economic resource in China are between 400 GW and 550 GW, with more available at higher cost. The deployment levels in the IIASA scenarios therefore will not be limited by the available resource, and are a significant underestimate relative to China's current plans (almost 400GW by 2020); - The huge amounts of cement and steel used in large hydro projects may lead to the technology being less economically favourable in the long term [21]. - Climate change may become an issue affecting the hydropower resource in the longer term. Many parts of northern China are experiencing decreasing rainfall (with 20-40mm less rain every 10 years) [26].
The infrastructure requirements and systems integration challenges	- There is a separation of resource and demand, with most of the exploitable hydro in the West, particularly in Sichuan and Yunnan, away from population centres. The grid infrastructure required will be significant, but the individual size of the projects makes this realistic. This is not expected to be a bottleneck for hydropower.
Major policies, targets and supporting	- China has a firm commitment to its hydropower plan, and recently increased its national target from 300 GW in 2020 to 380 GW. The government continues to provide an environment of support for hydropower with VAT reductions and extended loan periods. Fixed tariffs could be

measures	introduced to accelerate the penetration of small hydropower.
Potential role of international community	- The international community, through the UN and the World Bank, has recently recommenced investment in, and recommendation of, hydropower after a period of investigation. Continuation of this will help to ensure the hydropower technologies are developed in a sustainable way.

Wind (onshore and offshore)

Installed capacity in IIASA abatement scenarios by 2050: 530 GW in both Mix and Efficiency by 2050

Current state of the technology and future development and commercialisation challenges	- Onshore wind is a mature technology with nearly 200 GW installed globally. Onshore wind power deployment has seen incredible growth in China in the last few years, due to strong policy incentives. An estimated 17 GW was installed in China in 2010 - nearly half of the capacity added globally - leading to a total installed capacity of around 42 GW. - Offshore wind is at an earlier stage of development, with only a few GW installed globally. The technical challenges are greater, and hence the costs higher. However, the offshore wind market is expected to increase rather rapidly over the coming years (Greentech Initiative [27]). China is expected to meet most of its targets for wind through onshore, due to the lower cost, but offshore wind has other advantages, such as the proximity to large population centres and potentially better transmission networks. Observers have suggested that China will need to install a significant amount of offshore wind in order to meet its interim target of 11.4% of primary energy from non-fossil sources by 2015 (15% by 2020).
Current/historic maximum deployment rates	- The maximum historic deployment rate for wind power was the 17 GW installed in China in 2010.
Current costs and how they are likely to develop over time	- The cost of turbines will depend strongly on the development of domestic large turbine technology [28]. - The unit cost for wind in 2005 (the historic data for the GEA models) was around $1520/kW. Estimates of the current unit cost of onshore wind vary between $1000-2200/kW globally ([24], [23], [20], [29], [30]). Estimates for China are at the lower end, at $1000-1400/kW, due to lower labour and material costs. Han et al. [30] suggests that this range is accounted for by the 30% lower cost of Chinese components versus foreign-made ones. The GEA scenarios show the unit cost decreasing from around $1400/kW in 2010 to $870/kW in the Baseline and Mix scenarios, and to $670/kW in the Efficiency scenario. For comparison, the IEA project a unit cost of $1200-1600/kW in the US in 2050. Rout et al. [31] give a floor cost of $1115/kW for onshore wind. Liu et al. [29] project that the unit cost could decrease to as low as $770/kW by 2030 if domestic technology has the whole domestic market by that time. [Imperial experts consider that a halving of the cost of onshore wind is very ambitious]. - The unit cost decreases in the GEA scenarios correspond to learning rates of 0.13 in the Efficiency scenario and 0.17 in the Mix scenario. For comparison, Liu et al. [28] have reviewed a number of studies to find an average learning rate for wind of 0.13. Neij et al. [32] suggest a learning rate of 0.08-0.12 and McKinsey a rate of 0.05. - The unit cost of offshore wind is currently higher, and is likely to remain so, given the greater technical challenge. The GEA scenarios aggregate onshore and offshore wind, with the aggregate cost dominated by onshore wind. However, as discussed above, offshore wind is expected to play a minor but significant role in China in the near future. This will require substantial investment, given that unit costs of offshore wind are 50-100% higher than for onshore ([24]; [27]; [31]). However, there will be at least the same potential for learning in cost as for onshore.
R&D, IP and skills (scientific,	- Currently, 40% of the turbines installed in China are made domestically. Sinovel, Goldwind and Dongfang are the largest domestic manufacturers, who alongside Vestas, GE and Gamesa

engineering, monitoring, regulatory) requirements to support this degree of technical rollout	dominate the Chinese market with 80% of the production. The Chinese turbines have a lower reliability than the foreign-made turbines, as quality control is not optimised. Turbine technology will be a key development challenge - China has not mastered large turbines with nameplate capacity >1 GW. Innovation in the sector is currently not very strong, due a relatively small number of technical experts [33]. - The deployment rates of wind suggested by the GEA scenarios are very aggressive. The deployment up to the economic resource of roughly 500 GW happens largely over the course of 1-2 decades. The maximum build-out rate in the GEA Efficiency scenario is around 400 GW between 2040 and 2050, and in the GEA Mix scenario around 250 GW between 2020 and 2030. These will require the construction of up to 1500 turbines per year, requiring a large manufacturing capacity for turbines and other components. However, it appears that by the time it is needed, China could feasibly have ramped up to this level.
The resources required to support the technology to the level deployed, and the feasibility of China obtaining/producing these resources	- Onshore wind resource estimates are on the order of 300 GW [33]. China's very large offshore wind resource is still under evaluation, but the MLTDP estimates this at around 700 GW [34]. The deployment levels suggested by the GEA scenarios are consistent with the economic resource available, provided the most economic parts of the offshore resource can be exploited.
The infrastructure requirements and systems integration challenges	- The bottleneck to the growth of wind has been, and continues to be, grid connectivity. The grid is typically not built until after the wind turbines have been installed, and the grid connectivity obligation is not usually enforced by punishment. This is being addressed, but may continue as a limit to growth in the near future.
Major policies, targets and supporting measures	- Wind was the first renewable resource targeted for strong financial incentives. The policy push for wind started earnestly in 2003 with financial incentives such as VAT reductions and duty exemption on imported components etc. In 2005 this was stepped up further with Wind Power Concession Program, based on Government auctions for >100MW projects, based on lowest offered price and other factors. This led to a huge expansion of wind base and increased competition, but also led to the development of low quality wind projects. - In line with the REL and the MLTDP, from 2009 China has had a more conventional effective feed-in tariff with four fixed prices (7.4-8.9 cents/kWh) for different regions across the whole country, and no bidding. This has maintained the boom in the sector, and it is hoped the project quality will be better controlled by this mechanism. - The current official target for installed wind capacity in 2020 is 100 GW, revised upwards from 30 GW as the target stood in 2007. There are plans for even further installation, with the 'mega-wind power base' project, which would take installed capacity to over 150 GW by 2020. - The issues with grid connection have been partly addressed by several amendments to the REL. However, the amendments have not yet been promulgated. In addition, they may not go far enough to allow the grid to keep up with the installed capacity.

Carbon capture and storage (CCS):

Installed capacity in IIASA abatement scenarios by 2050: Coal-fired power with CCS: 290 GW (Mix) and 23 GW (Efficiency). Gas-fired power with CCS: 120 GW (Mix) and 33 GW (Efficiency).

Current state of the technology and future development and commercialisation challenges	- China acknowledges that CCS could be an important abatement technology in the future and for this reason is increasing its activity and research in this area [35]. - It is, however, widely accepted that CCS is unlikely to achieve large-scale application in China before 2030. However, beyond this point it is likely that there would have to be rapid roll-out in order to significantly reduce CO2 emissions - China has strong experience of EOR technologies based on some projects in the 1990's: CO2 injection has been carried out in Daqing and I Subei (total of 0.7 MtCO2 has been injected) as well as injection of flue gas (12% CO2) in Liaohe. There is a joint program between the China National Petroleum Corporation and a number of Chinese Universities to research and optimise EOR technologies [35]. - Currently China has an Enhanced Coal Bed Methane micro pilot project. This is in Qinshui, Shanxi Province and demonstrates the feasibility of storing CO2 in high rank anthracite [35]. - The first CO2 capture demonstration plant was completed in July 2008 at the Beijing Thermal Power Plant (Huaneng Group). This demo plant has the capacity to capture 3000 t/yr [36]. - The GreenGen project was launched in China in 2000 and is focussed on a number of clean coal technologies including CCS, IGCC and hydrogen production from coal gasification. This project is largely owned by the Huaneng Group. Phase two of this project was due to end in 2010, including the construction of a 300 MW IGCC demo plant. However it appears that progress has been slower than expected [35]. - The individual capture, transport and storage technologies are mature however, there are few integrated large-scale applications of CCS worldwide.
Current/historic maximum deployment rates	- The China Coal Research Institute has put forward a roadmap for CCS in China. - The IEA CCS roadmap shows China having 3 power projects and 9 industry projects by 2020. This increases to over 300 projects each in power and industry by 2050 capturing a total of ~ 1900 Mt/yr (approx. 2/3rds from power and 1/3rd from industry).
Current costs and how they are likely to develop over time	- There are huge uncertainties in the cost of CCS since it has not been demonstrated on a large scale yet. The IEA estimates that - Pipeline transport: 1-3 $/tCO2; Storage: 15US$/tCO2 - It is expected that costs of CCS in China will be lower due to lower labour, material and fuel costs [37] - McKinsey estimates that a 12% learning rate for post combustion CCS is likely to be achievable (This is based on the historical learning rate for Flue gas desulphurisation and deNOx technologies).
R&D, IP and skills (scientific, engineering, monitoring, regulatory) requirements to support this degree	- To a certain extent a number of CCS companies see CCS as an export opportunity and are keen to develop expertise in this area. - The NDRC has identified that China lacks skills in the area of subsurface geological engineering, long term monitoring and long-distance transport infrastructure (see below on possibility for international knowledge transfer) - How intellectual property rights are managed will have a big impact on the prospect of joint collaboration projects on CCS. Since China views CCS as a possible export opportunity, it will be looking to develop its own IP and have access to the IPR from new

of technical rollout	projects. At the same time, international collaborators want reassurance that existing IPR is protected and to have access to new IPR arising from collaborative projects. Hence, an IPR framework needs to be developed which gives confidence to prospective international partners.
The resources required to support the technology to the level deployed, and feasibility of China obtaining/producing these resources	- The Asia-Pacific Economic co-operation Energy Working Group has researched the geological storage potential for CO2 in China. This study includes both an estimate of the storage capacity as well as the geographical location of these sites relative to point source emissions - The maximum theoretical storage capacity is generally agreed to be around 2000 Gt (even as high as 3000 Gt is offshore storage is included). Most of this is in deep saline aquifers. More work needs to be done in assessing the viable storage however. There is a high uncertainty, particularly in offshore values
The infrastructure requirements and system integration challenges	- It is estimated around 80% of China's large CO2 point sources are within 80km of a potential storage site [37]. - However, a large number of sources in China's industrialised South and Eastern coastal regions do not have sufficient onshore storage capacity and so offshore capacity will have to be investigated [37] .
Major policies, targets and supporting measures	- China's official view is that the international community should take the lead in demonstrating CCS technology. - The energy efficiency penalty is the major hurdle in the adoption of CCS technologies since this seriously impacts on China's fuel security
Potential role of international community	- The NDRC identifies 4 key areas in which the international community can speed up CCS in China: - 1) Knowledge transfer of specific areas of expertise where China is behind (subsurface geological engineering, long-term monitoring and verification and long-distance CO2 transport infrastructure). - 2) Joint R&D projects. There are a number of these already in existence and China already has a number of research institutions looking at CCS (Tsinghua University, Zhenjiang University, Chinese Academy of Science) - 3) To provide China with assistance in drawing up a regulatory system that ensures that CCS is safe and effective and provides the policy means to stimulate CCS technology - 4) Timely funding particularly in the area of large-scale integrated projects, research into offshore basins and improved research of onshore storage. - A strong signal from the international community that it is in support of CCS and committed to funding the roll out and development of this technology in developing countries is required

D.2. INDUSTRY

Total final energy use in industry in IIASA abatement scenarios by 2050: 45.7 EJ/yr (Mix) and 42.8 EJ/yr (Efficiency)

Current state of the technology and future development and commercialisation challenges	- The cement industry in China is made up of many small cement plants with an average company output of 200 kt (compared to the world average of 900 kt). The 10 largest companies account for only 18.75% of China's output. - China's iron and steel sector is characterised by a large number of small production sites (averaging 1045 kgce/t). The energy intensity of these sites remains high since it is uneconomical to apply advanced technologies to these smaller plants. This past decade has seen the development of a number of large advanced plants (averaging 705 kgce/t, similar to Japan which is 656 kgce/t), which has resulted in a decrease in the overall intensity of China's iron and steel sector [1]. - Aluminium production is highly energy intensive. Large electro baths (> 160 kA) now account for 86% of primary aluminium production in China. Although this is a significant advancement, there are still a number of areas where progress still has to be made: This electric current efficiency in China is 2-4% points lower than internationally. Also, the lifetime of the baths is around 1500-1800 days compared to 2000-3000 in the West [10]. - Ammonia production in China accounts for 35% of total energy consumed in the Chinese Chemicals industry. Currently, Ammonia is produced by coal gasification in China. This is highly energy intensive compared to ammonia production from gas or partial oxidation of fuel oil. The most widely used process in China is the UGI gasifier, which is economical to run but requires more energy compared to advance processes developed by international companies (Lurgi, Texco, Shell) [38]. - Ammonia with CCS: Ammonia production is highly suited to CCS. In China, already half of ammonia plants capture CO2 and reuse it for the production of urea [38].
Current/historic maximum deployment rates	- Through government orders, China has increased the share of New Suspension Pre-heated (NSP) Dry Process kilns from 13.7% in 2000 to 55% in 2007. This is still well below international levels, which can be as high as 98%. Despite this increase in advanced technology, a large share of inefficient vertical shaft kilns is still in operation and these and other out-dated methods account for the remainder of cement production in China. Additionally, some of the NSP kilns are small and have a lower efficiency compared to international levels. ([10], Tsinghua 2008) - The use of biomass and waste fuels as alternatives to fossil fuels in cement is practiced around the world. OECD nations have more than 20 years of experience, with the Netherlands and Switzerland leading the world in this area. The average substitution rates in these two countries are 83% and 48% respectively [39]. Biomass is often injected during secondary firing in the pre-heater. - Currently, the penetration of biomass/waste co-firing in Chinese cement kilns is low [39]. Chinese waste is not well classified or controlled which poses problems for co-firing and can cause technical difficulties. The Beijing cement plant has developed a kiln for disposal of urban industrial waste. (Tsinghua 2008). Less than 20 cement facilities currently burn alternative fuels [40]. - 20% substitution rate of agricultural biomass residues is feasible. Higher substitution rates require specially design boilers with the ability to control the kiln temperature and ensure flame stability [39]. - Coking: According to the CISA, the average energy intensity of coke making in China has been decreasing in recent years from 180 kgce/t in 1995 to 142 kgce/t in 2004. This is

	largely due to the installation of wet and dry quenching technologies: up to 25% of Chinese coke plants used CDQ in 2004. However, inefficient beehive coke ovens still exist in China today. It is estimated that these could account for up to 20% of coke production however this data is unreliable. Coke oven gas recovery is limited to onsite coke plants. In 2005, 1/3 of coke plants were located on integrated steel plants - 97% of coke oven gas was recovered on these plants. Of the remaining plants only 24% was usefully recovered [41]. - PCI: The average value of PCI in China in 2005 was 129 kg/thm. IISI recommends that the maximum PCI rate is 180 kg/thm [41]. - DRI plants are typically smaller scale plants and have the advantage of being easy to build and requiring relatively low capital investment. Currently, India and South Africa have the most advanced coal-DRI plants in the world. The Dunswart plant in South Africa represents industry best practise with an energy intensity of 15-19 GJ/t DRI. The Indian DRI reactors operate at an energy intensity of 20-25 GJ/t DRI [41]. - Currently around 0.4 Mt/yr of plastic waste is co-fired in Japan [41]. - In 2004, 66 BFs in China, making up half of the total production capacity, had TRT technology installed. Typically, TRT can produce between 15-40 kWh/t pig iron [41]. - Continuous casting in steel production has increased from 30% in 1992 to 95.8% in 2004 [1] - China's Energy Conservation Law aims for the energy efficiency of China's industry to reach current levels of advanced countries by 2030.
Current costs and how they are likely to develop over time	- Waste fuels can often be obtained for free or at a lower cost compared to fossil fuels. In some cases cement plants are even paid to accept waste fuels. Since energy accounts for 30-40% of the operating costs of a cement plant, these fuel savings are highly attractive [39]. - Wang et al 2007 has costs of various technologies for Iron and steel - The rapid rise of fuel and raw material costs and stringent policy control has resulted in many companies feeling unable to further invest in energy saving technologies [10]. - China relies on imported technologies for advanced ammonia production - these technologies are more expensive and so diffusion of these technologies is limited [38].
R&D, IP and skills (scientific, engineering, monitoring, regulatory) requirements to support this degree of technical rollout	- As for iron and steel, the existence of large, efficient plants in China indicates that China has the experience of running advanced technologies in China's cement industry. - A barrier to the adoption of large advanced BFs is the tendency to favour small mini-BFs to produce iron for use in EAFs. These smaller plants are better adjusted to local markets and require a lower capital investment but carry a heavy energy penalty [41]. - The existence of large, efficient plants in China indicates that China has the domestic experience of running these advanced technologies in China's iron and steel industry. - China does not own the IPR to most advanced iron and steel technologies and relies on imports from developed countries. It does not have the capacity for innovation, owing to lack of funding and human resources, according to Zeng et al. [42]. - China lacks sufficient monitoring and data collection capabilities. Databases are often inaccurate, out-dated and incomplete. There are no standardised methods of reporting in many sectors. Recently, China has made some attempts to rectify this - the Implementation Scheme of Statistical Index System/Monitoring System/Assessing system was published in 2007 [10], [42]. - Large-scale ammonia plants rely on imported technology from foreign companies such as Lurgi and Texco. Domestic capabilities lie only in small-medium scale units [38].
The resources required to support the technology to the level deployed,	- The quality of coal used in cement calcinations is on the decrease. This results in lower quality clinker and also increases the heat and energy consumption in the kiln. - The metal content of Chinese iron ore is low (around 33% compared to the world average of 55%) this increases the energy intensity of the blast furnace by 1-2 GJ/t. The high ash

and feasibility of China obtaining/producing these resources	content of coal in China increases the coke requirements in the blast furnace. Coke quality (mechanical strength of the coke) is a key factor since low quality coke reduces the potential for PCI. Typically Chinese coke from smaller ovens is of a lower quality [41]. - The main raw material for alumina is bauxite ore. Due to the properties of China's domestic bauxite, China cannot use the more efficient Bayer process and is limited to the sintering and joint processes. These processes have a much higher energy intensity (around 1200 kgce/t) compared to the Bayer process (375-446 kgce/t) [10].
Major policies, targets and supporting measures	- Cement Plant Energy Efficiency Design Specification was passed by the ministry of construction in China in Nov 2007. This states that cement plants built after 2005 and with a capacity of greater than 4000 t/day must reduce total energy use by 15% compared to plants built between 2001 and 2005 [39]. - Energy-saving grinding and waste heat co-generation technologies have been promoted. - It is now harder to enter into the cement market in China - the entrance conditions for new plants has been raised and loans will not be issued to plants that do not conform to industrial policies and development plants. Inefficient plants are being harder hit with increased electricity prices and the withdrawal of favourable tax policies [10]. - Current policies regarding biomass co-firing have limited the diffusion of this technology in China. Current policy states that credit will only be given to facilities that fire more than 80% biomass. This is problematic since such a high substitution rate requires a specially designed boiler [43]. - Recent government policy has been to close all BFs < 100m3 by 2007 and all < 300m3 by 2010. All steelmaking furnaces with outputs < 20t were to be closed by 2007 [41]. - The Steel Industry Development Policy was derived in 2005. This policy aimed to encourage restructuring by limiting the access of small firms to credit and land. - In the 11th 5-year plan China announced a closure timetable of inefficient production facilities across thirteen industries [10]. - China has set up a number of economic policies in order to limit the expansion of high energy and emissions intensive industries [10].

D.3. TRANSPORT

Total final energy use in transport in IIASA abatement scenarios by 2050: 18 EJ/yr (Mix) and 14 EJ/yr (Efficiency)

Electric vehicles

Current state of the technology and future development and commercialisation challenges	- China has a well-developed EV manufacturing capability, with BYD exporting to the USA market and a number of firms (Chery, BYD, Zotye) selling in China; - Commercialization challenges include improving range of vehicles, lowering costs of batteries, developing a charging infrastructure (including smart grids to integrate it with the electricity infrastructure), and achieving more efficient production processes [44].
Current/historic maximum deployment rates	- By the end of 2011, China is targeting production of 500,000 EVs (pure and hybrid) (New Energy Vehicle Focus Network, 2010); - Two-wheeler EV production has reached 22 million in a decade, indicating very high penetration rates are possible [44].
Current costs and how they are likely to develop over time	- Current battery cell costs are $500-800/kWh and these need to halve in order that electric vehicles (EVs) become cost-competitive with Internal Combustion Engine vehicles (this could happen by the 2020s) [45].
R&D, IP and skills (scientific, engineering, monitoring, regulatory) requirements to support this degree of technical rollout	- R&D effort is occurring in the EU, USA, Japan and China, and some 80% of core components of batteries in China come from overseas, so China by no means has the best technology [46]; - Most of the battery patents are foreign owned. For example the battery patent for Pyrolytic Carbon Deposit-LiFePO4 (carbon coating) cannot be bypassed as there is no current alternative. It is essential in the production of most commonly used Lithium Iron Phosphate batteries. This means Chinese firms must pay non-Chinese firms licensing fees for use of these patents in the manufacture of most electric vehicle batteries [47]. - China is putting substantial effort into developing electric vehicles (e.g. the “Ten Cities, Thousand Vehicles” demonstration project in 2009 [48]. The Chinese Academy of Sciences established the Advanced Electric Vehicle Research and Development Centre [49] in 2009. - In 2010, the “863” Key Technology and System Integration Project for Electric Vehicles (Phase I) was launched to provide total funding of RMB 738m (~ US$ 113m). Research organisations were invited to apply for funding for 3-year R&D projects in battery technology; electric, hybrid, fuel cell vehicle technology and system integration[1]. - Skills are also being scaled up through attracting PhD students studying overseas (especially UK and USA) to return to China. One good example is the Shenzhen Institute of Advanced Technology [50].
The resources required to support the technology to the level deployed, and the feasibility of	- China has ample supplies of several of the rare earth metals required in batteries and the mechanical components of electric vehicles. However, a potential constraint to the use of these is the significant environmental impact caused by their extraction, and China is now actively researching and implementing more efficient and less polluting rare earth extraction methods[2].

[1] www.most.gov.cn/tztg/201010/P020101028623871204363.pdf

[2] Formation cause, composition analysis and comprehensive utilization of rare earth solid wastes”; Tao et al.; Journal of Rare Earths, Vol. 27, No. 6, Dec. 2009, 1096-1102

China obtaining/producing these resources	- The "Rare Earth Industrial emission standards" is the first national standard issued by the Ministry of Environmental Protection during the 12th Five Year Plan period. It will be implemented from October 1, 2011. Those standards have regulated the water pollutants and air pollutants emission limits, monitoring and control requirements of the rare earth industry enterprises [51]. - Electric Vehicles are heavy users of lithium, for which China has a large share of both production and resources [(Humphries, 2010) However, iron ore has significant imports and prices are going up, exposing China to high costs [52], [53], [54].
The infrastructure requirements and systems integration challenges	- Whilst grid infrastructure constraints are a potential barrier, the Chinese government has made electric vehicles a strategic priority, and is investing $3bn over the next 3 years in this; - Electric Vehicles will increase electricity demand and will require access to a low-carbon electricity grid. This is likely to require a High Voltage Direct Current super grid to ensure wind, solar and hydro electricity generation from North/West reaches population centres in South/East; - Plug-in electric vehicles connected to Smart Grid can be used as energy storage to stabilise the grid. They can feed electricity back to the grid during demand peaks if intermittent electricity generation sources (e.g. solar and wind) are not available [45].
Major policies, targets and supporting measures	- The "Ten Cities, Thousand Vehicles" pilot scheme provides subsidies for pure and hybrid electric vehicle buyers in participating cities to encourage adoption [48]. - A number of cities are already planning charging infrastructure, although it is not clear how ambitious this is. - A number of cities have also announced trials of battery leasing and battery swapping schemes (New Energy Vehicle Focus Network, 2010); - In March 2011, the China State Grid Corporation announced a plan for the comprehensive construction of a smart grid network, to build 2300 charging stations and 220,000 charging posts during the period of 12th Five Year Plan; - Going forward the main policies will be in the 12th Five Year Plan, with intentions to deepen R&D, standardization, international cooperation, and test business models (e.g. battery leasing, vehicle leasing)[3, 4,5].
Potential role of international community	- Prescribing higher battery recycling rates (such as the 95% requirement in the EU) would help ease these environmental and energy resource impacts [55]; - China may benefit from lessons on improving material and resource efficiency, including designing in easier recyclability of vehicles [56]; - China could benefit from international collaboration on urban planning and design to ensure electric vehicles can be supported by charging infrastructure (The Climate Group, 2010 and 2011).

[3] "Wen Jiabao, Full Text of Government Task Report, Ta Kung Pao", www.takungpao.com.hk/news/11/03/05/2008lianghui03-1351376.htm

[4] "New Energy Vehicle Focus Network: Pilot Subsidies for Private Purchase of Electric Vehicles (Summary of Planning and Implementation Programme for Five Cities)": www.nevfocus.com/news/20100816/886.html

[5] "Quan-Shi Chen: New energy vehicle industry requires urgent standardisation", finance.sina.com.cn/hy/20100515/12317941988.shtml]

Biofuels

Current state of the technology	- Currently, 10 provinces have promoted the utilisation of Biofuel E10 supplied by 5 authorised corporations. In 2007, 2008 and 2009, bioethanol market supply reached 1.33, 1.62, and 1.73 million tonness respectively [57]. - China's fuel ethanol is mainly produced from corn and wheat, with a small amount from cassava. The Chinese government recently announced its intention to halt building corn-based ethanol plants and to develop non-food feedstocks mainly because of food security concerns [58]. - According to the NDRC, total Chinese biodiesel output in 2006 was 190,000 tons. The U.S. Department of Agriculture estimates that production was around 300,000 tons in 2007 (GSI, 2008). - Biodiesel in China is currently produced from used cooking oil (UCO) and the potential for future production from this is believed to be less than 2 million tonnes. Rapeseed and soybean are the two most commonly used feedstocks for biodiesel production worldwide. However, being a large net importer of edible oil and oilseeds, China may not be in a position to produce biodiesel from rapeseed and soybean [58].
Suitable feedstocks for future sustainable production	- Sweet sorghum and cassava are identified as promising feedstocks for bioethanol production because they can be grown on mountainous land or marginal cropland and hence would not compete with food production. Sugarcane could be another option since its production increased from 81 Mt in 1997 to 106 Mt in 2008, with half of the increase from productivity improvements and the other half from land expansion [58]. - At the moment, the suitable feedstock to produce biodiesel both in terms of quantity and cost is cottonseed oil, with 1 million tons of biodiesel resource potential. In the 11th FYP period, the major aim is to construct pilot plants and projects based on cottonseed oil and rapeseed oil grown on winter-idle land, two types feedstock suitable for current large-scale production (CAE, 2008).
Projects and efforts to commercialize the non-food based biofuels technology	- Jilin bioethanol Ltd. Invested in constructing a 3000 tonnes per year sweet sorghum based bioethanol pilot project and planted 333 - 400 thousand m^2 of sweet sorghum. COFCO (China Oil and Food Corporation)also started sweet-corn derived bioethanol research. In March 2007, COFCO, in collaboration with BP set up sweet sorghum pilotsd in Hebei, Shandong, and Inner Mongolia. Meanwhile, with the approval by NDRC, Henan TianGuan Group Ltd. built on its traditional potato-derived bioethanol have already to form a 200 thousand tonnes per year production capacity [57] . - According to the 11th Five-Year Plan of renewable energy, the barren land in northeast China and Shandong Province are designated to plant sweet sorghum to develop sorghum-based biofuel. The barren land in Guangxi Province, Chongqing Province, Sichuan Province and other places are designated to grow cassava and thus develop cassava-based biofuel [59]. - Trials of Jatropha cultivation have been underway in South-west China. The NDRC has designated South-west China as the official target area for Jatropha cultivation and envisions around 600,000 ha of Jatropha plantations in each of China's South-western provinces [60].
Official targets for the biofuels in the near to medium term	- In August 2007, the NDRC announced a Medium and Long Term Development Plan for Renewable Energy. Biofuels are expected to play an important role in the achievements of these targets. Bioethanol production is projected to reach 2 million tonnes by 2010 and 10 million tonnes by 2020 (NDRC, 2007). - For biodiesel, the target is 200,000 tons (225 million litres) by 2010 and 2 million tons (2.25 billion litres) by 2020 (NDRC, 2007).

Current status and policies to support second-generation biofuels development	- China will strengthen the cellulosic biofuel research and support cellulosic biofuel demonstration project. The plan targets that non-food-based fuel ethanol production will be 2 million tons in China by 2010 [59]. - Tianguan Group Co., Ltd. constructed a pilot cellulosic ethanol production line, with a capacity of 300 tons/year. The enterprise plans to invest another production line with a capacity of 1000 tons/year based on the experiences and lessons from the 300 tons/year production line [59]. - In 2006, COFCO, signed with Novozymes, a world's leading producer of enzymes, an agreement to construct a pilot project with production capacity 10,000 tons/year of cellulosic biofuels in Zhaodong County, northeast China's Heilongjiang Province. The small-scale testing with a capacity of 500 tons/year proved successessful in 2006 [59]. - Considering the constraint on vegetable oil resources, straw-based Fischer-Tropsch (FT) biodiesel is regarded as one of the important measures to solve the energy problem. The cost of biomass derived FT biodiesel is 50% higher than cellulosic bioethanol. - The Ministry of Finance provides direct support of second-generation cultivations with allowances amounting to US$438 per hectare for Jatropha plantations and US$394 per hectare for cassava cultivations [61].
Major obstacles for the development of biofuels	- Traditional non-food crops are not advantageous as bioethanol raw material due to their short harvesting period; difficulty to preserve/store; low-productivity as the plant is moved from tropical to subtropical regions (e.g. cassava); and difficulty to achieve a continuous supply [57]. - Marginal land for non-food crops is hard to develop: There is still a need for reliable statistics for the marginal land suitable for non-food crops, and what ecological influences will be if these non-food crops are planted in these places at large scale. Moreover, who should shoulder the cost of developing these marginal lands is a big problem. It requires a long timeframe and a sustained large amount of input (Feng, 2010). - Cellulosic bioethanol technology faces many challenges. The main challenges are: the pre-treatment for cellulose hydrolysis still needs improvement, especially in terms of energy and water consumption; the production for cellulosic enzyme is high cost and non-efficient; the ratio between energy input and output still needs improvement; cellulosic bioethanol products are high cost, not competitive with food-based bioethanol; Straws are low energy density, highly sparse, hard to collect and with high collection cost (Feng, 2010). - The major problem for biodiesel development is the high cost (3500 – 5000 Yuan/tonne – about $550-750/tonne) and scarcity of raw material. Another problem is the lack of corresponding standards and regulations. Finally, the technologies used by the few private enterprises are backward, while more advanced methods have so far only been used in pilot plant trials (CAE, 2008).
Coordination with international communities	- Research and development on second generation biofuels, especially the enzymes, to reduce the cost[6]. - Biofuels suitable to replace conventional jet fuels[7].

[6] **"COFCO, Sinopec and Novozymes to build cellulosic ethanol demonstration plant": http://www.energyglobal.com/sectors/unconventional-resources/articles/COFCO,_Sinopec_and_Novozymes_to_build_cellulosic_ethanol_demonstration_plant.aspx**

[7] "Boeing and Chinese Academy of Science to Expand Collaboration on Algae-Based Aviation Biofuels": http://www.greencarcongress.com/2010/05/boeing-cas-20100527.html

D.4. BUILDINGS

Total final energy use in buildings in IIASA abatement scenarios by 2050: 22 EJ/yr (Mix) and 18 EJ/yr (Efficiency)

Lighting and appliances

Current state of the technology and future development and commercialisation challenges	- Compact fluorescent lighting is a mature technology in common use in China, and contributes to lighting systems in Chinese residences which are already estimated to be more efficient than in many OECD countries [24]; - Solid state technologies (e.g. LEDs) close to the commercialisation stage [24]; - Global best available technology (BAT) standards for most major appliances are available in China, with a number of multinationals manufacturing in China to a common global technical standard (e.g. Siemens, as cited in Dan [62]); - In general, savings identified from appliances and lighting do not require major technical developments, but rather higher penetrations of the most efficient standards. However, global R&D effort will be required to go beyond current BATs [24]
Current/historic maximum deployment rates	- China's 11th Five Year Plan targeted 1 billion energy-efficient lamps to be installed in 2009, having achieved over 600 million installations in 2008 [63]. However, McKinsey [23] asserts that in a decade the penetration rate of CFLs has only reached 10%, due to their higher initial cost – subsidies or mandatory phase out of incandescent lamps, as has happened in a number of countries, could speed this penetration rate up dramatically; - The Chinese Home Electrical Appliances Association carried out a market survey in Beijing, Shijiazhuang, Qingdao, Chongqing and Baoding and found that energy-saving refrigerators accounted for 90% of the market, implying a theoretical ability to penetrate high efficiency appliance markets swiftly.
Current costs and how they are likely to develop over time	- New, efficient lighting systems are often the same as or lower than current systems [24] - Given the current high CO_2 intensity of electricity in China, abatement costs are already negative for a wide range of appliances [24]; - However, cost challenges remain: energy-saving refrigerators account for the majority of sales, but energy-saving air-conditioners (up to 30% more expensive than less efficient models) are far less common. Manufacturers cannot drop prices until production has increased, but a lack of consumer interest means that production remains stagnant [62].
R&D, IP and skills (scientific, engineering, monitoring, regulatory) requirements to support this degree of technical rollout	- Multinationals are targeting the high-end market in appliances, increasing their investment in personnel, technology, R&D and new products. Specific measures have included bringing in executives who know the Chinese market, establishing R&D centres in China and competing on technological strengths [62]; - Domestic firms target the mid- and lower-end market, in general lacking R&D ability relying on imports for advanced components [62] ; - A major challenge for increasing the penetration of high efficiency lighting and appliances is the ability to effectively monitor and enforce standards. The China Energy Label Centre had just six full-time staff in 2008, and lacked a regular budget for monitoring label compliance [63]
The resources required to support the technology to the level deployed, and the feasibility of China	- Unlikely to be specific material resource constraints. - Phosphors of rare earth metals are used in the manufacture of efficient fluorescent lighting and LEDs. However, advanced LED technology requires substantially reduced material per unit of output. China currently accounts for 80% of lighting phosphor production, and dominates the manufacture of efficient lighting [64].

obtaining/producing these resources	
The infrastructure requirements and systems integration challenges	- More efficient lighting and appliances does not present particular electricity grid systems challenges; - Smart technology applied to appliances could help level out peak/off-peak load demand variations, and help balance the grid which will have an increasing share of intermittent renewable (solar, wind) generation. - Electricity pricing mechanisms in China are complex and do not reflect market prices, and residential electricity enjoys generous subsidies (39% cheaper than the industry rate in 2007). This creates low consumer incentives for conserving energy or purchasing energy efficient electrical equipment, as well as high barriers for demand-side management. Recently more market-oriented mechanisms have been introduced at the local level (e.g. via peak-valley pricing systems), but real-time response to changes in supply and demand could prove difficult [65].
Major policies, targets and supporting measures	- China's 11th Five Year Plan promoted the use of high-efficiency lighting systems, through subsidised production of efficient lamps to be sold at a discount to consumers. This achieved an installation of 62 million efficient lamps in 2008, with a target of 100 million in 2009 [63]. - China has introduced labelling schemes and Minimum Energy Performance standards (MEPs) for a range of appliances [24]. The China Energy Label (launched in March 2005) covers a number of appliances and lighting products, with estimated emissions savings of about 50MtCO2 in 2010 [63]; - China's 12th Five Year Plan specifically identifies the promotion of energy saving technologies and equipment as part of its Energy Saving and Environment Protection industry – one of its seven emerging industries.
Potential role of international community	- There are a number of areas in enforcing standards for lighting and appliances based on international best practice: a clear mandate for the programme with stakeholder roles and responsibilities; a defined methodological approach to standards development; and sufficient funding and trained personnel for standards and label development, implementation, monitoring and compliance [63]

Building efficiency standards

Current state of the technology and future development and commercialisation challenges	- The thermal insulation performance of buildings in China still lacks the world's best, with the average energy consumption for heating in an efficient house in China (20W/m²) still almost twice as high as in the most efficient houses in Sweden, Denmark, the Netherlands and Finland (11W/m²) [66] - Heat loss through exterior walls in Chinese commercial buildings are 3-5 times higher than in Canada or Japan [67]; - A number of accessible and cost-effective technologies are available to improve building thermal efficiency, including advanced insulation materials and techniques; passive solar design, and double or triple glazing [66] - A number of super-insulation technologies are close to commercialisation, including a number of vacuum-filled panel designs [24].
Current/historic maximum deployment rates	- New urban-zone housing in China could reach 15-20 billion m^2 between 2005 and 2020, equivalent to the entire EU15 housing stock [66]. However, highly energy-efficient buildings have been constructed mostly for demonstration purposes [66].
Current costs and how they are likely to develop over time	- The most efficient building designs can be achieved at lower costs than current standards (Urge-Vorsatz, 2011), or at relatively modest additional cost (e.g. +5% in Li [66] +2-7% in IEA ETP [24]); - However, retrofitting and renovation to passive house standards could be very high (e.g. \$800/tCO_2) in Germany (McKinsey, 2007).
R&D, IP and skills (scientific, engineering, monitoring, regulatory) requirements to support this degree of technical rollout	- Realizing energy-saving measures in buildings requires an integrated design process involving architects, engineers, contractors and end-users [66]; - R&D is required to lower costs and improve the performance of current materials [24]; - There is a lack of knowledge and skills to manage the energy performance of buildings, and lack of enforcement of standards: even where mandatory energy-saving building standards exist; only a small proportion of new residential buildings (50% for colder northern areas, 11% for warmer southern areas, and 14% for transition areas) adhere to these standards [26].
The resources required to support the technology to the level deployed, and the feasibility of China obtaining/producin g these resources	- China's buildings sector is a huge user of cement, due to limited availability of timber, and the relatively short turnover of Chinese buildings (some 30 years compared to 70 years in the EU) The new building construction rate will mean continued demand for cement, but R&D into alternative materials as substitutes would be necessary in order to lower demand for cement and associated life cycle emissions of buildings [66] - China has more than adequate manufacturing capability in low emissivity glass for windows [66]
The infrastructure requirements and systems integration challenges	- Energy efficient housing is unlikely to place specific additional infrastructure demands on China's urban and rural areas – more efficient housing would help lower electricity consumption which could contribute to helping system balancing challenges in the electricity grid.
Major policies, targets and supporting measures	- In 2005, MOC (Ministry of Commerce) and AQSIQ (China's General Administration for Quality Supervision, Inspection and Quarantine) co-issued design standard GB 50189-2005 for energy-efficient design in public buildings (administrative buildings, hospitals, schools, shopping malls, offices etc,), whereby newly constructed public buildings should cut 50% of energy compared with those that do not comply with the norm. This standard regulates the values of energy consuming services in commercial buildings: lighting, heating, air-conditioning, ventilation [66]; - The Civil Building Energy Conservation Ordinance, released in 2008, introduced or amended a wide variety of regulation regarding energy efficient retrofits, the implementation of building

	standards (covering all new construction in urban areas), and requires retrofits in existing government buildings and large public buildings. - The 11th five year plan set a target of 2.93 EJ to be saved from buildings, through a combination of strengthening and enforcing of building standards (60% of savings), and retrofitting of existing buildings (16%) among other measures. However only 14% of the retrofit target was achieved by 2008 [63] . - Increase retrofitting of existing buildings for energy-saving, and actively promote the new building energy efficiency
Potential role of international community	- A great deal of institutional capacity building is required to ensure that energy efficiency standards are adhered to, and that there are incentives to exceed them. Currently, the compliance rate in building standards is very low (5-10%) [67]. - The complex institutional structure in China, often lacking in interagency collaboration, needs better coordination and could benefit from best practices in setting and monitoring building efficiency standards, including integrating sustainability into building design (e.g. as in the BEDZED project in the UK) [68]; - A number of incentive mechanisms used in the EU such as white certificates and supplier obligations which provide an incentive to energy suppliers to deliver energy efficiency measures to end-users [66] - There are opportunities for international collaboration on the Chinese built environment, including the sharing of knowledge on improving energy design in buildings [69].

Low carbon heating

Current state of the technology and future development and commercialisation challenges	- Urban residential building stock in cold climate parts of China was about 4 billion m^2 in 2004, and could grow to 9 billion m^2 by 2020. Much of this building stock could be fitted with high carbon coal-fired central heating [68]. A key challenge will be to avoid locking this stock into coal-fired heating. - Heat pump technologies are proven and mature, and are common in a number of countries, but operate with a range of efficiencies (Coefficients of Performance) - typically 2.5 to 3.5 (for air-to-air), and 3.5 to 5 for ground-source heat pumps [24]. - CHP technologies are already widely deployed in northern China, with 90% of the total floor area of some northern cities supplied by District Heating in 2004 [67] ; - Solar heating technologies are mature and reliable, with full life costs often below incumbent technologies, but in general with higher capital costs.
Current/historic maximum deployment rates	- - The global market for solar thermal grew by 35% globally (20% average from 2000), adding $29GW_{th}$ to the energy mix. China's capacity grew by 35% [70]. - The total number of heat pumps in Europe has doubled in four years, with Germany experiencing the largest growth. Air source heat pumps are faring particularly well in the EU, experiencing a 58% compound annual growth in 2008 [71]. - In 2008, China had the world's highest installed capacity with about 88GW [24].
Current costs and how they are likely to develop over time	- CHP costs vary greatly depending on the scale and technology: the most expensive are fuel cell small scale systems, with installed costs in the range $8000-28000/kW in 2006, estimated to fall to $3000-7000/kW by 2050. At the cheaper end, reciprocating engines at a large scale have installed costs of $1000-16000/kW in 2006, falling to $800-1100/kW by 2050 [24]; - During the last decade, capital cost reductions of about 20% have occurred for each doubling of installed capacity of solar water heaters;
R&D, IP and skills (scientific, engineering, monitoring, regulatory) requirements to support this degree of technical rollout	- R&D is required to improve efficiencies, and to better integrate heat pumps with other technologies (solar thermal, storage, and other energy sources) [24]; - CHP technologies will need to increasingly rely on low carbon fuel sources – but a significant degree of development is required to develop fuel cell CHP technologies to a commercial deployment cost level [24]; - Solar panels for solar thermal technologies are already highly efficient, but further R&D could benefit and drive costs down in a number of areas, including the development of new flat-plate collectors that can be more easily integrated into building facades and roofs [24]; - There will be a need for appropriately skilled architects and engineers to ensure all low-carbon heating technologies are sufficiently well integrated into new building designs and construction.
The resources required to support the technology to the level deployed, and the feasibility of China obtaining/producing these resources	- Physical resources do not appear to constrain the potential of low carbon heating technologies.

The infrastructure requirements and systems integration challenges	- The central government has only encouraged the development of large-scale CHP, which can be contracted to supply power to the electricity grid in significant quantities. This has disadvantaged small-scale systems [66]; - In general the implementation of low-carbon CHP will require significant planning to ensure integration of the heating and electricity networks. - In addition, the large-scale electrification of heat with high efficiency heat pumps and the high growth in cooling demand (with most of the growth occurring in densely urbanised transition and south regions), will require significant development of electricity network infrastructure, demand-side management and 'smart' grid solutions to manage peak demand. - A major challenge for low carbon heating in China concerns pricing and billing infrastructure; heating consumption is billed on the basis of floor area instead of actual consumption, so consumers have no incentive to conserve energy, and there is no economic incentive for housing developers to build more efficient houses than the building codes [66]
Major policies, targets and supporting measures	- China's 11th Five Year Plan had a specific target for savings from its "Ten Key Projects" initiative, one of which is for increased penetration of urban district heating from 27% in 2002 to 40%, and 40GW of new CHP units [63]; - In 2006, the Ministry of Finance and Ministry of Commerce released funding to support (through subsidies) a range of renewable technologies in buildings including solar water heating and ground source heat pumps [63].

Annex E: Abatement cost estimates

The following cost estimates are taken from a variety of sources, and do not reflect original work by Imperial College. The overall cost range is based on an overall judgement of whether these costs are Low (broadly in the range Low= \$0-50/tCO_2, Medium =\$50-100/tCO_2, or High>\$100/tCO_2).

Table E.1: Industry abatement costs

Abatement option	**Abatement cost / \$/tCO2 Region and year of applicability are given under the source**						
	Wetzelaer et al., 2007 China 2010	*McKinsey, 2009* China 2030	*LBNL, 2009* "Economies in Transition" 2009	*Grantham Institute, 2011* Global 2010	*Wang et al., 2007* China 2007	*CDM database* China 2010	*Imperial judgement China* *2010-2050*
Adoption of Best available technology (BAT) and energy efficiency	-13 to +5	0 to 65	< 20 (paper, ethylene, ammonia, some refining, some other) <50 (steel, cement, other refining, some other) <100 (aluminium)		-50 to 0 (approx. first third of emissions) 0 to +60 (rest)		Negative to Low
Fuel and feedstock switching		~ 0 (cement: clinker and waste co-firing, landfill gas) +95 (ammonia coal to gas)		0 to +200 (iron/steel)		+35 (Zhejiang clinker subn.) +11(Shanxi clinker subn.) +5 (Mongolia clinker subn.)	Low to High
Recycling and energy recovery		-110 to -40 (steel)				-36 (Jidong cement WHR) -29 (Changjiang cement WHR)	Negative
CCS		+65 to +90		+25 to +170 (iron/steel, cement and refineries) +4 to +47 (other)			High

Notes: 'CDM Database abatement costs were estimated from the CDM project design documents available at the UNFCCC website**http://cdm.unfccc.int/Projects/projsearch.html**

Table E.2: Transport abatement costs

Abatement option	Abatement cost / $/tCO2 Region and year of applicability are given under the source			
	McKinsey, 2009 China 2030	*AEA, 2009* EU To 2050	*McKinsey, 2009* Global 2030	*Imperial judgement* *China* *2010-2050*
Road - Electric vehicles	> 65 (hybrids) > 1200 (pure electric)		19 (plug-in hybrid) -43 (full hybrid) 135 (pure electric)	High
Road - Biofuels	+13 (bioethanol second gen)		-4 (1st generation) 9 (2nd generation)	High uncertainties
Air-Efficiency		Moderate payback periods	19 (total for air)	Low to medium
Air - Biofuels				High uncertainties
Rail - Efficiency		Moderate payback periods		Low to medium
Rail - electrification		Expensive		High
Water- Efficiency			-10 (total for water)	Low to medium
Water-Biofuels		Short payback periods		High uncertainties

Table E.3: Buildings abatement costs

Abatement option	Abatement cost / $/tCO2 Region and year of applicability are given under the source				
	Wetzelaer et al., 2007 China 2010	*McKinsey, 2009* China 2030	*CDM database* China 2010	*IEA, 2010* Global 2050	*Imperial judgement* *China* *2010-2050*
CHP/District Heating		-25 to +13		-800 to 800	Low
Heat pumps		-70		-100 to -200	Negative to Low
Lighting	-9	-165 (not retrofit) +100 (retrofitted controls)	-55 (Qiangling CFL distribution)	Largely negative	Negative to Low
Building standards	-4 (DSM) -27 (Motor efficiency)	-100 to 0 (retrofits, passive design and building codes, except those below) 0 to 50 (commercial retrofit and passive design in south)		-500 to +1000	Negative to Medium
Appliance standards		-160 to -135		Largely negative	Negative
Cooking					High (based on discussions with Imperial buildings academics)

Notes: 'CDM Database abatement costs were estimated from the CDM project design documents available at the UNFCCC website**http://cdm.unfccc.int/Projects/projsearch.html**

Annex F: Additional analysis for cross-cutting issues

Table F.1 Oil exporting regions/countries to China in 2009 (Source: BP Statistical Yearbook 2010)

Country of export	**2009 crude oil imports (mb/day)**
Middle East	2.08
West Africa	0.84
Other Asia Pacific	0.57
Former Soviet Union	0.54
S. & Cent. America	0.36
East & Southern Africa	0.24
North Africa	0.18
Singapore	0.14
Japan	0.08
US	0.06
Australasia	0.03
Europe	0.01
Total Chinese imports	*5.13*

China is currently most dependent on the Middle East for its oil imports – that region makes up 40% of China's total oil imports.

Table F.2: Summary of Coal reserves, production, imports and usage

Scenarios for Coal (Gt/yr except where noted)[8]		2005	2010	2020	2030	2040	2050
Historic	*Proved reserves (Gt)*	*1020*					
	Proved recoverable reserves (Gt) [9]	*189*					
	Cumulative usage (Gt)	*36.9*	*47.8*				
	Coal production	*2.21*	*3.05*				
	Imports		*0.17*				
	Exports		*0.03*				
Baseline	Coal demand	2.23	2.90	3.81	4.48	5.32	6.58
	Coal imports	-0.11	-0.11	-0.09	-0.16	-0.19	-0.23
	Coal production	2.35	3.01	3.90	4.64	5.51	6.81
	Coal proved recoverable reserves (Gt)	189	177	147	108	62	7
Mix	Coal demand	2.23	2.90	2.79	2.21	1.73	1.64
	Coal imports	-0.11	-0.11	-0.08	-0.09	-0.11	-0.13
	Coal production	2.35	3.01	2.87	2.30	1.84	1.77
	Coal proved recoverable reserves (Gt)	189	177	147	118	96	77
Efficiency	Coal demand	2.23	2.82	2.56	2.46	2.13	1.47
	Coal imports	-0.11	-0.11	-0.08	-0.08	0.00	0.00
	Coal production	2.35	2.93	2.64	2.54	2.13	1.47
	Coal proved recoverable reserves (Gt)	189	177	148	122	96	75

Even considering the relatively conservative estimates of China's proved coal reserves, it has a sufficient supply to service its demand in all three IIASA scenarios to 2050 at least. But in the Baseline scenario there will be pressure to mine deeper as these reserves start to be exhausted soon after 2050.

[8] IEA 2009 Cleaner coal in China, BP 2010 Statistical
[9] Note that this figure is based upon a 57% rate of recovery from coal mines, which may be optimistic according to some (WEC 2010 Surrey of energy resources). This figure is likely to increase in the future though.

Table F.3: Summary of Oil reserves, production, imports and usage

Scenarios for Oil (mb/day except where noted) [10]		2005	2010	2020	2030	2040	2050
Historic	*Proved reserves (mb)*	*133,000*					
	Proved recoverable reserves (mb)	*16,900*					
	Cumulative usage (mb)	*36900*	*47200*				
	Production	*3.63*	*3.79*				
	Imports [11]		*5.13*				
	Exports [12]		*0.71*				
Baseline	Oil demand	6.6	8.3	12	13.7	17	16.1
	Oil imports	2.7	2.6	3.7	5.7	6.3	5.8
	Oil production	3.9	5.7	8.3	8	10.7	10.3
	Oil proved recoverable reserves (mb)	16900	9783	-11023	-41318	-70518	-109573
Mix	Oil demand	6.6	8.3	12.2	13.3	13.1	7.3
	Oil imports	2.7	2.6	4.8	9.3	8.4	4.6
	Oil production	3.9	5.7	7.3	4	4.7	2.7
	Oil proved recoverable reserves (mb)	16900	9783	-11023	-37668	-52268	-69423
Efficiency	Oil demand	6.6	8.3	9.7	11.1	12.3	9.4
	Oil imports	2.7	2.6	2.4	4.4	4.2	4.3
	Oil production	3.9	5.7	7.3	6.7	8.1	5.1
	Oil proved recoverable reserves (mb)	16900	9783	-11023	-37668	-62123	-91688

IIASA's projections of oil imports are somewhat counter intuitive, as the Mix scenario has generally lower oil demand that the Baseline, but greater imports during the period 2020 to 2040. This is a result of simulated investment decisions in oil production technology – when faced with a lower forward demand for oil, domestic production (which would require long-lived, lumpy fixed assets) reduces. For Imperial's analysis in Section 8: Cross cutting issues of the main report, we have focused on Tsinghua university's views that production is likely to remain at 180-200 million tonnes per year (about 4 million b/d) for the foreseeable future, regardless of demand.

[10] LNBL China Energy Databook 2008 v 7.0, BP 2010. Note: Using lower heating value of oil for conversion calculations.
[11] Note that this includes 80% crude imports and 20% oil product exports.
[12] Note that this includes 13% crude imports and 87% oil product exports.

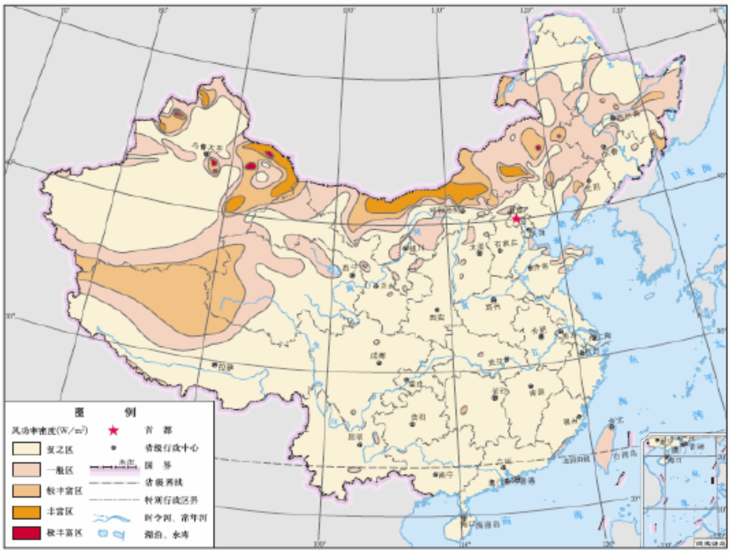
Table F.4: Summary of Gas reserves, production, imports and usage

Scenarios for Gas (bcm/yr except where noted) [13]		2005	2010	2020	2030	2040	2050
Historic	*Proved reserves (bcm)*	*4960*					
	Proved recoverable reserves (bcm) [14]	*2460*					
	Cumulative usage (bcm)	*605*	*901*				
	Production	*50.7*	*85.2*				
	Imports		*7.63*				
	Exports						
Baseline	Gas demand	61.9	97.9	98.5	133	252	385
	Gas imports	0	23.8	10.3	18.9	36.8	49.1
	Gas production	61.9	74.1	88.2	114	215	336
	Gas proved recoverable reserves	2460	2150	1410	527	-616	-2764
Mix	Gas demand	61.9	97.9	117	213	507	747
	Gas imports	0.0	23.8	12.0	30.3	89.5	109
	Gas production	61.9	74.1	105	182	417	638
	Gas proved recoverable reserves	2460	2150	1410	357	-1466	-5637
Efficiency	Gas demand	61.9	97.5	99.0	133	236	456
	Gas imports	0	20.8	12.3	30.9	67.5	140
	Gas production	61.9	76.7	86.8	102	168	317
	Gas proved recoverable reserves	2460	2150	1384	516	-506	-2188

Gas projections in IIASA's model suggest that new sources will be found, as in all three IIASA scenarios, cumulative usage will have exceeded current estimates of proved recoverable reserves by the 2030s. The IIASA Mix scenario increases gas demand significantly over the Baseline scenario, as a result of increased usage in the electricity generation, industry and buildings sectors.

[13] IEA 2007 WEO, BP 2010 Statistical. Note: An 80% derating factor has been applied to the CPA region for gas usage to account for China's proportion of gas usage in the region.
[14] This figure is likely to increase in the future if unconventional gas deposits are mined.

Figure F.1: Estimated wind resources (Source: China Meteorological Administration- *Results of the National Wind Resources Survey*, China Meteorological Administration, 5 January 2010, *www.cma.gov.cn/mtjj/201001/t20100105_55807.html*.**)**



Height above ground	Wind Class IV ≤50 W/m^2	Wind Class III 50 W/m^2- 150 W/m^2	Wind Class II 150 W/m^2 – 200 W/m^2
50 m	1 130 GW	2 380 GW	3 940 GW
70 m	1 510 GW	2 850 GW	4 790 GW
110 m	2 310 GW	3 800 GW	5 730 GW

China has concentrations of wind resource along its Eastern coast and Northern regions. Highest available wind resources in W/m^2 are shown in orange/red.

Figure F.2: The extent of China's regional power grids (IEA 2011 Integration of renewable and originally from Wang, Z. (2009), *Market potential and technology transfer,* NDRC Energy Research Institute, 9 November 2009.)

China has a number of regional electricity generation grids, increasingly interconnected. It is notable that Xinjiang province, with large coal reserves, is not currently connected to the densely populated Southern and South-Eastern areas of energy and electricity demand.

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