Major Economies and Climate Change Research Group

Reduction Potential in Energy Production

Spencer Jones
Dustin Stephenson Reynolds
Carson Stones

April 2014

Supervised by Dr. Joshua Busby
busbyj@utexas.edu

http://blogs.utexas.edu/mecc/

ACRONYMS AND ABBREVIATIONS

Bcf/d	Billion cubic feet per day
BTU	British Thermal Unit
CAIT	Climate Analysis Indicator Tool
CCGTs	Combined Cycle Gas Turbines
CCS	Carbon Capture and Sequestration
CH_4	Methane
CO_2e	Carbon Dioxide Equivalent
CoG	Cost of Generation
CP	Capacity
CSP	Concentrated Solar Power
EDGAR	Emissions Database for Global Atmospheric Research
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
ERCOT	Electric Reliability Council of Texas
ETP	Energy Technology Perspectives
FERC	Federal Energy Regulatory Commission
FiT	Feed-in-tariffs
GHG	Greenhouse Gas
$GtCO_2$	Gigatonne Carbon Dioxide
$GtCO_2e$	Gigatonne Carbon Dioxide Equivalent
GW	Gigawatt
HELE	High Efficiency Low Emissions
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IRENA	International Renewable Energy Association
ISOs	Independent system operators
LCOE	Levelized Cost of Electricity
LNG	Liquefied Natural Gas
MATS	Mercury and Air Transmission Standards
MW	Megawatt
NOx	Nitrogen Oxide
OCGTs	Open Cycle Gas Turbines
OECD	Organization for Economic Cooperation and Development
PV	Photovoltaic
RD&D	Research, Development and Demonstration
RE	Renewable Energy
SHP	Small Hydropower
SO_2	Sulphur Dioxide
TCEP	Tracking Clean Energy Progress
TSOs	Transmission system operators
TWh	Terawatt hours

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The energy production sector is one of the largest contributors to greenhouse gas emissions on the global level. This report identifies the top five emitters within the energy production sector (China, the US, Russia, the EU, and India) and examines three complementary strategies for reducing energy production emissions within each country. These include carbon capture and sequestration (CCS), renewable technologies, and fuel switching, which offer the greatest abatement potentials within the energy production sector. The IEA identifies 36.25 $GtCO_2$ emissions reduction potential within the top five emitters in the year 2050. Key findings of the paper include:

(1) Coal Will Persist as Important Energy Source

- Coal will likely remain the primary fuel source for most of the world's energy production. However, the top five emitters have or are shifting their policies with respect to coal use.
- As China and India continue to develop, citizens will increasingly demand government policy to mitigate pollution and the negative health externalities associated with coal-intensive power production.
- High-efficiency low-emissions coal generation technology in the medium-term will help to reduce emissions in pursuit while CCS technology becomes commercially feasible.

(2) Renewables Have Strong Potential but Barriers Remain

- Renewable technologies are in many cases cost competitive with fossil fuel powered sources in the long term, although up front capital costs and limited technical capacity present obstacles in both OECD and non-OECD countries.
- Poor grid interconnections and rigid market structures limit China's ability to take advantage of renewable technology, while India's decentralized decision-making approach with respect to renewable deployment has resulted in large inefficiencies.
- Russia's dependence on fossil fuel intensive industries makes it unlikely that it will race to deploy renewables on a large scale basis in the near to medium term.

(3) The Shale Gas Revolution Needs Assistance to Take Off Globally

- Currently, the US and Canada are the only countries that commercially extract domestic shale-gas, which is ultimately driving the transition in these countries.
- The EU remains politically divided on natural gas and the current cost calculus for a coal-to-gas transition does not work for member countries. Eastern European countries could remove the ban on fracturing to reduce their dependence upon coal and Russian gas.
- China and India possesses large natural gas reserves but currently lack the infrastructure and regulatory framework to take advantage of it. In the short-term, China and India will continue to burn domestic coal in order to meet their growing demands for electricity.

RECOMMENDATIONS

(1) HELE / CCS

Policymakers should focus on encouraging the adoption of high-efficiency low-emission technology in new coal generation. This includes increasing supercritical generation capacity while further developing ultra-supercritical and advanced ultra-supercritical technologies. Access to finance to support cleaner coal may be an issue.

Policymakers should adopt strict environmental standards limiting carbon emissions for existing plants to encourage the retirement of older, less efficient coal powered plants. With over 75% of world coal generation at subcritical standards, this will significantly reduce the levels of emissions associated with coal generation.

Continued investment and development of carbon capture and sequestration technology could provide the long-term mitigation carbon emissions from coal-generated electricity. Further investment will help to speed the development of the technology from its current levels of limited deployment and testing towards a mature and practical solution.

(2) Renewables

The Indian government should attempt to better align existing policies. India has considerable potential for expanding renewable energy but suffers from a lack of harmonized policies. Simply put, there are too many incentive programs in place.

The EU should reform either its renewable energy subsidy programs or the market-based ETS system, because they are poorly aligned to work toward emissions reductions. Reducing some subsidy programs within the EU may be preferable, due to the market distortions and inefficiencies that result from them.

The Chinese government should relax rigid electricity market structures that reduce incentives to invest in renewable technologies. Long term contracts lock different regions into selling at fixed prices, often at a loss, thus discouraging investment in renewables capacity.

(3) Fuel Switching

Stricter emissions standards in OECD countries can encourage utilities to retire their aging coal-fired power plants. Replacing this capacity will lower carbon alternatives will be a major challenge. The United States, in particular, is using natural gas to displace coal.

Non-OECD countries should build out their natural gas infrastructure to supplement their new coal-fired power plants. Coal provides the most electricity at the lowest cost to meet the growing demand in non-OECD countries. China and India possess natural gas reserves that they could build out to someday reduce their reliance on coal-fired electricity generation.

Eastern European member states should remove their bans on hydraulic fracturing to reduce the EU's reliance on coal and Russian gas. The phase out of EU nuclear power and the moratorium on fracking has forced European utilities to increase their coal-fired generation and has raised electricity rates. EU member states with significant shale gas reserves should lift the moratorium on fracturing and put in place strict standards to regulate drilling activities.

INTRODUCTION

This paper examines sectoral global greenhouse gas emissions (GHG) in the energy production sector. This report identifies the top five emitters within the energy production sector (China, the US, Russia, the EU, and India) and examines three complementary strategies for reducing energy production emissions within each country. These strategies include carbon capture and sequestration (CCS), renewable technologies, and fuel switching.

The rationale for choosing CCS, renewables, and fuel switching is that they offer the greatest abatement potential within the energy production sector in the near term. This report draws on data from McKinsey & Company (McKinsey), the International Energy Agency (IEA), Energy Information Agency (EIA), Climate Analysis Indicators Tool (CAIT), and the Emissions Database for Global Atmospheric Research (EDGAR) to establish ranges for emissions reductions potentials, and uses McKinsey data to examine abatement costs for each respective technology. The Appendix details the composition of electricity generation across the top 5 emitters from 1990-2011. Moreover, the analysis draws on recent data from the International Renewable Energy Association (IRENA) to establish a cost range for renewable technologies. The intention behind including numerous data sources was to illustrate a spectrum of costs and abatement potential and to identify general trends in the energy production sector.

The report is structured as follows. The first section describes the major country level emitters, lists the primary sources of CO_2 emissions by fuel type, and outlines the projected future trends for CO_2 emissions relating to energy production. The second section describes the overall outlook for emissions reductions in energy production along with the costs of the technologies that will allow the greatest emissions reductions. The third, fourth, and fifth sections outline the technologies and policy solutions which have the greatest potential for reducing GHG emissions. In order, they are CCS, Renewables, and Fuel Switching. The paper concludes with a summary of major findings and recommendations for policymakers.

MAJOR COUNTRY ENERGY PRODUCTION EMISSION LEVELS AND FUTURE TRENDS

According to both the Climate Analysis Indicators Tool (CAIT) and the Emissions Database for Global Atmospheric Research (EDGAR) data from 2008, the energy production sector contributed between 28% (EDGAR) and 32% (CAIT) to worldwide emissions. The CAIT figure includes all electricity and heat related carbon emissions, whereas the EDGAR figure only includes power industry specific emissions. The top five emitters worldwide (in order of their percentage of total CO_2 emissions) include China, the United States, the European Union, India and the Russian Federation. These "Top 5" countries are responsible for between 55-60% of all GHG emissions, and between 62-69% of CO_2 emissions.[1] Both databases suggest that the Top 8 countries contribute from between 70-76% of global CO_2 emissions. To better focus our analysis, we narrowed our selection of countries down to the Top 5 country (or country group) emitters. The Top 5 countries also comprise the largest share of the energy production

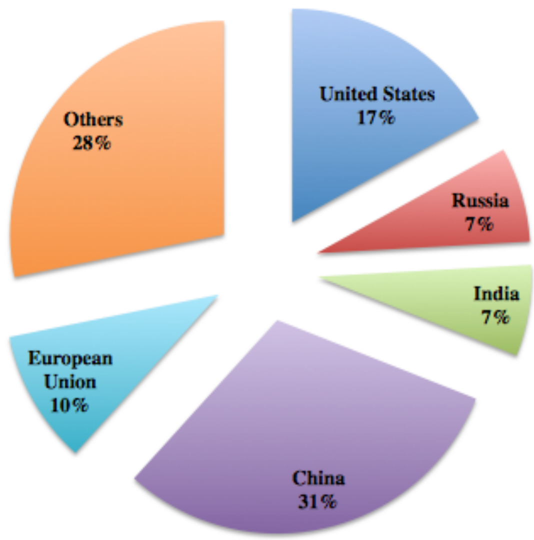
[1] CAIT & EDGAR databases 2008.

sector. Their combined contributions consist of roughly 70% of total sectoral emissions. Of this percentage, energy production constituted between 27% (the EU 28) and 35% (China) of their respective total country emissions. This analysis will focus on areas in which these Top 5 countries can reduce their emissions within the energy production sector.

EMISSIONS LEVELS OF TOP 5 COUNTRY EMITTERS

The tables below show estimates for country level emissions within the energy production sector from CAIT and EDGAR (2008) databases as well as from the IEA (2011). Units are given as $GtCO_2$. The magnitude of concentrated emissions within the top 5 countries justifies the focus on technological solutions to reduce emissions levels in these countries.

Figure 1. IEA Estimated Emissions in Electricity and Heat Production in 2011



Percentages are of the estimated 13 $GtCO_2$ of total sector emissions in 2011.[2]

[2] International Energy Agency, Energy Technology Perspectives 2012 - www.iea.org/etp.

Table 1: EDGAR 2008 Country Level Energy Production CO_2 Emissions

Country	Electricity/Heat ($GtCO_2$)	% Total Sector Emissions
China	3.48	28.52
United States	2.19	17.89
EU 28	1.44	11.78
Russian Federation	0.90	7.37
India	0.82	6.70
Total Top 5	8.83	72.27
Remaining Countries	3.39	27.73

Table 2: CAIT 2008 Country Level Energy Production CO_2 Emissions

Country	Electricity / Heat ($GtCO_2$)	% Total Sector Emissions*	% Country Emissions
China	3.38	24.85	38.77
United States	2.67	19.66	38.88
EU 28	1.60	11.74	32.30
Russian Federation	0.95	6.98	39.77
India	0.85	6.29	39.51
Total Top 5	9.45	69.52	
Remaining Countries	4.14	30.48	

**As a percentage of total global energy production sector emissions*

Although CAIT and EDGAR statistics vary slightly, they both demonstrate the importance of the energy sector as a contributor to total GHG emissions worldwide. The top five countries contribute almost twice as many GHG emissions than the remaining countries combined. Although both CAIT and EDGAR data are from 2008, more recent IEA data from 2011 reflects the same basic distribution and trends between the top 5 emitting countries. Energy production across all countries represents from between 40 - 45 %, EDGAR and CAIT respectively, of total worldwide GHG emissions.

EIA ENERGY PRODUCTION AND WORLDWIDE EMISSIONS

According to the US EIA, energy demand within non-OECD countries, mainly led by China and India, will rise 112% between 2010 and 2040. The slowest growth in demand will exist in Europe and Eurasia as Russia and other former Soviet Republics face declining population numbers and increasing energy production efficiency by replacing Soviet-era equipment.[3] Moreover, non-OECD energy demand growth will outpace OECD demand growth 20% by 2010, 50% by 2020, and 90% by 2040 at the margin. These trends suggest that significant GHG emission reductions will need to occur in non-OECD countries. Along the same lines, projections suggest that by 2040, ASEAN group countries (as a whole) will replace Russia in the Top 5 Country emitters.[4]

IEA REGIONAL PROJECTIONS FOR FUTURE SECTOR EMISSIONS

Estimates suggest that energy production emissions in 2011 totaled 13 $GtCO_2$ and that this level will increase to 15.2 $GtCO_2$ by 2035.[5] The Top 5 emitters include both OECD members and non-OECD members, and the emissions reduction solutions differ according to their projected growth rates and levels of development. The IEA projects that total energy production-related CO_2 emissions will increase at an average rate of 1.3% annually. OECD countries will account for only 0.2% of this increase.

Within the OECD countries, the United States, Japan, and European member states contributed 84% of energy production sector emissions in 2010. These countries' share of sector emissions growth, however, only account for 11% (0.09 $GtCO_2$) of total OECD energy production growth, while the remaining OECD countries will contribute the remaining 89% (0.73 $GtCO_2$) of total OECD emissions growth.[6] Based on projected growth in energy demand, China, India, and Indonesia along with the ASEAN countries will constitute 60 % of total primary energy demand growth worldwide from 2011-2035. [7] [8]

Countries outside of the OECD will account for 94% of total emissions growth from 2010-2040, and Asian countries in this group could represent 71% of the total increase. China's projected contribution could account for 69% of non-OECD Asia emissions growth and 49% of total world increases in carbon dioxide emissions.[9] The sheer size of emissions growth across Asia makes it important to consider the source of these current emissions

[3] United States Energy Information Administration, "International Energy Outlook 2013." July 2013.
[4] IEA, ETP 2012.
[5] IEA, "World Energy Outlook 2013." November 2013.
[6] Ibid.
[7] Ibid.
[8] Ibid.
[9] Ibid.

SOURCES OF CO_2 EMISSIONS WITHIN THE ENERGY SECTOR

Table 3. Total Worldwide Emissions Energy Production / Consumption 2011[10]

Country	Coal Consumption	%	Gas Consumption	%	Oil Consumption	%
US	1.89	13%	1.29	21%	2.32	21%
Russia	0.46	3%	0.98	16%	0.32	3%
India	1.26	8%	0.12	2%	0.43	4%
China	7.59	51%	0.26	4%	1.11	10%
EU 28	1.08	7%	0.94	15%	1.85	16%
Others	2.66	18%	2.60	42%	5.25	47%
Totals	14.94		6.20		11.29	

Units are $GtCO_2$. This data includes production and consumption of fossil fuels across sectors, rather than energy-production specific fossil fuel data.

ENERGY PRODUCTION EMISSIONS REDUCTION POTENTIAL - TOP 5 EMITTERS

EMISSIONS REDUCTION POTENTIAL - ENERGY SECTOR

There are significant opportunities for emissions reductions in the energy production sector. The IEA estimates suggest that emissions reductions potential for the energy production sector increase to 11 $GtCO_2$ in 2030, 18 $GtCO_2$ in 2040, and 22 $GtCO_2$ in 2050.[11]

The table below outlines McKinsey's estimates for 2005 emissions levels in the top 5 emitters as well as the abatement potential for 2030 in the energy production sector. Consistent with the IEA data, China, the United States, and India represent the greatest gains out to 2030.

[10] The Shift Project Data Portal.

[11] These emissions reductions are based on a scenario to keep global emissions levels below the amount that would increase global temperatures by more than 2 degrees Celsius by 2050.

Table 4. McKinsey Climate Desk 2005-2030 BAU Scenario and Energy Sector Abatement[12]

Country	2005 Total Emissions	2030 Total BAU Emissions	2030 Energy Only Abatement Potential*	Emissions Change Relative to 2030 BAU
United States	6.60	7.29	1.58 (14.6%)	-22%
EU 27	4.89	5.20	0.73 (6.8%)	-14%
Russia	2.40	2.94	0.62 (5.7%)	-22%
China	7.52	16.67	3.67 (34%)	-22%
India	1.75	4.72	1.19 (11%)	-25%
Total	**23.16**	**36.82**	**7.79 (72%)**	

** Percentages represent the country's share of emissions reductions based on the total reductions of 10.8 $GtCO_2$. Unless specified, units are in $GtCO_2$,*

EMISSIONS REDUCTION POTENTIAL - SPECIFIC TECHNOLOGIES

Within the energy production sector, carbon capture and sequestration (CCS), fuel switching, and renewable technologies have the greatest potential for reducing emissions. The tables below detail both the annual abatement potential in 2030 and the abatement costs for each technology.

Table 5. Abatement Costs and Associated Potential Annual Reductions 2030[13]

Technology	2030 Annual Abatement ($GtCO_2$)	Implementation Costs (€/ton CO_2 avoided)	($/ton $/$CO_2$ - avoided)
CCS	2.185	335.51	447.86
Shift of coal new builds to increased gas generation	0.013	11.94	15.96
Nuclear	1.23	7.46	9.97
Renewables Ω	4.046	188.22	251.63

Ω - Renewables includes deployment of hydroelectric, geothermal, wind power, solar PV, solar concentrated, and biomass technology.

Although the table above suggests that nuclear power represents a cost-effective option for reducing emissions, the strict regulatory environment surrounding the nuclear power industry along with the massive capital costs will likely prevent a significant increase in nuclear power worldwide. This particularly holds true in the United States where cost overruns, low perception of return on investment compared with other energy industry investments, the fallout after the Fukushima disaster in Japan, and the policy challenges associated with disposing of nuclear waste all contribute to the lack of feasibility of nuclear power in the immediate

[12] McKinsey and Company, 2009.

[13] Data taken from McKinsey Climate Desk. Assumes full implementation of listed technologies and lists CO_2 abatement potential at 2030.

future. While the legacy of Fukushima left a dark cloud over much over the industry, China, is still moving forward on plant construction, though the disaster in Japan may have had some effect on the pace of implementation.[14] Japan, after much vacillation, is poised to restart its nuclear sector in 2014.[15] However, in the absence of a major change in politics of nuclear power and/or the up-front costs of investment, it is difficult to see nuclear power offering a viable solution to climate change in the medium run. This is problematic given that nearly a 1/3 of the IEA's mid-century emissions reductions for a 2 degree scenario are estimated to come from nuclear power.[16]

CCS represents the most expensive technology in terms of its abatement potential relative to its cost, although technological innovation in the major coal-dependent economies could quickly change this. Renewables comes in second place with respect to costs / ton CO_2, but the potential emissions reductions overshadow those of CCS, fuel switching, and nuclear.

Table 6. IEA Estimates of Annual Emissions Reductions Potential ($GtCO_2$) Required by Solution for 2 Degrees Celsius Warming Scenario to 2050[17]

Solution	2015	2020	2025	2030	2035	2040	2045	2050
Carbon capture and storage	0.03	0.16	0.65	1.48	2.66	3.69	4.35	4.81
Renewables	0.75	1.81	2.99	4.66	6.12	7.38	8.41	9.47
End-use energy efficiency	0.00	0.09	0.64	1.02	1.56	2.06	2.46	2.70
End-use fuel switching	0.03	0.11	0.39	0.88	1.48	1.99	2.46	2.89
Nuclear	0.56	1.59	3.00	5.05	7.29	9.40	10.93	12.29
Generation efficiency and fuel switching	0.00	0.18	1.06	1.66	2.46	3.13	3.70	4.09
Total	1.37	3.94	8.73	14.75	21.57	27.65	32.31	36.25

** Units are reported as $GtCO_2$. While end-use energy efficiency falls outside the scope of this report, the projections to meet the 2 degree Celsius warming scenario included this component of overall emissions reductions.*

[14] Busby 2011.
[15] Fackler 2014.
[16] Busby 2013.
[17] IEA ETP, 2012.

Table 7. Annual Emissions Reductions Potential ($GtCO_2$) of Technologies for Top 5 Emitters[18]

Technology	US	CN	IN	RU	EU
Carbon capture and storage	0.91	2.31	0.83	0.26	0.50
Renewables	1.10	3.12	1.21	0.43	0.75
End-use energy efficiency*	1.57	3.97	2.33	0.79	0.81
End-use fuel switching	0.35	2.20	0.17	0.17	0.25
Nuclear	0.18	1.81	0.42	0.15	0.14
Power generation efficiency and fuel switching	0.00	0.00	0.05	0.00	0.00
Total Annual Reduction 2050	**4.11**	**13.41**	**5.01**	**1.80**	**2.45**

** Units are reported as $GtCO_2$. While end-use energy efficiency falls outside the scope of this report, the projections to meet the 2 degree Celsius warming scenario included this component of overall emissions reductions.*

The tables above clearly demonstrates the magnitude of emissions reductions that China, India, the United States, and the EU must achieve over the next 40 years to remain on target for a 2 degrees Celsius warming scenario.

Based on the above data and a review of the political, cultural, and social environment of the top five emitters and the future trends for global energy related emissions; carbon capture and storage, renewables, and fuel switching are the solutions with the greatest potential for implementation.

The next section will discuss each emissions reduction technology in detail and provide context and analysis for the potential of each technology.

[18] IEA ETP, 2012.

HIGHER EFFICIENCY COAL AND CARBON CAPTURE AND STORAGE/SEQUESTRATION (CCS): RATIONALE AND CHALLENGES[19]

For many developing economies, coal and other fossil fuel energy sources will remain the primary method for electricity generation in the near future. Following the Fukushima nuclear accident in Japan, many developed nations have shifted their own generation towards coal.[20] This shift away from nuclear power, particularly among European nations, coupled with the low price of coal, could increase fossil fuel dependence worldwide. Given the level of worldwide emissions from coal today, and the projected growth in energy demand over the next few decades, a technology that could allow for its continued use while mitigating its emissions contribution has a significant place in future climate policy. This is the goal of CCS. Although it has not reached full development or commercial feasibility, the technology has significant potential for reducing the GHG impact of coal for much of the developing world. The continued use of coal in power generation presents a significant challenge to overall emissions reductions commitments. An emissions reduction portfolio that does not address coal, as CCS aims to do, will not make a significant impact on global CO_2 emissions.

In the medium-term, plants employing high-efficiency and low-emission technology (HELE) will provide a vital link between conventional coal-generated electricity and CCS-generated electricity. Today 50% of new coal-generating plants use HELE technologies including supercritical and ultra-supercritical generation.[21] While this is promising in terms of reducing the emissions impact of coal-generation, roughly 75% of all coal-generation today do not employ HELE technology, and about half of current coal-generating capacity is over 25 years old.[22] Implementing super-critical generation will provide a link to even more efficient ultra-super critical technology that will further reduce the emissions associated with coal-generation.

HELE technology includes three tiers of carbon-intensity and coal-consumption intensity: supercritical, ultra-super critical, and advanced ultra-supercritical technology.[23] Non-HELE technology, or sub-critical generation, is most common in coal-generated electricity today. Plants combust pulverized coal in a boiler to produce steam that powers a generator. Sub-critical generation both requires more coal and higher carbon emissions than its more efficient descendants. Supercritical generation produces steam at higher pressures and allows for greater efficiencies in coal consumption that help offset its higher costs.[24] Ultra-supercritical technology operates at greater pressure levels and higher temperatures to improve the efficiency of generation. While both of these technologies are in production, the final HELE technology, advanced ultra-supercritical technology requires substantial capital costs due to the extreme

[19] Jones, 2013.
[20] The Economist, 2013.
[21] The International Energy Agency, 2013.
[22] Ibid.
[23] The International Energy Agency, 2013.
[24] Ibid.

pressure and temperature of generation. The requirement for super alloys that can withstand the higher pressures is a major challenge to implementation today.[25]

It is clear, however, that HELE technology will not provide the emissions reductions necessary to achieve the 2 degrees Celsius warming scenario by 2050. The IEA estimates that a 6 degree Celsius warming scenario will require the growth of HELE capacity from 27% in 2015 to 39% in 2030 and 68% by 2050.[26] While HELE technology provides a vital link, IEA projections suggest that HELE technology along with substantial CCS technology implantation in the 2030s will be required to stay within a 2 degrees Celsius warming scenario.

Table 8: Reductions Potential for Top 5 Emitters from BAU through CCS (2C to 6C scenario range)

Countries	2020	2030	2050
China	0.05	0.67	2.31
European Union	0.03	0.23	0.50
India	0.02	0.17	0.83
Russia*	0.01	0.09	0.26
ASEAN Countries	0.01	0.01	0.36
United States	0.05	0.32	0.91
Total	**0.16**	**1.48**	**4.81**

Source: IEA ETP

**According to projections, by 2035, the emissions reduction potential from CCS for ASEAN countries will replace that of Russia. The difference in emissions reductions is, however, small enough that Russia will remain among the major energy production emitters.*

OVERVIEW OF CCS METHODS

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

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

[25] Ibid.
[26] Ibid.

The final method is *oxy-fuel combustion* where producers burn fuel in an environment of pure oxygen, rather than normal air. At this point flue gases (primarily water vapor and carbon dioxide) are re-circulated into the chamber, cooled, and the result is a stream of carbon dioxide and a byproduct of condensed water. Each of these methods has its own drawbacks and limitations, and there is no question that each of these will require significant investment to come to fruition as a viable technology for reducing greenhouse gas emissions.[27] All ultimately require underground disposal in geologic formations.

Much of the development of CCS technology is taking place in the developed world. In the United States, new regulations from the Environmental Protection Agency will require new coal-fired power plants to adopt CCS technology to limit carbon dioxide emissions to 1,100 lbs. per megawatt hour. This is far less than the 1,768 lbs. per megawatt hour generated on average at U.S coal power plants.[28] At this point, development of the technology has not proven a wide-scale commercial potential. The Department of Energy has invested significant resources (Congress apportioned $3.4 billion as part of the Recovery Act of 2009) in a research, development, and demonstration (RD&D) program to stimulate interest in the technology. While there are no commercial ventures that have adopted CCS technology solely for the purposes of carbon sequestration, the RD&D program has demonstrated for the technology to function at a commercial scale.

One facility that is under development in Kemper County, Mississippi, is a lignite-fueled integrated gasification combined-cycle (IGCC) facility. The technology in this type of plant resembles the pre-combustion process for carbon capture above. According to the Congressional Research Service, this facility will transport its estimated 3 million tons of CO_2 each year for use in enhanced oil recovery operations in Mississippi by early 2014.[29] Estimates suggest that the total cost for the project will reach $3.4 billion. Supporters of the technology argue that over time this figure will fall as more and more plants adopt the technology. Its critics argue that it is too costly; the significant investment on the part of the Department of Energy furthers their skepticism.

BARRIERS TO HELE AND CCS

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

[27] IPCC, 2005.
[28] Plumer, 2013.
[29] "Kemper Timeline." Mississippi Power.

find a way for employing worldwide coal resources without undermining the 2 degrees Celsius warming scenario.

UNITED STATES: FINANCIAL AND MARKET BARRIERS

As detailed in the later section on fuel switching, the coal sector in the United States has suffered a historic and possibly permanent decline as a consequence of low cost natural gas and new regulations. Though any new coal plant builds in the United States would likely conform to higher efficiency coal technology, the combination of low natural gas prices and the regulatory environment are making new coal plant construction in the United States cost prohibitive.[30]

At the same time, the favorable cost environment for natural gas makes it less attractive to invest in CCS technology, since there is a significant cost premium associated with CCS. Those concerns were accentuated during the financial crisis which made large-scale capital projects difficult to support at a time of austerity. The more difficult challenge is the costs for commercial coal burning power plants to incorporate CCS capture technology that also include the transportation costs to more distant geologic formations. Demonstration plants like the Kemper County facility rely on on-site enhanced oil recovery, which limits the transportation distance between the coal burning facility and underground storage locations.

Adding CCS technology to a coal burning power plant adds costs because the operation of the technology itself requires energy, thus imposing an "energy penalty" of anywhere between 7%-10% upwards[31] on 15-25% depending on the technology.[32] As a consequence, a 2012 study by the Congressional Budget Office concluded that the first plant with CCS will likely cost 76% more than a conventional coal plant, though that cost differential was estimated to decline to 35% when 210 gigawatts of CCS coal plants are installed worldwide.[33]

While the United States is less likely to be building many new coal plants in the immediate future, should natural gas prices increase significantly. Coal may make a resurgence, and CCS may yet have a future in the United States.

CHINA: THE CHALLENGES OF ECONOMIC REBALANCING[34]

While the relevance of CCS in the United States is uncertain given the coal sector's current weakness, CCS may be especially relevant in China, where coal is the dominant source of energy. China's headlong push for economic growth led to an over-reliance on energy-intensive heavy industry like steel, cement, and glass production, both to serve burgeoning

[30] IEA, ETP 2012, 68.
[31] IEA, ETP 2012, 275.
[32] European Environment Agency 2011.
[33] The levelized cost was estimated to be $110 per megawatt of electricity for the first CCS plant compared to $59 for a conventional coal plant in 2010 dollars. Those costs were estimated to decline to $74 and $55, respectively. CBO 2012, 9.
[34] Jones, 2013.

domestic demand in China and for international markets. With nearly 70% of China's energy needs coming from coal and 51% of worldwide emissions coming from coal combustion in China alone,[35] changing China's trajectory on coal quickly is both a high priority but exceedingly difficult.

China continues to develop at a substantial pace and coal continues to provide a reliable source of inexpensive energy production, the percentages of sectoral emissions from China will likely continue to grow. The IEA estimates that the total energy supply will remain roughly the same until 2020, and this includes coal as a source for 30% of total worldwide energy. To achieve lower CO_2 emissions by 2050 in line with a 2 degrees Celsius warming scenario, total coal demand would need to fall 45% from its 2009 levels.[36] Understanding this reality is important to develop policies that curtail GHGs in the near term. This coal dependence is creating major problems for both the Chinese people and the central government.

While most of China's new coal builds are set to conform to HELE technology, the challenge is the sheer volume of plants being considered. After the 2013 "airpocalypse" episode that left much of northern China blanketed in dense smog, China restricted the construction of about fifteen new coal plants in and around Beijing and neighboring provinces. However, China was still set to build about 350 new coal plants all across the country.[37]

The government's acknowledgment of the air quality problems associated with coal dates to the 11th Five-Year Plan (2006-2010), which required the closing of 85 GW of generating coal plants that did not meet efficiency standards. The current 12th Five-Year Plan (2011-2015) sets a cap on total production of coal by 2015 and requires large coal plants (600 MW or greater) to employ supercritical or ultra-supercritical technology. The overall goal of the increased efficiency standards for coal plants is to reduce the carbon intensity of power generation by 17 percent (from 2010) by 2015 and 40-45 percent by 2020.[38] This level of air pollution poses a threat to internal security and threatens sustained economic growth, which is changing the government's calculations with respect to investment in CCS and other alternatives to coal.

Even as China struggles to reduce its dependence on coal through diversification of fuel sources, efficiency, and economic rebalancing, it is also investing heavily in CCS technology. As of February 2014, China has 12 large-scale CCS pilots, up from 6 in 2011.[39] However, none of them are connected to major coal-fired power plants but are rather connected to natural gas wells and refineries.[40] Beyond the sheer scale of the problem, the main barriers in China may be technical and economic. Can CCS be deployed in power plants incorporating the latest technology from around the world and drive down costs of deployment? Here, China would benefit from outside expertise and be able to quickly incorporate new intellectual property into practice.

[35] EIA, 2012.
[36] IEA & OECD, 2012.
[37] Yang and Cui 2013.
[38] IEA, 2013.
[39] Global CCS Institute, 2014.
[40] Mann, 2014.

INDIA: FINANCIAL AND POLITICAL BARRIERS

Policies within India's 12th Five-Year Plan (2012-2017) acknowledge the need for more efficient coal generation, but as India's situation differs from that of China, it is less restrictive. The goal is that 50-60 percent of new coal generation should fall under supercritical standards. The 13th Five-Year Plan, however, does require that all new coal plants should at least employ supercritical technology. This represents a shift towards more efficient coal generation, but the policies appear to not have the same urgency as the policies that China is implementing.[41]

India's continued reliance on the cheap and reliable coal-generated electricity will require stronger commitments towards implementing HELE technology to at least the supercritical level. In 2008, India's supercritical coal generation capacity was less than 5% of its total coal generation. [42] To adhere to a 2 degrees Celsius scenario, India must employ HELE technology to 50% of its coal-generation and up to 88% in 2050 with substantial implementation of CCS generation. The IEA's scenario projects that, without CCS technology, even if India reached 40% HELE adoption by 2040 and 80% by 2050, the 2 degrees Celsius warming scenario cannot be reached.[43] Policymakers should encourage the retiring of older, less efficient coal plants and act to speed the adoption of HELE technology in new plants.

Given that China's present is potentially India's future when it comes to air pollution from coal burning power plants, why is India at the very least not phasing in cleaner burning coal technology faster? Possibly the main reason is cost. IGCC plants which are potentially even more efficient than ultrasupercritical coal plants but estimates suggest that India's high-ash coal would mean that IGCC plants require significant auxiliary power consumption, possibly doubling the costs of energy production compared to subcritical coal burning power plants.[44] India might not be willing to embrace more efficient coal technology without outside finance. However, both the World Bank and the U.S. government, have largely eliminated international finance for coal plants, which may be appealing but ineffective in shaping India's plans to build large numbers of new coal plants.[45]

EUROPEAN UNION: POLITICAL BARRIERS

The EU's inclusion of power generation in the emissions trading scheme has taken place over several phases. While in the past, generation emissions have not been part of the carbon trading market; beginning in 2013 with "Phase 3," power generators will no longer be "grandfathered" into the scheme. This means that coal plants across Europe will face stricter standards along with a cost associated with their emissions. In many cases, countries have responded by phasing out their coal plants rather than upgrading them for compliance. In the United Kingdom, for example, more than 25 percent of all coal plants will close by 2016.[46]

[41] IEA, 2013.
[42] Major Economies Forum on Energy and Climate, 2009.
[43] IEA,2013.
[44] Pahuja et al., 2014.
[45] Plumer 2013; Barron-Lopez 2013.
[46] IEA. 2013.

However, other policy decisions are sending an inconsistent signal about the future of coal in Europe. The Fukushima nuclear accident in 2011 has prompted Germany's government to phase-out its nuclear capacity completely by 2022.[47] Germany has expanded its coal-fired electricity generation by 5.3 GW in 2013 and a further 10 new plants are under construction.[48] Given the challenges of implementing renewables along with their costlier and less consistent electric supply compared with coal-generated electricity, the adoption of low-carbon coal generated electricity will continue to play an important part in emissions reductions within the European Union.

RECOMMENDATIONS AND CONCLUSIONS

1) Policymakers should focus on encouraging the adoption of high-efficiency low-emission technology in new coal generation.

The 2 degrees Celsius scenario requires substantial worldwide implementation of CCS starting in the 2030s and on into the 2050s. In the United States, China, and Europe, all coal power plants must use HELE technology along with a substantial percentage of CCS by 2030.[49] While a strong reliance on this technology seems hopeful, given its current level of development, the opportunities for emissions reductions that HELE technologies provide in the interim give policymakers a near-term solution to the environmental challenges of continued worldwide reliance on coal-fired generation. International donors, including the World Bank and the United States, might need to reconsider the near blanket elimination of support for coal to incentivize both a transition to cleaner fuels, fuel efficiency, but also efficient coal plants.

2) Policymakers should adopt strict environmental standards limiting carbon emissions for existing plants to encourage the retirement of older, less efficient coal powered plants.

Stricter standards on coal burning power plants may encourage countries, particularly China and India, to diversity to renewables energy sources, to develop their own gas fields, and possibly to import natural gas from abroad. Development of local industry, particularly of domestic natural gas, may require international technical assistance. This could take the form of information and technology exchange for hydraulic fracturing technology and other unconventional extraction methods that have spurred the US shale gas production boom.

3) Continued investment and development of carbon capture and sequestration technology could provide the long-term mitigation carbon emissions from coal-generated electricity.

CCS offers potential gains in reducing carbon emissions, but the technology must reach a development level consistent with deployment by 2020 to allow the gains to contribute to the necessary level for a 2 degrees Celsius warming scenario. Hope for potential commercial deployment is still behind target for 2020 deployment given only 13 large-scale demonstration

---

[47] Institute for Energy Research, 2013.
[48] Ibid.
[49] IEA, 2013.

projects are under construction or operation.[50] This slow speed of demonstration of CCS and the requirement for large-scale projects will likely continue to limit the learning and experience curve in the short term until a large-scale break-through occurs with respect to commercial feasibility. Given the reality of the coal problem, particularly in India and China, CCS development should continue to provide a solution for coal dependency of developing economies. As these countries continue to develop, their citizens, and therefore policymakers, will put a higher priority on reducing the impact of coal and its emissions on the environment.

IMPLEMENTING RENEWABLES: CHALLENGES AND SCALE-UP POTENTIAL

According to the IEA, renewable technologies have the potential to create 1 $GtCO_2$ emissions reductions by 2020, decreasing BAU rates from 40 $GtCO_2$ to 39 $GtCO_2$. This represents a 2.5% reduction in worldwide emissions. By 2030, it identifies 4 $GtCO_2$ reductions potential, reducing BAU rates from 45 to 41 $GtCO_2$. Moving out to 2050, the reductions grow larger: the IEA predicts total global emissions to be roughly 58 $GtCO_2$ as a BAU scenario. Renewable technologies could reduce emissions by 10 $GtCO_2$, bringing the emissions of CO_2 to approximately 48 $GtCO_2$. This represents a 17% reduction in total GHG emissions in 2050. [51]

The top 5 emitters in the energy production sector represent a large percentage of the worldwide emissions reductions potentials. In 2030, the top 5 emitters account for 3.8 of the 4 Gt CO_2 reductions, or 95% of the reduction. Going out to 2050, the top 5 emitters account for 8.3 out of the 10 $GtCO_2$ reductions potential – an 83% decrease over BAU emissions.[52]

The following table breaks down the same IEA emissions reductions model by country, and identifies the emissions reduction potential in the top emitters using the same model.[53]

Table 9: Renewables Reductions Potential for Top 5 Emitters In Energy Production Sector

Countries	2020	2030	2050
US	0.1 (5.7 to 5.6)	0.7 (5.5 to 4.8)	1.0 (5.4 to 4.4)
China	1.0 (12 to 11)	2.0 (14 to 12)	4.0 (18 to 14)
Russia	0.1 (1.9 to 1.8)	0.2 (2.0 to 1.8)	0.5 (2.4 to 1.9)
India	0.1 (3 to 2.9)	0.5 (4.2 to 3.7)	1.3 (7.4 to 6.1)
EU 27	0.1 (4.1 to 4)	0.4 (4.2 to 3.8)	0.7 (4.1 to 3.4)
Total	1.4 $GtCO_2$	3.8 $GtCO_2$	8.3 $GtCO_2$

Source: IEA ETP[54]. All units are in $GtCO_2$.

[50] Ibid. p. 55.
[51] IEA, 2012.
[52] Ibid.
[53] Ibid.
[54] Ibid.

In order, China, the US, and India present the greatest opportunities for emissions reductions with the expansion of renewable technologies. China could contribute 1 $GtCO_2$ reduction in 2020, roughly 71% of the total reduction potential in the top 5 emitting countries. That relative contribution may decline by 2050, when China represents a 48% contribution to emissions reductions among the top 5 emitters. The US contribution, only representing around 7% of the reductions potential in 2020 (or .1/1.4 $GtCO_2$), will rise to 12% (or 1/8.3 $GtCO_2$) by 2050. India in particular will see its relative contribution rise from 7% of the reductions potential in 2020 (or .1/1.4 $GtCO_2$) to roughly 16% in 2050 (or 1.3/8.3 $GtCO_2$).

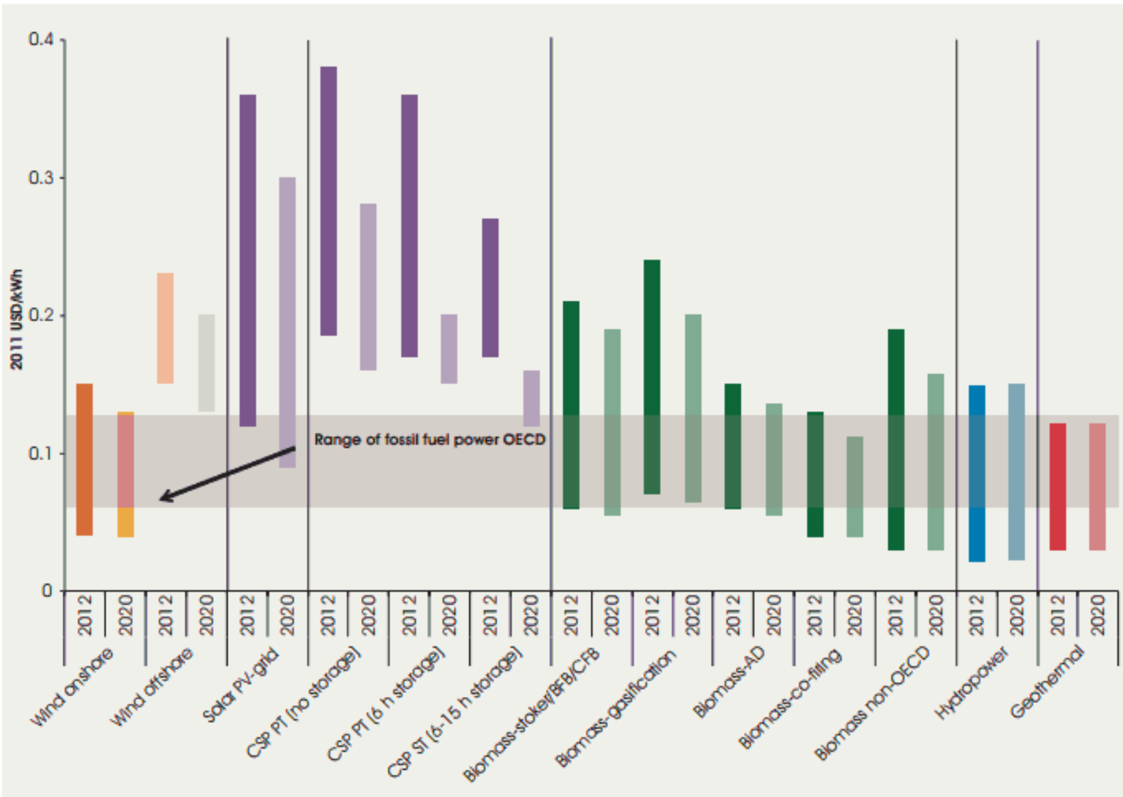
While the IEA's projections are imperfect and only identify rough estimates for reductions potential, their model does identify the major trends and areas for improvement with respect to the deployment of renewable technology. The remaining sections dedicated to renewable technologies will explore the potential for renewable technologies including recent cost estimates, investments and additions as of 2011, current renewable capacity by top emitter, and a discussion of the unique barriers to renewable deployment within each of the top 5 emitters.

RENEWABLES POTENTIAL

In many cases, renewable technologies are already cost-competitive with fossil fuel sources – assuming one looks at the lifetime of the technology, rather than the up-front costs. Onshore wind, biomass, geothermal, and hydropower vary in terms of their up-front costs and maintenance costs; however, the levelized cost of electricity (LCOE) -- the cost of a technology over its lifetime as a power producer -- is already comparable to similar fossil fuel powered sources in OECD countries.

Figure 2 illustrates the LCOE for various renewable technologies as compared to a range of fossil fuel-powered sources within the OECD. Onshore wind is, in many cases, already cost competitive with a range of fossil fuel power sources, and will likely continue to become more cost competitive in the medium term. The same is true for biomass sources, hydropower, and geothermal. Because concentrated solar power (CSP), a technology that uses lenses or mirrors to concentrate sunlight and convert it into heat, is the most expensive of the renewable technologies listed below and also unlikely to become cost-competitive with fossil fuel power in the near term, it is excluded from the following sections. This is because it is difficult to justify the purchase of CSP when other cost-competitive renewable technologies and fossil fuel power sources – such as coal or natural gas plants – already exist.

Figure 2: Typical LCOE Cost Ranges for Renewable Power Generation Technologies, 2012 and 2020



Source: IRENA[55]

The projections above suggest that the costs of solar PV and onshore wind will continue to decline quickly and thus reduce the cost barriers to their implementation. Offshore wind and CSP cost reductions are proceeding much more slowly, while biomass, hydropower and geothermal technologies offer some of the most cost effective strategies within the renewables space.[56]

Now that the costs of technologies are set in place, this report will turn to trends in renewables technologies. Specifically, it will attempt to assess the preferences of each government of the top 5 energy production emitters in the world.

[55] IRENA, 2013.
[56] IEA, 2013.

INVESTMENT AND ADDITIONS IN 2011

Table 11 ranks the top five countries with respect to additions in renewable technology capacities as well as total investment in new capacity in 2011. As such, it can serve as a rough proxy for each government's preferences for deploying renewable technology. Because one of the chief obstacles to the adoption of renewable technologies is up-front cost, this table ranks which countries are willing to pay those costs, and it also captures the countries that could find the technologies appropriate for their circumstances. One of the key themes is that Russia, a Top five emitter in the energy production sector, is conspicuous by its absence. Another key theme is that the top five countries with respect to annual additions of renewables in 2011 do not necessarily match up to the top 5 emitters in the energy production space.

Table 11. Annual Additions/Production of Renewables in 2011

Rank	New Capacity Investment	Hydro Capacity	Solar PV Capacity	Wind Power Capacity
#1	China	China	Italy	China
#2	United States	Vietnam	Germany	United States
#3	Germany	Brazil	China	India
#4	Italy	India	United States	Germany
#5	India	Canada	France	U.K./Canada

Source: REN21[57]

Another way of getting at a government's preferences is by using total installed renewable energy capacity. The following table in some ways reflects historical preferences of governments by illustrating where their total renewable capacity comparison lies with respect to other governments. It is clear that some countries, the US, China, and Germany, are leaders across renewable technologies. Some countries have specific geographic factors facilitating the use of one technology. For example, the Philippines and Indonesia are world leaders in geothermal capacity, while Brazil leads in bioenergy capacity. India does not appear on this list despite being a top 5 emitter in the energy production sector, and Russia only registers at number five in hydropower capacity. They thus represent two countries where significant progress could occur.

[57] REN21, 2012.

[57]Ibid.

Table 12a. Total Renewable Energy Capacity (CP) 2011

Rank	Renewable Power CP (including Hydro)	Renewable CP (excluding Hydro)	Renewable CP/Capita (excluding Hydro)	Bio CP
#1	China	China	Germany	United States
#2	United States	United States	Spain	Brazil
#3	Brazil	Germany	Italy	Germany
#4	Canada	Spain	United States	China
#5	Germany	Italy	Japan	Sweden

Source: REN21[58]

Table 12b. Total Renewable Energy Capacity (CP) 2011

Rank	Geo CP	Hydro CP	Solar PV CP	Solar PV CP/ capita	Wind CP
#1	United States	China	Germany	Germany	China
#2	Philippines	Brazil	Italy	Italy	United States
#3	Indonesia	United States	Japan	Czech Republic	Germany
#4	Mexico	Canada	Spain	Belgium	Spain
#5	Italy	Russia	United States	Spain	Indonesia

Source: REN21[59]

Another means of measuring a country's preferences for renewables is its use of policy to increase the supply of renewable technology. Policy strategies are numerous, and include regulatory policies, fiscal incentives, and public financing to create incentives for the use of renewable technologies. Table 13 provides a list of different policies the top 5 emitters have used in order to stimulate the use of renewable technologies.

Table 13a. Incentive policies related to Renewable technologies in the top five emitters

Policies for encouraging RE	Capital Grant, Subsidy or rebate	Feed in tariff	Electric utility quota obligation	Energy Production payment
China	National Level	National Level	National Level	National Level
Russia	National Level	No	No	No
US	National Level	State Level	State Level	State Level
India	National Level	National Level	National Level	No
EU	Most*	Most*	Most*	Most*

[58] REN21, 2012.
[59] REN21, 2012.

Table 13b. Incentive policies related to renewable technologies in the top five emitters

Country	Public investment (Ω)	Public competitive bidding	Biofuels obligations/mandate	Heat obligation/mandate	Tradable REC
China	National Level	National Level	National Level	National Level	No
Russia	No	No	No	No	No
US	National Level	State Level	National Level	State Level	State Level
India	National Level	National Level	National Level	State Level	National Level
EU	Most*	Most*	Most*	Most*	Most*

Source: REN 21[60]
Ω Includes public investment, loans or grants.
* Within the EU, most member countries have this policy, but there are still countries that have not adopted them.

BARRIERS

While renewable technologies have significant potential for reducing GHG emissions, they also suffer from serious limitations and face many challenges. Renewable technology may present an opportunity to substitute, or complement traditional fuel sources for power, but the problem of variable contributions to the grid may be difficult to overcome in the absence of either cheaper energy storage technologies or complementary renewable fuel sources. Moreover, renewables may simply be too expensive for some countries to incorporate into their existing power production structure, because they have high up-front costs and may require large amounts of investment to cover maintenance and upkeep costs.

While the levelized cost of electricity, the average cost of electricity over the lifetime of the renewable technology, is declining,[61] coal still remains a cheap fuel source and will continue to be so in the near term. Purchasing coal for existing power plants may be cheaper in the short term than investing in renewables, even if in the long term they may be competitive with fossil fuel sources. Governments that have adopted renewable policies have focused on supply side interventions to promote the use of renewable technologies;[62] moving forward, the question becomes one not just of increasing supply, but how to integrate them into the existing power grid infrastructure.[63]

The remainder of this section will focus on country-specific obstacles toward implementing renewable solutions, or realizing the full potential of these solutions.

[60] REN21, 2012.
[61] Ibid. pg. 13.
[62] See Table: Incentive Policies Renewable Technology.
[63] Stephenson-Reynolds, 2013.

CHINA: MARKET BARRIERS AND A FRAGMENTED ELECTRICITY GRID

China does not have a unified electricity grid. It has six independent regional power grid clusters, including the Northeast, North, East, Central, South, Northwest, Xinjiang, and Tibet. Three companies manage these clusters: State Grid Corporation of China manages four (the East, Central, Northwest, Northeast, and part of the North grid); the Western Inner Mongolia Corporation manages the remainder of the North Grid, and the China Southern Grid Company manages the Southern grid.[64] In each regional grid cluster, balancing of supply and demand take place at the provincial level. Trading of power takes place at both the provincial and regional level, although cross-regional trade is minimal.[65]

Figure 3. Map of Chinese Electric Grid

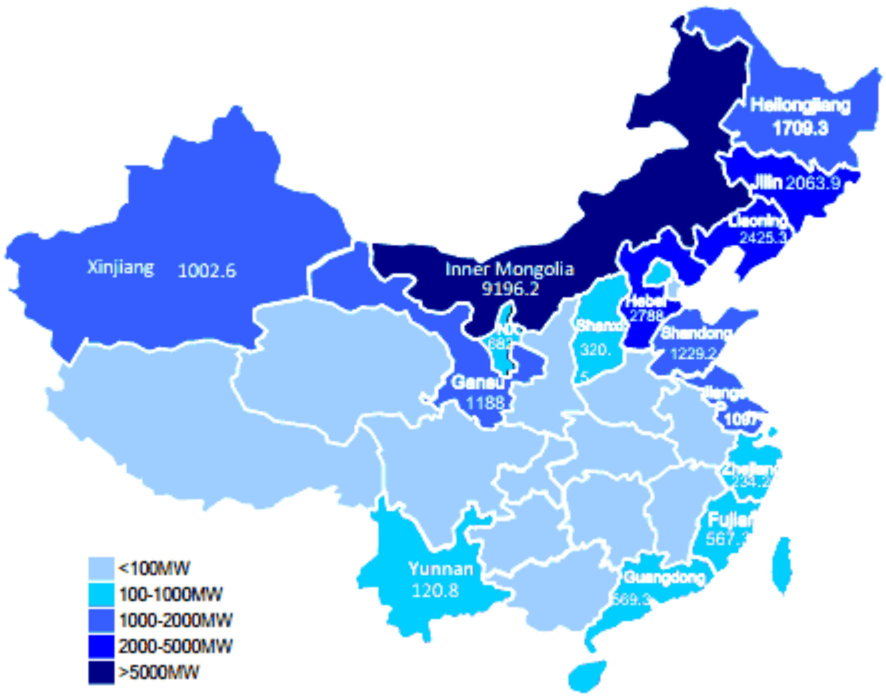
Source: Wang, 2009

The three grid companies apply a three-step process toward integrating variable power from renewable sources into the grid. The companies first aim to accommodate the variable supply, and then curtail surplus generation. The final option, transmitting the surplus to other regional power systems, is not feasible given the lack of connections between power grids.[66] Moreover, the three companies are each responsible for losses as well as profits; as such, very little inter-company cooperation occurs. Renewable technologies are not equitably distributed

[64] Cheung, 2011.
[65] Ibid. pg.13.
[66] Ibid pg. 10.

across all regions and all provinces: for example, hydropower is disproportionately located in south and central China and does not to contribute substantial power to the grid to meet demand in other regions. Wind power, which is located in the north, faces the same obstacle.[67]

Figure 4. Installed Wind Capacity by Province (MW)



Source: CWEA 2010

Electricity trading practices are also a challenge to realizing the full potential of renewable technologies in China. Even if new capacity additions improve prospects for inter-regional electricity trading, rigid market structures will dampen China's ability to realize the full potential of renewable technologies. Long term contracts govern around 80% of the trading that does occur between provinces and regions; multi-year forecasts form the basis for which regions and provinces set the quantity and price at which they trade.[68] Because the electricity market is so rigid, and because long-term contracts form the basis of the market, even if electricity-importing provinces have developed enough generation capacity over the year to meet demand, they must still receive electricity because of a prior agreement. As a result, the province must sell the surplus capacity to another region by significantly lowering its export prices, thus creating large inefficiencies within the electricity market.[69]

[67] Ibid pg. 18.
[68] Ibid pg. 18.
[69] Ibid pg. 18.

RUSSIA: POLITICAL BARRIERS

Vast fossil fuel reserves and powerful fossil fuel intensive industries present significant barriers toward developing renewable energy capacity in Russia. In 2009, Russian subsidies for gas and electricity generated from fossil fuels cost almost $34 billion, equivalent to 2.7% of GDP; meaning consumers paid only 77% of the full cost of their energy products.[70] The prospects for renewable energy in Russia will depend to a very large extent on the pace at which reforms may reduce subsidy levels; however, given Russia's wealth of resources, it remains unlikely that Russia will do so. Although a top 5 emitter in the energy production sector, it is unlikely Russia will race to implement renewable technologies. In 2011, it did not register in the top 5 countries for investment in renewable capacity, or in renewable capacity additions.[71]

That is not to say, however, that the Russian government has completely ignored the climate change agenda. In 2009, the Russian government adopted a national target for 4.5% of electricity generation to come from renewable sources (excluding hydropower) by 2020; however, implementation of specific renewable support programs has come at a slow pace.[72] Indeed, it was not until September 2013 that President Putin ratified Russia's first renewable energy subsidy program which aims to install 504 MW of renewable capacity. Similar to the programs Russia offers to normal power plants, renewable plants can receive payments for up to 15 years provided they can offer at least 5 MW power during peak demand hours.[73]

Russian leadership has at times shown that it has the political will to expand renewable energy programs. In addition to Putin's new renewables subsidy program, former President Medvedev has stated "we should no longer burn our energy reserves" and that "alternative energy will sooner or later replace hydrocarbons."[74] While this hardly constitutes "smoking gun" evidence for strong pro-renewable energy preferences within the government, it does indicate that there is at least a willingness to consider alternative fuel sources.

However, in the end, cost concerns will win out. The Russian government has a history of using price controls in electricity markets, and consumers are very sensitive to energy price fluctuations. Even if LCOE levels are competitive with fossil fuel sources, the large scale up-front costs to promote renewables on a large scale in Russia would be hard to sell to the domestic constituency.

[70] International Finance Corporation, 2011.
[71] See Table 1.1 Annual Additions/Production in 2011.
[72] International Finance Corporation, 2011.
[73] PV Magazine, 2013.
[74] International Finance Corporation, 2011.

INDIA: FINANCIAL BARRIERS AND A PLETHORA OF INCENTIVE PROGRAMS

There are numerous barriers to the expansion of renewable technologies in India. The first is quite simple: renewable technologies have high up-front capital costs, and so may be difficult to acquire and deploy. Existing infrastructure limitations and grid interconnections may inhibit access to, or distribution of sources of renewable power -- similar to the challenges in China. Furthermore, the lack of an existing Indian value chain for renewable technologies means that technologies are more expensive; middlemen take a premium when selling component parts, or, in the case of biomass, add a large markup on to farm prices.[75]

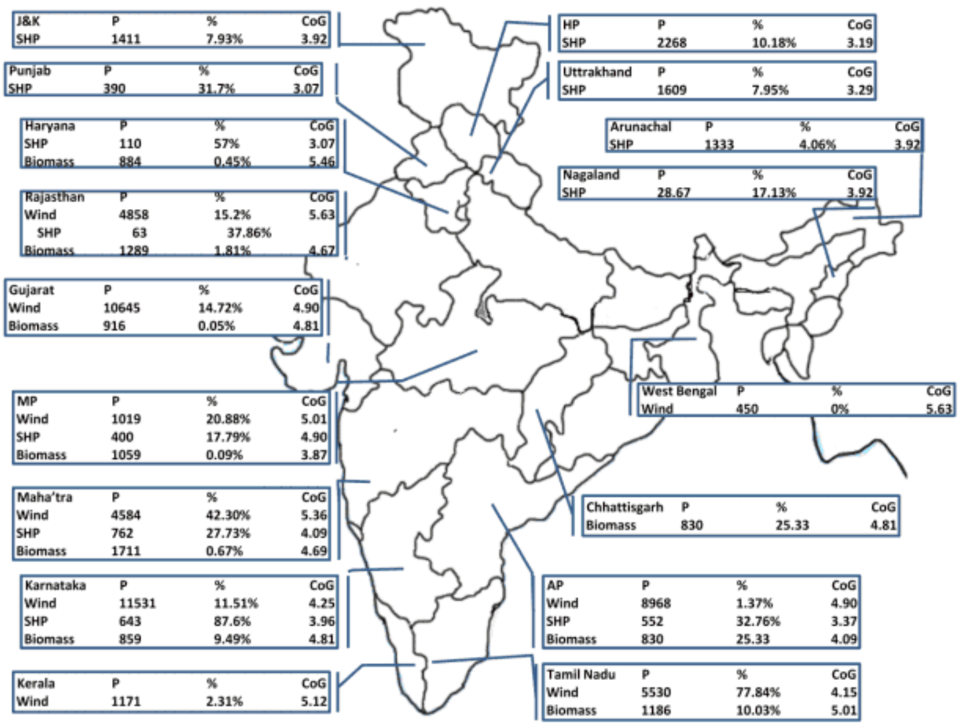
But these are not the only obstacles: existing structures may also limit the potential to deploy renewable technologies. Part of the problem is due to the lack of coordination of state policies. The result of a decentralized decision making process regarding the use of renewable technologies has been that some of the state's richest in renewable energy potential -- such as the northern provinces of Himachal Pradesh and Jammu Kashmir -- have a large share of potential hydropower resources but are far behind in terms of developing their capacity.[76]

Another problem is that there are too many incentive programs. India offers almost every imaginable type of incentive, including feed-in tariffs; generation-based incentives; central, state, and regional capital subsidies; and tax incentives.[77] An array of central and state agencies offers these incentives, creating overlaps, inefficiencies, and reducing the level of fiscal discipline.[78] Some policies have the perverse effect of discouraging utilities from encouraging renewable development; for example, utilities must meet targets set by regulators, if a utility is unable to do so it must pay for losses not included in the average cost of the power supply.[79]

The following map identifies renewables deployment as well as regions where renewable capacity is lacking. While the map does not capture the RE capacity for every state in India, it does identify large gaps between potential capacity and installed capacity with respect to Small Hydropower (SHP), Biomass, and Wind.

[75] Sargsyan et al., 2010.
[76] Ibid pg 20.
[77] Ibid pg. 39; Also, See Table 1.4 Policies for Encouraging RE Table.
[78] Ibid. pg 39.
[79] Ibid.

Figure 5. Renewable Technologies in India: Potential Capacity, Installed Capacity, and Cost of Generation*



P: Potential capacity %: Installed capacity CoG: Cost of Generation[80]

* *Note - this data came from a World Bank report that uses a different methodology for calculating cost than does the IRENA data previously cited. The point is not to compare costs, but rather to identify gaps between renewables potential and capacity.*

EU: FINANCIAL BARRIERS, SUBSIDIES, AND TOO MUCH OF A GOOD THING

Countries within the EU, such as Germany, Italy, and Spain have some of the highest levels of renewable capacity in the world.[81] It is perhaps for this reason that IEA does not identify great emissions reductions in the EU by increasing the use of renewable technologies. For example, the IEA data only identifies a 0.7 $GtCO_2$ reductions potential moving out to 2050 for the entire EU. While the EU has set rigorous standards and targets for its member states, it is unclear to what extent reductions will continue, or if a domestic political backlash will slow down the process of expanding the supply of renewable technologies.

The problem in the EU is twofold: first, the European Trading System, the EU's tradable permits scheme for putting a price on carbon emissions has not succeeded in its stated goal,

[80] Sargsyan et al., 2010.
[81] See Table 1.2.

and second, both utilities and electricity consumers are increasingly opposing the direction various renewable subsidy incentives programs have taken.

Under the ETS, carbon prices are extremely low – currently around $8.22 a ton[82]; part of this is due to the fact that the EU issued too many preliminary permits, and part of it is due to the unintended consequences of generous renewable energy subsidy programs such as feed-in tariffs (FiT).[83] When utilities reduce emissions by using more renewable energy sources in their energy portfolio, they end up with a surplus of permits, and so are able to sell them on the market. Due to the high increase in the supply of permits on the market, carbon prices have consequently dropped to extremely low levels.

In addition, utility companies and consumers have come to oppose subsidy programs. Increased supply of intermittent renewable energy has caused a steady decline in wholesale electricity prices, creating large losses for utility companies. Since 2008, the major European utility companies have lost over $822 billion in market capitalization.[84] Utilities have been very vocal about criticizing subsidy programs for renewable technologies which have driven down their market shares; for example, E.ON, Germany's largest utility, recently threatened to relocate to Turkey if the German government continued to implement policies which undercut the profitability of its nuclear and fossil fuel powered plants.[85] German consumers also face some of the highest residential electricity prices in the world, even though the wholesale price has declined. Subsidies have distorted the market such that the residential electricity prices are around $390.45 per MWh, while the wholesale price languishes at a mere $52 Euro per MWh.[86]

The German government has released a plan to reduce these subsidies, but even though utilities and many consumers support this decision, a powerful constituency consisting of both rural farmers and urban green party members have voiced a strong preference for maintaining incentives programs. A political storm is brewing, and the future of these programs remains unclear.[87]

UNITED STATES: POLITICAL BARRIERS

The U.S. is one of the world's leaders in renewable capacity and investment.[88] It has an array of incentive programs in place to promote the use of renewable technologies. Historically dependent on coal, the US has recently made use of hydraulic fracturing technology to greater exploit the resource and use natural gas in power generation. It is unclear to what extent low natural gas prices may in effect "crowd out" the use of renewable technologies. While natural

---

[82] Converted at 1 Euro = 1.37 USD. All Euro to USD conversions were performed at this rate.
[83] The Economist, 2014.
[84] The Economist, 2013.
[85] Pentland, 2013.
[86] The Economist, 2013
[87] Vasagar, 2013.
[88] See Table 1.1 and 1.2.

gas may burn cleaner than coal, it remains more detrimental with respect to CO_2 emissions than renewables. At the federal level, the intermittent provision of tax credits, particularly for wind power, have led to boom and bust cycles, as tax credits expire and developers wait to install new capacity upon the expectation that new tax credits might be available. More detailed discussion of the renewables sector is in the U.S. country paper that will accompany the sectoral series.

RENEWABLES TECHNOLOGY IN DEVELOPING COUNTRIES

The above analysis has focused primarily on the top emitters in the energy production sector worldwide. While the largest gains are to be had in the largest emitters, this does not mean progress could not be made in other countries. The obstacles outlined above, however, are only magnified when looking to developing countries (outside of China and India). In addition to capacity restrictions, some incentive programs are difficult to implement in developing countries. Feed-in tariffs (FiT), one of the more common types of incentive programs, may not be the best policy choice in countries with poor governance structures: subsidy programs in general and FiT programs in particular may be prone to collusion.[89]

Moreover, many developing countries are simply not able to pass on higher costs to consumers of electricity. In the Philippines and Malaysia, for example, consumers are long used to subsidized electricity prices. Even if governments had the capacity to implement complementary policies, such as ones exempting low-income or low-volume consumers, they would likely have a difficult time selling these policies to the middle and upper classes.[90]

RENEWABLES RECOMMENDATIONS AND CONCLUSIONS

The cost of renewable technologies has fallen dramatically in recent years, and many are already cost competitive with fossil fuel burning sources. Up-front costs for certain technologies remain a barrier in some cases, and infrastructure constraints may slow the deployment of others. Renewable technologies present an opportunity to reduce emissions in the top 5 emitters within the energy production sector, but each country faces unique circumstances that may slow or prohibit the deployment of renewable technologies. China faces technical barriers and employs rigid market structures that reduce incentives to invest in renewable technologies. India suffers from technical barriers in addition to a lack of policy coherence. There is little indication that domestic constituencies in Russia demand higher levels of renewable energy, and are unlikely to do so in the near term. Member states of the EU are facing unique domestic challenges as renewable energy subsidy programs have passed on high costs to both consumers and utility companies.

[89]UNEP, 2012.
[90] Ibid. pg. 5.

(1)The Indian government should attempt to better align existing policies. India has considerable potential for expanding renewable energy, but suffers from a lack of harmonized policies. Simply put, there are too many incentive programs in place, creating too many overlaps and inefficiencies.

(2) The EU should reform either its renewable energy subsidy programs or the market-based ETS system, because they are poorly aligned to work toward emissions reductions. Reducing some subsidy programs within the EU may be preferable, due to the market distortions and inefficiencies that result from them.

(3) The Chinese government should relax rigid electricity market structures that reduce incentives to invest in renewable technologies. Long-term contracts lock different regions of the country into selling at fixed prices, often at a loss, thus discouraging investment in renewables capacity.

FOSSIL FUEL SWITCHING FROM COAL TO NATURAL GAS

RATIONALE AND CHALLENGES

The IEA estimates that 1,980 GW of installed electric generation capacity worldwide will be retired between 2012 and 2035, primarily in OECD countries, where older plants will be phased out.[91] Furthermore, non-OECD countries will continue installing additional capacity to meet the needs of their growing populations and rising per capita incomes.

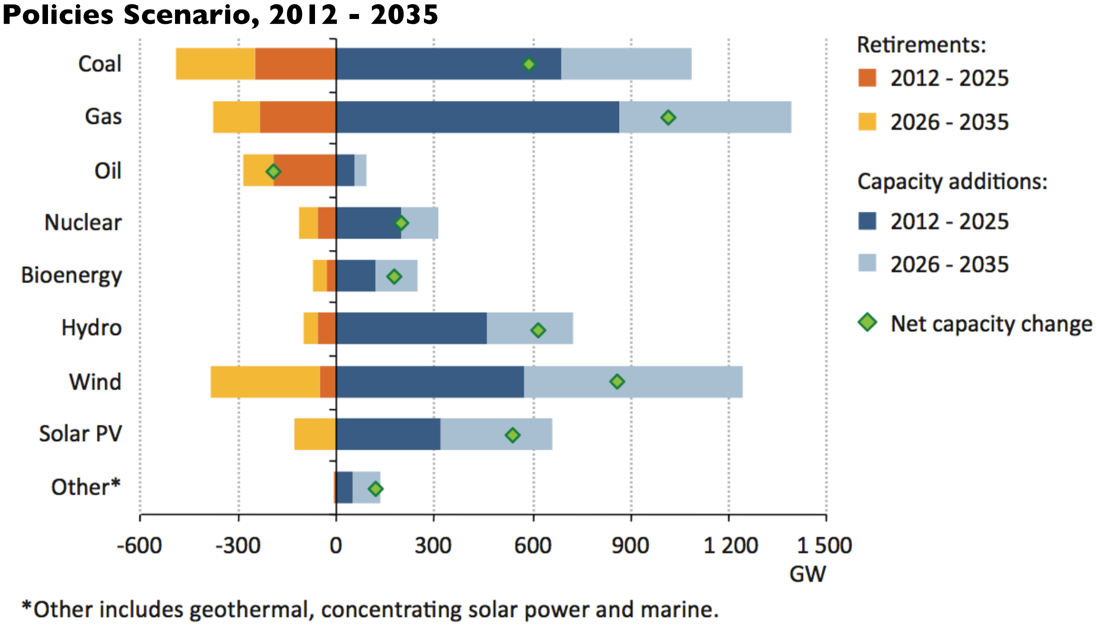
Table 14. Reductions Potential for Top 5 Emitters from BAU through Fuel Switching (2C to 6C scenario range)

Countries	2020	2030	2050
US	0.1 (5.8 to 5.7)	0.4 (5.5 to 5.1)	0.3 (5.4 to 5.1)
China	1.0 (12 to 11)	1.0 (14 to 13)	3.0 (18 to 15)
Russia	0.1 (1.9 to 1.8)	0.1 (2 to 1.9)	0.2 (2.4 to 2.2)
India	0.1 (3 to 2.9)	0.2 (4.2 to 4)	0.2 (7.4 to 7.2)
EU-27	0.0 (4.1 to 4.1)	0.2 (4.2 to 4)	0.2 (4.1 to 3.9)

Source: IEA ETP. All units expressed in $GtCO_2$.

POWER PLANT RETIREMENTS

Figure 6. Power generation gross capacity additions and retirements in the New Policies Scenario, 2012 - 2035



Source: IEA WEO 2012[92]

[91] IEA, WEO 2013.
[92] IEA, 2013.

This chart from the IEA's 2013 World Energy Outlook summarizes the current trends in new plant construction. Based on projections to 2035, 520 GW (18%) of new nuclear and fossil-fuel capacity is already under construction. Of that total, coal and gas-fired power sources comprise 54% and 30% of new plant construction, respectively. Based upon these projections, fossil fuels will continue to dominate the world's energy generation capacity.[93] Therefore, to realistically limit greenhouse gas emissions in the energy production sector, it will be imperative to develop policies that encourage less emission-intensive generation from fossil fuels.

The construction lead times for new power plants make natural gas a very attractive alternative to coal and nuclear power generation in the short- to medium-term. On average, coal fired power plants can take more than four years to complete and nuclear power plants can take decades. Combined-cycle gas turbines (CCGTs), on the other hand, can be completed in two to three years and open-cycle gas turbines (OCGTs) can be finished in under two years.[94]

OCGTs are small, quick start units similar to an aircraft engine. Also known as "peakers", these plants are not intended to run continuously and are instead only dispatched at times of very high demand or when other plants are offline for maintenance. Cycling in this way leads to a shorter operational life than other power plants.[95]

CCGTs combine design elements of OCGTs with heat recovery steam generators and significantly increase the plant's efficiency. According to the Federal Energy Regulatory Commission (FERC), "CCGTs produce negligible amounts of SO_2 and particulate emissions and their NO_x and CO_2 emissions are significantly lower than a conventional coal plant[96]…. CCGTs, on average, require 80 percent less land than a coal-fired plant, typically 100 acres for a CCGT versus 500 acres for a comparable coal plant."[97] With shorter construction lead times, fewer greenhouse gas emissions, and the flexibility to serve as both a base-load and peak-load source of electricity, natural gas is a short- to medium- term solution in countries where environmental regulations and fuel prices make coal a less attractive investment.

The extent to which gas-fired power will replace coal as a base-load energy source remains unclear. Market forces, resource scarcity, infrastructure limitations, emissions regulations, utility portfolios, and many other factors determine whether a new natural gas plant will be constructed instead of a coal-fired power plant to meet regional demands for electricity. The IEA projects that electricity generation from gas-fired power plants will continue to expand from 4,760 TWh in 2010 to about 8,470 TWh in 2035.[98] 75% of this growth is expected to occur in non-OECD countries, with 20% of worldwide growth in China,

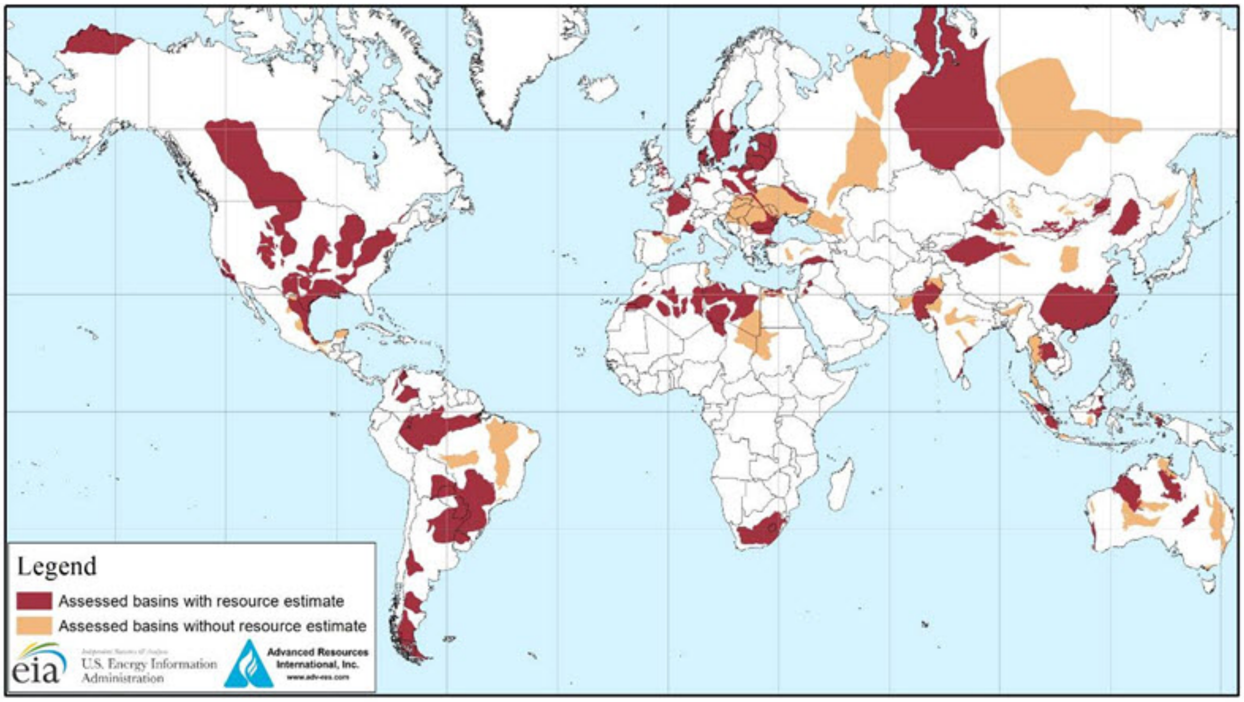
---

[93] IEA, WEO 2013. p 185.
[94] Ibid. p 185.
[95] FERC, n.d.
[96] Though this does not take extraction into account, particularly methane leakage from hydraulic fracturing - a concern which may significantly change the greenhouse gas emission reduction potential of fuel switching
[97] Ibid. p 52.
[98] IEA, WEO 2013. p 189.

and 18% in the Middle East.[99] For comparison, coal-fired generation was at 8,660 TWh in 2010, increasing at 7% per year in 2010 and 2011.[100] Much of this uncertainty arises from natural gas pricing and the extent to which political opposition will limit shale gas extraction.

NATURAL-GAS EXTRACTION: THE NORTH AMERICAN SHALE GAS BOOM

Figure 8. Map of basins with assessed shale oil and shale gas formations



Source: United States basins from U.S. Energy Information Administration and United States Geological Survey; other basins from ARI based on data from various published studies.

Source: U.S. EIA (2013)

Due to geological constraints, oil and gas tend to be co-located. The largest oil reserves in the world are located in Saudi Arabia, Venezuela, Canada, Iran, and Iraq; while the largest gas reserves in the world are located in Russia, Iran, Qatar, the United States, and Saudi Arabia.[101] As a result of these natural resource endowments, it is no surprise that the United States, Russia, Iran, Canada, and Qatar lead the world in gross natural gas production.[102]

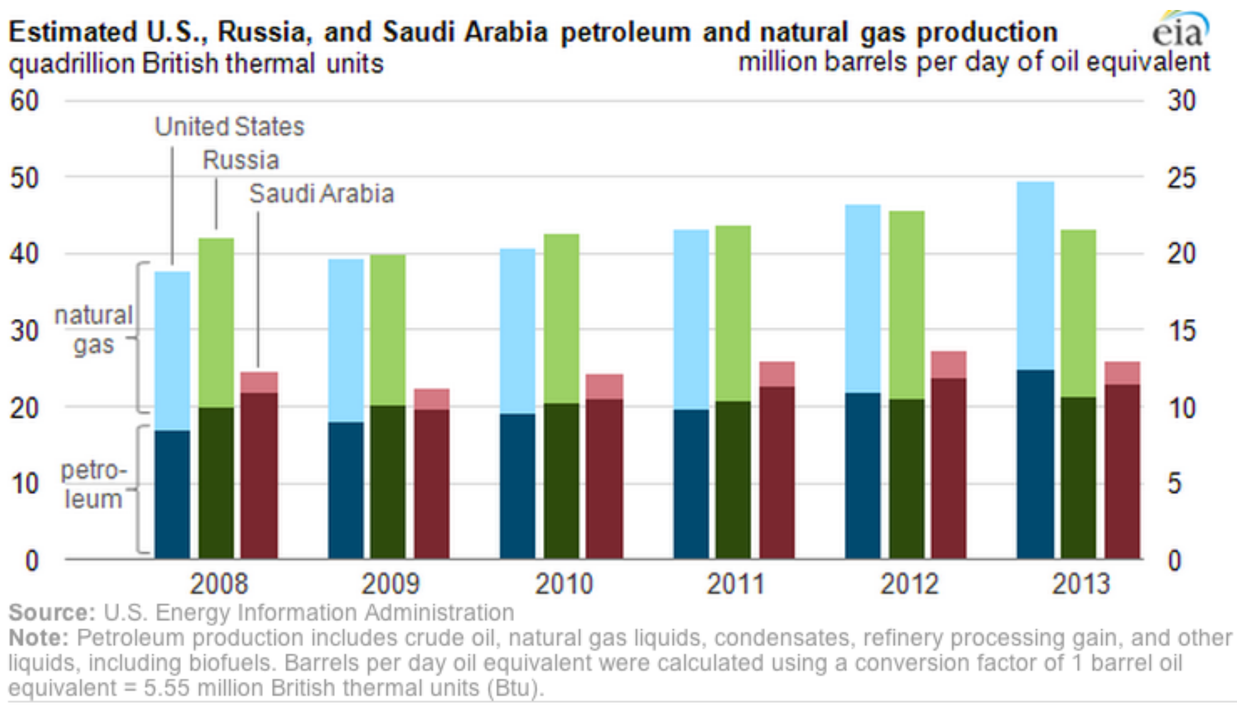
Like crude oil, natural gas is not a homogenous fossil fuel. Gas is typically classified into two categories, conventional and unconventional, which refers to the location of the gas and

---

[99] Ibid. 189.
[100] IEA, 2013.
[101] EIA, 2012.
[102] Ibid.

not its chemical structure. Conventional gas is found in large permeable sandstone reservoirs and is extracted through traditional drilling techniques. Unconventional sources are typically more difficult to reach and therefore, more expensive to extract. Unconventional sources of gas include coal seam gas (coal bed methane), tight gas, and shale gas. Coal bed methane occurs near coal seams and has typically been a major hazard for underground coal mining around the world. Tight gas occurs in impermeable rock formations or in sandstones or limestone that are non-porous.[103] Shale gas exists in fine-grained sedimentary rocks called shale deposits, which formed approximately 350 million years ago. Natural gas only exists in shale at the microscopic level and, until the early 2000s, was typically too expensive for companies to extract economically.

Figure 9. US leads the world in Natural Gas Production



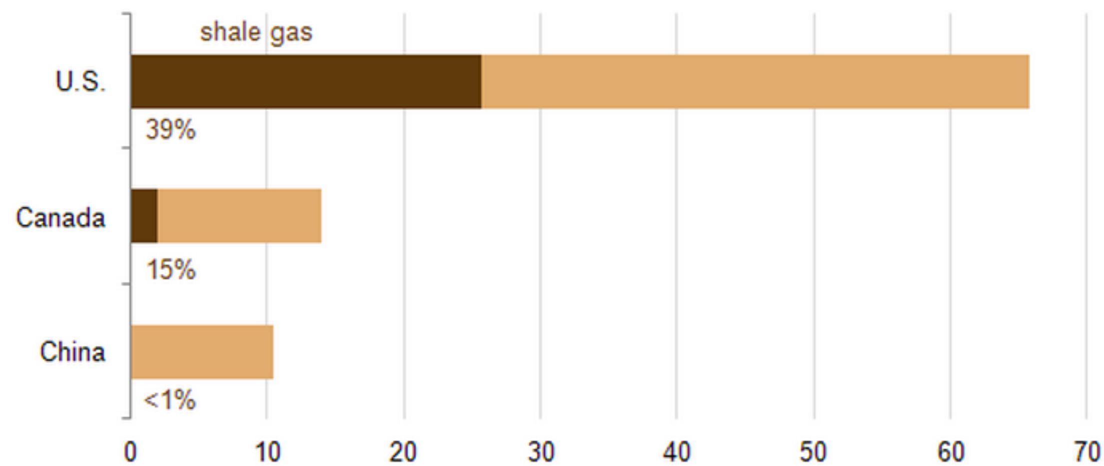
Source: U.S. EIA (2013)

Two revolutionary but related trends have occurred since 2005 in energy production. Due to innovations in horizontal drilling, hydraulic fracturing, and CO_2 re-injection, Canada and the United States have substantially increased their hydrocarbon production from shale gas. Since 2008, booms in several U.S. states, including Texas, Pennsylvania, North Dakota, and Louisiana have led to a petroleum production increase of 7 quadrillion Btu and a natural gas

[103] Naturalgas.org., n.d.

production increase of 3 quadrillion Btu.[104] Extracting these "unconventional resources" has allowed the United States to outpace two of the world's largest fossil fuel producers.

Figure 10. Shale gas as a share of total dry natural gas production in 2012

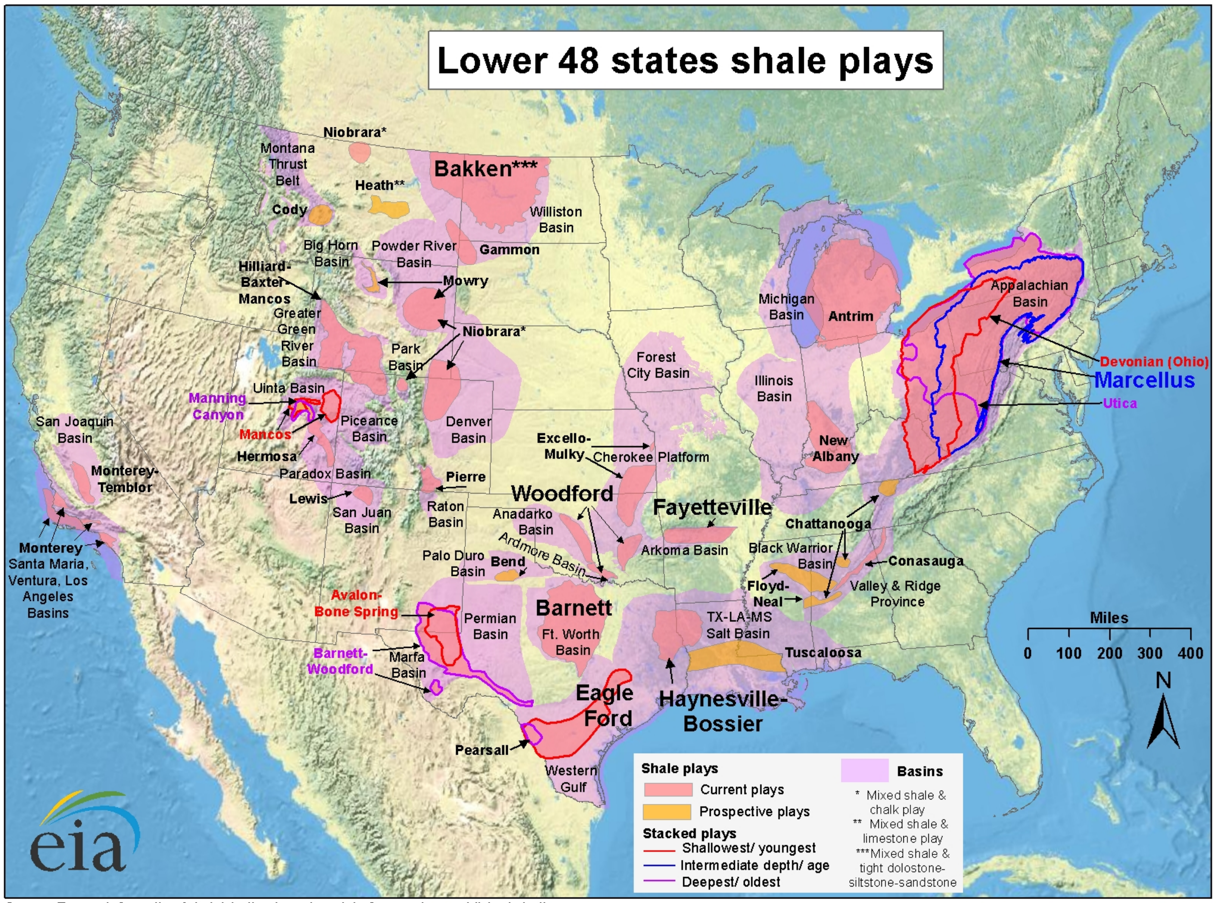


Source: U.S. Energy Information Administration, LCI Energy Insight, Canada National Energy Board, and Facts Global Energy
Note: Canadian data uses "marketable production," which is comparable to dry production.
Source: U.S. EIA (2013)

According to the U.S. Energy Information Agency (EIA), as of 2013 only the United States and Canada possess the technology, legal framework, and geology to commercially produce shale-gas. Test wells have been drilled in more than ten countries but China is so far the only nation that has shown their capability of producing shale-gas, though shale gas volume still contributes less than 1% of China's total natural gas output.[105] Shale gas dry production in the United States from the major shale plays averaged 25.7 billion cubic feet per day (Bcf/d) in 2012.[106] Meanwhile, Canada averaged 2.8 Bcf/d in 2013, up from 2.0 Bcf/d in 2012. Most of Canada's production originates in two major shale plays of British Columbia: the Horn River Basin or the Monterey basin. According to the EIA, "higher production from these two plays is currently constrained by limited pipeline infrastructure."[107] Because fuel switching is primarily occurring in the United States in the short term, this paper will analyze the domestic market in depth to understand why this is the case. After fully examining the success of fuel switching in the United States, this section will analyze the international market and explain the significant barriers they will need to overcome before fuel switching is economically feasible.

[104] Fawzi, 2013.
[105] Ibid.
[106] Ibid.
[107] Ibid.

Figure 11. Shale Gas Plays in the United States



Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011

Source: Energy Information Agency (2013).

ENVIRONMENTAL CONCERNS ABOUT SHALE GAS EXTRACTION VIA HYDRAULIC FRACTURING

In order to free hydrocarbon molecules in shale formations, companies must drill between 6,000-10,000 feet below the surface, then turn the drill bit horizontally before injecting millions of gallons of water and other chemicals at incredibly high pressure to fracture and hold open the cracks in the shale formation. Like any industrial-scale extraction project, this process is environmentally intensive and can have many detrimental effects on the local resources, the extent of which are not fully understood. While there are significant issues concerning groundwater, surface water, and air quality problems associated with hydraulic fracturing, given our limited space, this paper will limit its scope to methane leakage and flaring given their incredible greenhouse gas potential.

Methane leakage can occur at various stages of the extraction process, but in *Kuuskra* 2013, a University of Texas research team partnered with experts from the Environmental Defense Fund, Andarko Petroleum corporation, BG Group PLC., Chevron, and others to measure exactly how much methane leaks from a typical hydraulic fracturing well in the United States of America.[108] The team went to 190 pre-selected production sites throughout the United States at times pre-determined by the nine participating companies. They found that the majority of well completions with modern equipment reduced emissions by 99%.[109] These methane emissions levels were 97% lower than 2011 national emissions estimates released from the U.S. Environmental Protection Agency in April 2013.[110] These findings have been widely criticized by opponents of hydraulic fracturing who claim that the study is deeply flawed because the industry pre-selected the wells before the researchers tested them and thus, do not represent typical industry practices.[111] These findings also contradicted another study, published by the National Academy of Sciences in 2013, which found that methane emissions in certain regions of the United States may be 50% higher than originally thought due to oil and gas drilling.[112]

Many advocates of hydraulic fracturing tout fuel switching from coal to natural gas as the bridge to a cleaner burning, lower emission, energy future. While there is no question that burning coal emits more harmful toxins and greenhouse gasses than natural gas, when the emissions from extraction and transportation of natural gas are factored in, the difference between the two fossil fuels may not be as large as originally thought.

Another practice that could potentially undermine the efficacy of natural gas over coal is methane flaring. Flaring is the act of igniting excess natural gas that bubbles to the surface of drilled well. From an engineering standpoint, flaring is an egregious waste of resources, especially when considering the effort spent to extract the resources in the first place. But from

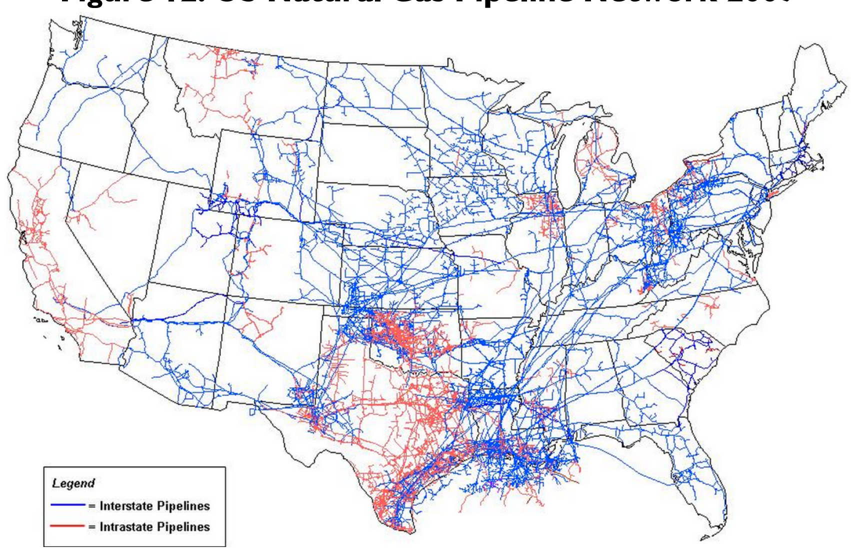
[108] Allen et al., 2013.
[109] Ibid.
[110] Ibid.
[111] Ingraffea, n.d.
[112] Miller et al., 2013.

a business standpoint, drilling companies do not have the luxury of time when searching for oil and must make the most of their leases (typically 3 years). When oil is priced around $100/blue barrel of liquid and natural gas is only worth $2/thousand cubic foot, if the cheap gas reaches the surface before the well has access to a pre-existing pipeline, and it may not be profitable for them to build a pipeline, then they will flare the gas instead.[113] This process releases excess carbon dioxide and methane into the atmosphere without displacing a single watt of coal-fired electricity. The practice is currently so widespread that the Bakken field in North Dakota and the Eagle Ford Shale in South Texas can be seen from space.

NATURAL GAS INFRASTRUCTURE IN THE UNITED STATES

Despite organized, vocal political opposition centered largely around environmental concerns, hydraulic fracturing continue to prosper and grow in the United States. The reason for the industry's growth is largely attributed to the United States' extensive natural gas infrastructure and regulatory structure. The United States has one of the world's most extensive natural gas pipeline and distribution networks which has undergone significant deregulatory pressure in recent decades (see figures 12 and 13).

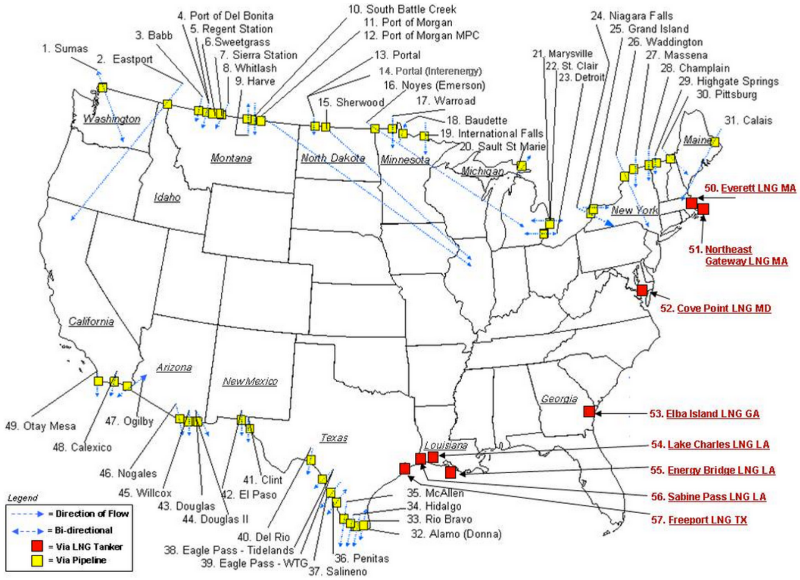
Figure 12. US Natural Gas Pipeline Network 2009



Source: U.S. EIA

[113] Krauss, 2013.

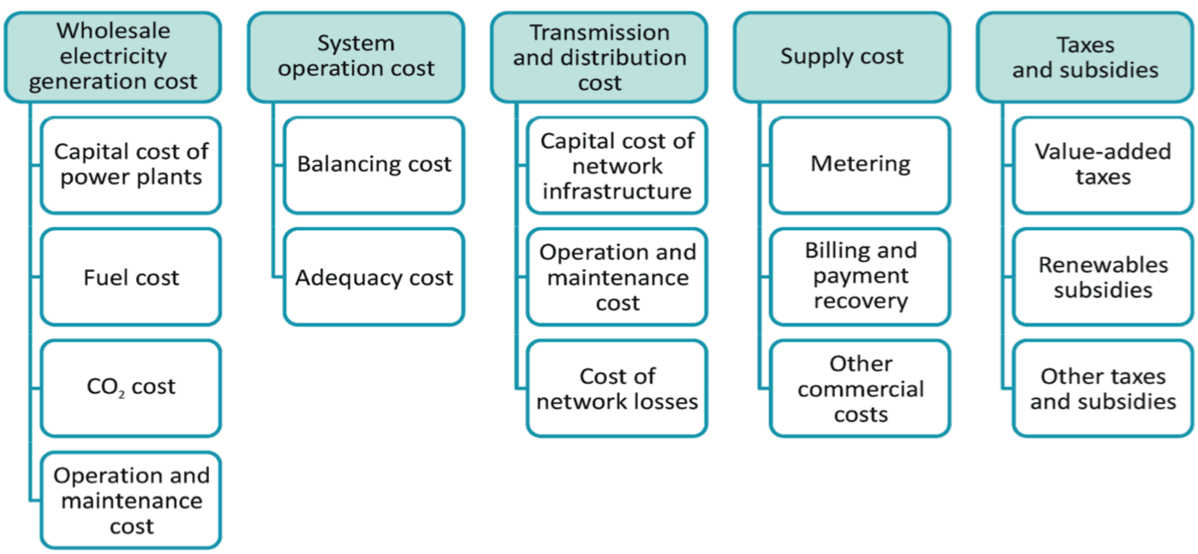
Figure 13. US Natural Gas Import/Export Locations



Source: U.S. EIA

THE WHOLESALE ELECTRICITY MARKET IN THE UNITED STATES

Figure 14. Components of the End-User Price of Electricity



Source: IEA WEO 2013. p 203

The price of natural gas is extremely difficult to predict because the market is prone to volatility and there are many variables build in to the price. However, after the first stage of the shale gas revolution in North America, the price of natural gas has stabilized enough that the commodity is now considered as a reliable base-load power source, capable of displacing some of coal's current market share. In order to understand how fuel switching actually works in the United States, it is necessary to understand how utilities purchase electricity on the wholesale market.

In the last two decades, several electricity markets around the world have moved away from vertically-integrated natural monopolies. In the old system, one company owned the power generation, transmission, and distribution and set rates accordingly. In electricity market liberalization, these monopolies were "unbundled", meaning that ownership of each section in the supply chain was now owned and operated by separate entities. In North America and Australia, independent system operators (ISOs) were formed which allowed previous owners to maintain transmission. Denmark, Norway, and Sweden formed transmission system operators (TSOs) in which the states maintained transmission ownership and system ownership.[114] According to the IEA, the ultimate goal of these market reforms was to create more "economically efficient power generation that would provide investors with the right signals and framework to invest in new capacity."[115]

Deregulation of electricity markets is very important to explaining why utilities would retire old coal plants and construct natural gas plants to replace them. Because the immediate effects of fuel switching are being felt in the United States, this analysis will focus on the U.S. market first and then examine potential global consequences for the future.

In the United States, there are three electric grids - the Eastern Interconnect, the Western Interconnect, and the Texas grid. Within these three grids are seven Regional Transmission Organizations, created in 1996 by the FERC by Order No. 888 with the stated purpose of "promoting wholesale competition through open access non-discriminatory transmission serviced by public utilities."[116] Traditional, vertically-integrated utilities still exist in the US alongside these RTO/ISOs, primarily in the Northwest and Southeast where large hydropower installations were constructed during the Great Depression. In the traditional markets, the utilities still own the generation, transmission, and distribution of electricity. However, in the wholesale markets under the RTO/ISOs, each section of the supply chain is operated by an independent entity. In these markets, generators will sell their power to the RTO, who then dispatches that power where it is needed using competitive market mechanisms. The result is different prices and different incentives for electricity generation in different regions in the United States.

[114] IEA, 2005. p 50.
[115] IEA WEO 2013. p 205
[116] Bosselman et al., 2010. p. 631.

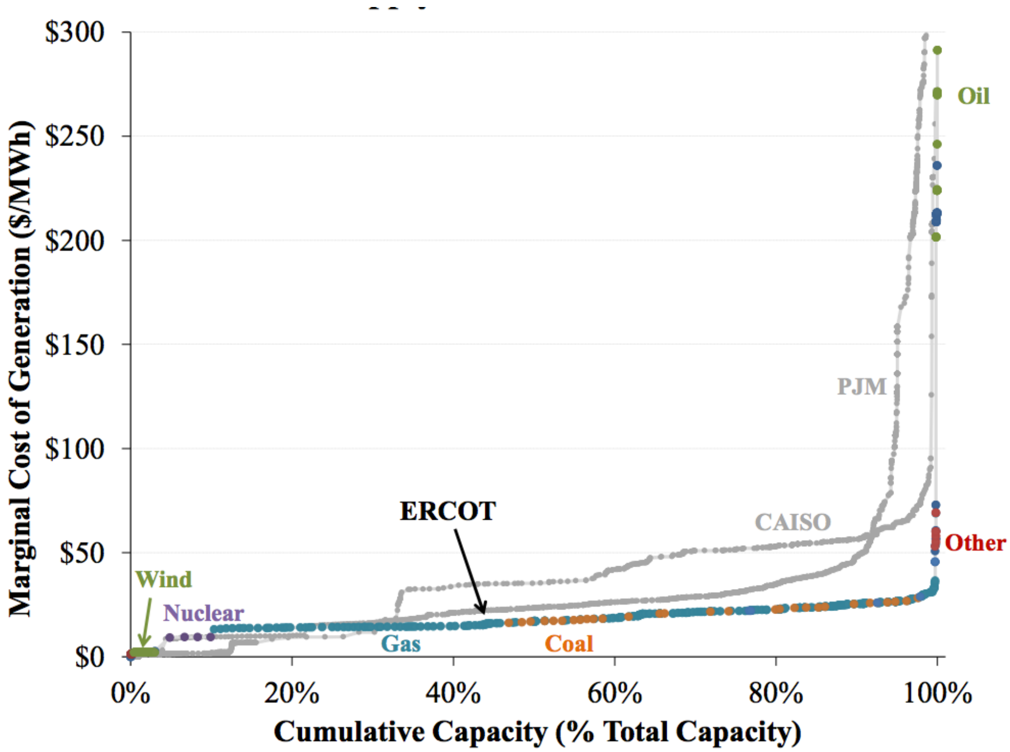
Figure 15. On-Peak Spot Electric Prices 2012 ($/MWh)

Source: FERC[117]

Not only are there significant price differences between regions, but wholesale market prices can also vary significantly throughout the day depending on demand. In the Electric Reliability Council of Texas (ERCOT) market, for instance, peak demand can be as high as 68,000 MW from 4 pm to 5 pm.[118] ERCOT is unique because it possesses no mechanism for excess capacity and prices are set entirely by supply and demand based on estimated power usage one day beforehand. Based upon these estimations, ERCOT will hold an energy auction where electricity is bid upon based on the marginal cost per kilowatt of generation. Because some electricity is more expensive to burn than others, the cheapest electricity will be purchased first, followed by incrementally more expensive electricity until the estimated demand is met.

[117] FERC, 2012.
[118] ERCOT, 2013.

Figure 16. ERCOT Supply Stack vs. Other Markets

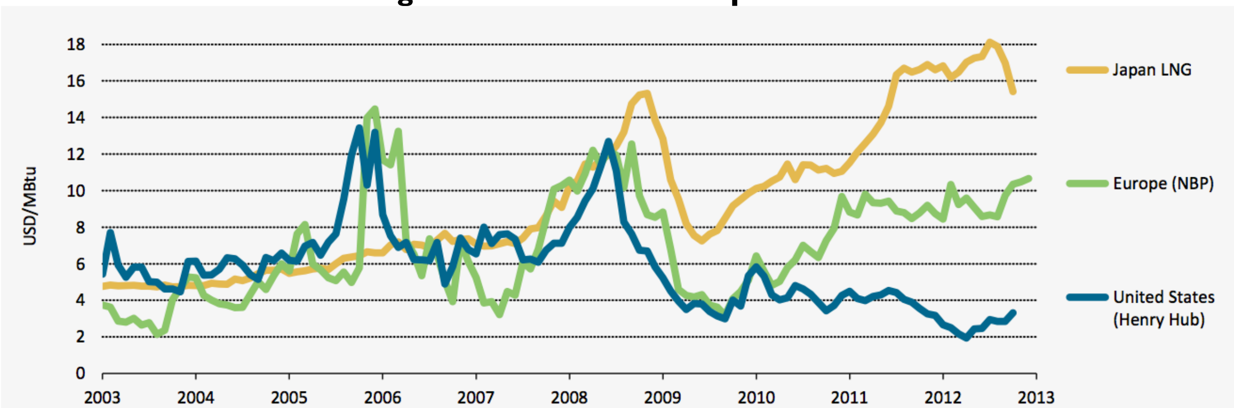


Source: Brattle Report[119]

Since there is no fuel price for wind generation, it is purchased first in the ERCOT market. The nuclear plants in Texas were constructed over 30 years ago and require very little fuel to produce consistent power throughout the day, so they have a very low marginal cost of generation as well. Natural gas-fired power is purchased next, followed by coal. A key difference between the two sources of power is that a coal plant cannot ramp up and down like a gas-fired plant, so coal is treated instead as a base-load source of power while open-cycle gas turbines will be used to respond to spikes in demand.

[119] Newell, 2012.

Figure 17. Natural Gas Spot Prices



Note: NBP = National Balancing Point (United Kingdom), representative of European gas prices.
Sources: Henry Hub: IntercontinentalExchange; NBP: GasTerra; Japan LNG: Japan Customs.

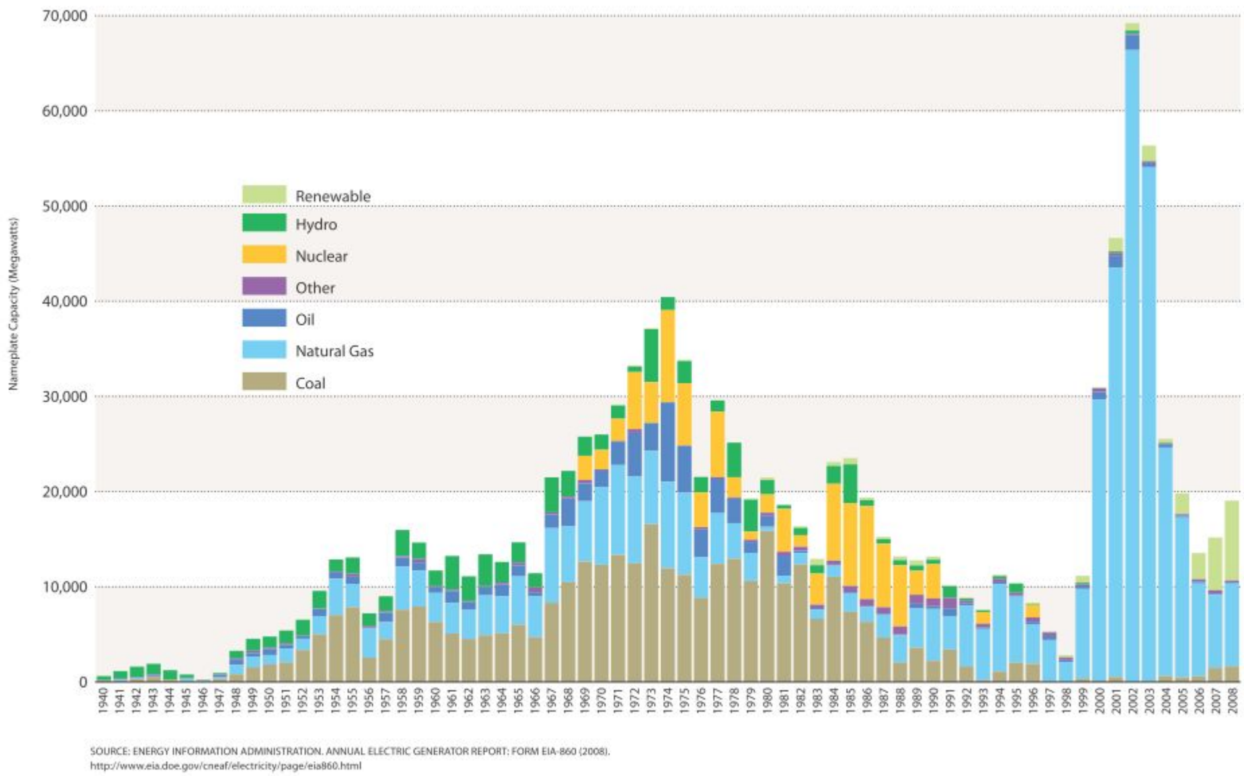
Source: IEA TCEP[120]

According to the IEA Tracking Clean Energy Progress 2013 report, in Europe, it is currently cheaper to generate electricity from coal than from natural gas. The shale boom in the United States created an interesting market dynamic where US coal producers exported their product to European markets, which led to a dramatic increase in coal generation. While US gas prices fell below $2/mm BTU, European spot and contract gas prices stabilized at $8-10/mm BTU, and Japanese LNG import prices remained very high at $17/mm BTU.[121] From January to June 2012, gas-fired power generation dropped by 15% in Germany, 12% in Spain and 33% in the United Kingdom, while coal-generation grew by 8% (Germany), 65% (Spain) and 35% (United Kingdom).[122] Inversely, the low gas prices in the United States increased gas-fired generation by 24% compared with a decrease in coal-fired generation by 14%.[123]

The price of natural gas and the price of coal are only half of the marginal cost of generation - the other half is regulation. The commodity price of natural gas is currently favorable to coal, but this is not a global trend. The price of these commodities is heavily dependent on regional geography, infrastructure, and regulation. Another reason that utilities in the United States are retiring old coal plants and constructing natural gas plants instead is because federal legislation makes investment in coal-fired generation unfeasible.

[120] IEA, 2013.
[121] Ibid. p 41.
[122] Ibid. p 40.
[123] Ibid. p 40.

Figure 18. U.S. Electricity Generating Capacity by In-Service Year



Source: Grist (based upon data from the U.S. EIA)[124]

The EPA Mercury and Air Toxics Standard (MATS) will limit the pollution coming from 1400 of the largest power plants in the United States. Though the rule was announced in 2011, it only recently survived court challenges and is set to go into effect in 2015 and 2016. While not the only reason coal-fired plant operators are planning on shuttering plants, the costs of meeting this regulation are part of the decision calculus of firms.[125]

In September 2013, the US Environmental Protection Agency (EPA) released the strictest carbon pollution standards for new power plants in the organization's history. These Clean Air Act standards are part of President Obama's Climate Action Plan to reduce carbon emissions into the atmosphere and show willingness by the current administration to combat climate change. Specifically, the standards require "new large natural gas-fired turbines to meet a limit of 1,000 pounds of CO_2 per megawatt-hour, while small natural gas-fired turbines would need to meet a limit of 1,100 pounds of CO_2 per megawatt-hour. New coal-fired units would need to meet a limit of 1,100 pounds of CO_2 per megawatt-hour."[126] These new standards mean that utilities around the United States will look at the price to upgrade their old coal-fired power plants versus the price to construct new renewable and gas-fired power generation. Overwhelmingly, utilities are choosing to close their coal plants, because the national average is

[124] Roberts, 2010.
[125] Johnson 2014; Volcovici 2013.
[126] U.S. EPA, 2013.

approximately for generated electricity in 2011 was roughly 2,249 pounds of CO_2 per/ megawatt hour.[127]

An excellent example of this fuel switching calculus for an individual utility is CPS Energy in San Antonio, the largest municipally owned energy utility in the United States and the 4th largest energy utility in ERCOT.[128] CPS generates 2,184 MW of electricity from four coal fired generators (Spruce 1 & 2 and Deely 1 & 2), 3,001 MW from four natural gas generators (AVR, Sommers, Braunig, and Rio Nogales). CPS also generates 1,080 MW from nuclear reactors (South Texas Project 1 &2), and from 631 MW from three quick-start natural gas generators called "Peakers", (Leon Creek, Tuttle, Braunig Peakers) which are used in times of high demand.[129]

J T Deely, an 871 MW coal plant in the CPS energy portfolio emitted 5,911,069 tons of CO_2e, 1,186 tons CH_4, and 27,995 tons of NO in both 2010 and again in 2011.[130] Due to the amount of emissions from the plant, Federal clean-air regulations to install sulfur dioxide scrubbers on the plant would have cost CPS $555 million.[131] CPS Energy was faced with a decision: either they could pay the half a billion dollars to upgrade the plant, or they could phase out the plant over time and make up the difference by taking advantage of the Texas Renewable Portfolio Standards which required them to generate a certain percentage of their electricity from renewable sources anyway. For CPS, the cost of investing in new wind and solar generation and taking advantage of existing natural gas generation was cheaper than the abatement costs to keep the coal plant running for another decade.

All over the United States, utilities are having conversations similar to CPS concerning the future of their energy portfolios. However, coal-to-gas switching is a very complex endeavor that is heavily dependent upon regional pricing and environmental concerns and faces significant obstacles overseas.

---

127 U.S. EPA, 2000.

128 Stones, 2013.

129 CPS Energy, 2013.

130 U.S. EPA.

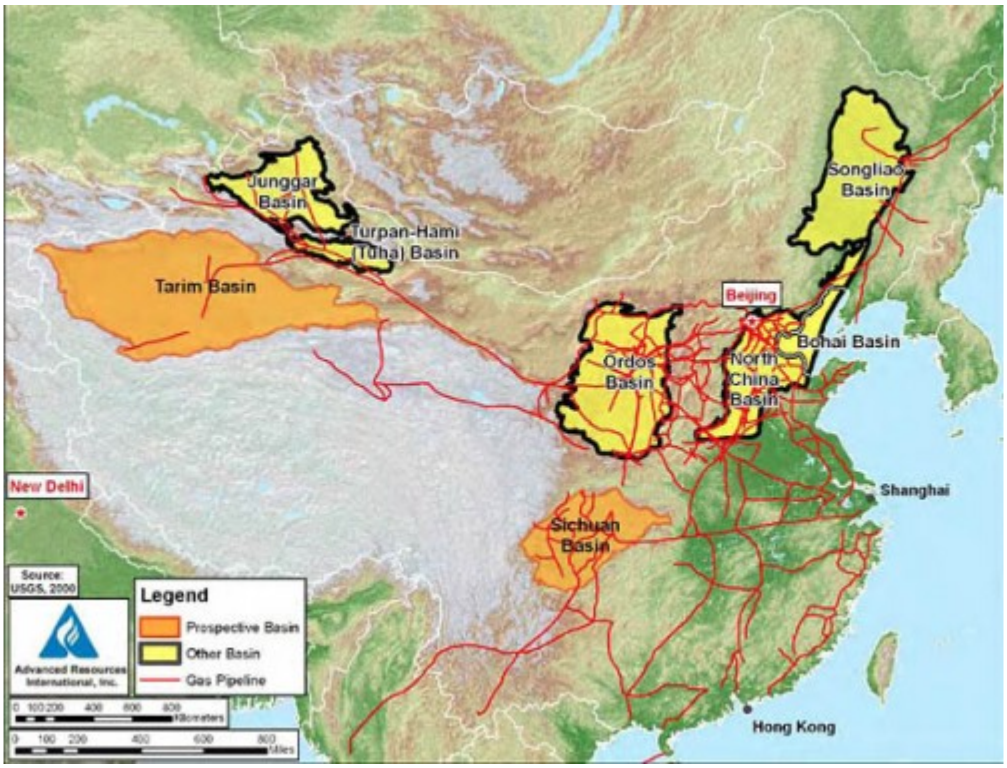
131 Wilder, 2011.

BARRIERS IN OTHER COUNTRIES

While the United States has had propitious circumstances for the development of shale gas, other countries face a variety of barriers in pursuing fuel switching to natural gas.

CHINA: TECHNICAL BARRIERS AND INEXPERIENCE[132]

Figure 19. Shale Gas Basins and Pipeline Infrastructure in China



Source: Advanced Resources International[133]

China possesses large natural gas reserves as well, but currently they are underdeveloped and the country has invested much more heavily into its coal, nuclear, and renewables generation sectors.[134] One of the biggest unknowns in fossil fuel switching is the effect it will have on the Chinese power grid. The unique system of mineral rights ownership in the United States and Canada is often attributed as the cause for the rapid expansion of unconventional drilling in North America. Because China has a very different system of land tenure, it is almost impossible to say at this point what the future holds for unconventional fossil fuel extraction in China.

[132] Jones, 2013.
[133] Advanced Resources International, 2011.
[134] Ibid.

In the United States in recent years, the shale gas boom continues to allow cheaper (and cleaner in terms of CO_2 emissions) natural gas to replace traditional coal-fired power plants. Coal's share of US electricity production fell from 50% in 2005 to only 37% in 2012.[135] This combined with the economic downturn in 2008 has allowed the US the potential to remain on track for meeting its emission reduction commitments.

Could China emulate this decline in coal reliance and reduction in emissions? A seemingly simple solution would entail US export of excess natural gas in the form of LNG to China to allow the increased adoption of natural gas in electricity production. Exports of US LNG could both allow US exporters to take advantage of significant world price differentials and affect the geopolitical balance in Europe and Asia. According to the FERC, there are 13 proposed LNG export terminals with many more potential sites for LNG export. The Obama administration has already allowed the approval of four LNG export terminals this year, and the Department of Energy seems poised to approve ten more.

US industrial interests advocate restricting LNG as they could threaten the US competitive advantage of low domestic gas prices, which averaged $2.75/ mm BTU in 2012.[136] According to the American Petroleum Institute, a trade organization, the impact of sustained LNG exports would only increase prices from $0.32 to $1.02 mm BTU on average from 2016-2035.[137] This suggests that the slight increase in price in the domestic market could allow significant near-term emissions reductions.

LNG exports could encourage the shift from coal generated to natural gas generated electricity worldwide. This shift would assuredly affect US coal exports and further shift investment from coal to natural gas extraction. LNG exports are not, however, a panacea for China's coal dependency. The process of liquefying natural gas is costly and typically adds between $5 and $8 per mm BTU.[138] These costs narrow the competitiveness of US LNG exports in Chinese energy markets. LNG exports could provide a boost for the US economy, but given the costs of exporting natural gas abroad, the US likely will not be able to match Chinese future demand for natural gas.

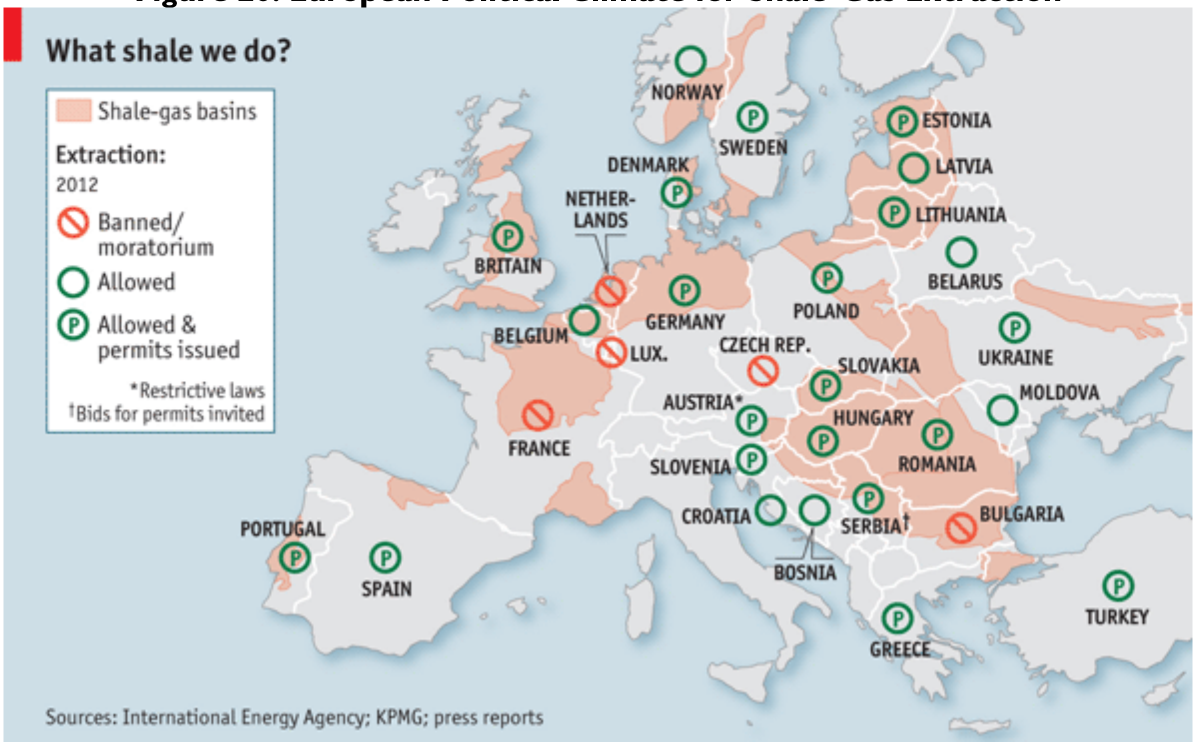
EU: POLITICAL BARRIERS

European countries are sharply divided on the future of natural gas. France has issued a ban on hydraulic fracturing citing worries about the practice's danger to water supplies. Bulgaria and the Netherlands have followed suit while Britain has only allowed limited drilling.[139]

[135] The Economist, 2013.
[136] U.S. EIA, 2014.
[137] ICF International, 2013.
[138] Holland, 2013.
[139] Jolly, 2013.

European Union lawmakers also voted tightened regulations on hydraulic fracturing companies, requiring them to carry out in-depth environmental audits before they drill.[140]

Figure 20. European Political Climate for Shale-Gas Extraction

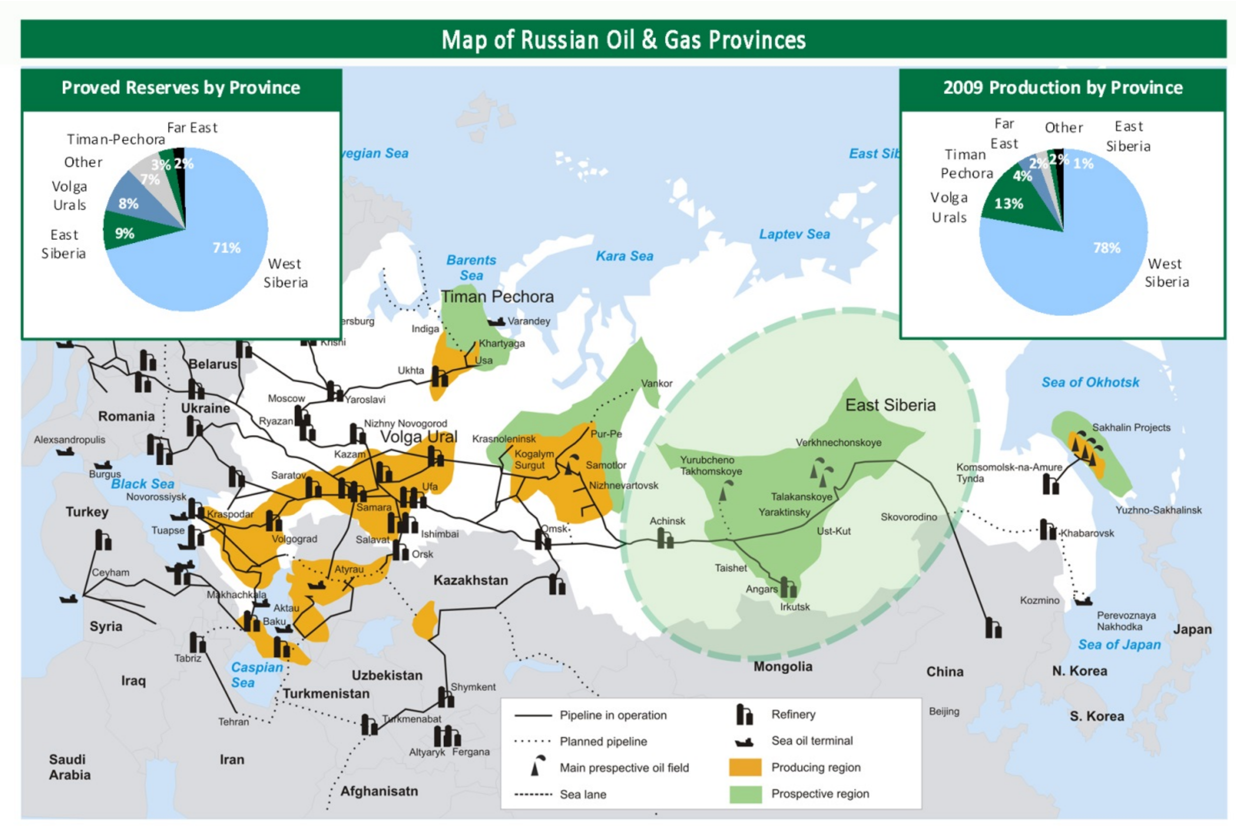


Source: The Economist (2013)[141]

Meanwhile, the U.S. Energy Information Administration has estimated that the combined gas reserves in Romania, Bulgaria, and Hungary could equal more than 535 billion cubic meters of gas.[142] Some analysts predict that Eastern Europe will depart from the hard-line opposition to fracking seen in France and the Netherlands. The rationale is that Eastern European countries are more likely to take advantage of their natural gas reserves in order to mitigate their heavy reliance on gas imports from Russia.[143] However, estimated reserves that can fluctuate wildly are no indication that fuel switching will take place in the EU with the current prices of coal and natural gas.

140 Kanter, 2013.
141 The Economist, 2013.
142 Lawrence, 2013.
143 The Economist, 2013.

Figure 21. Russian Oil and Gas Infrastructure



Source: Irkutsk Oil Company (2008)[144]

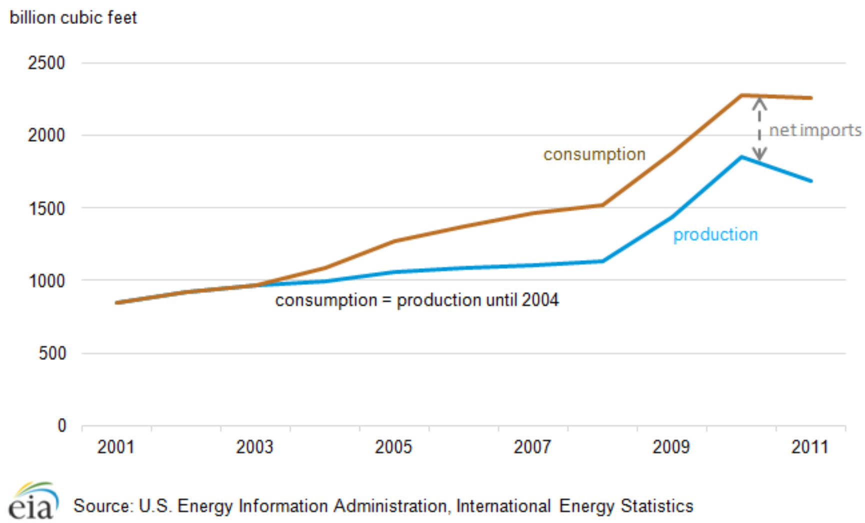
INDIA – FINANCIAL AND TECHNICAL BARRIERS

According to the EIA, India is the 4th largest consumer of energy in the world behind the US, China, and Russia, and consumption in the country has more than doubled in the last 20 years.[145]

Coal currently serves as the fuel source for the majority of baseload electricity in India and natural gas serves as a substitute. India was self-sufficient in natural gas until 2004, but due to insufficient infrastructure, the country was forced to begin importing LNG from Qatar.[146]

[144] Irkutsk Oil Company, 2008.
[145] U.S. EIA, 2013.
[146] Ibid.

Figure 21: Indian natural gas production and consumption, 2001-2011



Source: U.S. EIA (2013)[147]

The gap between consumption and production of natural gas in India is growing wider every year and the government will be forced to come up with a coherent policy solution to address the country's inevitable growth. In the Indian market, the government directly sets prices for public sector companies through the Administrative Price Mechanism, though joint-venture producers will generally index their prices to international rates.[148]

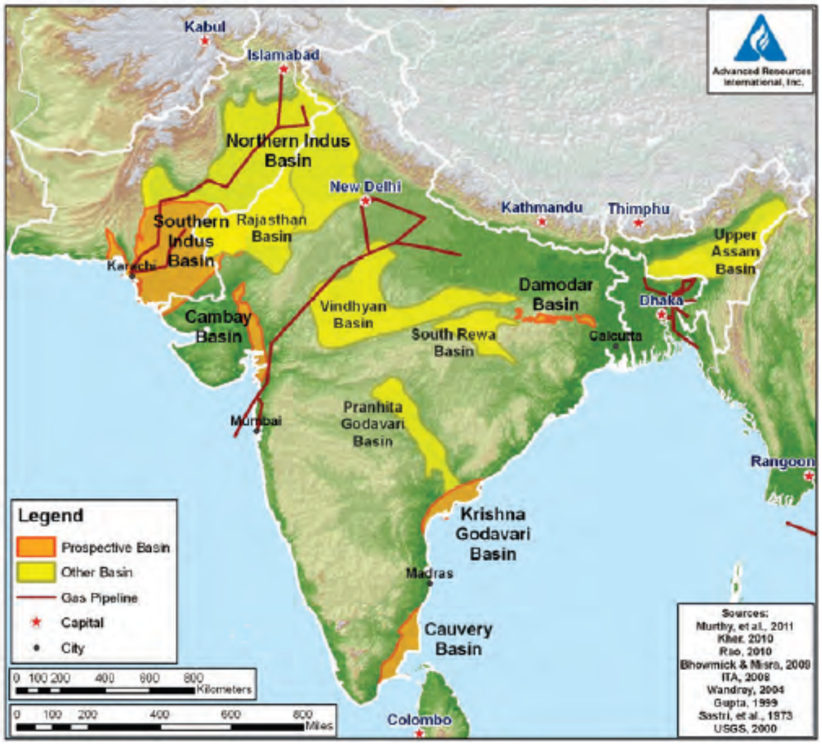
Up until this year, India's experience with domestic natural gas exploration has been inconsistent. According to the IEA, the two biggest state-owned companies, ONGC and Oil India Ltd., control India's upstream gas sector.[149] On the one hand, ONGC and Gujarat State Petroleum Corporation Limited (GSPCL) are developing several offshore areas in Krishna-Godavari basin. On the other hand, production in the major D6 oil field within the same basin has unexpectedly declined. Even if one of the country's large exploration companies was to find a massive field, "experts say it may take years for the country to access and realize profits from the valuable natural resource because of a lack of infrastructure, opposition to raising gas prices, and paucity of information about where exactly to find gas."[150]

Significant regulatory barriers also exist to successful shale gas development in India, which is crucial to providing cheaper natural gas to fuel a transition away from coal. India's gas reserves belong to the government, rather than private landowners. In the U.S., much of the tolerance for fracking "in my backyard" is because homeowners receive royalty checks from

[147] U.S. EIA, 2013.
[148] U.S. EIA, 2013.
[149] Ibid.
[150] Mukherji and Chaturvedi, 2013.

the oil and gas companies in exchange for leasing the land. Without a regulatory system in place that rewards the owners of the land on which you are drilling, it is unlikely that India's natural gas industry will achieve the economies of scale necessary to supply the country's need for cheap fossil fuels.

Figure 22. Shale Gas Basins and Natural Gas Pipelines of India/Pakistan



Source: U.S. Energy Information Administration (2011)[151]

FUEL SWITCHING RECOMMENDATIONS AND CONCLUSION

(1) Stricter emissions standards in OECD countries can encourage utilities to retire their aging coal-fired power plants. Replacing this capacity will lower carbon alternatives will be a major challenge. The United States, in particular, is using natural gas to displace coal.

Inevitable plant retirements in OECD countries will force utilities around the world to decide what to replace that lost capacity with. Historically low natural gas prices and stricter environmental regulations in the United States will continue to encourage the transition from coal to gas-fired electricity generation.

[151] U.S. EIA, 2011.

(2) Non-OECD countries should build out their natural gas infrastructure to supplement their new coal-fired power plants. Coal provides the most electricity at the lowest cost to meet the growing demand in non-OECD countries. China and India possess natural gas reserves that they could build out to someday reduce their reliance on coal-fired electricity generation.

China possesses incredible potential for natural gas development but currently lacks the infrastructure and regulatory framework to take advantage of it. The IEA's estimated reduction for China is 3 $GtCO_2e$ but not until 2030; therefore there is incredible uncertainty about the prospects for fuel switching there. Japan currently relies heavily on LNG imports from Southwest Asia, and would most likely benefit the most from American natural gas exports.

India may possess natural gas reserves, but with demand outpacing supply, most of India's natural gas will be LNG shipped from Qatar. In the near term, India will continue to rely on coal-fired power generation while attempting to build infrastructure to bolster domestic natural gas production. Fossil fuel switching appears increasingly unlikely in India.

(3) Eastern European member states should remove their bans on hydraulic fracturing to reduce the EU's reliance on coal and Russian gas.

The EU remains divided on natural gas and the current cost calculus for a coal-to-gas transition does not work for member countries. Further, many EU countries have placed a ban on hydraulic fracturing within their borders which will inevitably hamper development in the region. However, eastern European countries that possess very large potential reserves may embrace the new technology and sell their natural gas to the European market. Until that happens or the US chooses to export its natural gas, the EU will continue to acquire most of its natural gas from Russia and burn coal alongside its renewable energy installations.

CONCLUSION

The energy production sector currently emits more greenhouse gases than any other sector and is projected to grow rapidly through 2050, especially in non-OECD countries. The top 5 producers of greenhouse gases from energy production are the United States, China, the EU, India, and Russia. To reduce emissions in the energy production sector, these 5 countries could employ a mix of HELE coal generation and CCS technology, renewable energy development, and coal-to-gas fuel switching.

Until adoption of CCS technology is commercially feasible, HELE technology at the supercritical level will serve as a crucial bridge to reduce coal-related carbon emissions. As the coal continues to represent a consistent and economic method of generating electricity, policymakers must act to ensure that new coal generated plants are equipped with emissions-reducing technology and less-efficient, older plants are retired. Further development of ultra-super critical and advanced ultra-supercritical is needed in the interim until CCS technology reaches further maturity.

CCS offers the greatest potential reductions in carbon emissions because coal-fired power generation remains the largest single source of energy production - a trend that will continue into the near future. Currently, there are only 13 large-scale demonstration projects worldwide. The number of projects will need to increase considerably in order to meet the targets for the 2 degree Celsius warming scenario. The cost of CCS remains prohibitively expensive for widespread adoption, but the impact of the technology will provide the necessary emissions reductions in line with a 2 degrees Celsius warming scenario by 2050.

Renewable energy technologies present an opportunity to reduce emissions in the top 5 emitters within the energy production sector, but each country faces unique circumstances that may slow, or prohibit the deployment of renewable technologies. Among all renewable technologies, wind generation has experienced the most growth worldwide, particularly in the US and China. Germany remains a leader in in solar PV adoption, though up front cost remains a significant barrier to the technology. While the cost of renewable technologies has fallen dramatically in recent years, infrastructure constraints and political opposition may potentially hamper the growth of the industry.

As OECD countries continue to retire old, inefficient fossil-fuel power plants, national legislation and regional fuel prices will ultimately determine which technologies replace these retired fleets. Shale-gas production in the United States has brought the price of natural gas in North America to historic lows. Low fuel prices combined with strict emission standards have shifted the US energy portfolio to favor gas-fired power generation, known as the "coal-to-gas transition." The ramifications of this transition have global consequences, particularly if China and the EU decide to exploit their own abundant shale gas reserves. As the domestic market for coal dries up, US coal producers are shipping their products to Asian and European markets to power growing worldwide coal generation. Meanwhile, American policymakers weigh the potential consequences of exporting natural gas to lucrative Asian and European markets.

REFERENCES

Advanced Resources International. World Shale Gas Resources: An Initial Assessment. "Figure XI-10. China's Other Shale Gas Basins." http://www.adv-res.com/pdf/ARI%20EIA%20Intl%20Gas%20Shale%20APR%202011.pdf

Allen, David T., et al. Measurements of methane emissions at natural gas production sites in the United States. PNAS 2013 110 (44) 17768-17773; published ahead of print September 16, 2013, doi:10.1073/pnas.1304880110

"Appalachian fall: New carbon regulations will make life harder still for a beleaguered region." *The Economist,* September 28, 2013.

Bosselman, Fred, Joel B. Eisen, Jim Rossi, David B. Spence, and Jacqueline Lang Weaver. *Energy, Economics, and the Environment*. 3rd ed. New York, NY: Foundation Press, 2010.

Busby, Joshua. 2011. *Time for a Safety Check: China's Nuclear Power Sector after Fukushima*. Long Term Strategy Group.

Busby, Joshua W. 2013. Vaunted Hopes: Climate Change and the Unlikely Nuclear Renaissance. In *The nuclear renaissance and international security*, edited by Adam N Stulberg and Matthew Fuhrmann, 124–153. Stanford, Calif.: Stanford University Press.

Cheung, Kat. *Integration of Renewables: Status and Challenges in China*. International Energy Agency. Working Paper. 2011. Deploying p.12

Climate Analysis Indicator Tools Database, September 30, 2012.

China Wind Energy Association, "Outlines Prepared by CWEA for the China 2050." 2010

China Wind Energy Association,"Wind and Grid Integration Roadmap." November 2010.

Congressional Budget Office. Federal Efforts to Reduce the Cost of Capturing and Storing Carbon Dioxide. 2012. http://cbo.gov/sites/default/files/cbofiles/attachments/43357-06-28CarbonCapture.pdf

CPS Energy. "Generation and Distribution by the Numbers." 2013.

Deng, Chao, "China Offers Cash in Bid to Cut Air Pollution." *The Wall Street Journal.* October 15, 2013.

The Economist. "Frack to the Future: Extracting Europe's shale gas and oil will be a slow and difficult business." February 2, 2013. http://www.economist.com/news/business/21571171-extracting-europes-shale-gas-and-oil-will-be-slow-and-difficult-business-frack-future.

The Economist. “Worse than Useless”. January 25th, 2014. http://www.economist.com/news/leaders/21595002-current-policies-are-mess-heres-how-fix-them-worse-useless . Accessed 2/3/2014.

Electric Reliability Council of Texas. “ERCOT experiences highest demand this year, generation keeps up”. News Release. August 8, 2013. http://www.ercot.com/news/press_releases/show/26528

Emissions Database for Global Atmospheric Research, September 30, 2012.

Energy Information Agency. Lower 48 Shale Gas Plays. Updated May 9, 2011. http://www.eia.gov/oil_gas/rpd/shale_gas.jpg. Accessed 2/3/2014.

Energy Information Agency. Shale oil and shale gas resources are globally abundant. June 10, 2013. http://www.eia.gov/todayinenergy/detail.cfm?id=11611

“Europe’s Dirty Secret: The unwelcome renaissance.” The Economist. January 5, 2013. Accessed at: http://www.economist.com/news/briefing/21569039-europes-energy-policy-delivers-worst-all-possible-worlds-unwelcome-renaissance

European Environment Agency. 2011. Air pollution impacts from carbon capture and storage (CCS). http://www.eea.europa.eu/publications/carbon-capture-and-storage/download

Fackler, Martin. 2014. Warily Leading Japan’s Nuclear Reawakening. The New York Times. Available from <http://www.nytimes.com/2014/03/21/world/asia/warily-leading-japans-nuclear-reawakening.html>.

Fawzi A., Energy Information Agency. 23 October 2013

Federal Energy Regulatory Commission - The Division of Energy Market Oversight, Energy Primer: A Handbook of Energy Market Basics, Rep., at 128 (2012) http://www.ferc.gov/market-oversight/guide/energy-primer.pdf

Global CCS Center. CCS in China. 2014. http://www.globalccsinstitute.com/location/ccs-china

Holland, Andrew, “How shale gas can slow global climate change.” *The Christian Science Monitor.* June 25, 2013.

ICF International, “U.S. LNG Exports. Impacts on Energy Markets and the Economy.” May 15, 2013.

Ingraffea, Anthony. Physicians, Scientists, & Engineers for Healthy Energy. “Fracking Methane Leakage Study Financed by Gas Industry with Partner, EDF, is Deeply Flawed”. September 17, 2013. http://www.psehealthyenergy.org/events/view/176.

Institute for Energy Research, "Germany's Grim Nuclear Phase-out." August 5, 2013. Accessed at http://www.instituteforenergyresearch.org/2013/08/05/germanys-grim-nuclear-phase-out/

International Energy Agency, Energy Technology Perspectives (ETP) 2012. Accessed at http://www.iea.org/etp/explore/.

The International Energy Agency, "Technology Roadmap High Efficiency Low Emissions Coal-fired Power Generation," March 2013.

International Energy Agency. "Lessons from Liberalised Electricity Markets." 2005. p 50.

International Energy Agency, "Tracking Clean Energy Progress (TCEP) 2013." Accessed December, 2013. http://www.iea.org/publications/TCEP_web.pdf

International Energy Agency, "World Energy Outlook, 2013." November 2013. Accessed at: http://www.worldenergyoutlook.org/publications/weo-2013/

International Energy Agency and the Organization for Economic Cooperation and Development,"Energy Technology Perspectives 2012: Pathways to a Clean Energy System." 2012.

International Finance Corporation. *Renewable Energy Policy in Russia: Waking the Green Giant* World Bank Group. 2011. p. 24

Intergovernmental Panel on Climate ChangeChange, 2011: Summary for Policymakers. In: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen,S. Schlömer, C. von Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. p. 8

Intergovernmental Panel on Climate Change, "IPCC Special Report on Carbon Dioxide Capture and Storage," 2005.

International Renewable Energy Association. IRENA. Renewable Power Generation Costs in 2012: An Overview. pg. 5

Irkutsk Oil Company. East Siberia. Map of Russian Oil & Gas Provinces. 2008. http://irkutskoil.com/section_29/section_64

Jing, Li, "Life grinds to a halt as dense smog descends on northern Chinese cities." *South China Morning Post.* October 21, 2013.

Jinran, Zheng, "Govt offers 5b yuan to fight pollution." Accessed: http://www.chinadaily.com.cn/china/2013-10/14/content_17032103.htm

Johnson, Elias. “Planned Coal-Fired Power Plant Retirements Continue to Increase.” *The Energy Collective.* March 23, 2014. http://theenergycollective.com/todayinenergy/357226/planned-coal-fired-power-plant-retirements-continue-increase

Jolly, David. “France Upholds Ban on Hydraulic Fracturing”. The New York Times. October 11, 2013.

Jones, Spencer, “Capture Capture and Sequestration: What is it?” Major Economies and Climate Change Research Group Blog, October 31, 2013. http://blogs.utexas.edu/mecc/2013/10/31/carbon-capture-and-sequestration-what-is-it/

Jones, Spencer, “China’s Dark Matter.” Major Economies and Climate Change Research Group Blog. October 25, 2013. http://blogs.utexas.edu/mecc/2013/10/25/chinas-dark-matter/

Jones, Spencer, “China’s Synthetic Gas Revolution?”. Major Economies and Climate Change Research Group Blog. 2013. http://blogs.utexas.edu/mecc/2013/09/27/chinas-synthetic-gas-revolution/

Kanter, James. “Europe Votes to Tighten Rules on Drilling Method.” *The New York Times*. October 9, 2013.

“Kemper Timeline.” Mississippi Power. Accessed at http://www.mississippipower.com/kemper/project-timeline.asp

Krauss, Clifford. “Oil Companies are Sued for Waste of Natural Gas”. New York Times. October 17, 2013. http://www.nytimes.com/2013/10/18/business/energy-environment/oil-companies-are-sued-over-natural-gas-flaring-in-north-dakota.html?_r=0

Kuuskraa, Vello A. “EIA/ARI World Shale Gas and Shale Oil Resource Assessment.” June 17, 2013. Accessed at http://www.eia.gov/conference/2013/pdf/presentations/kuuskraa.pdf

Lawrence, Diana. “Eastern Europe seeks shale gas ‘Revolution.’” *The Globe and Mail*. August 15, 2013.

Mann, Charles. “Renewables Aren’t Enough. Clean Coal Is the Future.” *Wired.* March 25, 2014. http://www.wired.com/2014/03/clean-coal

Major Economies Forum on Energy and Climate, “Technology Action Plan: High Efficiency, Low-Emissions Coal.” December 2009.

McKinsey and Company, 2009. Climate Desk Model. https://solutions.mckinsey.com/climatedesk/app/Login.aspx?ReturnUrl=%2fclimatedesk%2fapp%2fSecure%2fDefault.aspx

Miller, Scot M., et al. "Anthropogenic emissions of methane in the United States." Proceedings of the National Academy of Sciences 110.50 (2013): 20018-20022. http://www.pnas.org/content/early/2013/11/20/1314392110

Mukherji, B. and Chaturvedi S. “Why India Can’t Unlock Its Shale Gas”. The Wall Street Journal – Blogs. June 11, 2013. http://blogs.wsj.com/indiarealtime/2013/06/11/why-india-cant-unlock-its-shale-gas/

NaturalGas.org. Unconventional Natural Gas Resources. http://www.naturalgas.org/overview/unconvent_ng_resource.asp. Accessed 2/3/2014

Newell, Samuel, et al. "ERCOT Investment Incentives and Resource Adequacy." The Brattle Group, prepared for the Electric Reliability Council of Texas (2012). http://www.ercot.com/content/news/presentations/2013/Brattle%20ERCOT%20Resource%20Adequacy%20Review%20-%202012-06-01.pdf

Plumer, Brad. “The World Bank cuts off funding for coal. How big an impact will that have?” *The Washington Post*, July 17, 2013.

Plumer, Brad, “China’s plan to clean up air pollution could be a climate disaster.” *The Washington Post*, September 26, 2013.

Plumer, Brad, “Coal pollution in China is cutting life expectancy by 5.5 years.” The Washington Post. July 8, 2013.

Plumer, Brad. “Will Coal Survive the EPA’s New Carbon Rules?” The Washington Post. September 20, 2013. Accessed at http://www.washingtonpost.com/blogs/wonkblog/wp/2013/09/19/will-coal-survive-the-epas-new-carbon-rules/

PV Magazine. Russia Offers First Ever Subsidies for Renewable Energy. http://www.pv-magazine.com/news/details/beitrag/russia-offers-first-ever-subsidies-for-renewable-energy_100012889/#axzz2sMvMEIt0 . Accessed 2/2/2014

REN21. 2012. Renewables 2012 Global Status Report (Paris: REN21 Secretariat). p. 19

Roberts, David. “The U.S. power sector: where the power plants are, when they were built, and what they pollute”. Grist. August 11, 2010. http://grist.org/article/2010-08-10-us-power-sector-where-plants-are-when-built-what-they-pollute/

Sargsyan,Gevorg, Mikul Bhatia, Sudeshna Ghosh Banerjee, Krishnan Raghunathan, Ruchi Soni Unleashing the Potential of Renewable Energy in India. 2010.South Asia Energy Unit.Sustainable Development Department The World Bank. 2010 pgs 40-41

The Shift Project Data Portal, 2013. Accessed at: http://www.tsp-data-portal.org/.

Spegele, Brian, “China Pledges to cut Coal Consumption.” *The Wall Street Journal,* September 11, 2013.

Stephenson-Reynolds. Dustin. "Introduction to Power Production and Renewables," Major Economies and Climate Change Research Group Blog. November 29, 2013. http://blogs.utexas.edu/mecc/2013/11/29/introduction-to-power-production-and-renewables/

Stones, Carson. "Why Texas Matters." Major Economies and Climate Change Research Group Blog. October 13, 2013. http://blogs.utexas.edu/mecc/2013/10/07/why-texas-matters-or-if-youre-not-first-youre-last/

UNEP. Feed-in Tariffs as a Policy Instrument for Promoting Renewable Energies and Green Economy is Developing Countries. 2012. pg. 5

United States Energy Information Administration. India. March 18, 2013. http://www.eia.gov/countries/cab.cfm?fips=in

United States Energy Information Administration, Energy Statistics, 2012.

United States Energy Information Administration, "Henry Hub Gulf Coast Natural Gas Spot Price." Accessed: http://www.eia.gov/dnav/ng/hist/rngwhhdA.htm

United States Energy Information Administration, "International Energy Outlook 2013." July 2013. Accessed at: http://www.eia.gov/forecasts/ieo/pdf/0484(2013).pdf

United States Energy Information Agency. "North America leads the world in production of shale gas." October 23, 2013. http://www.eia.gov/todayinenergy/detail.cfm?id=13491&src=Natural-b2

United States Energy Information Administration. "U.S. expected to be largest producer of petroleum and natural gas hydrocarbons in 2013. October 4, 2013. Accessed at: http://www.eia.gov/todayinenergy/detail.cfm?id=13251

U.S. Energy Information Administration. US Natural Gas Import/Export Locations at the end of 2008. http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/ngpipeline/impex_map.html

U.S. Energy Information Administration. Office of Oil & Gas, Natural Gas Division, Gas Transportation Information System. http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/ngpipeline/ngpipelines_map.html

United States Environmental Protection Agency. "EPA Proposes Carbon Pollution Standards for New Power Plants". Release Date: 09/20/2013. http://yosemite.epa.gov/opa/admpress.nsf/0/da9640577ceacd9f85257beb006cb2b6!OpenDocument

United States Environmental Protection Agency. "Facility Level Information on Greenhouse Gasses Tool." J T Deely, San Antonio, TX 78223. http://ghgdata.epa.gov/ghgp/main.do

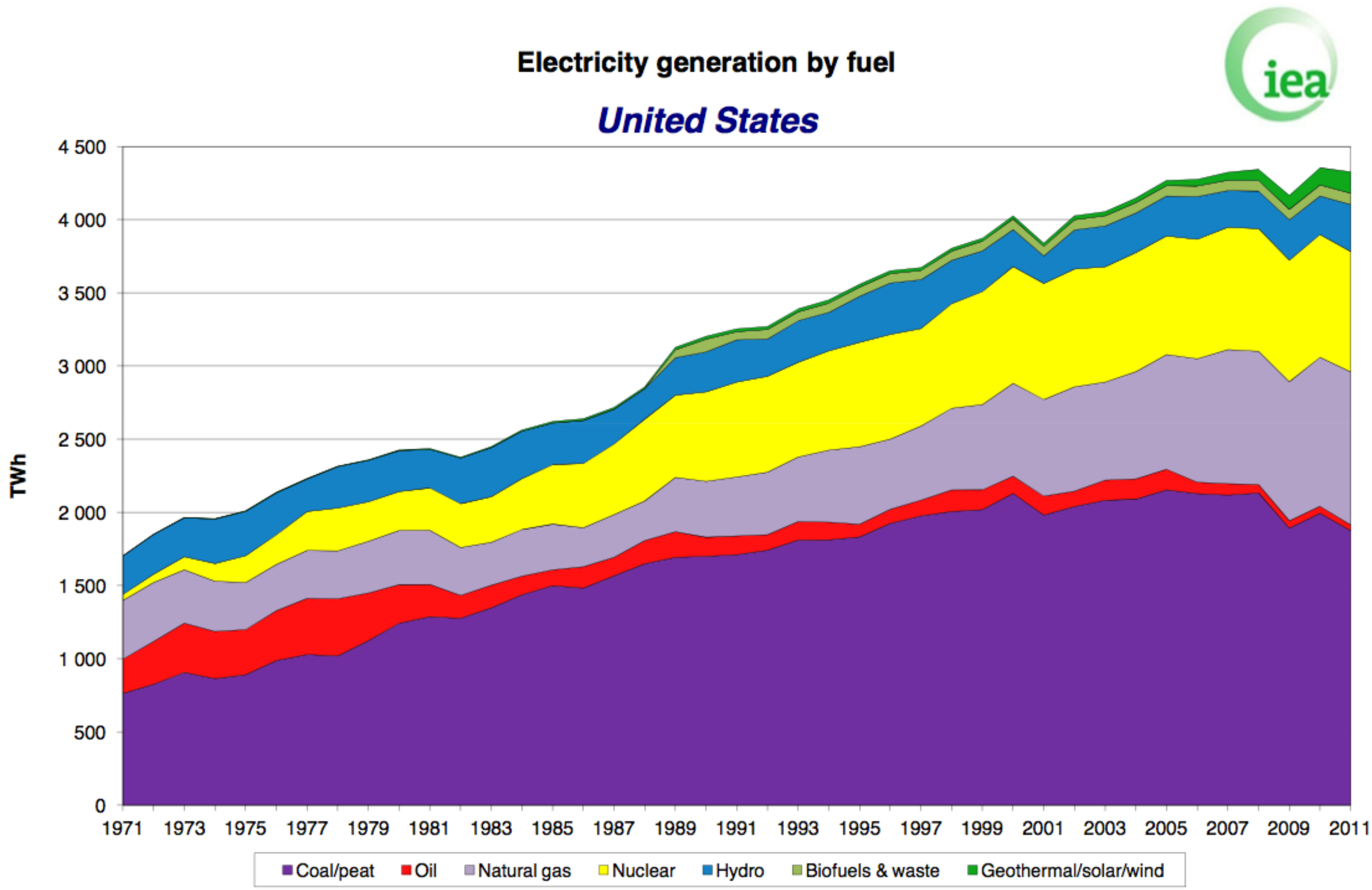
United States Environmental Protection Agency. eGRID2012 Version 1.0. U.S. Environmental Protection Agency, Washington, DC. 2012.

Volvovici, Valerie. "EPA tells court U.S. mercury, toxics rule is legally justified." *Reuters.* December 10, 2013. http://www.reuters.com/article/2013/12/10/us-usa-energy-air-pollution-idUSBRE9B91AL20131210

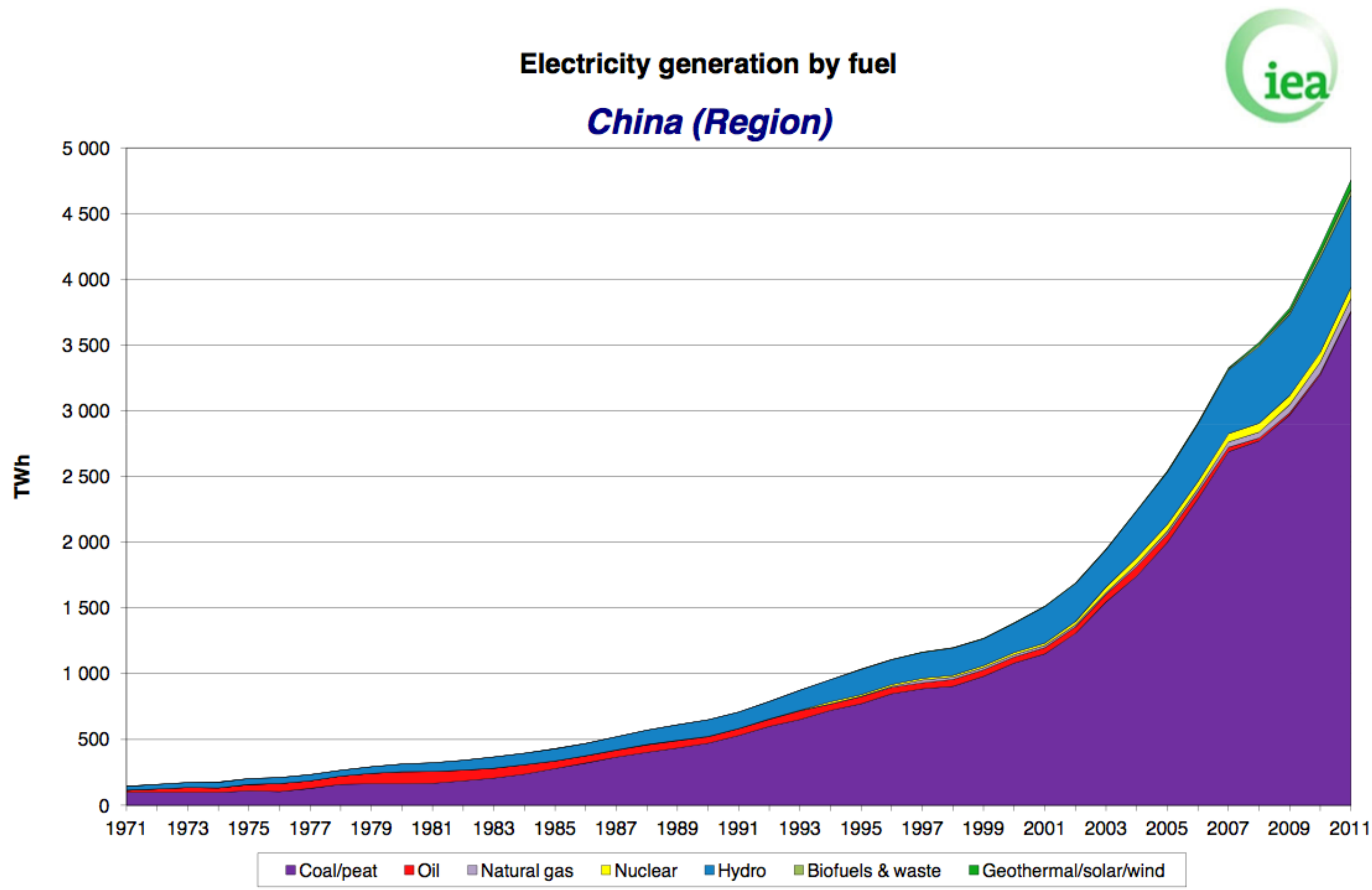
Wang, Z. (2009), Market potential and technology transfer, NDRC Energy Research Institute, 9 November 2009.

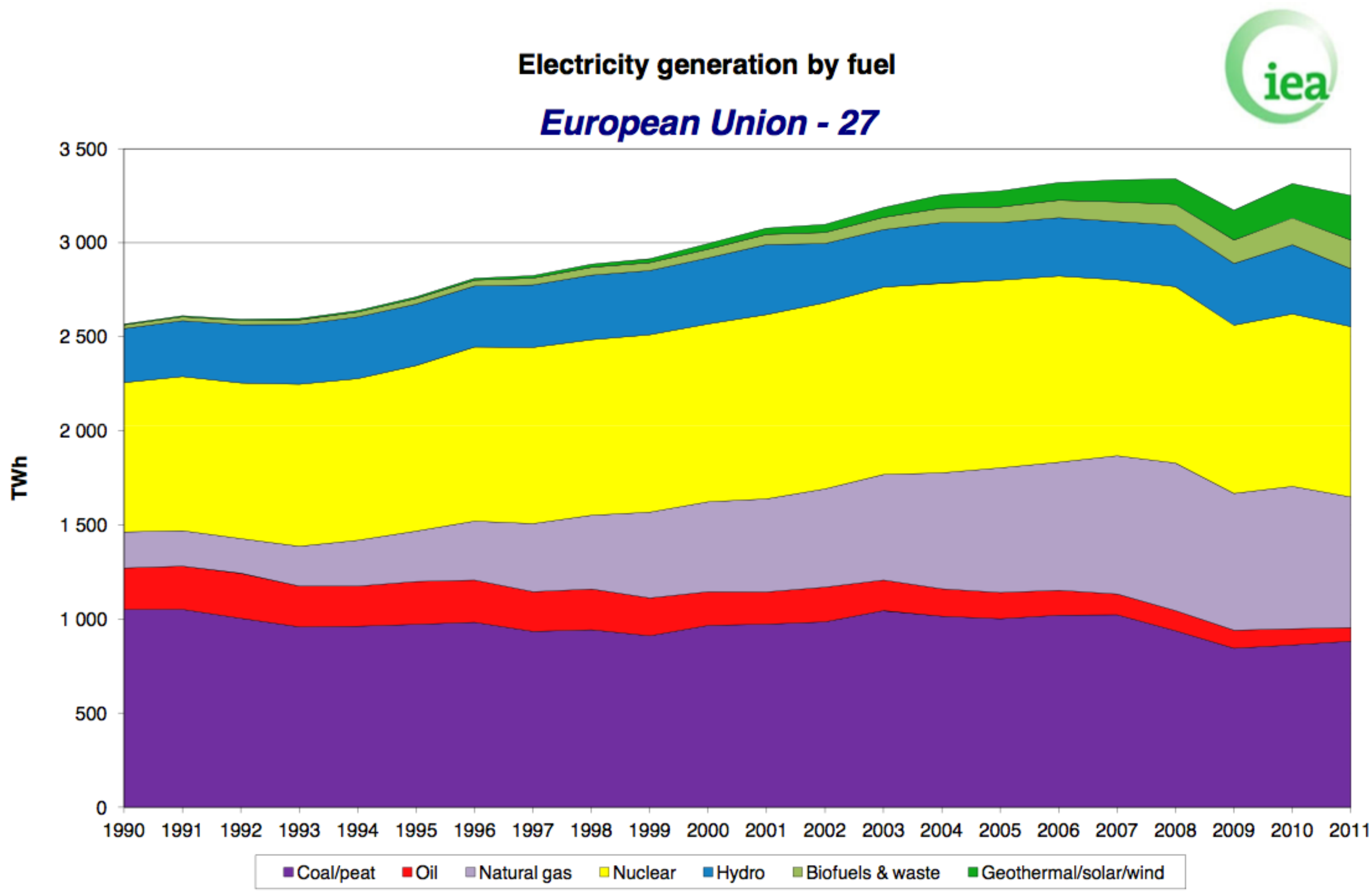
Wilder, Forrest. "San Antonio, the Clean-Energy City?". Texas Observer. June 20, 2011. http://www.google.com/url?q=http%3A%2F%2Fwww.texasobserver.org%2Fsan-antonio-the-clean-energy-city%2F&sa=D&sntz=1&usg=AFQjCNFBkofcEW9wRztzF9I85wcPpyywB

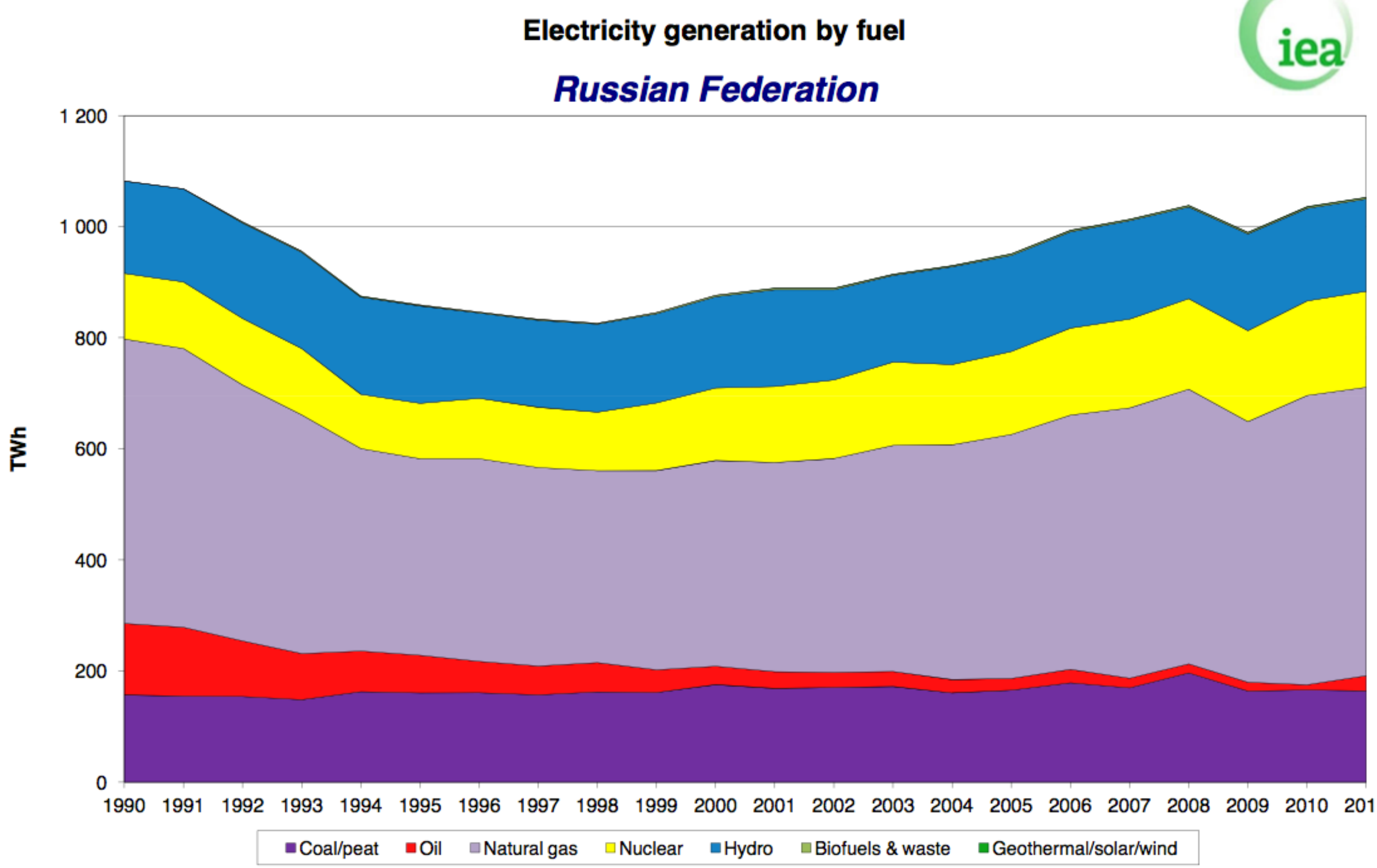
Yang, Ailun and Ryna Yiyun Cui (2013). Can China's Action Plan to combat air pollution slow down new coal power development?. ChinaFAQs, October 8, 2013. http://www.chinafaqs.org/blog-posts/can-china%E2%80%99s-action-plan-combat-air-pollution-slow-down-new-coal-power-development#sthash.viYTbcJG.dpuf



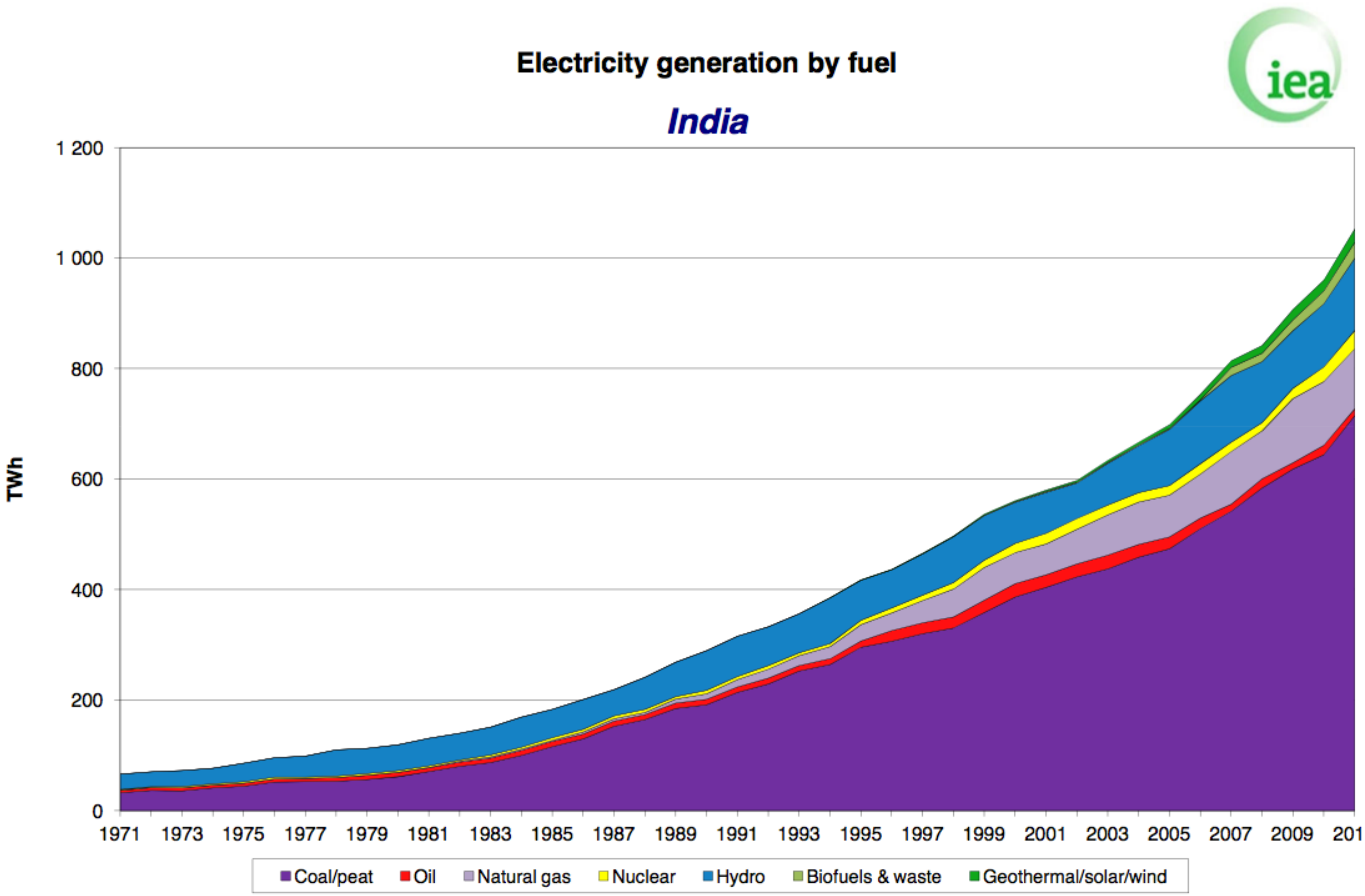
Electricity generation by fuel
United States
iea
4 500
4 000
3 500
3 000
2 500
2 000
1 500
1 000
500
0
TWh
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
Coal/peat
Oil
Natural gas
Nuclear
Hydro
Biofuels & waste
Geothermal/solar/wind


Electricity generation by fuel
China (Region)
iea
TWh
5 000
4 500
4 000
3 500
3 000
2 500
2 000
1 500
1 000
500
0
1971 1973 1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011
Coal/peat
Oil
Natural gas
Nuclear
Hydro
Biofuels & waste
Geothermal/solar/wind


Electricity generation by fuel
European Union - 27
iea
TWh
3 500
3 000
2 500
2 000
1 500
1 000
500
0
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
Coal/peat
Oil
Natural gas
Nuclear
Hydro
Biofuels & waste
Geothermal/solar/wind



Electricity generation by fuel
Russian Federation
TWh
1 200
1 000
800
600
400
200
0
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
Coal/peat
Oil
Natural gas
Nuclear
Hydro
Biofuels & waste
Geothermal/solar/wind


Electricity generation by fuel
India
iea
TWh
1 200
1 000
800
600
400
200
0
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
Coal/peat
Oil
Natural gas
Nuclear
Hydro
Biofuels & waste
Geothermal/solar/wind