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Task Force on Increasing Efficiency of Fossil Fuel-fired Power Plants and Potential Normative Instruments

Baseline Efficiency Analysis of Fossil Fuel Power Plants

1. We Rely on Fossil Fuels

Electricity generation through the use of fossil fuels is a foundational pillar to modern society. Over two thirds of the world's electricity is supplied by fossil fuels with coal alone accounting for 42% of global electricity[1]. Electricity production has been built upon fossil fuels because they have historically been abundant and inexpensive. The power plant technologies needed to convert fossil fuels into electricity also have a history of being easy to construct without excessively high capital costs and have lent themselves to economies of scale[2]. Inexpensive fossil fuels and technology has created an electricity sector designed around these fuels where power plants have been constructed in locations where the energy-dense fossil fuels were readily available, delivered and are cheap and easy to handle[3]. The continued use of these fuels is expected in part because global supplies of abundant and inexpensive fossil fuels are estimated to last well into the future. At current production levels, proven coal reserves are estimated to last 118 more years and proven oil and gas reserves should last around 46 and 59 years respectively[4]. To summarize: with the growth of electricity demand and production, the security of supply, and economic competitiveness of fossil fired plants, fossil fuels have become deeply engrained into the energy foundation that modern societies are built upon. However, the high carbon content of fossil fuels make them a major contributor to rising CO_2 levels in the atmosphere and attempts are underway to ensure adequate environmental performance of fossil-fired power plants.

2. Fossil Fuels Have Adverse Effects

Unfortunately there are drawbacks from continuing to use fossil fuels as a primary energy source. The combustion of fossil fuels releases carbon dioxide (CO_2) into the atmosphere and thus contributes to climate change. The CO_2 emissions from fossil fuel combustion for power generation is the single largest source of anthropogenic greenhouse gas (GHG) emissions[5]. These emissions make up 28% of the total CO_2 emissions from all sources[6]. More specifically, coal-fired power plants are the largest emitters of CO_2. Over the past 15 years, the rapid increase in capacity of coal-fired electricity

[1] World Coal Association 2011, via UNECE Energy Week 2011;IEA data, staff calculations http://www.unece.org/fileadmin/DAM/energy/se/pp/clep/ahge8/3_Opening_Budinsky_item_7.pdf
[2] UNECE (2013) *Mitigating Climate Change Through Investments in Fossil Fuel Technologies*, 8
[3] Ibid., pg14
[4] World Coal Association 2011, via UNECE Energy Week 2011;IEA data, staff calculations http://www.unece.org/fileadmin/DAM/energy/se/pp/clep/ahge8/3_Opening_Budinsky_item_7.pdf
[5] UNECE (2013) *Mitigating Climate Change Through Investments in Fossil Fuel Technologies*, 18
[6] Ibid., 18

generating stations has raised concerns about the surge in carbon emissions[7]. The current levels of carbon dioxide and other GHG emissions are exceeding the worst case scenarios outlined by climate experts. Still global emissions are increasing and are expected to continue increasing in the future[8]. The emissions from China and India are the world's first and third largest CO_2 emitters. Both nations have very large coal burning power sectors and their emissions have shown very strong growth in the past decade[9]. As a response to the rising level of emissions, there have been some calls in developed countries to completely abandon fossil fuels, especially coal, as a source of electricity. These calls make no economic sense for either the immediate or distant future because of the abundance of fossil fuel resources, their high energy content and relatively low cost that most economies depend on[10].

3. Improving Efficiency Can Mitigate These Problems

The most effective means of benefitting from continuing to use fossil fuel plants while reducing GHG emissions has proven to be increasing the energy efficiency of existing power plants. There is a direct, inverse correlation between running a fossil fuel fired power generator at higher efficiency and reducing the generator's CO_2 emissions. It can be assumed that for each 1 per cent increase in efficiency of a coal burning power plant there is a 2-3% reduction of CO_2 emissions[11]. This means that if all coal burning power plants were able to achieve a 1% efficiency increase, 0.23 $GtCO_2$ per year would be avoided. This amount equals the total emissions from the Netherlands and Denmark combined. Best practices at all plants would save 1.7 $GtCO_2$ per year.[12]

4. The Technology Exists

Improving energy efficiency has been a focus of intensive energy research over the past two decades[13]. As a result, there has been steady technological innovation towards increasing efficiency and reducing emissions from the power generation of fossil fuels, most notably from coal where most of the research has been focused[14]. Cleaner more efficient fossil fuel combustion technologies such as supercritical pulverized coal (SCPC) and ultra-supercritical pulverized coal (USCPC) steam generators are being increasingly introduced to electricity generation fleets in order to replace les efficient sub-critical generators[15]. China for example implemented a program in 2006 called "Large Substitute for Small" that removes smaller and older coal fired plants to replace them with newer and larger plants with advanced technology such as the SCPC and USCPC generators. China plans to add 525 GWs of new coal-burning power plants by 2020[16]. Other advanced technologies for power generation from fossil fuel plants are being developed that also offer higher efficiencies and lower carbon emissions. These include: Combined Cycle Gas Turbines (CCGT), Combined Heat and Power gas turbines (CHP), and Integrated Coal Gasification combined cycle plants (IGCC)[17]. IGCC plants have several advantages over pulverized coal plants: relatively higher efficiency, better environmental performance, relative ease of CO_2 capture, suitability for co-generation and flexibility of fuel used[18]. The capital costs of IGCC are expected to decrease with the use of advanced gas turbines and fuel cells. At

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7 Ibid., 9
8 UNECE Energy Week 2011
9 UNECE (2013) *Mitigating Climate Change Through Investments in Fossil Fuel Technologies,* 65
10 Ibid., 21
11 Ibid., 21
12 EURACOAL, ECE/ENERGY/GE.5/2011/INF.1 - http://www.unece.org/fileadmin/DAM/energy/se/pp/clep/ahge8/4_RICKETTS.pdf
13 UNECE (2013) *Mitigating Climate Change Through Investments in Fossil Fuel Technologies*, 21
14 Ibid., 21
15 Ibid., 65
16 Ibid., 66
17 Ibid., 21
18 NETL Commercial Power Production based on Gasification. http://www.netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/igcc

present, the high capital cost value and complexity of design are major barriers to its wide-spread implementation. Unless greater efforts are made to encourage higher penetration of such high-efficiency, low-emissions (HELE) technologies into the existing power grid, overall CO_2 emissions will continue to rise despite current measures due to increasing energy use in growing energy sectors.

5. Some Areas Still Using Old Technology

Since these technological advancements are a relatively new area of research, power plants older than a few decades are significantly far behind in the race to increase efficiency. Many countries in Asia and Eastern Europe[19] with economies in transition still rely on power plants built with old and obsolete technology. It's often the case that countries with power plants built prior to 1992 rely on coal for up to 80% of their electricity and were designed based on self-sufficiency energy policies that focused on the high availability and low costs of coal[20]. The construction of the power plants was followed by a serious economic contraction in the 1990s and then a lack of investment funds resulting in very little new building capacity[21] in these regions. In Ukraine for example, nearly 47% of the total power generating fleet, or 75% of its thermal power capacity is more than 40 years old with a thermal power fleet that runs at an average load capacity of 31.5%[22].

Besides, according to EIA, approximately 73% of U.S. coal fired power plants were age 30 years or older at the end of 2010. The service life for coal fired power plants in the UNECE region normally averages between 35 and 50 years, and varies according to boiler type, maintenance practices, and the type of coal burned, among other factors.

Over the past few years, some countries have recognized their increasing energy demand and aging power plants. Mongolia, Kazakhstan and Uzbekistan have recently begun programs of modernization or of constructing new power plants but the average energy intensities in the countries with economies in transition are still significantly higher than most other countries. This situation suggests that future investment in the energy sector will most likely go into energy conservation and increasing energy efficiency rather than into building new electricity generation capacity so there will most likely not be strong growth in the electricity sector expansion in the near future[23].

The efficiency of coal-fired power plants, in particular, decreases with age. While good maintenance practices can keep power plant efficiency high in the early years of life, as the plant ages, power plant performance and efficiency erode after about 25 to 30 years of operation[Error! Bookmark not defined.], and substantial work may be required to keep the plant operating efficiently and economically. Since much of this loss in efficiency is due to mechanical wear on a variety of components resulting in heat losses, refurbishing steam turbines could be a cost effective procedure to improve coal plant efficiency.

6. Technology Transfer

While there is pressure for developing countries to use these new technologies, adaptation can be difficult as the technology is expensive and requires engineering skills, materials, and equipment which are not available in most developing countries[24]. A means of diffusing low-carbon technology from developed to developing nations is therefore necessary and will be globally valuable to all nations considering the implications of climate change. The emission reduction potential of advanced

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[19] Purvis et.al (2014), Retrofitting Coal-Fired Power Plants in Middle-Income Countries: What Role for the World Bank?
[20] Ibid., 21, 65
[21] Ibid., 27
[22] Ibid., 28
[23] Ibid., 27
[24] Ibid., 6

fossil fuel power plant technologies has been recognized as an incentive to promote the transfer of energy efficient power plant technology to developing nations.

The international climate change negotiations conducted by the United Nations Framework Convention on Climate Change (UNFCCC) could act as a possible stage to enable this transfer. Access to advanced, low-carbon technologies was a considerable incentive for developing nations to support the UNFCCC during the convention's creation in 1992[25]. The Clean Development Mechanism (CDM) was created under the UNFCCC to promote sustainable development, reduce emissions and has been a significant driver of more efficient power plant technology transfer[26]. Emission reduction permits can be issued to, then sold by developed nations in exchange for the reduced emissions in developing nations after transferring power plant technologies. The sale of the permits creates the necessary financial incentives to drive the technology transfer to upgrade obsolete, high-emitting power plants while achieving the dual goals of reducing emissions and supporting global development. Studies on technology transfer in CDM projects estimate that technology transfer has occurred in 36% - 46% of CDM projects[27].

The UNFCCC has extended the Kyoto Protocol and therefore the CDM until 2020 with hopes of drafting a successor document by 2015. There are possibilities that technology transfer will be included in a post-Kyoto climate agreement. The first step in continuing the transfer of technology is to gather sufficient information on the current efficiencies of existing power plants. Although private corporations often have records containing this information, they are considered proprietary information and as such are not publicly available Any post-Kyoto agreement on reducing emissions will most likely require a detailed baseline measure of existing power plant efficiencies and emissions in order to properly measure how upgrades have improved both efficiency and emissions. Accurate baseline measurements will be exceptionally important if a emissions trading scheme is included as part of the post-Kyoto agreement from the UNFCCC after 2020.

7. Increase energy efficiency of existing coal-fired power plants

Upgrading from subcritical operation to supercritical steam conditions (with required pollution technology) could add at least 20 years to a plant's service life, depending on the regulatory and environmental regime in place. A subcritical plant could achieve at best 40%**Error! Bookmark not defined.** efficiency (on an LHV basis), while a supercritical steam plant could potentially achieve an efficiency two points higher and emit 4% less CO_2. Advancing the technology from a supercritical to an advanced ultra-supercritical coal-fired power plant could see an efficiency of 46% to 48%, which could mean as much as 18% to 22% less CO_2 per MWh generated than an equivalent-sized subcritical PC unit**Error! Bookmark not defined.**. However, "[m]ajor plant upgrading involving conversion of subcritical to supercritical or ultra-supercritical ... has seldom progressed beyond studies because of the high

[25] Sussex Energy Group (2010) *Low Carbon Technology Transfer: Lessons from India and China,* pg. 1
[26] Schneider, M., A. Holzer and V. Hoffmann (2008) *"Understanding the CDM's Contribution to Technology Transfer".* Energy Policy. 36:p 2936 Accessed via : Ecologic Institute (2010) Technology Transfer in the International Climate Negotiations.
[27] Data taken from: Ecologic Institute (2010) *Technology Transfer in the International Climate Negotiations* p34 with statistics based on the following:
-Haites, Erik, Maosheng Duan, and Stephen Seres (2006) "*Technology transfer by CDM projects*." Climate Policy 6, no. 3: pp. 327-344.
- Dechezleprêtre , Antoine, Matthieu Glachant, and Yann Ménière. (2007) "*The North-South Transfer of Climate-Friendly Technologies through the Clean Development Mechanism*." CERNA, Ecole des Mines de Paris. http://www.cerna.ensmp.fr/Documents/AD-MG-YM-ReportMDM.pdf
- de Coninck, H., F. Haake and N.H. van der Linden. (2007) "*Technology transfer in the Clean Development Mechanism*." Energy Research Centre of the Netherlands.

cost."[28].This may be because the economic benefits from energy efficiency improvement did not justify the high investments necessary for the upgrade or because these upgrades have not been performed in the past on an industrial scale and the perceived risks for investment of capital in such projects were large.

The options most often considered for increasing the efficiency of coal-fired power plants include equipment refurbishment, plant upgrades, and improved O&M schedules. Cost of the improvements is often compared to the expected return in increased efficiency as a primary determinant of whether to go forward with a program.

The IEA Clean Coal Center released a study in 2013[29] looking at opportunities to reduce CO_2 emissions using upgrades and efficiency improvements at coal fired power plants. IEA concluded that substantial improvements (i.e., retrofits) may be seen as cost-effective if these economically restore the efficiency of a power plant. The following table summarizes results from an NETL study performed in 2010 to assess energy efficiency improvements in coal-fired plants for different types of technology used.

8. Existing Coal-Fired EGU Efficiency Improvements

Efficiency Improvement Technology	Description	Reported Efficiency Increase
Combustion Control Optimization	Combustion controls adjust coal and air flow to optimize steam production for the steam turbine/generator set. However, combustion control for a coal-fired EGU is complex and impacts a number of important operating parameters including combustion efficiency, steam temperature, furnace slagging and fouling, and NOX formation. The technologies include instruments that measure carbon levels in ash, coal flow rates, air flow rates, CO levels, oxygen levels, slag deposits, and burner metrics as well as advanced coal nozzles and plasma assisted coal combustion.	0.15% to 0.84%
Cooling System Heat Loss Recovery	Recover a portion of the heat loss from the warm cooling water exiting the steam condenser prior to its circulation through a cooling tower or discharge to a water body. The identified technologies include replacing the cooling tower fill (heat transfer surface) and tuning the cooling tower and condenser	0.2% to 1%
Flue Gas Heat Recovery	Flue gas exit temperature from the air preheater can range from 250 to 350°F depending on the acid dew point temperature of the flue gas, which is dependent on the concentration of vapor phase sulfuric acid and moisture. For power plants equipped with wet FGD systems, the flue gas is further cooled to approximately 125°F as it is sprayed with the FGD reagent slurry. However, it may be possible to recover some of this lost energy in the flue gas to preheat boiler feedwater via use of a condensing heat exchanger.	0.3% to 1.5%

[28] Campbell, Richard.J (2013) *Increasing the Efficiency of Existing Coal-Fired Power Plants,* Congressional Information Service

[29] IEA Clean Coal Center (2013) *Upgrading and efficiency improvement in coal-fired power plants*, Profiles

Low-Rank Coal Drying	Subbituminous and lignite coals contain relatively large amounts of moisture (15% to 40%) compared to bituminous coal (less than 10%). A significant amount of the heat released during combustion of low-rank coals is used to evaporate this moisture, rather than generate steam for the turbine. As a result, boiler efficiency is typically lower for plants burning low-rank coal. The technologies include using waste heat from the flue gas and/or cooling water systems to dry low-rank coal prior to combustion.	0.1% to 1.7%
Sootblower Optimization	Sootblowers intermittently inject high velocity jets of steam or air to clean coal ash deposits from boiler tube surfaces in order to maintain adequate heat transfer. Proper control of the timing and intensity of individual sootblowers is important to maintain steam temperature and boiler efficiency. The identified technologies include intelligent or neural-network sootblowing (i.e.,sootblowing in response to real-time conditions in the boiler) and detonation sootblowing.	0.1% to 0.65%
Steam Turbine Design	There are recoverable energy losses that result from the mechanical design or physical condition of the steam turbine. For example, steam turbine manufacturers have improved the design of turbine blades and steam seals which can increase both efficiency and output (i.e., steam turbine dense pack technology).	0.84% to 2.6

Source:
NETL. Available at Office of Air and Radiation, Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from Coal-Fired Electric Generating Units, U.S. Environmental Protection Agency, October 2010, http://www.epa.gov/nsr/ghgdocs/electricgeneration.pdf.

Note: Reported efficiency improvement metrics adjusted to common basis by conversion methodology assuming individual component efficiencies for a reference plant as follows: 87% boiler efficiency, 40% turbine efficiency, 98% generator efficiency, and 6% auxiliary load. Based on these assumptions, the reference power plant has an overall efficiency of 32% and a net heat rate of 10,600 Btu/kWh. As a result, if a particular efficiency improvement method was reported to achieve a 1% increase in boiler efficiency, it would be converted to a 0.37% increase in overall efficiency. Likewise, a reported 100 Btu/kWh decrease in net heat rate would be converted to a 0.30% increase in overall efficiency.

9. Alternative Plant Concept: Increase efficiency through coal gasification technology

Gasification differs from more traditional energy-generating schemes in that it is not a combustion process, but rather a conversion process. Coal Gasification has been proven to be an efficient technology, the process produces syngas, which can be converted to multiple products and thus allowing a wider range of applications.

The clean syngas can be combusted in turbines or engines using higher temperature (more efficient) cycles than the conventional steam cycles associated with burning carbonaceous fuels, allowing possible efficiency improvements. Syngas can also be used in fuel cells and fuel cell-based cycles with yet even higher efficiencies and exceptionally low emissions of pollutants.

The IGCC technology is very appealing due to its high efficiency characteristic approximately 60%. This is much higher than the efficiency estimated for a conventional coal-based boiler plant which employs only a steam turbine-generator and is typically limited to 33-40% efficiencies.
Higher efficiencies mean that less fuel is used to generate the rated power, resulting in better economics.

10. Greenhouse gas reduction through coal gasification technology

The IGCC process removes both impurities and the CO_2 before the combustion, allowing a cleaner production of syngas and reducing total emissions. The CO_2 removed through the syngas production process can then be captured and stored underground.

Gasification-based processes are unique among other fossil fueled technologies in their ability to efficiently and cost-effectively capture large amounts of those CO_2 emissions. The Kemper County integrated gasification combined cycle (IGCC) plant is a prime example. Two-thirds of the plant's CO_2 emissions will be captured and used in enhanced oil recovery (EOR) operations, effectively storing the CO_2 and preventing it from contributing to potential global warming. As a result, the Kemper County IGCC plant would have less impact on potential global warming than an equivalently sized conventional natural-gas fired power plant.The Kemper County plant, which came online on August 9th, 2014 and supplies power to Missippi Power customers, was reported to have saved its customers more than $15 million, having displaced other higher cost methods of generation in the past year[30].

The allure of the Underground Coal Gasification(UCG) technology is that it has potential advantages over today's traditional approaches to coal mining. It has a lower environmental footprint, as it does not involve strip mining or mountaintop removal. It leaves coal's most toxic elements underground, such as mercury and arsenic. It may create a low-carbon way of exploiting the coal resource and facilitates a cheaper way of capturing greenhouse gases.

UCG can generate electricity through combined cycle gas turbines with approximately 25 per cent lower GHG emissions than modern coal-fired power stations. The thermal efficiency of UCG syngas power generation is about 12 per cent better than conventional coal-fired power generation.

There are numerous advantages for this process compared to the conventional coal gasification. For example, the risks related to the mining process are eliminated (such as surface damage and mine safety issues) and the emissions generated from shipping the coal are greatly reduced. Further, the underground coal gasification gives the opportunity of pollution control (sulfur, nitrous oxides, and mercury), thereby decreasing in volume the pollutants and reducing the global emission generated by the activity. Besides, the ashes remain in the underground and are thus isolated from the environment. Unfortunately, operational data from such plants are currently unavailable, therefore some uncertainty regarding the benefits of industrial scale deployment of such units still remains.

11. Normative instruments to cut-down CO_2 emissions by improving efficiency of coal fired power plants

It is important to summarize different normative instruments that could be used within the UNECE region to improve the efficiency and cut-down GHG emissions of fossil-fired power plants with

[30] Kemper Milestone: Combined Cycle Completes First Year of Operations. Available at: http://kemperproject.org/blog/2015/08/12/kemper-milestone-combined-cycle-completes-first-year-of-operations/ Accessed August 17th, 2015

special emphasis on coal plants. In this context, normative instruments may be defined as the construction of appropriate regulatory and/or legal framework to oversee the implementation of international treaties and agreements.

Unlike the normative instruments for energy efficiency improvements, most of the regulatory structure at the national and international level for improving coal plant efficiency was found to be in the form of proposals, and academic research outlining normative instruments that could prove to be effective but are yet to be implemented in practical settings. A review of proposals and existing regulations as well as policy instruments indicated that the following potential normative instruments could be used to implement agreements to cut-down CO_2 emissions by improving the efficiency of coal plants at the national and international levels:

(a) Establishing baseline standards of performance for new and existing coal plants especially those regarding minimum heat rate characteristics would help reduce the consumption of coal, thereby reducing CO_2 emissions from coal plants[31] [32]. For example, improving the heat rate of Electric Generating Units (EGUs) was one of the building blocks for achieving CO_2 emissions reductions in the US Environmental Protection Agency's (EPA's) clean power plan proposals **Error! Bookmark not defined.**.

(b) Government regulations and financial support for on-site performance engineers focusing on efficiency improvements of the power plants could maintain and improve efficiency of power plants. Current rate structures allow utility owners to pass on the extra costs due to plant inefficiencies to customers. Requirements for performance engineers, and a framework for measuring improvements would create an incentive to improve the power plant efficiency, as well as enable the customers to benefit from reductions in fuel costs[33].

(c) Mandates enforcing transparent measurement metrics for energy efficiency improvements and compulsory dissemination of energy efficiency data, thereby creating indirect competition among power producing companies, as well as helps to set realistic targets for efficiency improvements**Error! Bookmark not defined.**.

(d) Incentivized tariffs for energy efficiency improvements in coal plants**Error! Bookmark not defined.**. This proposed tariff structure calculates tariff such that it is a linear function of heat rate, thereby incentivising the utility owners to invest in efficiency improvements of their coal plants. Incentivized tariffs would also protect consumer interests by lowering the cost of electricity production.

(e) Environmental regulations, such as restrictions on maximum GHG emissions from the power plants help to increase efficiency in power plants to a certain extent[34]. Efficiency is one of the

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[31] A. P. Chikkatur, A. D. Sagar, N. Abhyankar and N. Sreekumar, "Tariff-based incentives for improving coal-power-plant," *Energy Policy*, vol. 35, p. 3744–3758, 2007.

[32] Environmental Protection Agency, "Regulatory Impact Analysis for the Proposed Carbon Pollution Guidelines for Existing Power Plants and Emission Standards for Modified and Reconstructed Power Plants," Environmental Protection Agency, Durham, North Carolina, USA, 2014.

[33] R. Brindle, J. Eisenhauer, A. Greene, M. Justiniano, L. Kishter, M. Munderville and R. Scheer, "Improving the Thermal Efficiency of Coal-Fired Power Plants in the United States," US Department of Energy and National Energy Technology Laboratory , Baltimore, MD, 2010

[34] European Energy Agency, "Efficiency of conventional thermal electricity and heat production (ENER 019) - Assessment published Jan 2015," 20 January 2015. [Online]. Available: http://www.eea.europa.eu/data-and-maps/indicators/efficiency-of-conventional-thermal-electricity-generation-3/assessment#policy_context. [Accessed 07 July 2015].

most cost effective ways to cut-down GHG emissions and it is likely that stringent emission restrictions for power plants will encourage investments in efficiency of power plants[35].

(f) Regulatory frameworks requiring periodic retrofits and up-gradation of existing coal plants would also lead to efficiency improvements[36].

(g) Technological developments play a key role in improving the overall performance as well as efficiency of power plants. Therefore, financial and policy support for research and development in the area of power plants efficiency improvements, is of utmost importance at the national and international levels.

(h) Coal plants are designed to operate on a wide variety of coal qualities. However, the quality of coal used (determined by calorific value, moisture, ash, volatile matter, grindability, sizing etc)[37] [38] affects the efficiency of plant operation to a great extent. While environmental regulations provide some indirect control over the type of fuel, commercial purchase regulations can directly control this. One examples of such an agreement is the contractual standards for coal quality in the New York Mercantile Exchange.

[35] J. Shenot, "Quantifying the Air Quality Impacts of Energy Efficiency Policies and Programs," Regulatory Assistance Project (RAP), 2013

[36] European Power Plant Suppliers Association (EPPSA), "Letter addressed to the Heads of government of EU Member States," 16 October 2014. [Online]. Available: http://www.eppsa.eu/tl_files/eppsa-files/EPPSA_Publications/2014.10.16_Letter%20addressed%20to%20the%20Heads%20of%20government%20of%20EU%20Member%20States_Final.pdf. [Accessed 27 July 2015].

[37] "Improve Coal Quality" . [Online]. Available: http://www.4cleanair.org/sites/default/files/Documents/Chapter_4.pdf [Accessed 17 August 2015].

[38] James et. al, "International Best Practices Regarding Coal Quality", Regulatory Assistance Project (RAP), 2013.

ANNEX: Data and Analysis

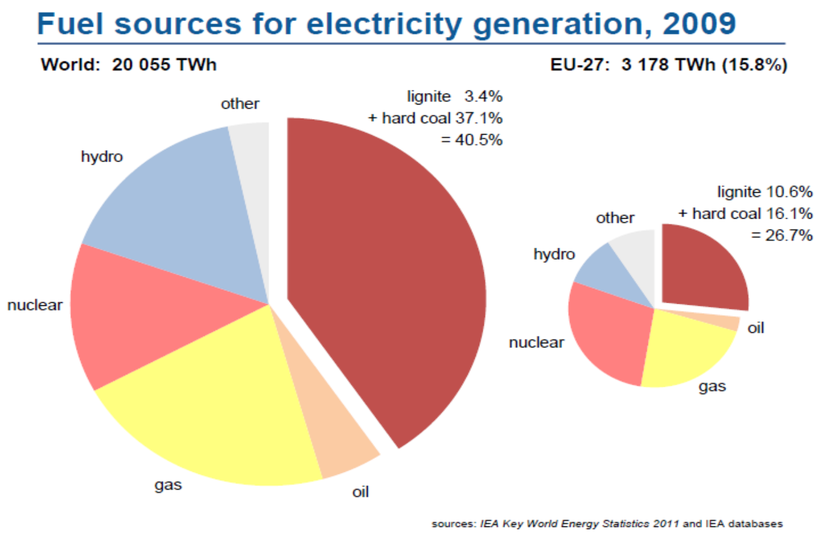
Why is the energy efficiency of fossil fuel power plants important?

1. We Rely on Fossil Fuels

Fossil fuels account for a significant portion of electricity production. Coal alone accounts for 42 percent of the world's electricity, with fossil fuels as a whole supplying over 2/3 of the world's electricity.

At current production levels, proven coal reserves are estimated to last 118 more years and proven oil and gas reserves should last around 46 and 59 years, respectively.

Source: World Coal Association 2011, via UNECE Energy Week 2011; IEA data, staff calculations
http://www.unece.org/fileadmin/DAM/energy/se/pp/clep/ahge8/3_Opening_Budinsky_item_7.pdf



Source: EURACOAL, 2011
http://www.unece.org/fileadmin/DAM/energy/se/pp/clep/ahge8/4_RICKETTS.pdf

Countries heavily dependent on coal for electricity include:

South Africa	93%
Estonia	91%
Poland	90%
China	79%
Kazakhstan	70%
Serbia	70%
India	69%
Israel	63%
Czech Rep.	56%
Greece	55%
USA	45%
Germany	44%

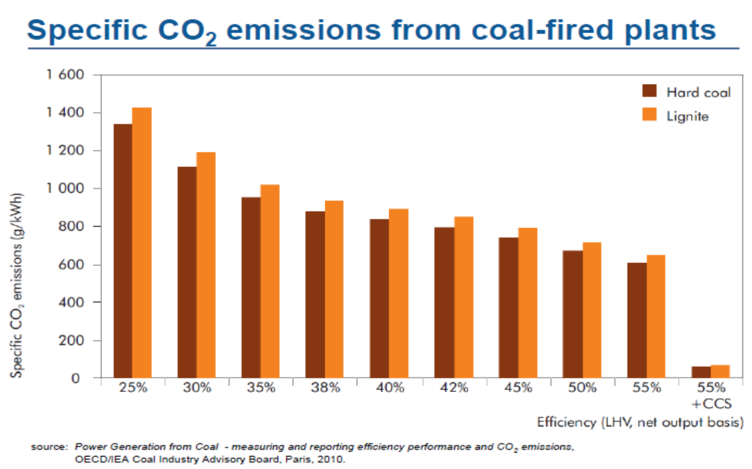
Source: World Coal Association 2011, via UNECE Energy Week 2011; IEA data 2005-2011 averages

http://www.unece.org/fileadmin/DAM/energy/se/pp/clep/ahge8/3_Opening_Budinsky_item_7.pdf

2. Fossil Fuels Have Adverse Effects

The burning of fossil fuels emits greenhouse gases into the atmosphere. As discussed in the UNECE Energy Week in November 2011, levels of greenhouse gases are exceeding worst case scenarios outlined by climate experts, and global emissions are increasing.

Source: UNECE Energy Week 2011
http://www.unece.org/fileadmin/DAM/energy/se/pp/clep/ahge8/3_Opening_Budinsky_item_7.pdf



Source: EURACOAL, 2011
http://www.unece.org/fileadmin/DAM/energy/se/pp/clep/ahge8/4_RICKETTS.pdf

Countries heavily dependent on natural gas for electricity include:

Turkmenistan	100%
Belarus	97%
Azerbaijan	81%
Uzbekistan	74%
Russian Fed.	49%
USA	29%
Germany	12%

Source: IEA, Based on 2012 data

3. Improving Efficiency Can Mitigate These Problems

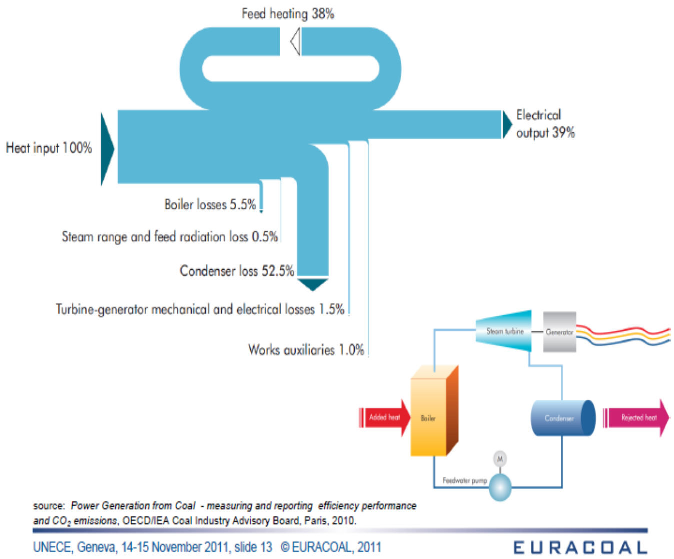
A one percentage point improvement in coal-fired power plant efficiency would save 0.23 $GtCO_2$ per year – the total CO_2 emissions from the Netherlands and Denmark. Best practices at all plants would save 1.7 $GtCO_2$ per year.

Yet some power plants still in operation today date back to the 1950s, with thermal efficiency ranges between 27 per cent and 35 per cent.

To address this, many European countries have set goals to increase the energy efficiency of coal-fired installations to over 40 per cent and the target of some of the latest projects is to achieve more than 50 percent efficiency by 2020.

Source: EURACOAL, ECE/ENERGY/GE.5/2011/INF.1
http://www.unece.org/fileadmin/DAM/energy/se/pp/clep/ahge8/4_RICKETTS.pdf

Example energy flows in a typical 500 MW subcritical pulverised coal-fired boiler



Source: EURACOAL, ECE/ENERGY/GE.5/2011/INF.1
http://www.unece.org/fileadmin/DAM/energy/se/pp/clep/ahge8/4_RICKETTS.pdf

How do we measure energy efficiency?

According to the World Bank, "Thermal efficiency (%) in power supply… is calculated by dividing gross electricity production from electricity and cogeneration plants by total inputs of fuels into those plants…. In the case of cogeneration plants, fuel inputs are allocated between electricity and heat production in proportion to their shares of the annual output."

$$E = \text{Energy efficiency } (E) = (P + H * s) / I$$

Where:

P	=	electricity production from public electricity plants and public CHP plants
H	=	useful heat output from public CHP plants
s*	=	correction factor between heat and electricity, defined as the reduction in electricity production per unit of heat extracted
I	=	fuel input for public electricity plants and public CHP plants

* s depends on temperature of the heat extracted, and can be between 0.15 and 0.2. This analysis uses 0.175.

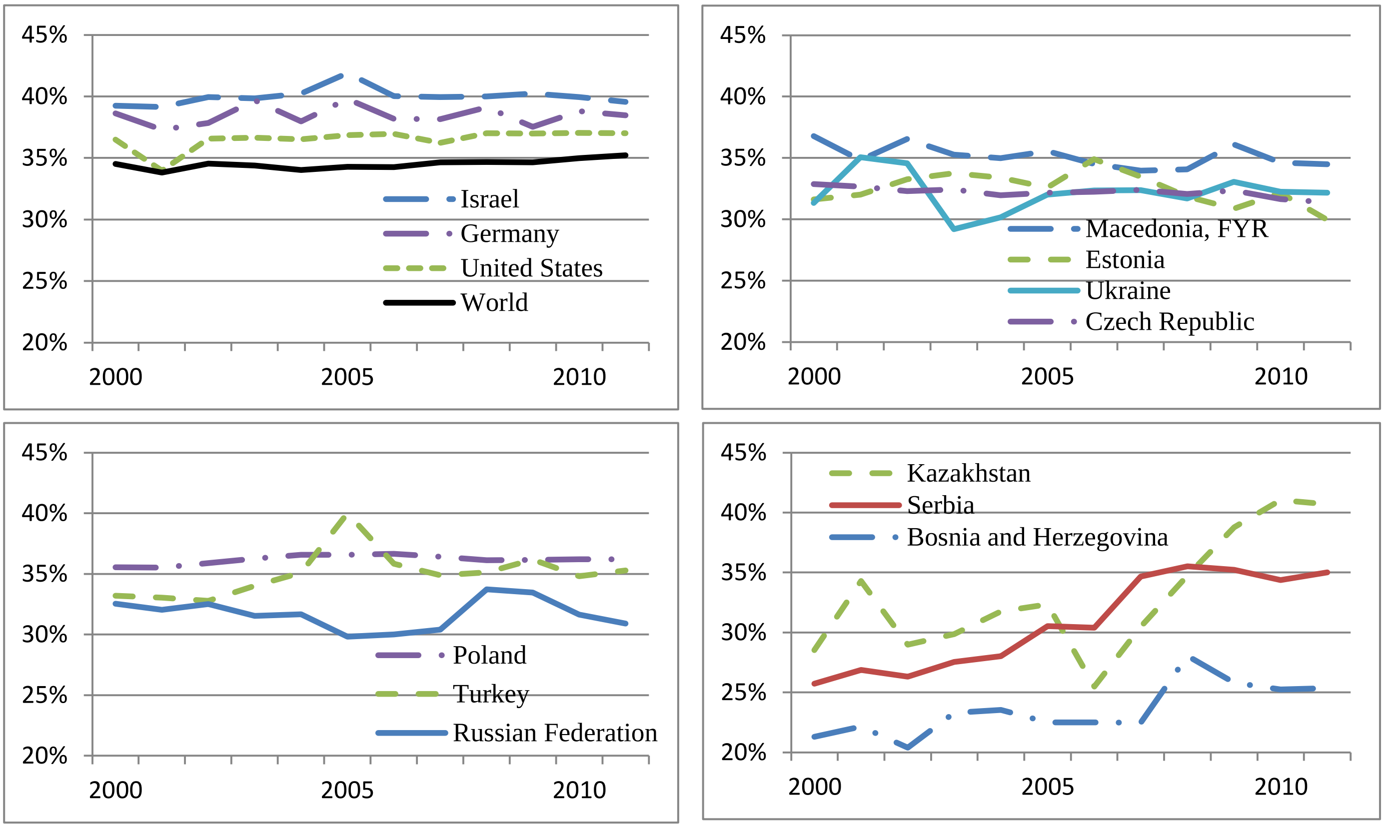
Source: IEA Information Paper: Energy Efficiency Indicators for Public Electricity Production from Fossil Fuels, 2008
http://www.iea.org/publications/freepublications/publication/En_Efficiency_Indicators.pdf

4. Trends in Coal Energy Efficiency

Coal: Worldwide efficiency of coal-fired power plants has remained relatively constant over the last 20 years, at around 35 percent efficiency, but some countries, such as Denmark, the Netherlands, and Norway, have achieved fleet averages of over 40 percent efficiency. Meanwhile, new and retrofitted plants have efficiency levels of up to 47 percent.

Source: IEA data, staff calculations

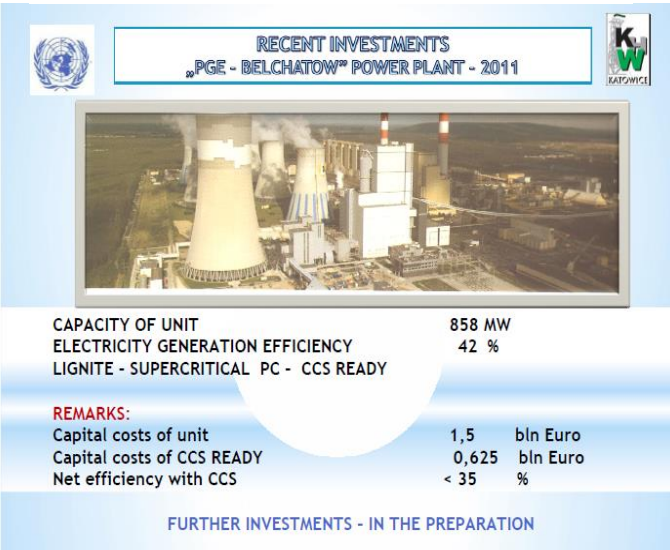
Evolution of Coal-Fired Power Plant



Source: IEA data, staff calculations

Newly Constructed Coal-Fired Power

Poland: PGE- Belchatow Power Plant



Source: Katowicki Holding Węglowy SA/ CEEp
http://www.unece.org/fileadmin/DAM/energy/se/pp/clep/ahge8/6_Poland_Kurzabenski.pdf

State-of-the-art coal-fired power plants

Canada Genessee 3	sub-bituminous coal	Genessee 3 supercritical once-through Benson type, two-pass, sliding pressure	41.4%
Japan Isogo New Unit 1	bituminous coal	Isogo New Unit 1 supercritical once-through, tower type, sliding pressure	42.0%
Germany Niederaussem K	lignite	Niederaussem K once-through supercritical tower type	43.7%
Denmark Nordjyllandsværket 3	international steam coals	Nordjyllandsværket 3 supercritical, Benson, tower type, tangential firing	47.0%
South Korea Younghung	international bituminous	Younghung supercritical once-through, tower type, sliding pressure	43.3%

Source: EURACOAL, ECE/ENERGY/GE.5/2011/INF.1
http://www.unece.org/fileadmin/DAM/energy/se/pp/clep/ahge8/4_RICKETTS

Refurbished Coal-Fired Power Plants

Bulgaria: Maritza East 3 Power Plant

- Increased capacity from 840 MW to 908 MW
- Rehabilitation and modernization program on all four lignite-fired units
- Improvement of efficiency from 30% to 35%
- 15-year lifetime extension
- Cost 700 million euros, of which 160 million euros were for environmental improvements
- Construction of two desulfurization units to reduce SO_2 emissions by over 94%; a new system for capturing dust from the boiler process; and a comprehensive water management system for reduction of fresh water consumption

Source: Enel Environmental Report 2010, Presentation 2011 http://www.unece.org/fileadmin/DAM/energy/se/pp/clep/ahge8/5_Enel_Geneva.pdf

Czech Republic: Tusimice Project

- 4x200 MWe
- Enhancing net efficiency from 33% to 38.67%
- Lifetime extension till 2040
- CO_2 reduction from 1.1 to 0.9 tCO_2/MWh
- Installation of new once-through, double-pass boilers

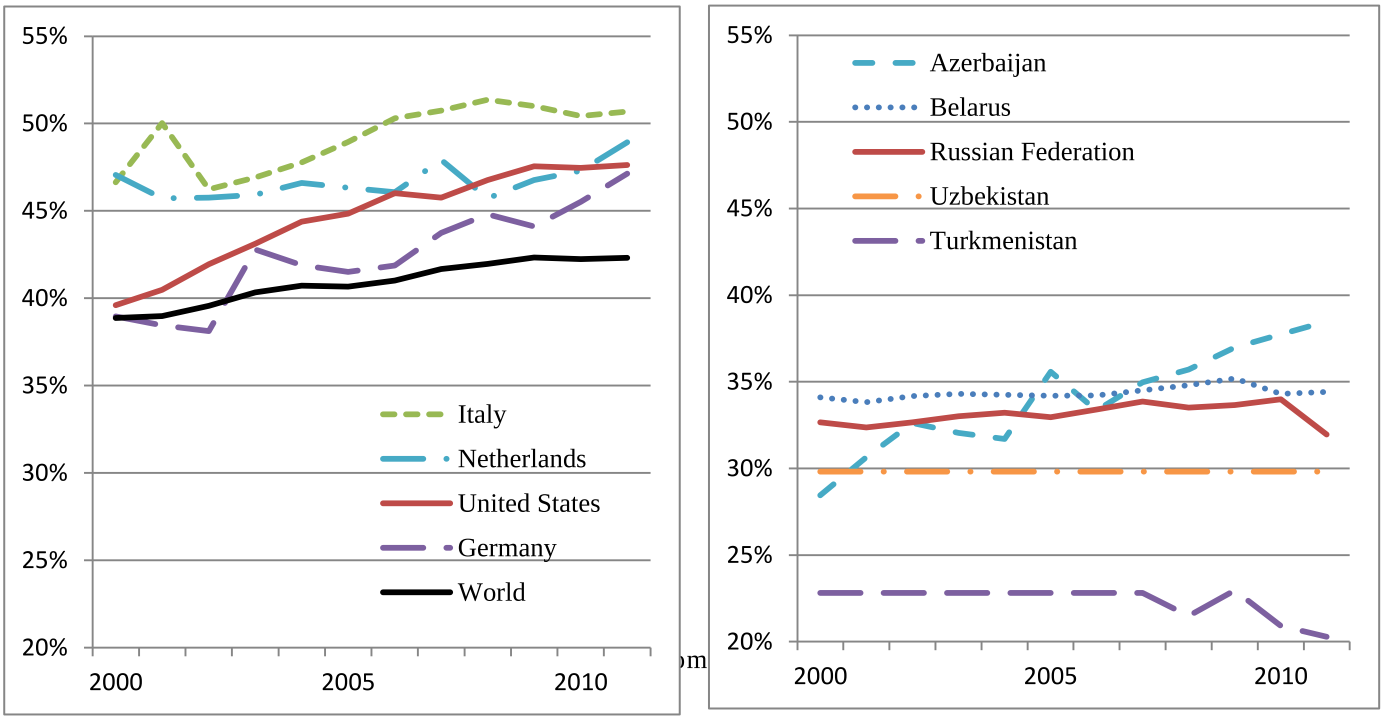
Source: Severoceske doly a.s., CEZ Group Presentation 2011; http://www.cez.cz/en/power-plants-and-environment/coal-fired-power-plants/cr/tusimice.html

5. Trends in Natural Gas Energy Efficiency

Natural Gas: The average efficiency of worldwide gas-fired electricity generation has increased substantially over the last 20 years, from around 35 percent to 42 percent. Spain, Portugal, and Luxembourg have achieved national fleet efficiencies of over 50 percent.

Source: IEA data, staff calculations

Evolution of Natural Gas-Fired Power Plant Efficiency



Source: IEA data, staff calculations