Pulverised Coal Combustion with higher efficiency

http://www.climatetechwiki.org/technology/sup_crit_coal

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Pulverised coal power plants account for about 97% of the world's coal-fired capacity. The conventional types of this technology have an efficiency of around 35%. For a higher efficiency of the technology supercritical and ultra-supercritical coal-fired technologies have been developed. These technologies can combust pulverised coal and produce steam at higher temperatures and under a higher pressure, so that an efficiency level of 45% can be reached (ultra-supercritical plants). Supercritical power plants have become the system of choice in most industrialised countries, while ultra-supercritical plant technology is still in the process of demonstration. Supercritical and ultra-supercritical plants are more expensive (because of the higher requirements to the steel needed to stand the higher *pressure and temperature) but the higher efficiency results in cost savings during the technical lifetime of the plants. The emissions of CO_2 per MWh delivered to the grid could reduce from 830 kg to 730 kg.*

Introduction top:

Producing electricity in coal power plants can take place in a number of ways with varying degrees of efficiency. In conventional coal-fired plants coal is first pulverised into a fine powder and then combusted at temperatures of between 1300 and 1700°C. This process heats water in tubes in the boiler so that it becomes steam at a pressure of around 180 bar and a temperature of 540°C. This steam is passed into a turbine to produce electricity (see Figure 1). Pulverised coal power plants account for about 97% of the world's coal-fired capacity (IEA 2008, p. 225). The average net efficiency (energy produced minus energy used within the plant) is around 35%, which means that 35% of the energy in one unit of coal is transferred into electricity. Pulverised coal power plants can have a size of up to 1000 MW and are commercially available worldwide.

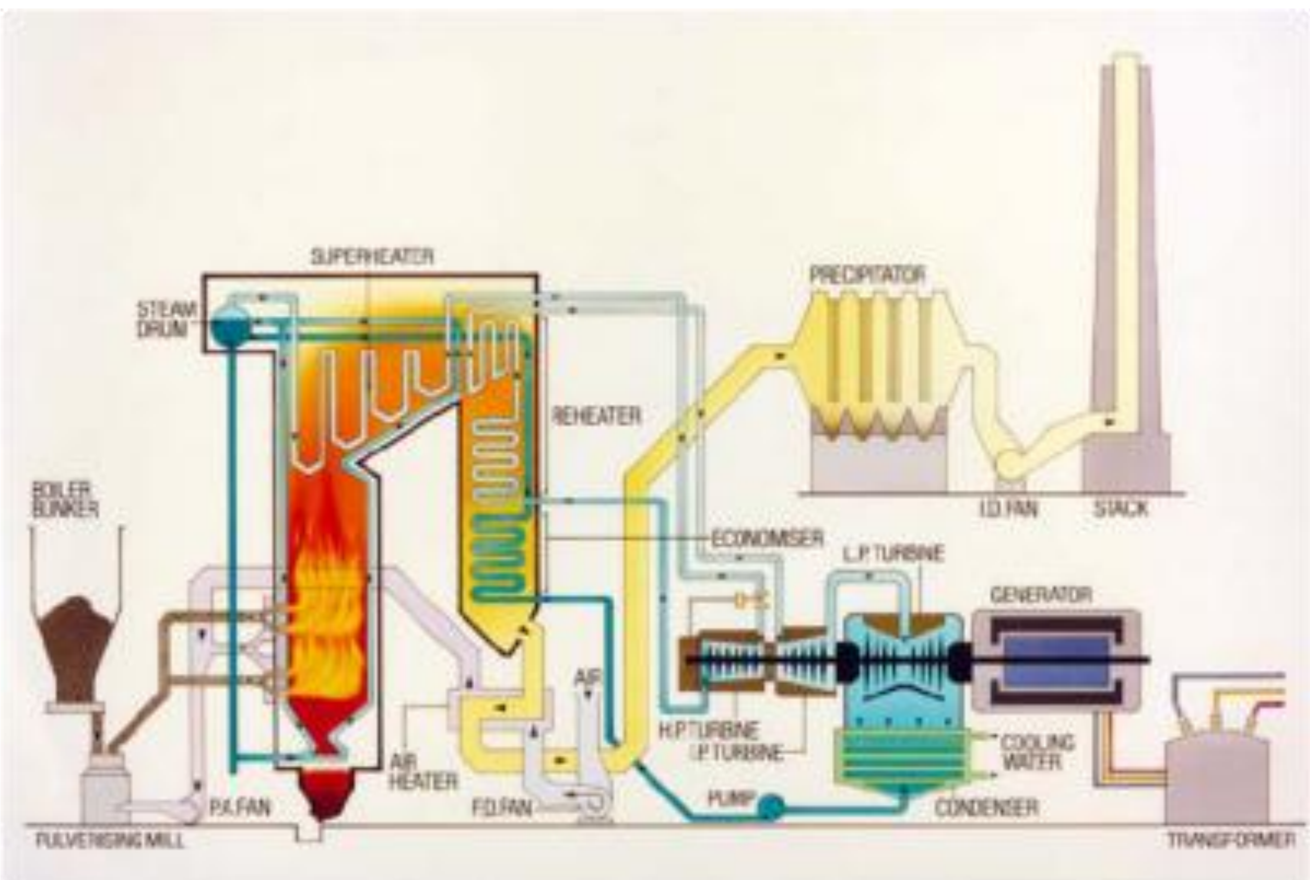

Figure 1: Lay out scheme of supercritical pulverised coal plant for electricity production

OECD/IEA, 2003

Over the years, improvements have been made to make the technology more efficient, including measures to minimise emissions of SO_2, NO_x and particulates and application of advanced steam cycles that allow for greater plant efficiency. An example of this improvement is the 'supercritical' pulverised fuel (SPF) technology which can reach efficiency levels of up to 45%. Further improvements can be made in ultra-supercritical plants, which are still in the phase of research and development but which could be deployed in the market around 2020. An example of a research project on this technology is AD700, which is supported by EU equipment manufacturers and several end users. It has been the subject of a significant EU cooperative R&D programme involving 39 companies from 12 Member States.

Figure 2: AD 700 ultra-supercritical coal fired power plant

https://projectweb.elsam-eng.com/AD700/default.aspx

The eventual efficiency level that can be achieved depends on whether hard or brown coal (lignite) is used and on the quality of coal (e.g. high vs low ash content).

A summary of the performance of the differenct PF power plants is presented below:

Steam cycle	*Subcritical*	*Supercritical*	*Ultra-supercritical (best available)*	*Ultra-supercritical (AD700)*
Steam conditions	*180 bar (540^{o}C)*	*250 bar (560^{o}C)*	*300 bar (600^{o}C)*	*350 bar (700^{o}C)*
Net output (MW)	*458*	*458*	*456*	*457*
Net efficiency (%)	*40.2*	*42.0*	*43.4*	*45.6*
CO_2 emissions (t/MWh-net)	*0.83*	*0.80*	*0.77*	*0.73*

Source: IEA 2008, p.257, Table 7.2

Other higher efficiency coal-based techniques are Integrated Coal Gasification Combined-Cycle (IGCC) and Fluidised Bed Combustion (FBC).

Feasibility of technology and operational necessities top:

Early supercritical steam-cycle plants in the USA and Europe in the 1970s had problems with operational flexibility and maintenance, but these problems have nowadays been largely solved. The technology is now considered reliable and economically viable. The main technical challenge with supercritical plants is that the higher steam pressure and temperature require components (superheaters, headers, water tubes, steam chests, rotors and turbine casings) which are produced from nickel-based alloys.

Nickel is an expensive commodity so that for an increased use of SPF at lower costs further developments are needed in new steels for water and boiler tubes and high-alloy steels that minimise corrosion.

Another operational aspect which would support the market penetration of supercritical and ultra-supercritical plants is the development of advanced control equipment and procedures (i.e. expert systems, condition monitoring) to operate a plant more flexibly.

With respect to developing countries with a high coal consumption, such as China and India, SPF technology transfers could take place by the sale of equipment, licensing, joint ventures, co-operative production, subcontracting of the manufacture of components, and co-operative research and development (Beijing Research Institute of Coal Chemistry, 2000). Possible forms of co-operation between industrialised and developing countries in *this context could be selling licenses to developing countries, mounting joint ventures, and agreeing co-operative production.*

Status of the technology and its future market potential top:

As explained above, approximately 97% of global coal-base power production capacity is based on pulverised coal combustion. Improvement of this technology can take place in different steps. Many conventional pulverised coal-fired power plants have been improved by upgrading the system so that emissions of several pollutants could be reduced, but the efficiency gains are minimal as the heat rates can only be improved at existing plants by 3 to 5%-points at best. This is because the heat rate is primarily dependent on unit design, specific fuel type, and capacity factor, and because the plant design cannot be changed once built.

Supercritical and ultra-supercritical pulverising coal technologies have been identified as major measures to achieve efficiency increases. In most industrialised countries, supercritical plants have become commercially viable, with capital costs only slightly higher than those of conventional subcritical plants, but with significantly lower fuel costs due to increased efficiency. Presently, over 500 SPF plants are in operation worldwide, including a number in developing countries. Most of the new power plants in Europe and Asia are equipped with supercritical coal-fired technology and in China this technology has become the standard on all new plants of 600 MW and more capacity (http://knol.google.com/k/supercritical-coal-fired-power-plant).

IEA Technology Perspectives 2008 shows a scenario where global GHG emissions peak between 2020 and 2030 and will be halved by 2050. In this scenario, ultra-supercritical steam cycle technology components that can withstand steam temperatures of 700^{o}C and up to 300 bar pressures are presently in the process of Research and Development (see the AD 700 example). By 2020 cost-efficient plant design could be demonstrated, after which the technology could be deployed in the market with an expected global capacity of over 100 GW by 2025. In the commercialization phase, ultra-supracritical coal plants would be applied with a capacity of 550 GW by 2050 (IEA 2008, p.149).

Nowadays, ultra-supercritical plants are operation in Japan, Denmark and Germany, whereas the 4x1000 MW Huaneng Yuhuan power plant in Zhejiang Province in Eastern China is the world's largest coal-fired plant using ultra-supracritical technology (IEA 2008, p.254). China had more than 18 GW of supercritical unit capacity installed in 2006.

The stimulation of SPF plants in developing countries could partly be supported through the Clean Development Mechanism of the Kyoto Protocol (CDM). In September 2007, the CDM Executive Board decided to make supercritical coal-fired power plants eligible under the CDM. When the business-as-usual practice in a country is subcritical coal-based power plants, the introduction of supercritical power plants would ceteris paribus reduce GHG emissions. See 'Climate' below for a further explanation.

How the technology could contribute to socio-economic development and environmental protection:

The main environmental benefit of the supercritical technology is that it uses less coal per unit of power production in comparison with subcritical coal technologies and thus results in lower pollution levels. Individual cleaner coal technology 'components', such as flue gas desulphurisation (FGD), low-NO_X burners and gas reburn technology, can be retrofitted to existing conventional plant to reduce emissions of SO_2 and NO_x. The addition of such abatement technologies could extend the life of existing plants. Environmental benefits can also be achieved by increasing the thermal efficiency of electricity generation. A next step in the development of coal-based power production technologies would be carbon capture and storage.

Climate :

In September 2007, the CDM Executive Board decided to make supercritical coal-fired power plants eligible under the CDM. When the business-as-usual practice in a country is subcritical coal-based power plants, the introduction of supercritical power plants would ceteris paribus reduce GHG emissions. As shown in the table above, CO2 savings could be significant when increasing efficiency of coal-fired power plants. An efficiency improvement from 30 to 45% would bring about a 33% decrease in CO2 emissions. As two-thirds of all coal-fired plants are over 20 years old with an average efficiency rate of below 30%, replacing this capacity with supercritical and ultra-supercritical plants could contribute significantly to global GHG emission reduction (IEA 2008, p.259).

The final decision of the CDM EB, which took the shape of approving a supercritical coal-plant methodology for baselines and monitoring (approved consolidated methodology 13 – ACM0013), is directed to greenfield fossil fuel plants (e.g. new plants, no retrofits of existing plants), and could thus also include natural gas-fired plants. However, in order to limit the applicability of the methodology and the scope for these projects, it was decided that the methodology can only be applied in those countries which generate more than half of the electricity using coal or natural gas. In practice, this limits this type of projects to China, India, and South Africa.

Moreover, within these countries the number of projects is also limited since the baseline for the GHG emissions in the absence of a CDM coal-fired plant (or gas) project must be determined using the data of the 15% most efficient coal-based (or gas-based) power plants. Therefore, if 15% of the most efficient coal-based power plants are CDM projects, then a new CDM coal-based power plant can only generate credits if it increases its efficiency even further so that it can reduce GHG emissions below the benchmark or baseline.

Financial requirements and costs:

It is difficult to determine a general cost figure for a supercritical power plant because of the high number of variables involved: location of the plant, domestic fabrication or import of components, construction time, separation of cost and price, environmental protection measures taken as part of the plant, etc. A study by IEA Coal Research, in collaboration with Sydkraft Konsult and the US Department of Energy, modelled the competitiveness of various coal-based power generation systems (Scott and Nilsson, 1999). All inputs to the model were selected to form a common set of 'base assumptions' on matters ranging from costs of finance to steam conditions to coal type and price. The outputs allow a range of clean coal technologies to be compared.

The report concluded that SPF plant costs are comparable with subcritical PF boiler technology. However, overall economics are more favourable because of the increase in cycle efficiency. In a typical case, fuel costs account for 60-80% of the total operating cost of a PF power plant. In the example above, an increase in cycle efficiency from 38% to 46% would result in an annual coal saving of 300,000 tonnes (17%). At a nominal coal cost of € 45/t, this would represent a saving of around € 15 million per year. This saving can more than offset the slightly higher capital cost of SPF technology.

Economic performance is also influenced by other factors, such as plant availability, flexibility of operation and auxiliary power consumption. Its operational flexibility makes SPF more favourable than subcritical PF plants. The SPF boiler design is inherently more flexible than drum designs due to fewer thick section components, which allows increased load change rates. Typical average availability is 85%, but with appropriate design and materials, a plant availability of over 90% is achievable. Therefore, SPF boilers would improve plant efficiency, so that fuel cost savings and lower emissions for each kWh of electricity can be generated.

Finally, the diagram below shows the investment, operation and maintenance costs, and fuel costs of coal-fired power plants in comparison to natural gas-fired plants. The diagram shows, a.o., that coal plants are relatively capital intensive, but less sensitive to fuel costs than natural gas-based plants (IEA, 2008).

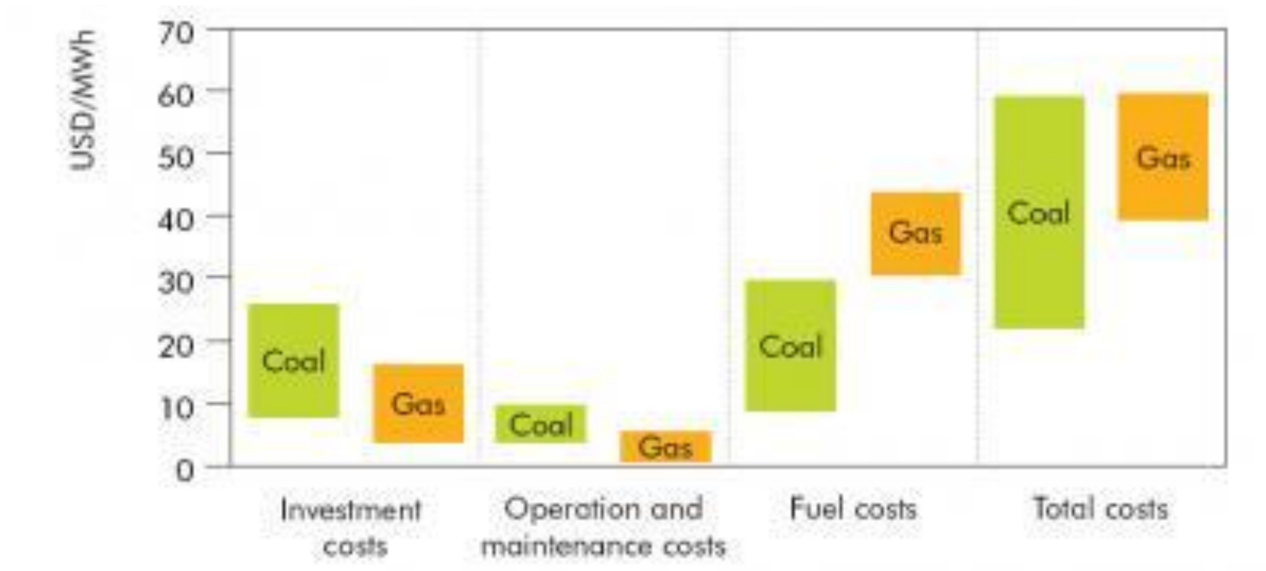

Figure 4: Investment, O&M and fuel costs of natural gas and coal-fired power generation

IEA, 2008
