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Comparative Analysis of Modeling Studies on China's Future Energy and Emissions Outlook

Nina Zheng, Nan Zhou and David Fridley
China Energy Group
Energy Analysis Department
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory

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Disclaimer

Executive Summary

The past decade has seen the development of various scenarios describing long-term patterns of future Greenhouse Gas (GHG) emissions, with each new approach adding insights to our understanding of the changing dynamics of energy consumption and aggregate future energy trends. With the recent growing focus on China's energy use and emission mitigation potential, a range of Chinese outlook models have been developed across different institutions including in China's Energy Research Institute's *2050 China Energy and CO2 Emissions Report*, McKinsey & Co's *China's Green Revolution* report, the UK Sussex Energy Group and Tyndall Centre's *China's Energy Transition* report, and the China-specific section of the IEA *World Energy Outlook 2009*. At the same time, the China Energy Group at Lawrence Berkeley National Laboratory (LBNL) has developed a bottom-up, end-use energy model for China with scenario analysis of energy and emission pathways out to 2050.

A robust and credible energy and emission model will play a key role in informing policymakers by assessing efficiency policy impacts and understanding the dynamics of future energy consumption and energy saving and emission reduction potential. This is especially true for developing countries such as China, where uncertainties are greater while the economy continues to undergo rapid growth and industrialization. A slightly different assumption or storyline could result in significant discrepancies among different model results. Therefore, it is necessary to understand the key models in terms of their scope, methodologies, key driver assumptions and the associated findings.

A comparative analysis of LBNL's energy end-use model scenarios with the five above studies was thus conducted to examine similarities and divergences in methodologies, scenario storylines, macroeconomic drivers and assumptions as well as aggregate energy and emission scenario results. Besides directly tracing different energy and CO_2 savings potential back to the underlying strategies and combination of efficiency and abatement policy instruments represented by each scenario, this analysis also had other important but often overlooked findings.

The key findings drew from the comparative studies could be summarized as follows:

Methodology and Scenarios

Although the modeling studies reviewed all present detailed energy and carbon outlooks for China to 2030 or later, they differ in their modeling methodology and scenarios analyzed.

ERI and Tyndall are the only two studies that incorporated a top-down modeling approach while LBNL, McKinsey and IEA all employed bottom-up modeling and analysis approach with physical drivers to different extents. LBNL's model based its assumptions mostly on physical drivers for energy activities for the end use and technologies instead of economic drivers such as price, and GDP growth rate. The IEA model had sectoral breakdown, but not at a disaggregated end-use level as those in LBNL, ERI and McKinsey's studies.

In terms of major scenarios generated by the models, all studies except the Tyndall report had at least one baseline or reference scenario and an alternative mitigation scenario. The Tyndall scenarios differ most significantly in that there is no baseline or reference scenario but rather four scenarios to assess two methods of allocating China's cumulative CO2 emissions given the global cumulative emissions limit of 490 GtC by 2100 needed to stabilize CO_2 concentration at 450 ppm and different storylines on changes in the economy, technology, governance and society.

The McKinsey and LBNL studies are similar in the underlying storylines for its baseline and alternative scenarios in that the baseline scenario is not a business-as-usual scenario but rather represents continued development with a focus on energy efficiency and carbon abatement. LBNL's Continued Improvement scenario (CIS) reflects this by assuming the current and planned portfolio of efficiency and abatement programs and policies and technology deployment continue and that sizable efficiency improvements occur across all sectors. In contrast, both ERI and IEA had reference scenarios that followed "business-as-usual" pathways of development with no new initiatives, policies or technologies beyond what is already currently in place.

The alternative scenarios also vary in the extent to which carbon capture and sequestration (CCS) technology is adopted as a mitigation measure, ranging from no utilization before 2050 under LBNL's Accelerated Improvement scenario (AIS) and ERI's Low Carbon scenario to ranges of 5% to 30% power capacity by 2030 and a high of 90% power capacity by 2050.

Aggregate Energy and CO_2 Emissions Outlook

Despite differing assumptions and modeling methodologies, there was general clustering in total energy consumption of different sets of scenarios in the five studies reviewed, with the only exception being the Tyndall study, where all scenarios had significantly lower total primary energy use because of the specified 2050 carbon budget.

The notable difference between LBNL's scenarios and others is the shape of the curves. LBNL's projected energy consumption increases at approximately the same rate as other models except Tyndall through 2030, but diverge after 2030 with a slow down or plateau whereas others still exhibit extrapolation of growth all the way out to 2050. This also results in the lower projected primary energy consumption in 2050 under LBNL's scenarios.

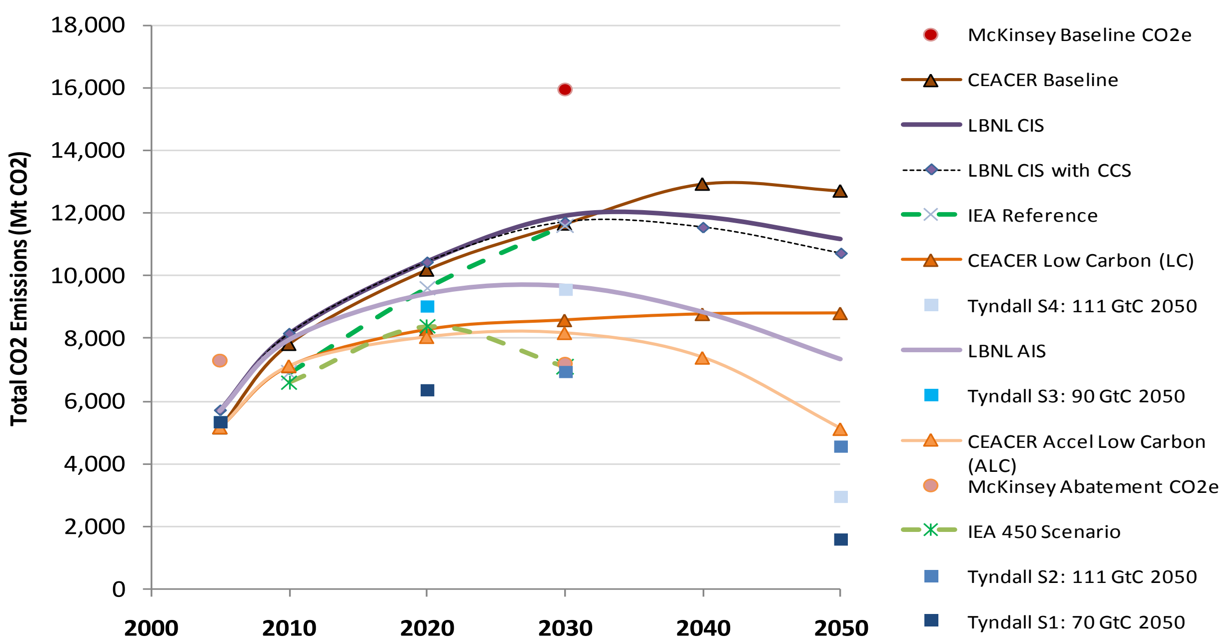
The difference is mostly because CIS was modeled from a highly disaggregated end-use level for the major sectors using physical drivers, and assumes a number of saturation effects will take place for drivers including the slowdown of urbanization, low population growth, change in exports to high value added products, and saturation of most appliances, floor area per resident and per employee, and infrastructure construction.

Another difference observed is the impact of the use of CCS. Most of the alternative scenarios examined have relied on the CCS application to bring down emissions. However, the LBNL CIS with CCS scenario demonstrates that all else equal, there would be a net increase in primary energy demand on the order of 36 million tonnes of coal equivalent (Mtce) more by 2050 due to CCS energy requirements for pumping, separation and sequestration.

For the alternative pathway, primary energy use results under AIS were also within the range of IEA 450 and ERI's Low Carbon and Accelerated Low Carbon scenarios. Despite the very aggressive (e.g., current world best practice by 2020s) efficiency improvements and technology deployments assumed under LBNL AIS, its total energy demand is still slightly higher than the ERI and IEA low carbon scenarios. Moreover, Tyndall scenarios 1, 3 and 4 stand out as the only scenarios with total primary energy demand peaking before 2050 as a result of the total carbon budget limits.

In terms of total CO_2 emissions, there is a much greater range in scenario results amongst the five different studies (Figure ES-1). Comparisons with the Tyndall scenarios are difficult due to its divergent back casting approach and lack of specific data points for a representative time series. Similarly, comparisons with the McKinsey baseline scenario is also difficult because of their inclusion of other greenhouse gases expressed in CO_2-equivalent terms. Their study projected total greenhouse gas emissions at 16 billion tonnes of CO_2e by 2030, compared to the clustering around 11.7 billion tonnes of CO_2 in the f LBNL, ERI and IEA baseline scenarios in 2030. If assuming that non-CO_2 greenhouse gases continue to account for approximately 30% of China's total greenhouse gas emissions, a rough estimate of McKinsey's baseline CO_2 emissions (excluding non-CO_2 GHG) at 11.1 billion tonnes puts it much closer to the other baseline scenarios.

Figure ES-1. Comparison of Total CO_2 Emissions in Different Scenarios



Because LBNL AIS scenario does not assume CCS deployment prior to 2050, while other studies relied heavily on CCS for carbon reduction, AIS still had the highest total carbon emissions at 9680 million tonnes of CO_2 in 2030 compared to ~8000 million tonnes under the two ERI's abatement scenarios and 7100 million tonnes under IEA 450 despite aggressive decarbonization. At the same time, LBNL's CIS with CCS scenario indicates that adding sufficient CCS technology to capture 500 Mt CO_2 by 2050 will have a net reduction of 476 Mt CO_2 in 2050.

While its baseline emissions were much higher in CO_2 equivalent terms, McKinsey's abatement scenario actually had one of the lowest total emissions by 2030 with comparable emissions to IEA 450 in CO_2 equivalent terms. If approximately 30% of the non-CO_2 greenhouse gases are excluded, McKinsey's abatement scenario would have the lowest total emissions at only 5 billion tonnes of CO_2 emissions. This suggests that the McKinsey abatement scenario relies heavily on CCS and other non-traditional mitigation technologies to achieve its sizable abatement potential. Likewise, three out of four of the Tyndall scenarios are outliers in having significantly lower total CO_2 emissions in 2050.

By 2050, however, the comparison between LBNL AIS scenario with other models demonstrates that efficiency improvements alone (e.g., current world best practice by 2020s) could achieve sizable emission reductions that would be much bigger than adopting CCS.

Of all the carbon outlooks in the scenarios examined, most forecast China's CO_2 emissions peaking in the 2030s. The key exceptions include the ERI low carbon scenario, which does not observe a CO_2 emissions peak before 2050, and Tyndall scenario 1 and 3, which observe much earlier emissions peak in 2020.

Macroeconomic Drivers

Although the methodologies and scenarios differ, most of the reviewed studies used generally accepted macroeconomic drivers and projections for China. However, some variations could be observed in the assumptions of GDP growth rate. LBNL assumed comparable but slightly lower GDP annual average growth rates (AAGR) after 2010 than CEACER and McKinsey. The Tyndall study, however, used a much lower GDP AAGR of 4.3% from 2015 to 2030 while the WEO 2009 AAGR of 6.1% from 2006 to 2030 is also on the low side compared to CEACER and McKinsey. Although the differences do not appear large, the compounded effect of annual economic growth actually result in more substantial divergences in economic activity related directly to GDP, such as industrial production and car ownership rates.

Industrial Sector

LBNL's assumptions on industrial production output differ from most of the other economic driver-based models. For instance, ERI's industrial output projections are based largely on IPAC-CGE, a top-down computable general equilibrium model, whereas LBNL's industrial output projections are based on physical activity drivers from a bottom-up model. As a result, the growth trends and magnitude of major industrial output of iron and steel, cement, and aluminum are significantly different from 2030 to 2050 between the two studies. LBNL assumes these industrial outputs are close to plateau in 2010 as the construction of building and infrastructure begin to slow down with per capita floor area and length of roads and railways nearing saturation over the course of the following decade.

Energy intensities of key industrial output between ERI and LBNL results from different level of efficiency improvement potential as well as differences in technology outlook. In the case of Iron and Steel making process, LBNL assumes more improvement in energy intensities by applying current international best practice levels for both BOF (Basic Oxygen Furnace) and EAF (Electric Arc Furnace) process. In terms of the technology shift, in general, McKinsey has higher estimate of abatement technologies such as EAF, and other emerging technologies as well as the potential emission reduction. The baseline scenario in McKinsey's model assumed 40% of the EAF penetration in 2030, whereas it is only 26% in 2030 and 40% in 2050 even in LBNL's alternative scenario (AIS), in which the constraints in the availability of scrap steel in China was considered.

Besides different underlying drivers for production output and technology trends, total energy consumption and carbon emissions also differ amongst the five studies as a result of the scope of subsectors considered and CO_2 abatement measures. McKinsey and ERI both had higher abatement potential for the industrial sector can be traced back to expectations of much greater roles for CCS, by-product and waste recovery measures and other emerging technologies in the industrial sector. McKinsey counts on carbon capture and sequestration in the cement, steel and chemical industries for a total abatement potential of 210 Mt CO_2. For the cement sector, it implies as much as four times higher abatement potential than that of LBNL's study.

Transport Sector

CIS and AIS scenarios have lower implied car ownership as well as total fleet of Light Duty Vehicles than other studies, mostly attributable to the slower GDP growth assumption used to derive income per capita which was in turn used as a function to project total car stock in LBNL's study. In contrast, McKinsey had the highest car ownership rate in 2030, at 91.1% of households, compared with 33.8% in CIS and 68.6% in AIS respectively under LBNL's assumptions, and 54.1% and 64.8% respectively under ERI's baseline and Low Carbon and Accelerated Low Carbon scenarios.

In terms of fuel economy, both LBNL and McKinsey studies assumed similar fuel economy levels for gasoline and diesel cars.

McKinsey abatement scenario had much higher reduction potential from switching to electric vehicles and efficiency improvements than LBNL's study. The assumed penetration of EVs reaches 91% market share by 2030 as opposed to 25% share under LBNL's AIS. Another difference in reduction potential is largely a result of the different baseline assumptions, for which McKinsey had much higher gasoline demand of 250 Mtoe in 2030 in the baseline, compared with 164 Mtoe in LBNL's baseline scenarios (CIS).

In terms of transport energy demand by mode, LBNL's model agrees with Tyndall model on 2050 shares for water and air transport, but Tyndall has much higher shares of transport energy consumption from railways in the range of 15% to 23% than either CIS or AIS at 5% and 6%, respectively. In addition, road transport in all four Tyndall scenarios has much smaller shares of transport energy demand than CIS and AIS.

Power Sector

A major difference in the power sector scenario analysis between the different studies is regarding CCS diffusion and utilization. The CIS with CCS scenario in LBNL's study is consistent and aligned with the IEA

450 scenario to 2030, with CCS expected to be installed and utilized for 4% of coal-fired capacity by 2030 and 7% by 2050. The CIS with CCS scenario further extends the IEA CCS deployment trend line out to 2050 by assuming sufficient CCS capacity to sequester 500 Mt CO_2 in 2050. Similarly, the ERI scenarios also do not expect CCS to play a major role in the power sector as CCS will only be installed to IGCC plants after 2030 under the most aggressive accelerated low carbon scenario and after 2050 for the low carbon scenario. In contrast, the McKinsey abatement scenario assumes a much higher CCS utilization rate of 25% of coal-fired capacity by 2030. The Tyndall study also assumes high CCS utilization rates after 2020 in most of their scenarios, including a high of 30% of coal-fired capacity in 2030 in S3. The Tyndall study further differentiates the pace of CCS deployment after 2030 depending on the policy basis for a given scenario's carbon budget, with a low of 33% of capacity by 2050 in S2 to a high of 80-90% in S3 and S4 by 2050.

As a result of different CCS assumptions, the carbon mitigation impact of CCS varies between IEA, LBNL and McKinsey. While the McKinsey abatement assumption with higher CCS deployment results in a much higher abatement potential of 1.4 Gt CO_2 emissions in 2030, both IEA 450 and CIS with CCS scenario assumptions abatement potential of only 230 Mt CO_2 emissions in 2030.

The assumptions on total power generation capacity, fuel mix and output of scenarios are to some extent similar among the models. The relative fuel shares of installed generation capacity under the two LBNL scenarios are particularly similar to the ERI baseline and low carbon scenarios, with the exception of natural gas and wind generation capacity shares.

Moreover, despite having similar installed capacity fuel mix assumptions as other studies, LBNL's two scenarios have different composition of power fuel mix than other studies with generally lower hydropower generation and much higher nuclear generation under AIS in 2050. Compared to ERI's baseline scenario, CIS also has smaller coal generation while AIS has the lowest coal generation of all scenarios, suggesting more accelerated power sector decarbonization than other scenarios with power dispatch prioritizing renewable and non-fossil fuel in the LBNL model.

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1. Introduction

The past decade has seen the development of various scenarios describing long-term patterns of future Greenhouse Gas (GHG) emissions. Each new approach provides additional insights to our understanding of aggregate future energy trends. With the recent growing focus on China's energy use and emission mitigation potential, a range of models of China's energy and emissions outlook have been developed across different institutions. In addition to scientific publications on China energy and emission modeling results, several influential reports have emerged in the international arena. One of these reports is the International Energy Agency (IEA)'s World Energy Outlook (WEO) 2009, which set out an aggressive "450 Scenario" under which the long-term concentration of greenhouse gases would be limited to 450 parts per million (ppm) of CO_2 equivalent by 2030 with China-specific policy assumptions and outlook. China's Energy Research Institute (ERI) also published a 2050 China Energy and CO_2 Emissions Report in 2009 which described potential energy and emissions scenarios to 2050 based on its own models. In addition, McKinsey & Company published a report examining frozen, baseline and abatement emission scenarios for China out to 2030. Lastly, the UK's Tyndall Centre for Climate Change Research also released a report in May 2009 investigating China's potential trajectories to 2050 to stabilize global atmospheric CO_2 concentration at 450 ppm. At the same time, the China Energy Group at Lawrence Berkeley National Laboratory (LBNL) has developed a bottom-up, end-use energy model for China and will be publishing a summary report on recent scenario analysis of different energy and emission pathways out to 2050 (LBNL).

It is clear that a robust and credible energy and emission model will play a key role in assessing policy impacts and energy saving and emission reduction potential. This is especially true for developing countries such as China, where uncertainties are greater while the economy continues to undergo rapid growth and industrialization. A slightly different assumption or storyline could result in significant discrepancies among different model results. Therefore it is necessary to understand the key models in terms of their scope, methodologies, key driver assumptions and the associated findings. A comparative analysis of LBNL's energy end-use model scenarios with other recent studies was thus conducted to examine similarities and divergences in key drivers and results. The studies included in the comparative analysis are: the *2050 China Energy and CO_2 Emissions Report (CEACER)* published by China's Energy Research Institute, the *China's Green Revolution* report published by McKinsey & Company, the *China's Energy Transition* report published by the Sussex Energy Group and Tyndall Centre for Climate Change Research, and the China-specific section of the *World Energy Outlook (WEO) 2009* published by the International Energy Agency. These reports were chosen because they represent some of the most recent work on Chinese energy and CO_2 emission scenarios or pathways to at least 2030, with ERI and Tyndall extending their scenario analysis as far as 2050. These studies also all included sectoral analysis as well as aggregate macroeconomic analysis. Where data was available and comparable, the LBNL study was compared with these other four studies in terms of methodologies, scenario storylines, macroeconomic drivers and assumptions as well as aggregate energy and emission scenario results. The fastest growing sectors of industry, transport and power were also selected for in-depth analysis of sector-specific assumptions and results.

2. Comparison of Modeling Methodologies, Scenarios, and Drivers

2.1 Methodology and Scenarios

Although the modeling studies reviewed all present detailed energy and carbon outlooks for China to 2030 or later, they differ in their modeling methodology and scenarios analyzed. An overview of each study's methodological approach and model structure is presented here to identify major similarities and differences that may ultimately affect the comparability of the results (Table 1).

Table 1 Overview of Model Methodologies and Scenarios in Different Studies

	LBNL	ERI/CEACER Study	McKinsey	IEA/WEO 2009	Tyndall
Model					
Approach	Bottom-up, technology and end-use based accounting model with five end-use sectors and ten supply-side and transformation subsectors	Hybrid: Top-down dynamic, computable general equilibrium model of 20 sectors with hybrid input-out table and feed-in from bottom-up IPAC/AIM technology assessment model	Bottom-up analysis of emissions across ten industries based on technology abatement potential and cost	Large-scale bottom-up mathematical model with six supply and demand modules for 24 regions, including China individually	Backcasting using a chosen cumulative emissions budget and two published medium-term pathways (IEA WEO 2007 and ERI 2004 Study)
Model Platform	LEAP Software	Integrated Policy Assessment Model of China (IPAC)-SGM, IPAC-AIM	N/A	World Energy Model, various software	N/A
Type of Energy Drivers	Physical and economic	Physical and economic	Physical and economic	Physical and Economic	Cumulative carbon budget
Outlook End-date	2050	2050	2030	2030	2050
Scenario Analysis					
Baseline Scenario	**Continued Improvement Scenario (CIS):** continuing current and planned portfolio of programs, policies and technology deployment	**Baseline Scenario:** business as usual scenario where economic growth continues at rapid pace	**Baseline Scenario:** sustainable technological development across all industries, with deployment of mature, proven technologies	**Reference Scenario:** no new initiatives related to energy sector beyond those already adopted by mid-2009	N/A: see Tyndall specific scenario descriptions
Alternative Scenarios	**Accelerated Improvement Scenario (AIS):** accelerated efficiency improvements and technology deployment across all sectors, decarbonization with growth in non-fossil fuel generation and greater electrification	**Low Carbon (LC) Scenario:** greater policy focus on energy security, environmental protection and low carbon pathways, adoption of all feasible measures **Accelerated Low Carbon (ALC) Scenario:** more aggressive policy action under global concerted efforts to reduce GHG	**Abatement Scenario:** potential and cost of 200+ technologies/techniques to maximize GHG abatement using well understood measures that are likely to be commercially available	**450 Scenario:** implications of coordinated global effort to achieve trajectory that would stabilize GHG concentration at 450 ppm CO_2e through effective policy mechanisms	
Inclusion of Carbon Capture & Sequestration (CCS) Technology	No - CCS examined in separate CIS with CCS scenario	IGCC with CCS used in ALC scenario after 2030	CCS in power sector and cement, steel and chemical industries	CCS in power sector only	CCS utilized to differing degrees in all four scenarios

As seen in Table 1, ERI and Tyndall are the only two studies that incorporated a top-down modeling approach while LBNL, McKinsey and IEA all employed bottom-up modeling and analysis approach with some physical drivers. ERI's IPAC-SGM model also differs from Tyndall in that it is a forward-looking computable general equilibrium (CGE) model whereas Tyndall is a backcasting model based on 2050 cumulative emissions budgets. It is also interesting to note that Tyndall incorporated WEO 2007 scenario into its medium term pathway projections to 2030. Of the three bottom-up models, the modeling platform and type of energy drivers differ between the different scenarios despite similar methodological approaches. For example, while both LBNL and McKinsey based future production of industrial products such as cement and steel off of macroeconomic drivers such as urbanization, infrastructure demand and new building construction, it is unclear if McKinsey's drivers for industrial production are only physical (as is the case in LBNL's model) or physical and economic-based (e.g., price-related). The IEA model also differs from both LBNL and McKinsey model in that it models final energy demand at the sectoral level, but not at a disaggregated end-use level.

In terms of major scenarios generated by the models, all studies except the Tyndall report had at least one baseline or reference scenario and an alternative mitigation scenario. The CEACER study by ERI had two alternative scenarios to distinguish between the paces of abatement and policy action. The Tyndall scenarios differ most significantly in that there is no baseline or reference scenario but rather four scenarios to assess two methods of allocating China's cumulative CO_2 emissions given the global cumulative emissions limit of 490 GtC by 2100 needed to stabilize CO_2 concentration at 450 ppm and different storylines on changes in the economy, technology, governance and society. The specific assumptions of the four scenarios are presented below, with the major differences being the assumed nature of technical innovation and society's preference for equity and efficiency. For example, scenarios 1 and 2 assumes that innovation enables rapid and successful restructuring with a pronounced shift away from heavy and conventional industries toward value-added manufacturing and service based economy while this is less successful in scenarios 3 and 4.

Table 2 Specific Assumptions of Tyndall Scenarios

	Scenario 1 (S1)	**Scenario 2 (S2)**	**Scenario 3 (S3)**	**Scenario 4 (S4)**
Cumulative Budget	70 GtC	111 GtC	90 GtC	111 GtC
	Allocated using equal emissions per capita approach	Allocated using equal carbon emissions per unit of GDP	Allocated using equal emissions per capita approach	Allocated using equal carbon emissions per unit of GDP
Medium-term Pathway	ERI 2020	ERI 2020	IEA WEO 2007	IEA WEO 2007
Emissions Peak	2020	2030	2020	2030
Population Growth Rate	Follows median population projections from 2005 United Nations Population Prospects			
Nature of Innovation	highly innovative, tendency for radical technical change	strong science and technology advance, but slower diffusion	significant technical change - cumulative, incremental process	incremental innovation, mainly in legacy industries
Equity and Efficiency Attitude	strong preference for social welfare and equity	globalized market and economic efficiency driven	inward investment and against communal disparity	focus on market and growth, individual success

Source: reproduced from Table 1 in Wang and Watson, 2009.

The McKinsey and LBNL studies are similar in the underlying storylines for its baseline and alternative scenarios in that the baseline scenario is not a business-as-usual scenario but rather represents continued development with a focus on energy efficiency and carbon abatement. LBNL's CIS scenario reflects this by assuming the current and planned portfolio of efficiency and abatement programs and policies and technology deployment continue and that sizable efficiency improvements occur across all sectors. Similarly, McKinsey's baseline scenario also assumes sustainable technology development across major industries, buildings, transport, power and agriculture sectors with the absorption of mature, proven technologies (Figure 1). In both cases, following the "baseline" pathway of development requires continued government policy support and technological development. In contrast, both ERI and IEA had reference scenarios that followed "business-as-usual" pathways of development with no new initiatives, policies or technologies beyond what is already currently in place.

Figure 1 Key Differences between McKinsey Baseline and Abatement Scenarios

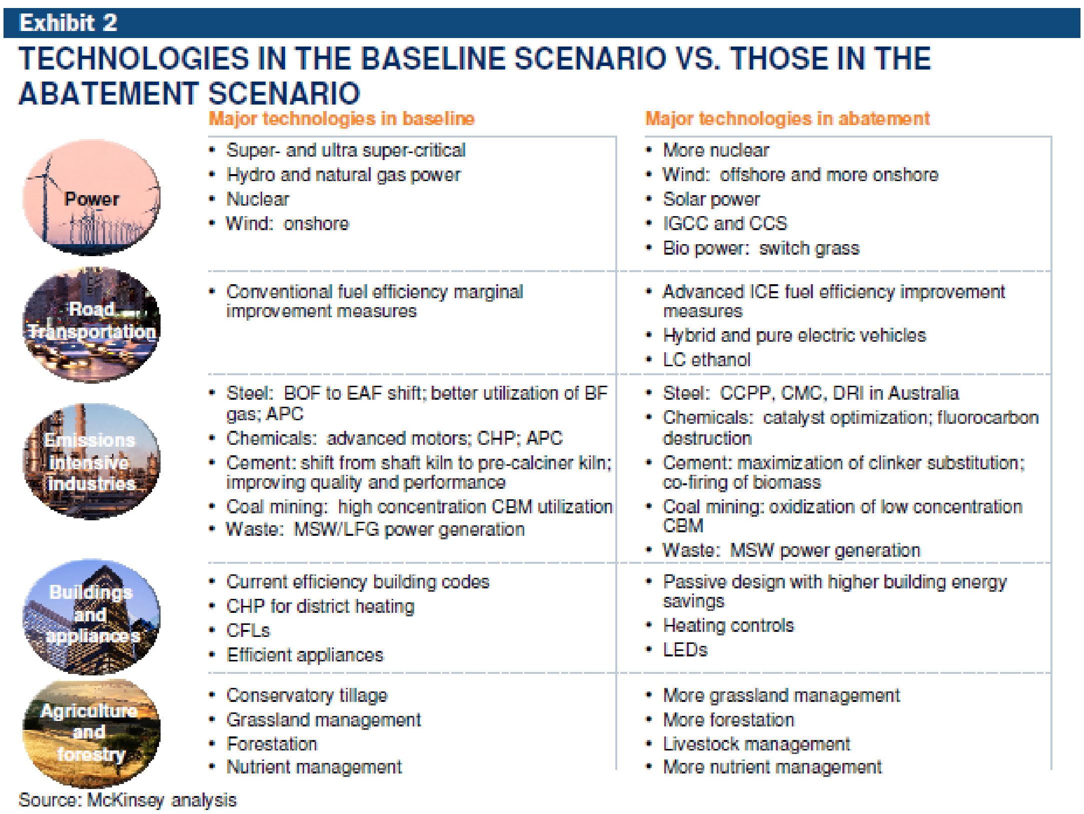


Exhibit 2

TECHNOLOGIES IN THE BASELINE SCENARIO VS. THOSE IN THE ABATEMENT SCENARIO

	Major technologies in baseline	Major technologies in abatement
Power	• Super- and ultra super-critical • Hydro and natural gas power • Nuclear • Wind: onshore	• More nuclear • Wind: offshore and more onshore • Solar power • IGCC and CCS • Bio power: switch grass
Road Transportation	• Conventional fuel efficiency marginal improvement measures	• Advanced ICE fuel efficiency improvement measures • Hybrid and pure electric vehicles • LC ethanol
Emissions intensive industries	• Steel: BOF to EAF shift; better utilization of BF gas; APC • Chemicals: advanced motors; CHP; APC • Cement: shift from shaft kiln to pre-calciner kiln; improving quality and performance • Coal mining: high concentration CBM utilization • Waste: MSW/LFG power generation	• Steel: CCPP, CMC, DRI in Australia • Chemicals: catalyst optimization; fluorocarbon destruction • Cement: maximization of clinker substitution; co-firing of biomass • Coal mining: oxidization of low concentration CBM • Waste: MSW power generation
Buildings and appliances	• Current efficiency building codes • CHP for district heating • CFLs • Efficient appliances	• Passive design with higher building energy savings • Heating controls • LEDs
Agriculture and forestry	• Conservatory tillage • Grassland management • Forestation • Nutrient management	• More grassland management • More forestation • Livestock management • More nutrient management

Source: McKinsey analysis

Source: McKinsey & Company, 2009, pg. 23.

The alternative scenarios also vary in the extent to which CCS technology is adopted as a mitigation measure, ranging from no utilization before 2050 under LBNL's AIS scenario and ERI's Low Carbon scenario to ranges of 5% to 30% power capacity by 2030 and a high of 90% power capacity by 2050.[1] In light of these methodological and scenario differences among the five studies, an in-depth analysis of

[1] See Table 14 for each scenario's specific CCS assumptions.

key macroeconomic drivers and selected sector-specific drivers is conducted to examine the comparability and implications of each model's energy and carbon emissions outlook for China.

2.2 Macroeconomic Drivers

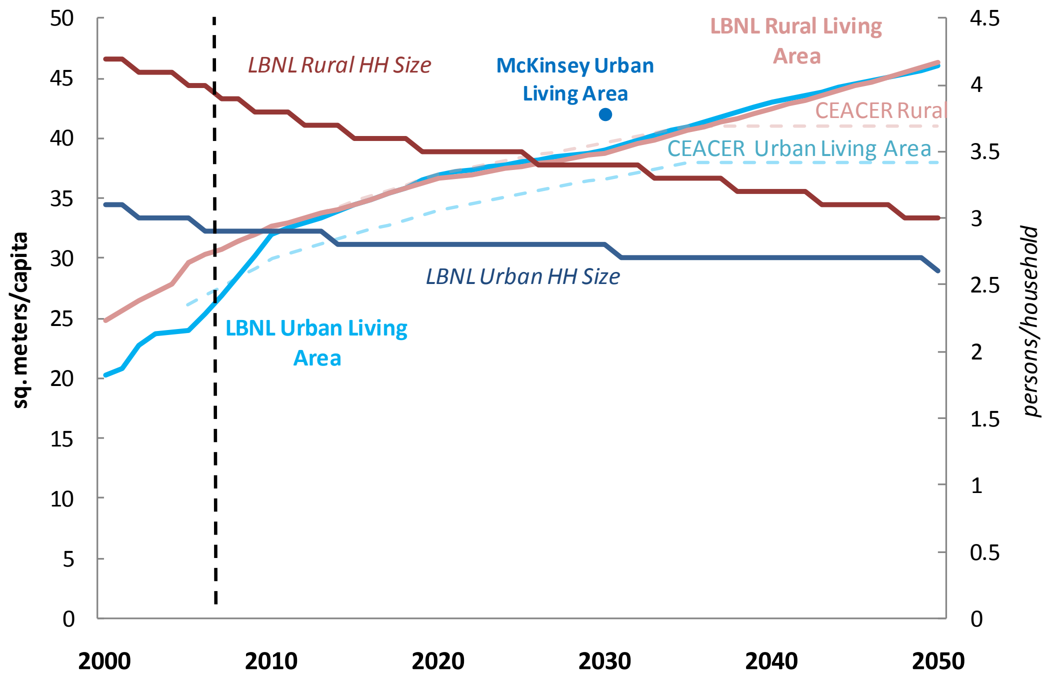
Although the methodologies and scenarios differ, most of the reviewed studies used generally accepted macroeconomic drivers and projections for China. Specifically, a closer examination of two macroeconomic drivers, population growth and urbanization, used in the other four studies reaffirms the values used in LBNL's model. Specifically, LBNL's population and urbanization rates for 2020 through 2050 are all within the range of CEACER, McKinsey, WEO and Tyndall Centre's assumptions. As seen in Table 3, McKinsey's urbanization rates are lower than LBNL and CEACER's values while Tyndall study assumed a slightly lower population as a result of following the United Nation's 2004, rather than 2008, World Population Prospects.

Table 3 Macroeconomic Drivers in Different Studies

	LBNL	CEACER 2009	McKinsey	WEO 2009	Tyndall
Population					
2020	1.42 Billion	1.44 Billion	1.4 Billion	1.429 Billion	1.40 Billion
2030	1.46 Billion	1.47 Billion	1.5 Billion	1.461 Billion	1.44 Billion
2050	1.41 Billion	1.46 Billion	N/A	N/A	1.40 Billion
Urbanization Rate					
2020	63%	63%	57%	Not Given	Not Given
2030	70%	70%	67%		
2050	79%	79%	N/A		
Growth in GDP					
2010 - 2020	7.5%	8.38%	8.20%	2006-30: 6.1%	2005-50 Avg: 4.8-5.9%
2020 - 2030	5.7%	7.11%	6.50%		
2030 - 2050	3.4%	4.29%	N/A	N/A	

A closely related driver to population and urbanization is the growth of residential buildings as measured by new construction area. Residential construction in turn is determined by per capita floorspace and building lifetime. As seen in Figure 2, there is a clustering of rural living area assumptions between ERI and LBNL, although LBNL assumes continued growth in rural living area after 2030 while ERI assumes it plateaus after 2030. Moreover, there is also a wider range of values for urban living area. ERI assumes a lower per capita urban living area than LBNL, while McKinsey assumes a slightly higher per capita urban living area in 2030. In terms of growth trends, LBNL and ERI assumed similar growth rates in urban living area between the mid-2010s through 2030, but LBNL has higher growth rates prior to the mid-2010s and after 2030.

Figure 2 Comparison of Residential Living Space and Household Sizes



Consequently, the CEACER study has the lowest stock of total residential building floor area as well as the lowest urban residential building floor area, while McKinsey has the highest floor area assumptions in urban, rural and total residential buildings. In fact, McKinsey's total residential floor area in 2030 is 10 to 11 billion square meters higher than the value in both LBNL and CEACER studies, respectively.

Table 4 Comparison of Total Residential Building Area (million m^2)

	2005	2010	2020	2030	2050
CIS/AIS Urban	13,547	21,192	33,130	39,815	51,197
CIS/AIS Rural	22,231	22,470	19,247	16,973	13,698
CIS/AIS Total	*35,778*	*43,662*	*52,377*	*56,788*	*64,895*
CEACER Urban	14,670	19,580	27,810	33,337	38,100
CEACER Rural	22,140	22,980	22,830	21,310	17,620
CEACER Total	*36,810*	*42,560*	*50,640*	*54,647*	*55,720*
McKinsey Urban	15,000	-	-	42,000	N/A
McKinsey Rural	22,000	-	-	24,000	N/A
McKinsey Total	*37,000*	-	*55,000*	*66,000*	*N/A*

In terms of annual GDP growth, a key economic indicator and driver of energy demand, there are slight variations amongst the different studies (Table 5). LBNL assumed comparable but slightly lower GDP annual average growth rates (AAGR) after 2010 than CEACER and McKinsey. The Tyndall study, however, used a much lower GDP AAGR of 4.3% from 2015 to 2030 while the WEO 2009 AAGR of 6.1% from 2006 to 2030 is also on the low side compared to CEACER and McKinsey. Although the differences do not appear large, the compounded effect of annual economic growth actually result in more substantial divergences in economic activity related directly to GDP, such as industrial production and car ownership rates.

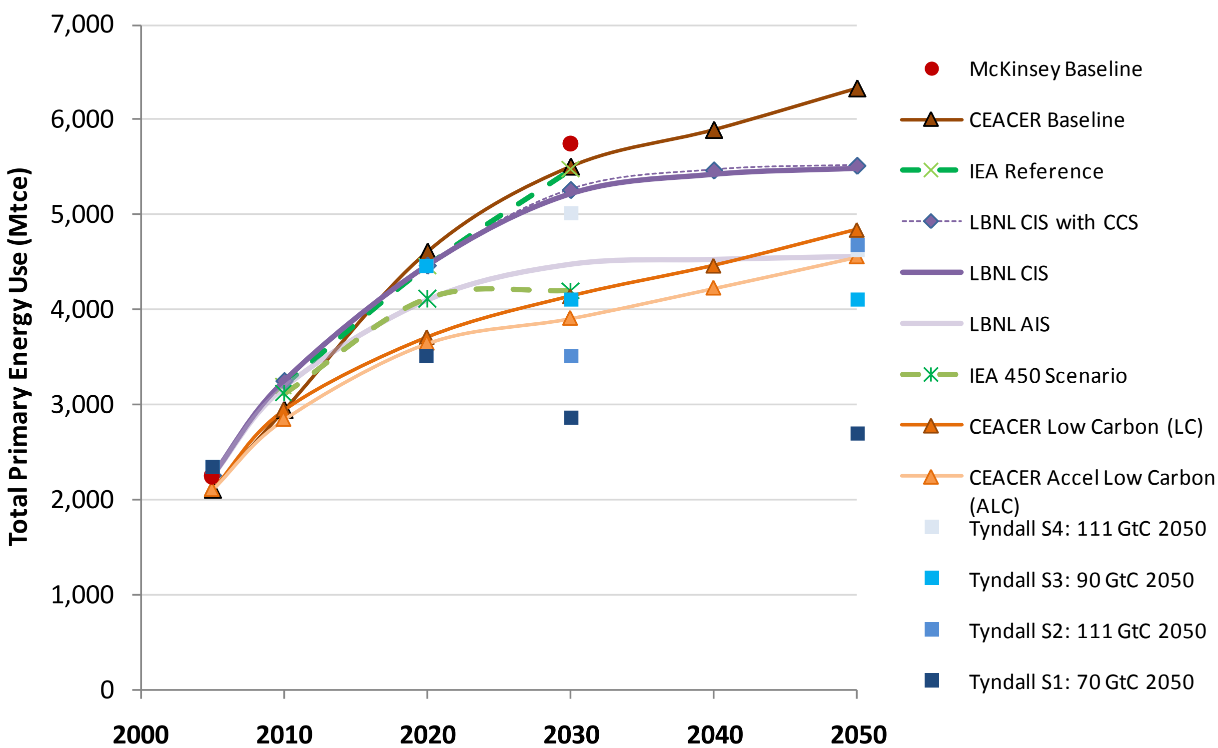
Table 5 Comparison of GDP Average Annual Growth Rates (AAGR) used in Different Studies

	LBNL CIS/AIS	CEACER Ref/Low Carbon	McKinsey	Tyndall (based on WEO 2006)	WEO 2009
2005-2010	9.58%	9.67%	9.90%	2004 -15: 7.3%	2006 - 2030: 6.1%
2010-2020	7.67%	8.38%	8.20%		
2020-2030	5.85%	7.11%	6.50%	2015-30: 4.3%	
2030-2040	4.09%	4.98%	N/A	IEA Tech Perspectives	N/A
2040-2050	2.82%	3.60%	N/A		
2005 - 2050	*5.45%*	*6.40%*	*N/A*	*N/A*	*N/A*

3. Comparison of Aggregate Energy and CO_2 Emissions Outlook

Despite differing assumptions and modeling methodologies, there was general clustering in total energy consumption of different sets of scenarios in the five studies reviewed. The only exception was the scenarios in the Tyndall study, which all resulted in significantly lower total primary energy use because each of the four scenarios had to meet a specific 2050 carbon budget.

Figure 3 Comparison of Total Primary Energy Use in Different Scenarios



Note: ERI/CEACER numbers converted following IEA convention of using calorific value equivalent for primary electricity.

The notable difference between LBNL's scenarios and others is the shape of the curves. LBNL's projected energy consumption increases at approximately the same rate as other models except Tyndall through 2030, but diverge after 2030 with a slow down or plateau whereas others still exhibit extrapolation of growth all the way out to 2050. This also results in the lower projected primary energy consumption in 2050 under LBNL's scenarios. The McKinsey and CEACER baseline scenarios and IEA reference scenarios followed very similar total primary energy use trends with range of 5473 to 5750 Mtce by 2030 and 4554 to 6328 Mtce by 2050 for CEACER scenarios, whereas the CIS scenario shows 5213 Mtce in 2030 and 5481 Mtce in 2050. The difference is mostly because CIS was modeled from a highly disaggregated end-use level for the major sectors and assumes a number of saturation effects will take place for drivers including the slowdown of urbanization, low population growth, change in exports to high value added products and frozen exports of energy-intensive products, and saturation of most appliances, floor area per resident and per employee, and infrastructure construction.

Another difference observed is the impact of the use of CCS. Most of the alternative scenarios examined have relied on the CCS application to bring down emissions. However, the LBNL CIS-with-CCS scenario, in which CCS technology was added to a CIS pathway of development (to achieve 230 million tonnes CO_2 reduction by 2030, matching the WEO 2009 450 ppm scenario), demonstrates that all else equal, there would be a net increase in primary energy demand on the order of 36 Mtce more by 2050 due to CCS energy requirements for separation and sequestration.

For the alternative pathway, primary energy use results under AIS were also within the range of IEA 450 and CEACER Low Carbon and Accelerated Low Carbon scenarios. It is interesting to note that despite the very aggressive (e.g., current world best practice by 2020s) efficiency improvements and technology deployments assumed under AIS, its total energy demand still slightly higher than the CEACER and IEA low carbon scenarios. Moreover, Tyndall scenarios 1, 3 and 4 stand out as the only scenarios with total primary energy demand peaking before 2050 as a result of the total carbon budget limits. It is not clear where the McKinsey abatement scenario would fall in terms of total primary energy use as all results for that scenario were given only in CO_2 equivalent terms.

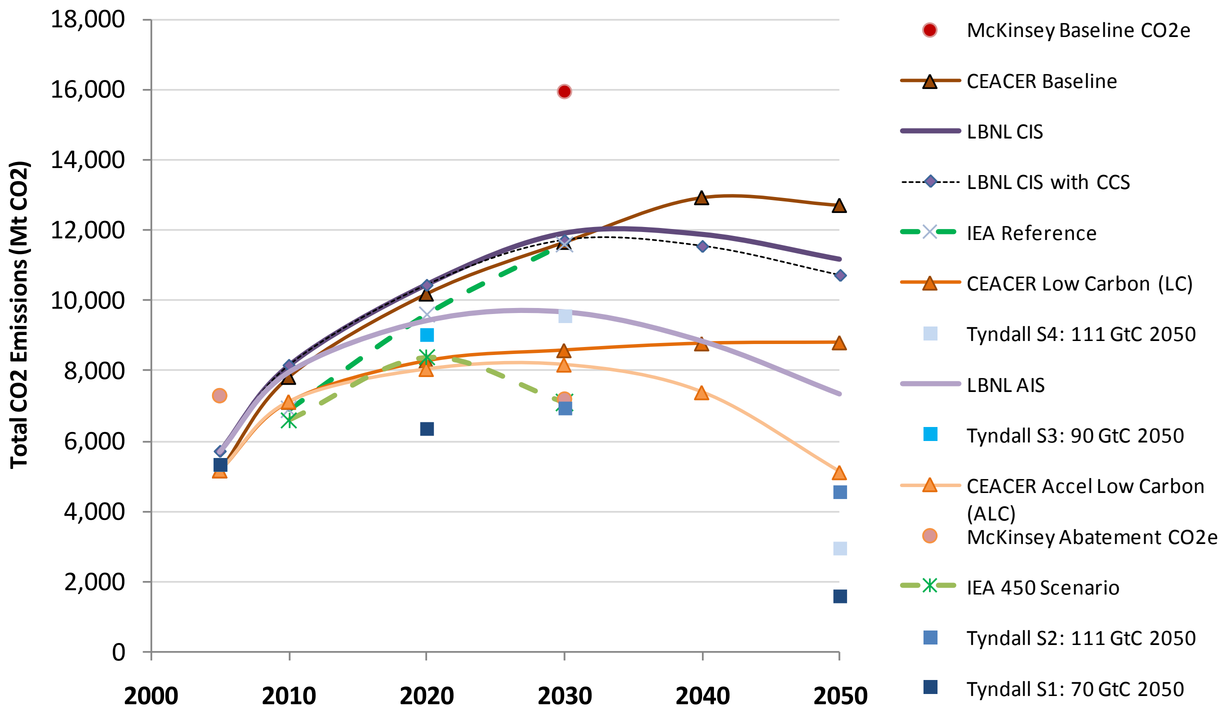
Table 6 Total Primary Energy Use under Different Scenarios (Mtce)

	2005	2010	2020	2030	2040	2050
CEACER Baseline	2,099	2,940	4,608	5,504	5,891	6,328
CEACER Low Carbon (LC)	2,099	2,941	3,712	4,144	4,468	4,847
CEACER Accel Low Carbon (ALC)	2,099	2,839	3,643	3,905	4,224	4,554
LBNL CIS	2,246	3,243	4,459	5,213	5,418	5,481
LBNL CIS with CCS	2,246	3,243	4,463	5,261	5,468	5,517
LBNL AIS	2,246	3,176	4,097	4,475	4,525	4,558
Tyndall S1: 70 GtC 2050	2,343		3,504	2,861		2,698
Tyndall S2: 111 GtC 2050	2,343		3,504	3,515		4,686
Tyndall S3: 90 GtC 2050	2,343		4,452	4,100		4,100
Tyndall S4: 111 GtC 2050	2,343		4,451	5,006		4,623
McKinsey Baseline	2,245			5,750	N/A	N/A
McKinsey Abatement	2,245			Not Given	N/A	N/A
IEA Reference		3195	4457	5,473	N/A	N/A
IEA 450 Scenario		3116	4114	4,197	N/A	N/A

In terms of total CO_2 emissions, there is a much greater range in scenario results amongst the five different studies due to differing assumptions about mitigation potential and abatement technology deployment, and, in the case of McKinsey, different scope of emissions calculations that includes non-CO_2 greenhouse gases expressed in CO_2-equivalent terms. Again, comparisons with the Tyndall scenarios are difficult due to its divergent backcasting approach and lack of specific data points for a representative time series. For the other studies, however, the McKinsey baseline scenario had significantly higher total CO_2-equivalent emissions at 16 million tonnes of CO_2e by 2030, compared to the clustering around 11,700 million tonnes of CO_2 in the of CIS, CEACER and IEA baseline scenarios at 2030. If non-CO_2 GHG are excluded by assuming that the current 30% share of non-CO_2 GHGs in China's emissions remain constant through 2030, then McKinsey's baseline emissions of approximate 11,200 million tonnes of CO_2 emissions is much closer to the other 2030 baseline emission estimates.[2]

[2] Different studies estimate that non-CO_2 greenhouse gases such as methane and nitrous oxide make up 25 to 30% of China's total greenhouse gas emissions in CO_2 equivalent terms between 2000 and 2010. See Hyman, et. al. 2002 and U.S. EPA, 2006.

Figure 4 Comparison of Total CO_2 Emissions in Different Scenarios



Comparing the LBNL AIS scenario, which does not assume CCS deployment prior to 2050, with the other abatement scenarios in terms of carbon reveal that the other studies relied heavily on CCS for carbon reduction as small differences in total primary energy demand under these scenarios translated into greater differences in CO_2 emissions. In spite of aggressive decarbonization, AIS still had the highest total carbon emissions at 9680 million tonnes of CO_2 in 2030 compared to ~8000 million tonnes under the two CEACER abatement scenarios and 7100 million tonnes under IEA 450. At the same time, LBNL's CIS with CCS scenario indicate that adding sufficient CCS technology to capture 500 Mt CO_2 by 2050 will result in a net reduction of 476 Mt CO_2 in 2050. By 2050, however, the AIS scenario is in line with the CEACER alternative scenarios as it falls within the range of the two CEACER scenarios even without CCS. This demonstrates that efficiency improvements alone (e.g., current world best practice by 2020s) could achieve sizable emission reductions that would be much bigger than adopting CCS at the scale assumed in the study. It is also interesting to note that while its baseline emissions were much higher in CO_2 equivalent terms, McKinsey's abatement scenario actually had one of the lowest total emissions by 2030 with comparable emissions to IEA 450 in CO_2 equivalent terms. In CO_2 only terms with the exclusion of non-CO_2 GHG emissions, the McKinsey abatement scenario's 2030 emission is the lowest at only 5000 Mt CO_2. This suggests that the McKinsey abatement scenario relies heavily on CCS and other non-traditional mitigation technologies such as large-scale biomass co-firing to achieve its sizable abatement potential. Likewise, three out of four of the Tyndall scenarios are outliers in having significantly lower total CO_2 emissions in 2050.

Table 7 Total CO_2 Emissions under Different Scenarios (Mt CO_2)

	2005	2010	2020	2030	2040	2050
CEACER Baseline	5,167	7,825	10,190	11,656	12,925	12,705
CEACER Low Carbon (LC)	5,167	7,124	8,294	8,598	8,793	8,822
CEACER Accel Low Carbon (ALC)	5,167	7,124	8,045	8,169	7,385	5,115
LBNL CIS	5,703	8,154	10,465	11,931	11,900	11,192
LBNL CIS with CCS	5,703	8,154	10,434	11,707	11,541	10,716
LBNL AIS	5,703	7,961	9,430	9,680	8,854	7,352
Tyndall S1: 70 GtC 2050	5,317		6,321			1,595
Tyndall S2: 111 GtC 2050	5,317			6,915		4,519
Tyndall S3: 90 GtC 2050	5,317		9,038			2,127
Tyndall S4: 111 GtC 2050	5,317			9,570		2,924
McKinsey Baseline CO_2 equivalent	7,300			15,950	N/A	N/A
McKinsey Baseline est. CO_2 only	5,110			11,165		
McKinsey Abatement CO_2 equivalent	7,300			7,210	N/A	N/A
McKinsey Abatement est. CO_2 only	5,110			5,047		
IEA Reference		6900	9600	11,600	N/A	N/A
IEA 450 Scenario		6600	8400	7,100	N/A	N/A

Note: McKinsey's estimated CO_2 emissions are the author's estimate assuming CO_2 emissions make up 70% of China's total greenhouse gases, based on estimates presented in Hyman, et. al. 2002 and U.S. EPA 2006.

Of all the carbon outlooks in the scenarios examined, most forecast China's CO_2 emissions peaking in the 2030s. The key exceptions include the CEACER low carbon scenario, which does not observe a CO_2 emissions peak before 2050, and Tyndall scenario 1 and 3, which observe much earlier emissions peak in 2020.

4. Comparison of Industrial Sector Results

As industry is the largest consuming sector of China's economy, it was the main focus in all the studies reviewed. With regard to the production of key energy-intensive industrial products, CEACER and McKinsey both assumed much higher levels of cement and ammonia production than the LBNL study in 2020 and 2030 and lower levels of steel production (Table 8). Besides different rates of economic growth, these differences may reflect assumptions in CEACER and the McKinsey study that China's manufacturing use of steel (separate from its use in construction) will decline in the future compared to expanding use in the LBNL model which keeps total steel demand fairly high. Similarly, LBNL's ethylene demand projection was tied to assumptions on per-capita plastic consumption, resulting in a higher future demand than forecast by ERI. In general, because ERI's industrial output projections are based largely on IPAC-CGE, a top-down computable general equilibrium model, whereas LBNL's industrial output projections are based on physical activity drivers from bottom-up model, the growth trends and magnitude of major industrial output of iron and steel, cement, and aluminum differ significantly from

2030 to 2050. LBNL assumes these industrial outputs are close to plateau in 2010 as the construction of building and infrastructure begin to slow down with per capita floor area and length of roads and railways nearing saturation over the course of the following decade.

Table 8 Comparison of Key Industrial Output Production Levels (Mt of product)

Study Source Scenario	2005			2020			2030			2050	
	LBNL *CIS/AIS*	**ERI** *LC/ALC*	**McKinsey** *Base/Abatement*	**LBNL** *CIS/AIS*	**ERI** *LC/ALC*	**McKinsey** *Base/Abatement*	**LBNL** *CIS/AIS*	**ERI** *LC/ALC*	**McKinsey** *Base/Abatement*	**LBNL** *CIS/AIS*	**ERI** *LC/ALC*
Iron & Steel	353	355	355	978	610	596	1,180	570	776	1,077	360
Cement	1,069	1,060	1,069	1,282	1,600	1,752	1,005	1,600	1,627	1,083	900
Ammonia	41	46	-	43	50	-	43	50	75	41	45
Ethylene	8	8	-	40	34	-	52	36	-	55	33
Aluminum	8	9	-	16	16	-	17	16	-	27	9

Besides differing production levels, the assumed energy intensity of production may also vary depending on the technological outlook for a given industrial subsector under different scenarios. For most key industrial products, LBNL's AIS scenario had the lowest energy intensity among various LBNL and ERI scenarios while the energy intensity in ERI's Low Carbon and Accelerated Low Carbon scenarios are comparable or within the range of LBNL's CIS scenario. However, ERI assumed notably higher energy intensities for ethylene and iron and steel production.

Table 9 Comparison of LBNL and ERI Energy Intensity of Key Industrial Products

Study Source Scenario		2005			2020			2030			2050		
		LBNL *CIS*	**LBNL** *AIS*	**ERI** *LC/ALC*	**LBNL** *CIS*	**LBNL** *AIS*	**ERI** *LC/ALC*	**LBNL** *CIS*	**LBNL** *AIS*	**ERI** *LC/ALC*	**LBNL** *CIS*	**LBNL** *AIS*	**ERI** *LC/ALC*
Iron & Steel	(kgce/ton)	712	712	760	525	481	650	484	401	564	406	327	525
Cement	(kgce/ton)	125	125	132	105	99	101	99	89	86	90	75	81
Ammonia	(kgce/ton)	1,670	1,670	1,645	1,508	1,000	1,328	1,402	901	1,189	1,189	787	1,170
Ethylene	(kgce/ton)	700	700	1,092	600	533	796	559	478	713	478	478	705
Aluminum	(kWh/ton)	10,798	10,798	14,320	8,688	8,688	12,870	7,847	7,692	12,170	7,005	6,313	12,000

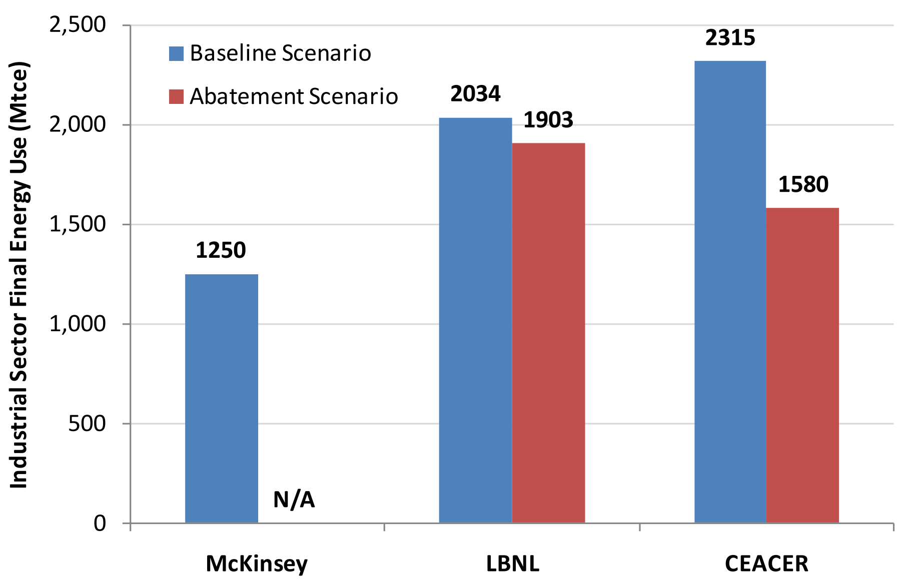
The different energy intensities between ERI and LBNL results from different approaches to deriving the average energy intensity of production as well as differences in technology outlook. For example, for iron and steel production, the LBNL study assumes that China will reach the current international best practice by 2050 under CIS and accelerated to 2030 under AIS. By achieving international best practice energy intensity earlier under AIS, China accelerates its utilization of electric arc furnace (EAF) technology from current levels of 12% to 26% share by 2030 and 40% share by 2050; EAF uses scrap steel and requires less energy to produce steel. Despite its aggressive trajectory of achieving best practice by 2030, the LBNL AIS share of 40% EAF for steel production remains below US shares of 58% because China faces constraints in the availability of scrap steel. McKinsey also assumes technology shift in the iron and steel production between its frozen and baseline scenarios, with 30% EAF share by 2030, which is much higher than the 19% share in 2030 under LBNL's CIS. However, it is unclear how comparable McKinsey's energy intensity assumptions are to LBNL's assumptions as the technology outlook and mitigation is presented only in terms of carbon abatement potential. In addition, McKinsey also attributes additional CO_2 mitigation to increased utilization of blast furnace while it is encompassed in LBNL's overall average energy intensity. In its abatement scenario, McKinsey also considers the mitigation potential of other emerging technology such as combined cycle power plants, coal moisture control and thin-strip direct casting. McKinsey further differs by taking into consideration carbon capture and sequestration in the cement, steel and chemical industries with total abatement potential of 210 Mt CO_2. This in turn helps explain why McKinsey's GHG abatement potential of 350 Mt CO2 equivalent for the cement subsector is four times higher than LBNL's estimated abatement potential. ERI's approach differs from both LBNL and McKinsey in that its overall average energy intensity of production is derived from 100% saturation of many advanced and more efficient technology options by 2050, rather than looking from a systems perspective of switching from more energy-intensive production using basic oxygen furnace (BOF) to EAF.

Table 10 Comparison of 2030 EAF Technology Shares in Steel Production

	Baseline Scenario	Alternative Scenario
LBNL	19%	26%
McKinsey	31%	N/A

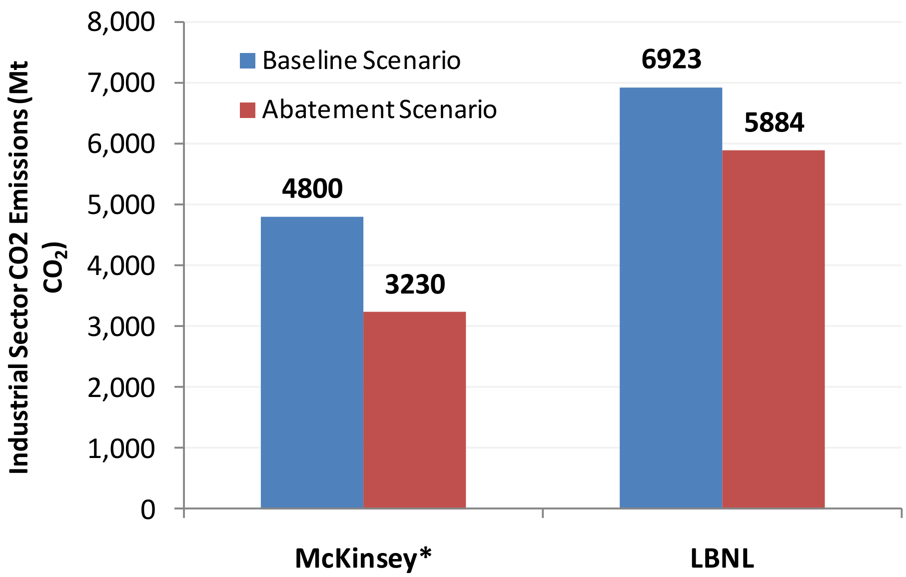
Besides differences in industrial production and technology outlook, the total energy consumption and abatement potential presented in different studies also differ due to differing scope of subsectors analyzed and the mitigation options considered. ERI's CEACER study does not provide CO_2 emissions breakdown on the sectoral level, but its total final energy consumption for industry under the reference and low carbon scenarios are within 15% of LBNL results (Figure 5). ERI's higher baseline energy but lower alternative scenario energy use implies higher abatement potential for the industrial sector, which is consistent with its broad expectations of achieving 100% saturation of advanced efficient technology.

Figure 5 Comparison of Industrial Sector Energy Outlook by Study Scenarios



While LBNL study focuses primarily on efficiency improvements in industrial production as reflected by declining overall energy intensity, McKinsey attributes 75% of the 2030 industrial abatement potential to CCS, fuel switching and relocating production and by-product and waste recovery measures. In turn, McKinsey's total industrial CO_2 emissions of only 3230 Mt CO_2 equivalent under the abatement scenario is significantly lower than LBNL's, especially considering that non-carbon greenhouse gases are included in the McKinsey study but not the LBNL study (Figure 6). This further reveals that small differences in underlying assumptions, subsector coverage and technology outlook could result in big divergence of projected industrial energy and emissions among different modeling studies.

Figure 6 Comparison of Industrial CO2 Emissions Outlook by Scenarios



*Note: McKinsey emissions are presented in terms of CO_2 equivalent but it is unclear how significant non-CO_2 GHGs are in terms of total industrial emissions.

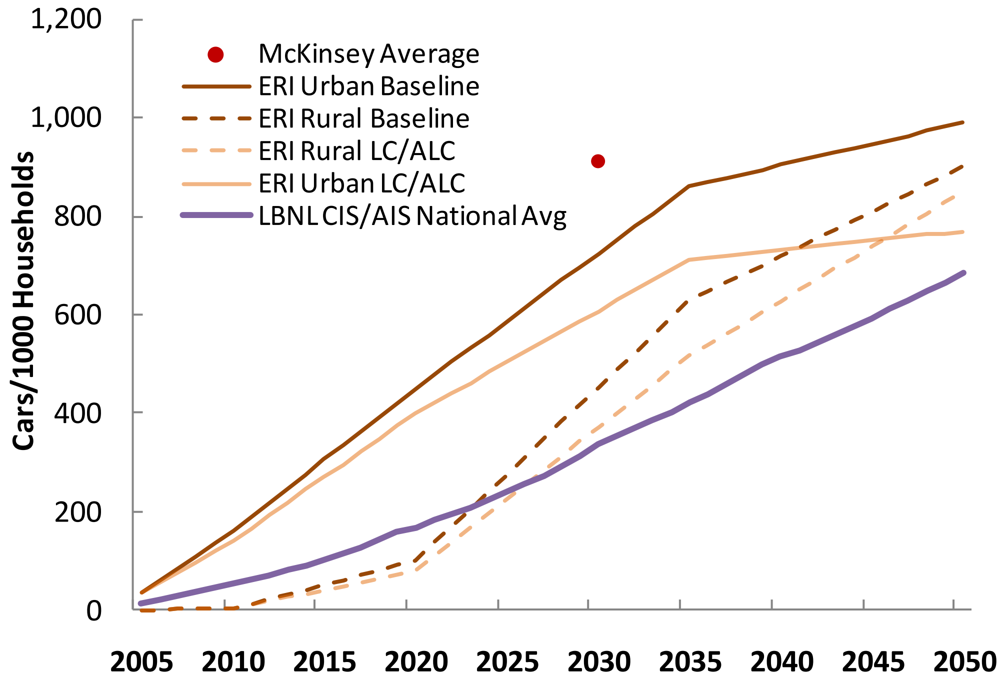
5. Comparison of Transport Sector Results

In understanding differences in scenario results for the transport sector, it is important to first acknowledge differences in methodology and key assumptions. The CIS and AIS scenarios have lower implied car ownership than both urban and rural ownership rates in the CEACER study because the total car stock is projected using a diffusion model based on income. As seen in Table 5, LBNL assumed slightly lower annual GDP growth rates and thus have lower per capita income levels that translate into lower implied car ownership rates of 338 cars per 1000 households in 2030 and 686 cars per 1000 households in 2050, which is comparable to Korea's current levels but well below that of other industrialized countries. LBNL's urban-rural average car ownership rate is also lower than urban and rural ownership rates in the CEACER scenarios. Specifically, the CEACER study included different urban and rural car ownership rates for the baseline versus abatement scenarios, with the baseline urban ownership rates of 724 cars per 1000 households is about double that of rural ownership rates in 2030 In 2050, the CEACER rural car ownership rate is only slightly lower than the urban car ownership rate, with rural ownership rates of 770 in the baseline scenario and 850 for the low carbon scenarios. Overall, this implies a weighted national average of 648 cars per 1000 households in 2030 and 965 in under the CEACER baseline scenario in2050. McKinsey stands out as having the highest car ownership rate of 911 vehicles per 1000 households in 2030, assuming China reaches Taiwan's 2005 ownership level by 2030.

Table 11 Comparison of Car Ownership Rates (cars per 1000 households)

	2030	2050
LBNL CIS/AIS	338	686
McKinsey	911	-
ERI Baseline	648	965
ERI Low Carbon/ALC	541	792

Figure 7 Comparison of Private Passenger Car Ownership Rates



Partly attributable to lower implied car ownership rates, CIS and AIS also have a smaller fleet of light duty vehicles than the scenarios in other studies (Table 12), 144 million less than ERI's Reference scenario and 97 million less than ERI's Low Carbon scenario in 2050. The scenario differences in light duty vehicle fleets is more evident after 2020, with CIS and AIS having 100 million more vehicles in its fleet between 2020 and 2030 whereas the ERI fleets experience jumps of 160 to 190 million vehicles from 2020 to 2030 while McKinsey study's fleet increases by 140 million vehicles.

Table 12 Comparison of Fleet of Light Duty Vehicles (million vehicles)

	CIS/AIS	ERI Ref	ERI LC/ALC	McKinsey	Ou et. al, 2010
2010	76	68	62	-	-
2020	164	195	186	152	-
2030	264	380	351	291	338
2050	461	605	558	N/A	550

Note: Ou, X. and X. Zhang. 2010b. Supporting information for "Scenario Analysis on Alternative Fuel/Vehicle for China's Future Road Transport: Energy demand and GHG emissions." *Energy Policy* 38 (8): 3943-3956.

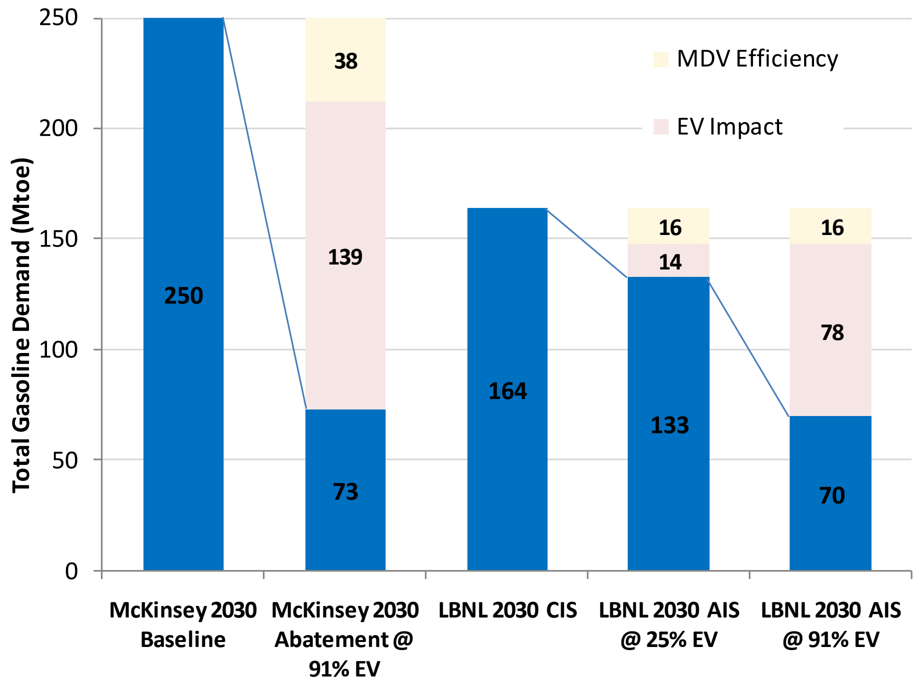
In terms of fuel economy, both LBNL and McKinsey studies assumed similar fuel economy levels for gasoline and diesel cars. McKinsey scenarios were based on slightly greater car efficiency improvements between 2005 and 2030, with 2005 intensity levels that are higher than LBNL levels but 2030 intensity levels that are lower than LBNL. For medium duty and heavy duty vehicles, however, LBNL assumes greater improvement on the order of 23% to 27% from 2005 to 2030 relative to McKinsey's improvements of 4% to 13%.

Table 13 Comparison of Fuel Intensity (MJ/km) and Fuel Economy Improvement Trends

	McKinsey 2005	McKinsey 2030	LBNL 2005	LBNL 2030
Gasoline Powered Car (MJ/km)	3.23	1.66-2.05	2.8	2.31
Diesel Powered Car (MJ/km)	2.93	1.38-1.70	2.2	1.97
MDVs	-	8-13% improvement	-	23-27% improvement
HDVs	-	4-10% improvement	-	23-27% improvement

Despite similar size of light duty vehicle fleets and car fuel economy levels, total gasoline demand under the McKinsey baseline scenario was 90 million tonnes of oil equivalent (Mtoe) higher than the LBNL CIS scenario (Figure 8). The McKinsey scenario also included much greater abatement potential from switching to electric vehicles and efficiency improvements with additional reduction of almost 130 Mtoe of gasoline than AIS. The much higher reduction potential of the McKinsey abatement scenario is partly due to its higher assumed penetration of EVs, with 91% market share by 2030 as opposed to 25% share under LBNL's AIS. However, even if AIS had a 91% market share of EVs by 2030, its reduction potential would still only be 78 Mtoe as opposed to 139 Mtoe, suggesting there are differences in other variables. Interestingly, though, this sensitivity analysis of 91% EV market share conducted by LBNL also shows similar total gasoline demand as the McKinsey abatement scenario, which indicates the difference in reduction potential is largely a result of the different baseline assumptions.

Figure 8 McKinsey and LBNL Transport Abatement Potential



In terms of transport energy demand by mode, CIS and AIS have similar 2050 shares for water and air transport as the Tyndall scenarios. However, Tyndall assumes much higher shares of transport energy consumption from railways in the range of 15% to 23% than either CIS or AIS at 5% and 6%, respectively (Figure 10). In contrast, road transport in all four Tyndall scenarios – including S4 which assumes high private road transport – have much smaller shares of transport energy demand than CIS and AIS.

Figure 9 CIS and AIS Transport Energy Use by Mode

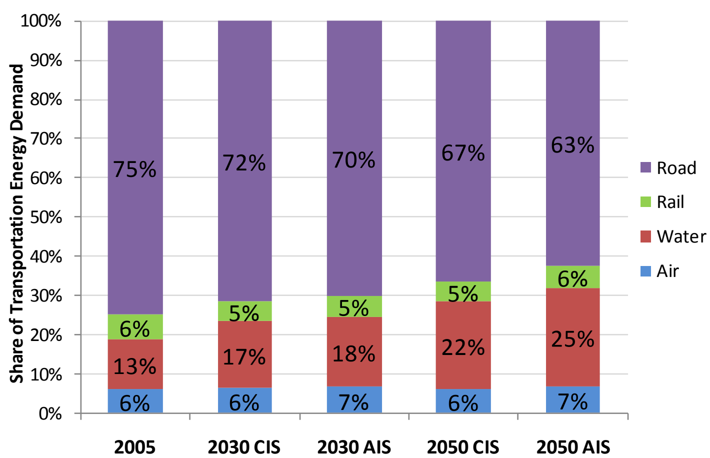
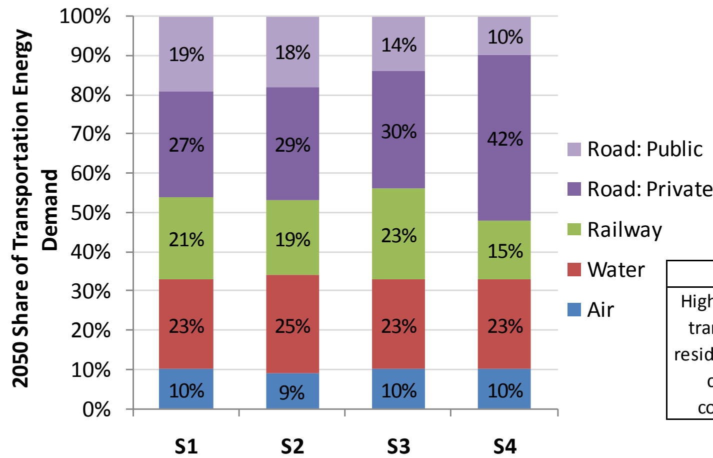


Figure 10 Tyndall Scenarios Transport Energy Use by Mode



S1	S2	S3	S4
High public road transport with residents in small cities and countryside	Similar to S1 but more private and public transport with highest mobility growth	Railways higher with few large and medium cities	Large private road transport, weak public transport

6. Comparison of Power Sector Results

A major difference in the power sector scenario analysis between the different studies is each scenario's assumptions regarding carbon capture and sequestration (CCS) diffusion and utilization in the power sector. As discussed earlier, CCS was not included in either the CIS or AIS scenarios in LBNL's model. However, a CIS-with-CCS scenario was created to assess the potential impact of CCS, and used to compare with CCS scenarios in other models. It is evident that some models assume large scale of CCS penetration while others do not expect CCS to play any roles in the power sector through 2030 (Table 14). The CIS-with-CCS scenario in LBNL's study is consistent and aligned with the IEA 450 scenario to 2030, with CCS expected to be installed and utilized for 4% of coal-fired capacity by 2030 and 7% by 2050. The CIS-with-CCS scenario further extends the IEA CCS deployment trend line out to 2050 by assuming sufficient CCS capacity to sequester 500 Mt CO_2 in 2050. Similarly, the ERI scenarios also do not expect CCS to play a major role in the power sector as CCS will only be installed to IGCC plants after 2030 under the most aggressive accelerated low carbon scenario and after 2050 for the low carbon scenario.

In contrast, the McKinsey abatement scenario assumes a much higher CCS utilization rate of 25% of coal-fired capacity by 2030 (as well as deployment in industry). The Tyndall study also assumes high CCS utilization rates after 2020 in most of their scenarios, including a high of 30% of coal-fired capacity in 2030 in S3. The Tyndall study further differentiates the pace of CCS deployment after 2030 depending on the policy basis for a given scenario's carbon budget, with a low of 33% of capacity by 2050 in S2 to a high of 80-90% in S3 and S4 by 2050. Finally, as a result of different CCS assumptions, the carbon mitigation impact of CCS varies between IEA/CIS with CCS and McKinsey. While the McKinsey abatement assumption about higher CCS deployment results in a much higher abatement potential of 1.4 Gt CO_2 emissions in 2030, both IEA 450 and CIS with CCS scenario assumptions abatement potential of only 230 Mt CO_2 emissions in 2030.

Table 14 Comparison of CCS Assumptions in Different Studies

	% of Coal Power Capacity	*Policy Basis for CCS Diffusion*	*CO_2 Impact*
CIS	None through 2050	-	
AIS	None through 2050		
CIS-with-CCS	7% of coal power capacity in 2050	-	500 Mt CO_2 in 2050, set following IEA 450 trend line
McKinsey Baseline	None in 2030	-	
McKinsey Abatement	25% of coal power capacity in 2030	CCS widespread application only after 2020	1.4 Gt CO2 total abatement in 2030; 120 Mt coal abatement in 2030
IEA Reference	None in 2030	-	
IEA 450	5% of coal and natural gas power capacity in 2030	-	230 Mt CO2 saved from CCS in 2030
Tyndall S1	Not given	compulsory after 2020 and older plants retrofitted where feasible	-
Tyndall S2	33% of coal and gas fired power plants equipped with CCS by 2050	CCS diffuse slower than S1 and only gradually over time	-
Tyndall S3	30% of coal power plants in 2030; over 80% in 2050	Urgent and mandatory from 2020, retrofitted where feasible	-
Tyndall S4	Almost none in 2030 to 90% in 2050	CCS rolled out quickly after 2030	-
CEACER Reference	None in 2030	-	-
CEACER LC	Not given	2050 begin CCS for IGCC	-
CEACER ALC	100% of IGCC Capacity after 2030	IGCC as main coal technology after 2020, all IGCC has CCS by 2030	-

In comparing the total power generation capacity and output of scenarios from different studies, CIS and AIS appear to be within the range of other scenarios (Figure 11, Figure 12, Figure 13). Although there is a range of values for the total 2030 and 2050 installed capacity, the CIS and AIS fuel mix of the installed capacity is similar to scenarios from the other studies. The relative fuel shares of installed generation capacity under the two LBNL scenarios are particularly similar to the CEACER baseline and low carbon scenarios, with the exception of natural gas and wind generation capacity shares.

Figure 11 Comparison of 2030 Installed Power Generation Capacity

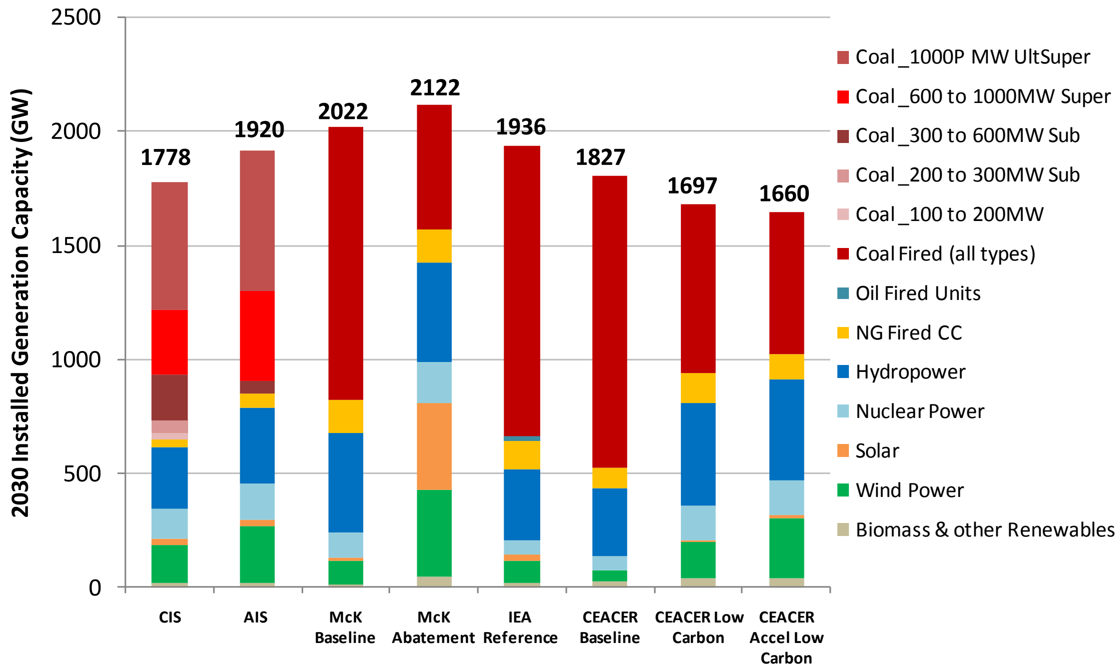
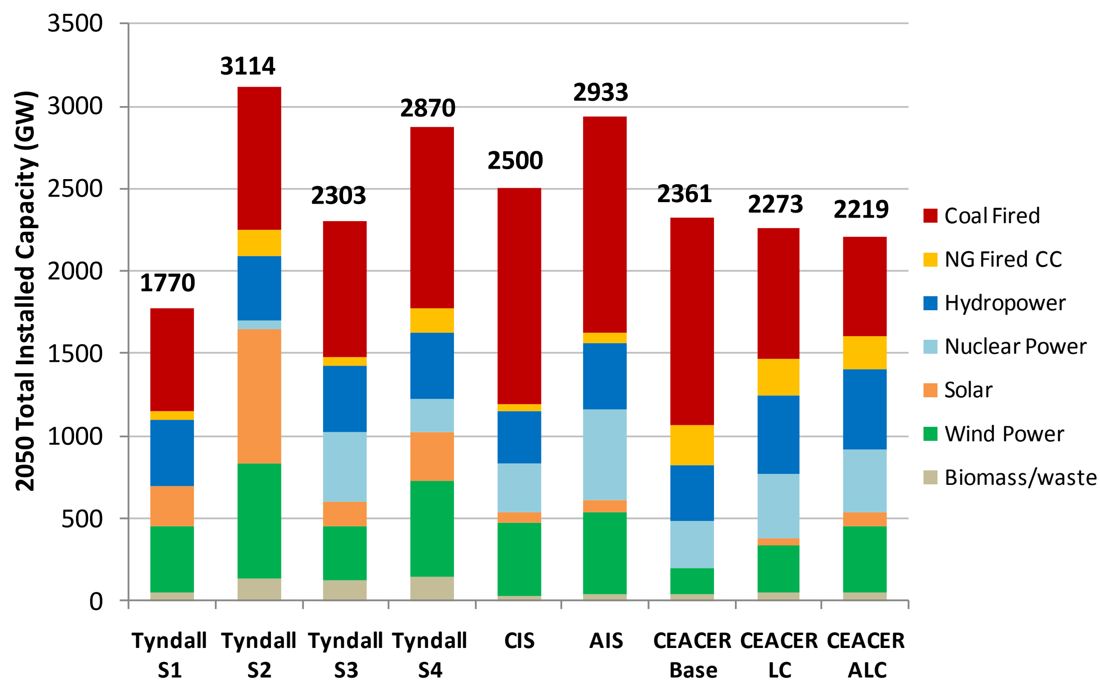
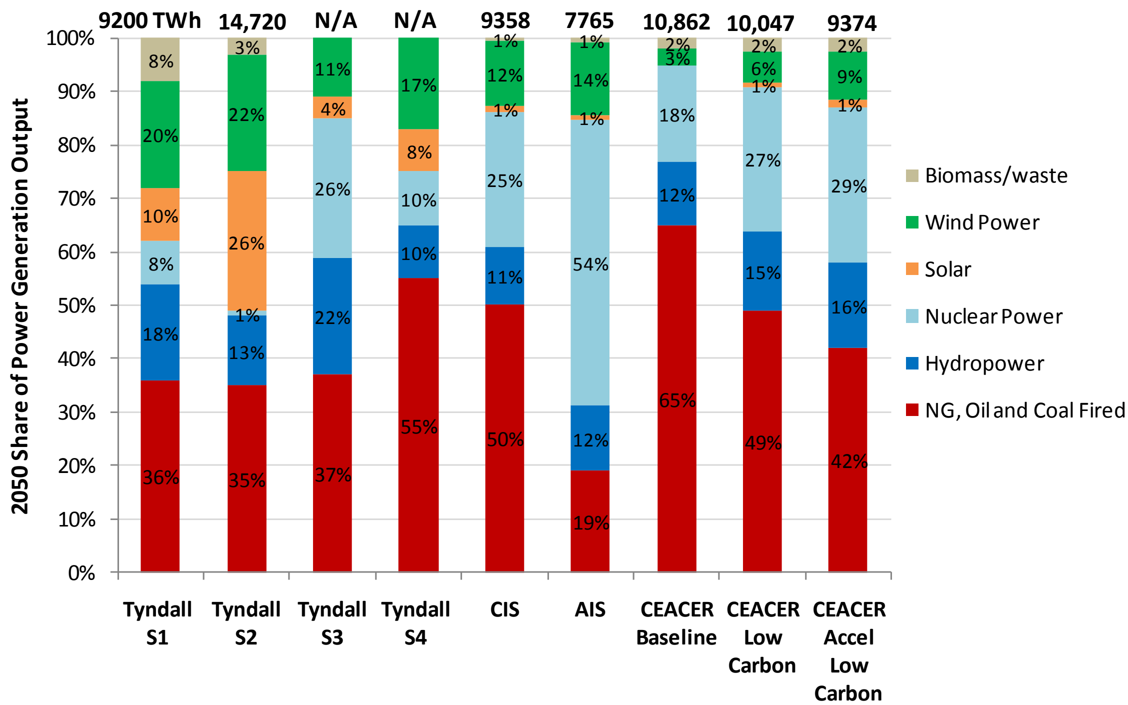


Figure 12 Comparison of 2050 Installed Power Generation Capacity



Generation output under AIS is slightly lower than other abatement scenarios, but this is most likely due to more aggressive and detailed assumptions about end-use efficiency improvements across residential and commercial sectors and subsequent electricity demand reduction. Moreover, despite having similar installed capacity fuel mix assumptions as other studies, CIS and AIS have different composition of power fuel mix than other studies with generally lower hydropower generation and much higher nuclear generation under AIS in 2050. Compared to ERI's baseline scenario, CIS also has smaller coal generation while AIS has the lowest coal generation of all scenarios, suggesting more accelerated power sector decarbonization than other scenarios with power dispatch prioritizing renewable and non-fossil fuel in the LBNL model.

Figure 13 Comparison of the Composition of Power Generation Output in 2050 by Scenario



7. Conclusions

The comparative analysis of LBNL's energy end-use model scenarios with other recent studies conducted highlighted important similarities and divergences in key drivers and results. The studies included in the comparative analysis are: the ERI *CEACER Report*, the *China's Green Revolution* report published by McKinsey & Company, the *China's Energy Transition* report published by the Sussex Energy Group and Tyndall Centre, and the China-specific section of the IEA *WEO2009*. Where data was available and comparable, the LBNL study was compared with these other four studies in terms of methodologies, scenario storylines, macroeconomic drivers and assumptions as well as aggregate energy and emission scenario results. The fastest growing sectors of industry, transport and power were also selected for in-depth analysis of sector-specific assumptions and results.

The analysis found that all the studies identified large potentials for reducing carbon emissions in the period to 2030 or 2050, with the contributions to these reductions coming broadly from energy efficiency, power sector decarbonization (from non-fossil fuel generation), and from CCS. Given the technological uncertainty over CCS and the additional demands it places on primary energy production, these results suggest taking an even closer look at the potential contributions from energy efficiency and power sector decarbonization, since these may have to shoulder the primary responsibility for emissions reductions.

The studies that looked to 2050 also projected a plateauing or decline in China's emissions after 2030, when China's population is expected to peak as well. Even in the most aggressive control scenarios, however, only the Tyndall study with its predetermined carbon budgets, and the ERI Accelerated Low Carbon scenario, found that CO_2 emissions by 2050 could return to their 2005 levels.

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