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The Need for Efficient Power Generation

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1. Introduction

This chapter makes the business case for energy efficient plant auxiliary systems and discusses some trends in electricity markets and power generation technologies. The information in these colored sections is specific to power generation industries and/or process plants with large on-site power and/or steam heat generation.

2. Trends in power demand and supply

Currently growing 2.6 percent per year, world electricity demand is projected to double by 2030. The share of coal-fired generation in total generation will likely increase from 40 percent in 2006 to 44 percent in 2030. The share of coal in the global energy consumption mix is shown in the figure below. This share is now increasing because of relatively high natural gas prices and strong electricity demand in Asia, where coal is abundant. Coal has been the least expensive fossil fuel on an energy-per-Btu basis since 1976.

China expanded coal use by 11 percent in 2005 and surpassed the U.S. as the number one coal user in 2009. Coal is the most abundant fossil fuel, with proven global reserves at the end of 2005 of 909 billion metric tons, equivalent to 164 years of production at current rates (International Energy Agency, 2006).

In the U.S., coal-fired plants currently provide 45%, down from 51% just a few years ago, of total generating capacity (Woodruff, 2005), or about 400 GW, from about 600 power plants. Total electrical generation capacity additions are estimated to be 750 GW by 2030 (International Energy Agency, 2006). Of that new capacity, 156 GW is projected to be provided by coal plants (Ferrer, Green Strategies for Aging Coal Plants: Alternatives, Risks & Benefits, 2008). Other estimates put capacity addition to 2030 at 280 coal-fired 500MW plants (Takahashi, 2007).

In North America, declining natural gas prices are again creating a trend toward more energy efficient and lower emission plant designs, a trend now expected to continue at least thru 2020. The generating costs of combined-cycle gas turbine (CCGT) plants, which use natural gas, are expected to be between 5–7 cents per kWh, while coal-fired plants are in the range 4–6 cents/kWh (International EnergyAgency, 2006). Integrated gasification combined cycle (IGCC) plants are not yet competitive as of 2008 (which is why government is subsidizing many such projects). Their low relative costs make coal-fired plants competitive in the U.S. with other large central generating plants.

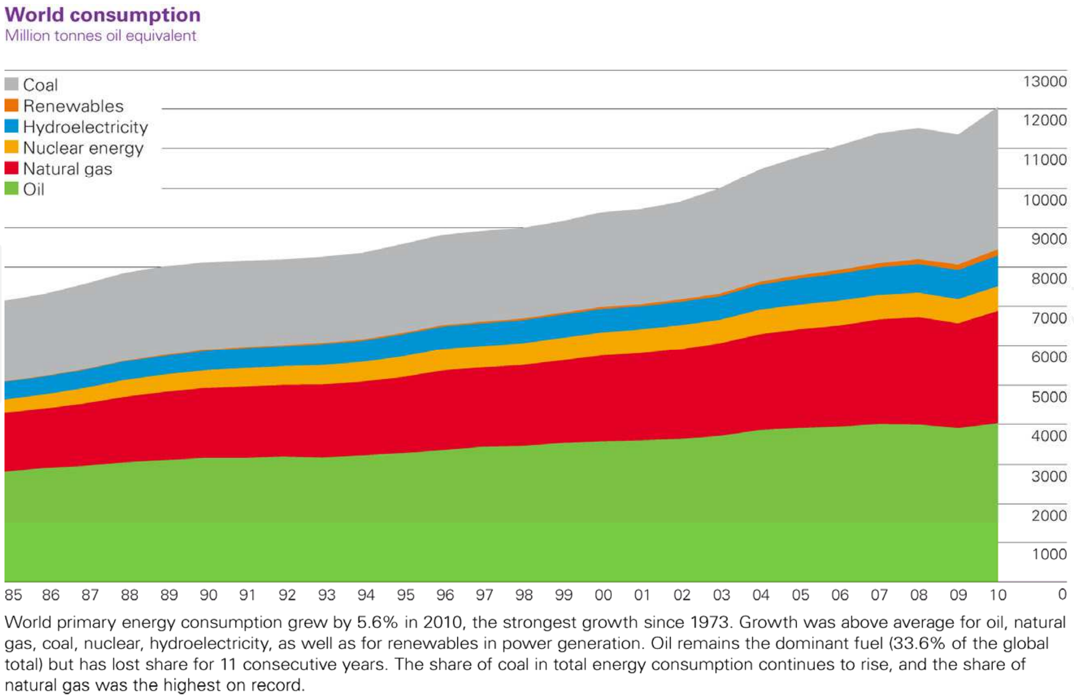

Fig. 1. Trends in energy consumption, (2011 BP Statistical Review of World Energy).

Many new coal plants were being planned or constructed as of 2008, but with some uncertainty regarding the future trend due to carbon footprint and other environmental concerns over current coal-fired plant technology. Regulations imposing carbon dioxide emissions charges will eventually change the economics in favor of CCGT and other more efficient fossil plant types. Even without emissions taxes, the licensing of new plants is threatened by growing grass-roots opposition at local and state levels. According to the US Department. of Energy (DoE), 59 of 151 planned new coal plants were either refused licenses or abandoned in 2007, and 50 plants are being challenged in court. Environmental groups have successfully challenged these new plants by arguing that the additional capacity could be gained through energy efficiency and renewable sources of power. With the industry facing a possible moratorium on new plants, it is more important than ever to make existing plants as energy efficient as possible.

Whether limited by emissions or supplies, the fossil-fuel power generation industry must sooner or later reduce the carbon per unit energy produced. The prominence of coal means that it will play an important role in the transition to a low-carbon future. Dr. Amory Lovins, a leading US energy analyst, anticipated the need for such a transition many years ago when he said; "It is above all the sophisticated use of coal, chiefly at modest scale, that needs development. Technical measures to permit the highly efficient use of this widely available fuel would be the most valuable transitional technologies." (A. Lovins, Energy Strategy: The Road Not Taken 1976)

3. Trends in steam plant designs and efficiency

Large fossil-fuel-fired steam plants use a closed steam cycle in which water is converted to steam in a boiler. This steam is then superheated and then expanded through the blades of a turbine whose shaft rotates an electrical generator. The steam exits the turbine and condenses to water, which is pumped back up to boiler pressure.

3.1 Sub-critical plant types

The most common type of plant using this design is alternatively referred to as 'drum boiler' or 'subcritical,' because water is circulated within the boiler between a vessel (the drum) and the furnace water-wall tubing where it absorbs combustion heat, but does not exceed critical pressure. Existing subcritical pulverized coal (PC) boiler steam power plants can theoretically achieve up to 36–40 percent efficiency at full load. Due to major process design changes such as supercritical boilers and other technology improvements, the average efficiencies of the newest coal-fired plants are up to 46 percent compared to 42 percent for new plants in the 1990s (IEA CoalOnline, 2008).

Energy efficiency improvements of several percentage points in new plants have resulted from improved designs of the main components and auxiliaries in steam power plants: including auxiliary drivepower:

- Improvements in turbine blade design
- Improvements in fans and flue gas treatment methods
- Reduction of furnace exit gas temperature
- Increase of feed water temperature
- Reduction of condensing pressure
- Use of double reheat on main steam flow
- Optimization and reduction of the consumption of auxiliary drivepower

3.2 Super-critical coal-fired steam plants

Supercritical plants, also called 'once-through' plants because boiler water does not circulate multiple times as it does in drum-boiler designs, have efficiencies in the mid-40 percent range. New 'ultra critical' designs using pressures of 4,400 psi (30 MPa) and dual stage reheat are capable of reaching about 48 percent efficiency (IEA Coal Online - 2, 2007). Plant availability problems with the first generation of large supercritical boilers led to the conclusion that pulverized coal-fired electricity generation was a mature technology, with an efficiency limited by practical and economic considerations to around 40 percent. However, improvements in construction materials and in computerized control systems led to new designs for supercritical boilers that have overcome the problems of the earlier plants (IEA Coal Online - 2, 2007). Although most new coal-fired plants are expected to use drum steam boilers, the share of supercritical technology is rising gradually (International Energy Agency, 2006).

3.3 Combined-Cycle Gas Turbine (CCGT)

A combined-cycle gas turbine (CCGT) power plant uses a gas turbine in conjunction with a heat recovery steam generator (HRSG). It is referred to as a combined-cycle power plant because it combines the Brayton cycle of the gas turbine with the Rankine cycle of the HRSG. The thermal efficiency of these plants has reached a record heat rate of 5690 Btu/kWh, or just under 60 percent.

3.4 Some steam plants are lagging

At the beginning of the 21st century, it was believed that a single-cycle coal-fired power station with an efficiency of more than 50 percent would be possible by 2015 (Kjær and

Boisen, 1996 in IEA Coal Online - 2, 2007). The efficiency of some new design plants may be high, but almost 75 percent of the existing coal-based fleet of plants in the U.S. is over 35 years old, with an average net plant efficiency of only slightly above 30 percent (Ferrer, 'Green Strategies for Aging Coal Plants,' 2008).

In addition to the less efficient design of core equipment, these older plants suffer an additional efficiency handicap due to plant aging; they become less reliable and generally less efficient due to leakage, fouling, and other mechanical factors. Another trend which lowers efficiency is the change in fuel supply systems toward off-design coals for which the boiler has not been optimized (IEA Coal Online - 2, 2007). Fuel supplies may be subject to further tweaking as generating companies seek to reduce their carbon footprint by substituting a portion of the coal they use with biomass.

Another important reason that older plants are lagging in efficiency is that many of them are operating at 30–50 percent below their rated capacities, where efficiencies of all sub-systems are lower. The realities of a more deregulated and competitive marketplace, with renewable and distributed energy sources and new system operating reserve requirements, have led to previously baseloaded plants being operated as dispatchable plants; an unforeseen operating regime (ABB Power Systems, 2008). One view of this latter issue is the global distribution of load factor of nominally baseloaded steam turbine plants less than 500MW for the period 2001–2005. The following figure shows that the median load factor is only 64 percent.

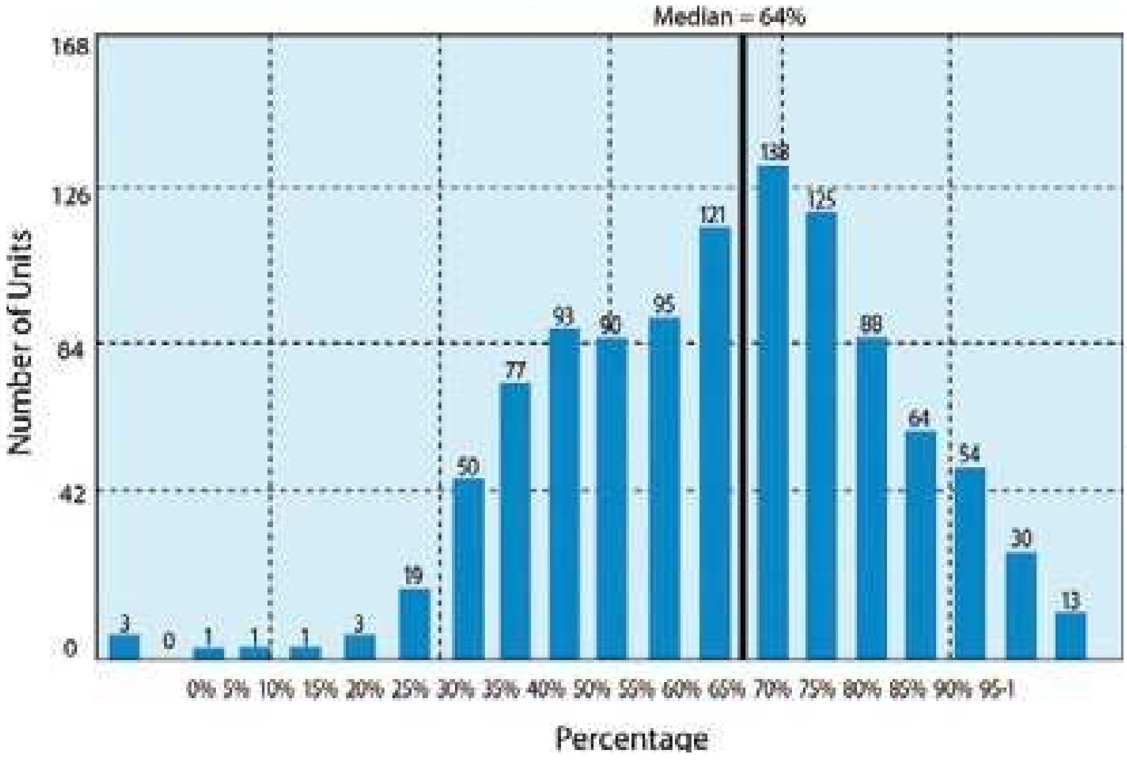

Fig. 2. Distribution of load factor of base-loaded plants, (World Energy Council, 2007).

3.5 Plant auxiliary power usage is on the rise

The share of total plant auxiliary electrical power in the fleet of fossil-fuel steam plants has been increasing due to these main factors:

- Addition of anti-pollution devices such as precipitators and sulfur dioxide scrubbers which restrict stack flow and require in-plant electric drive power. About 40 percent of the cost of building a new coal plant is spent on pollution controls, and they use up about 5 percent of gross power generated (Masters, 2004).
- Additional cooling water pumping demands to satisfy environmental thermal discharge rules.
- A trend away from mechanical (e.g. condensing steam turbine) drives toward electrical motors as the prime mover for in-plant auxiliary pump and fan drives.

For PC power plants, the auxiliary power requirements are now in the range of 7–15 percent of a generating unit’s gross power output for PC plants. Older PC plants with mechanical drives and fewer anti-pollution devices had auxiliary power requirements of only 5 to 10 percent (GE Electric Utility Engineering, 1983). These figures are for traditional drum boiler type plants, but the auxiliary power requirements of supercritical boilers are not any lower. The feedwater pump power required to reach the much higher boiler pressure is approximately 50 percent greater than in drum boiler designs. Increased demand for auxiliary power increases a plant’s net heat rate and reduces the amount of salable power.

4. Plant auxiliary energy efficiency improvements

In-plant electrical power, when taken from the generator bus, may be priced artificially low in some utility companies’ auxiliary lifecycle calculations. A process industry customer, however, must always pay high commercial rates (and sometimes penalties), thus providing a strong incentive to improve their auxiliary energy efficiency. Price dis-incentives, regulations permitting cost-pass thru, and other non- technical barriers are discussed in the handbook section on Barriers to Increased Energy Efficiency.

These barriers may result in sub-optimal energy designs for power plant auxiliaries, most commonly in oversized motors, fans and pumps. These design decisions have particularly negative consequences when the base-loaded plant then moves to a new operating mode at 50–70 percent capacity (see previous section for a discussion of this trend). Auxiliaries such as pumps and fans that use constant speed motors and some form of flow restriction for control will waste much more power when operating under such partial-load conditions. Other plant systems will also run less effectively below their design points. Boilers at partial loads, for example, run with relatively higher excess air to achieve complete combustion, which lowers efficiency; these topics are discussed in greater detail in the handbook sections on Drivepower and Automation.

5. The potential for energy efficiency

5.1 Technical efficiency improvement potential

A recent study by the International Energy Agency (IEA) suggests a technical efficiency improvement potential of 18–26 percent for the manufacturing industry worldwide if the best available (proven) technologies were applied. Most of the underlying energy-saving measures would be cost-effective in the long term. Another study, by the U.S. Dept. of Energy, focused on the energy efficiency opportunity provided by automation and electric power systems in process industries. An improvement potential of 10–25 percent was suggested by industry experts, who were asked to consider improvements within the context of operational or retrofit situations. The results of that study are shown in the figure below.

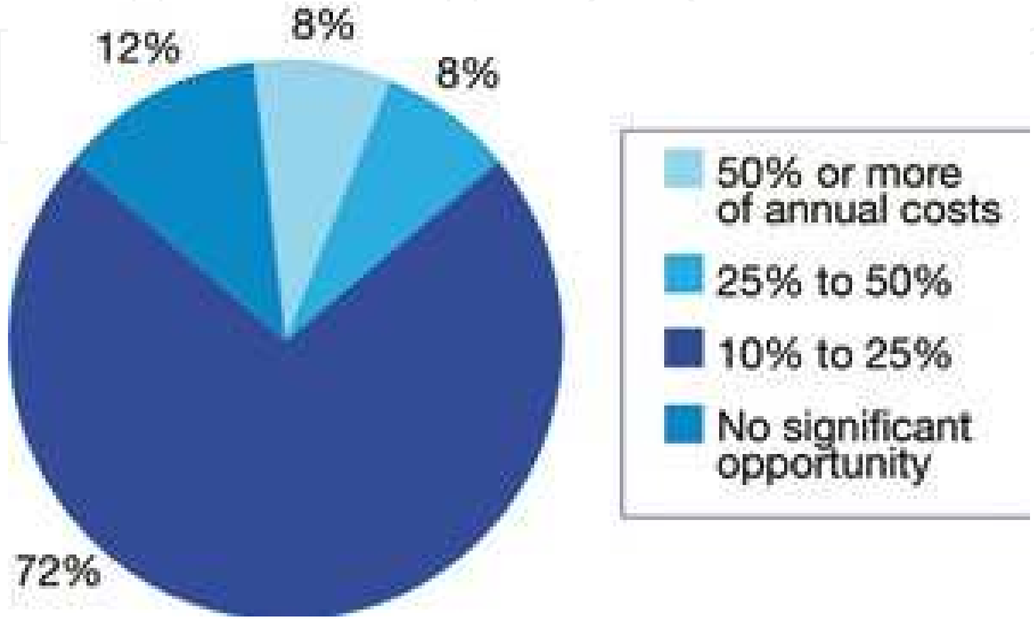

Fig. 3. Process industry survey results on potential of energy efficiency, (US DoE, 2004).

5.2 Potential revealed through performance benchmarking

Access to power generation plant performance data is important for identifying areas for improvement and for showing the results of best practice. Market fragmentation and the increased competitiveness of de-regulated markets in the past have made access to data difficult. There has also been a lack of standards or practices for measuring performance.

The World Energy Council (WEC), through its Performance of Generating Plant (PGP) Committee, is now gathering and normalizing such data so that valid comparisons can be made across countries and markets.

Similar performance benchmarking efforts are done in the U.S., but through industry-funded organizations like EPRI. Standardization efforts are best represented by IEEE Std 762-2006 IEEE Standard for Definitions for Use in Reporting Electric Generating Unit Reliability, Availability, and Productivity.

Interestingly, the WEC found that 'new drivers geared toward profitability, cost control, environmental stewardship, and market economics are shifting the focus away from traditional measures of technical excellence such as availability, reliability, forced outage rate, and heat rate' (World Energy Council, 2007). Their PGP database has added individual unit design and performance indices that can be used to compare efficiency and reliability across designs. The published performance data will help industry improve practices, and will put a spotlight on under-performing plants and companies.

5.3 Efficiency potential revealed by country comparisons

The potential for energy efficiency, at least from a U.S. perspective, is also indicated in a recent (2007) comparison of fossil-fuel-based power generation efficiencies between nations that together generate 65 percent of worldwide fossil-fuel-based power. The Nordic countries, Japan, the United Kingdom, and Ireland were found to perform best in terms of fossil-fuel-based generating efficiency and were, respectively, 8 percent, 8 percent and 7 percent above average in 2003. The United States is 2 percent below average. Australia, China, and India perform 7 percent, 9 percent and 13 percent, respectively, below average. The energy savings potential and carbon dioxide emissions reduction potential if all countries produce electricity at the highest efficiencies observed (42 percent for coal, 52 percent for natural gas and 45 percent for oil-fired power generation), corresponds to potential reductions of 10 exajoules of consumed thermal energy and 860 million metric tons of carbon dioxide, respectively (Graus, 2007).

The IEA analysis mentions that more than half of the estimated energy and carbon dioxide savings potential is in whole-system approaches that often extend beyond the process level (Gielen, 2008). 'Integrative Design' is this handbook's approach to the most challenging energy efficiency issues in plant auxiliary design.

6. Energy efficiency is attracting interest and investment

The previous sections showed an engineer's view of the importance of energy efficiency. What are the views and plans of corporate energy decision makers and investors?

6.1 From corporate energy managers

According to a recent survey on energy efficiency of corporate and plant-level energy managers at more than 1,100 North American companies (Johnson Controls, 2008):

- 57 percent expect to make energy-efficiency improvements during the same time period, devoting an average of 8 percent of capital expenditure budgets on energy-efficiency projects.
- 64 percent anticipate using funds from operating budgets, allocating 6 percent to energy-efficiency improvements.
- 40 percent have replaced inefficient equipment before the end of its useful life in the past year.
- 70 percent have invested in educating staff and other facility users as a way to increase support for increasing internal energy efficiency.

6.2 From industry investors

When 18 U.S. investment organizations were surveyed about energy efficiency, the results indicated that the technologists should have no trouble funding their projects. According to that study (Martin, 2004), the energy technology attracting the greatest investment interest is energy intelligence (smart instruments, advanced control, and automation). The handbook sections on Instruments, Controls & Automation discuss these technologies and how they can be used to improve plant energy efficiency.

6.3 Carbon dioxide emissions must be reduced

According to a 2005 report from the World Wide Fund for Nature (WWF), coal-based power stations are at the top of the list of least 'carbon efficient' power stations in terms of the level of carbon dioxide produced per unit of electricity generated. Based on current developments in Europe and in the U.S., regulations which limit or tax carbon dioxide emissions seem inevitable for all Western economies. A carbon charge of $25 per metric tonne (carbon dioxide) is a conservative estimate used in IEA scenarios. The impact of carbon pricing on fossil-fuel plant generating costs, shown in the figure below, is dramatic compared to most other generation methods. At prices above $20 per metric tonne coal-based plants become the most expensive type to operate at current non-optimized cost levels.

China and India account for four-fifths of the incremental demand for coal, mainly for power generation. For the first time, China's carbon dioxide power emissions in 2008 exceeded the United States' emissions; the lower quality coal used in India and other rapidly expanding economies, decreases plant efficiency and leads to increased carbon dioxide emissions per unit electricity (International Energy Agency, 2006).

6.4 Energy efficiency is key to CO_2 mitigation

The IEA Energy Technology Perspectives model is a bottom-up, least-cost optimization program. The model was developed to describe the global potential for energy efficiency and carbon dioxide emissions reduction in the period to 2050, particularly in the industrial sector. In the 'accelerated technology scenario' (ACT), the potentials for carbon dioxide reduction on all power consumption are shown in the figure below. This figure illustrates the scenario in which carbon dioxide emissions are stabilized globally in 2050 to 2005 levels, and the world narrowly avoids a costly climate crisis.

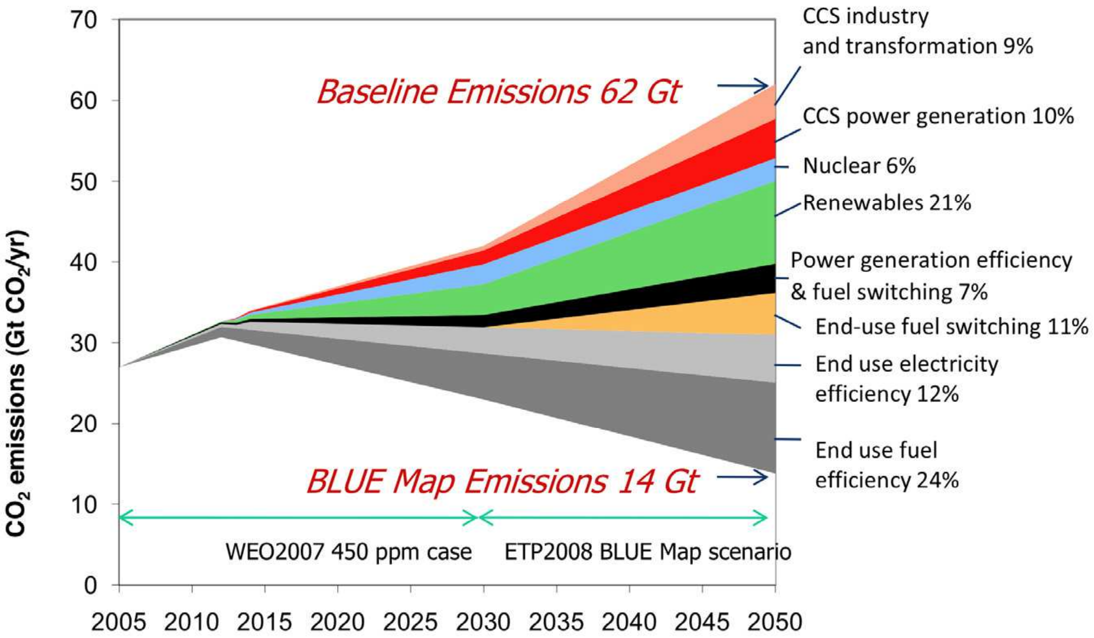

Fig. 4. Relative share of CO2 mitigation efforts, all consumption, (International Energy Agency, 2006).

7. The role of power generation in reducing emissions

The IEA's ACT scenario suggests that power generation efficiency can contribute significantly to the overall global effort to stabilize carbon dioxide emissions by 2050 at or near 2005 levels. Surprisingly, the model shows that power generation efficiency alone, which includes improved auxiliaries and other measures, has a larger climate impact than even nuclear power.

When the model is applied to process industries alone, the impact of energy efficiency is proportionately larger. The figure below shows the 'blue' scenario, which uses the same ACT scenario describe above, but with a higher carbon dioxide charge of $50 per (metric) tonne, instead of $25/tonne (Taylor, 2008).

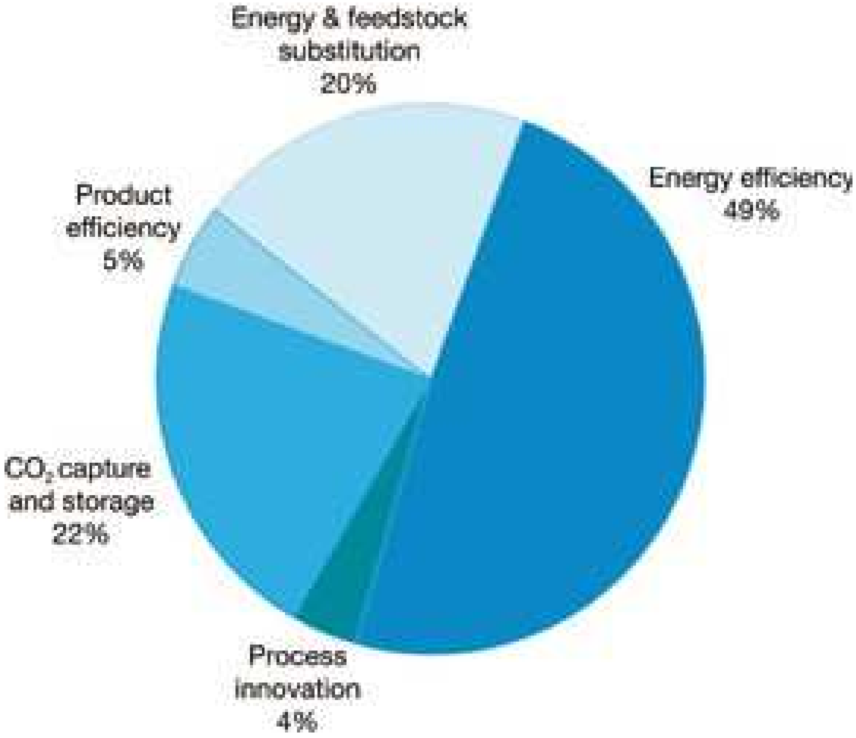

Fig. 5. Relative share of CO2 mitigation efforts in process industries, (Taylor, 2008).

Applying this model to the power generation sector in particular suggests that its carbon dioxide emissions are cut by 36 percent using all of the approaches shown. Half of those savings (18% of total) can be attributed to relatively low- technology energy efficiency measures alone.

Energy efficiency measures are the most important of all the carbon dioxide mitigation approaches for process industries, contributing to almost half of the impact on emissions (Martin, 2004). Although these predictions apply to process industries, the relative potentials are likely to be valid for the steam power generation sub-sector as well.

8. Multiple benefits of energy efficiency

The primary benefits of a increased plant energy efficiency are reduced emissions and energy or fuel costs.

Power plants which operate partially or wholly at full load will have more salable power. At less than capacity, the fuel savings are significant. In coal-fired steam power plants, fuel costs are 60-70% of operating costs.

The following is a more complete list of benefits accompanying energy efficiency design improvements for plant auxiliaries:

8.1 Operational benefits

- Improved reliability/availability. As has been found with stricter safety design regulations, any extra attention to the process is rewarded with improved uptime.
- Improved controllability: energy is wasted in a swinging, unstable process, partly through inertia in the swings, but mainly because operators in such situations do not dare operate closer to the plant's optimum constraints.
- Reduced noise and vibration, reduced maintenance costs.

8.1.1 Results of improved efficiency on plant operations and profitability

- Better allocation: under deregulation, as utilities dispatch plants within a fleet, heat rate improvement can earn plants a better position on the dispatch list (Larsen, 2007).
- Avoiding a plant de-rating due to efficiency losses after anti-pollution retrofits or other plant design changes.
- Improved fuel flexibility—by efficiently using a wider variety of fuels (coal varieties) and, in some cases, increasing the firing of biomass, for example.
- Improved operational flexibility 1) Improved plant-wide integration between units will reduce startup-shutdown times; this benefit applies mainly to de- regulated markets. 2) The heat rate versus capacity curve is made flatter and lower, which allows the plant to operate more efficiently across a wider loading range.

8.2 Plant investment benefits

- Avoiding forced retirement due to pollution non-compliance: An ambitious retrofit programme may save some older plants from early retirement due to non- compliance with regulations.
- Tax credits take advantage of newer policies such as EPACT 2005, which may provide tax credits for efficiency efforts. Similar policies are in effect in the EU and China.
- Mainstream industry authority Engineering News–Record's influential Top Lists rankings now include "Top Green Design Firms" and "Top Green Contractors":
- 'The market for sustainable design has passed the tipping point and is rapidly becoming mainstream' (http://enr.construction.com/).
- Increasingly, shareholders and capital markets are rewarding companies who treat their environmental mitigation costs as investments (Russel, 2005).

Retrofitting may save some older plants from early retirement due to non- compliance with regulations such as the EU's Large Combustion Plant Directive on pollution (nitrous oxides, sulfur dioxide, mercury, and particulates) (International Energy Agency, 2006). In the US, increased compliance may smooth permitting of new units or plants.

All of the 'dirty dozen' in Carbon Monitoring For Action's (CARMA) list of top carbon dioxide emitting sources in the U.S. are coal-fired power plants, emitting an average of about 20 million tonnes of carbon dioxide per year per plant. ‘Blacklists’ like these, which include rankings by company as well, are increasingly being consulted by large institutional investors and sovereign wealth funds. With tightened credit markets, there is therefore an even greater incentive for top management to watch carbon dioxide emissions. See the section on Benchmarking for other global efforts toward increased transparency.

Non-Technical Barriers to Energy Efficient Design Despite all of the benefits and incentives, and the low-capital-cost improvement potential described in previous sections, the implementation of integrative, energy efficient design and operation is still hindered by several obstacles. Methods for improved design are known and the required technologies are widely available ‘off the shelf.’ Individual components are generally available in high-efficiency variants. So why are power and industrial process plants energy inefficient in their design as a whole? One clue, is the fragmentation found in engineering disciplines, vendor equipment packages, and even in the way projects are executed.

The current situation with energy efficiency is analogous to the status of safety in process industries a decade or two ago. Operational safety was acknowledged as important and was codified, but there were no standards on how safety could be managed during the design process on how it could be ‘designed-in’ from the start. The recent Functional Safety standards IEC-61508 and 61511 point the way forward for energy design and management standards evolution.

Many of the barriers listed below are managerial or procedural rather than technical in nature. These important non-technical aspects are discussed elsewhere. The discussion here is generic for most large power and process facilities, but a specific industry will have additional competitive and regulatory pressures.

Local, State, National and International Regulatory Authorities Authorities provide the regulatory framework for the activities of all the other stakeholders. The efforts of authorities are closely linked with those of the standards organizations. These factors, however, may contribute to inefficient plant designs:

- Regulations often permit pass-thru of all fuel-related costs directly to the rate base. This financially discourages any economization efforts related to fuel consumption, i.e. efficiency.
- Lack of clarity, unity and commitment to emissions charging makes investors wary of long-term investments in energy efficiency and/or carbon dioxide emissions reduction.
- Deregulation and the ensuing volatility in fuel and energy prices may also discourage the long-term thinking necessary to make some efficiency and carbon dioxide emissions reduction schemes justifiable.

8.2.1 Shareholders & investors

The observations in this paragraph regarding shareholders and investors apply mainly to new construction or large-scale redevelopment projects. See the following paragraphs for barriers more applicable to facility owner/operators of older plants and retrofit project contexts. Shareholders and investors often influence project schedules, contract clauses, functional specs for new construction and major retrofits of plants. These factors, however, may contribute to plants that are ultimately energy inefficient:

- Project schedules are compressed; front-end design and concept studies are underfunded or curtailed.
- Scope of redevelopment projects is narrow because investors 'generally want to avoid changes to the long remaining lifespan of the standing capital stock' (International Energy Agency, 2006).
- Designs are 'frozen' early by a pre-established milestone date, even if important data may be missing.
- Cost analysis methods are too crude, or not coupled tightly enough to the conceptual process design, or have wrong initial assumptions regarding risk, return, and lifetime; calculations may ignore significant indirect costs and savings such as substitution costs, maintenance savings, and peak energy prices.
- Operational energy costs may be treated as a fixed cost and therefore receive much less attention than a variable cost.
- Low-bid, fixed-price contracting without strong, well-defined and enforceable energy performance guarantees, at the plant, unit and equipment levels.
- Purchasing managers seek multiple suppliers to reduce cost; this strategy leads to increased design and data fragmentation. Purchasing managers may still prefer individual vendors versus full-service/system integrators.
- Energy-expert consulting companies are usually the last to be hired, and therefore have much less influence over the conceptual design.
- Drawings are issued 'for construction' before even the first vendor drawing is seen, much less approved (Mansfield, 1993), leading to hasty, often energy- inefficient re-design at the interfaces.
- Capital scarcity might favor smaller plants with lower efficiency (Gielen, 2008).

8.2.2 Facility operators

Facility Operators craft the original specifications, validate the design during commissioning and acceptance trials, determine operational loading and maintenance of facility, and usually initiate and manage retrofit projects. These factors, however, may contribute to plants that are ultimately energy inefficient:

- Retrofit projects to improve energy efficiency are funded from operating budgets, not from larger capital expenditure budgets; payback expectations and discount rates are all generally much higher than in green-field projects.
- Managers focus on optimizing process productivity, in which energy is only one of several other cost functions and may not receive the consideration it deserves; many modern plant-wide optimization systems optimize for productivity, which only indirectly improves energy efficiency.
- There is a war for money between process improvement and energy efficiency camps in a typical plant; process improvement teams and their measures seem to 'get more respect.'
- An increasing number of plants are centralizing purchasing, which means less engineer involvement in purchasing decisions. 'Since purchasing centralization… we've seen companies shift away from using a lifecycle cost model, which seems very short-sighted to us. Some of the decisions customers have been making are committing them to a stream of ongoing expenses that could have been reduced.' (Control Engineering article 8/15/2005).

- Facility operators receiving a new/retrofitted plant/unit are under-pressure to begin operations as soon as possible so they are therefore less critical with respect to energy targets during acceptance tests.
- Facility operators do not or cannot operate plant at design capacities due to changes in market or other factors.
- Plant engineering and maintenance teams are losing experienced older staff; facility operators do not provide adequate training for staff on energy efficiency.
- Power plant/power house energy managers (superintendents or maintenance directors) lack the necessary communication and salesmanship skills to push through good energy efficiency proposals. (a post on J. Cahill's blog, 2007).
- Reluctance to admit non-optimal, energy inefficient, operation to upper management – the perception is that this reflects badly on plant management and their plant operations team.
- Fear of production disruptions from new equipment or new procedures to improve efficiency (International Energy Agency, 2006); doubts about safety, controllability or maintainability
- Expansion projects will simply duplicate an existing unit on the same site, repeating many of the same design mistakes, to reduce the up-front engineering hours; low-labor copy-and-paste projects may also overlook opportunities for rationalization & integration with the existing unit(s).

8.3 Design and engineering companies

Design and engineering companies determine design specs of facility, select components and execute the design. These factors, however, may contribute to energy inefficient plants:

- A tendency to oversize pumps, fans, and motors by one rating, and oversize them again after handoff to another discipline, and then again by project leaders:
- Bottom limits in standards already have a safety margin, but these limits are interpreted as a bare minimum (from fear of litigation) and an additional safety margin is added.
- Overload maximums received from process engineer are interpreted by mechanical and electrical teams as continuous minimums; fat margins are added in lieu of detailed loading study.
- Additional margins are then added for future, but unplanned, capacity increases.
- Engineers on auxiliary systems are inordinately fearful of undersizing and risk being singled out as the bottleneck that prevents operation at full design capacity of other, more expensive, hardware
- Large, commodity motors and fans are commercially available only in discrete sizes. After all the margins, an engineer will choose the next size up if the design point falls between two sizes.
- A tendency to aggressively reduce engineering hours to increase margins on fixed-priced contracts and to avoid selecting premium components for such contracts.
- Trade-offs between floor space and pipe/ductwork efficiency are not life-cycle cost-estimated; civil and architectural concerns are the default winners due to their early head start in most projects.
- Trade-offs between reliability and energy efficiency are not life-cycle cost- estimated. Higher energy costs are seen as insurance against large, but virtual opportunity costs.
- Lack of energy design criteria and efficiency assessment steps in the standard engineering workflow. There is typically a design optimization step for cost, safety, reliability, and other concerns, but not for energy efficiency.

- Shortage of engineers in key industries; junior and outsourced engineers are making higher-impact decisions.
- A reluctant to deviate from their 'standard design' templates, especially on expansion projects where the design has been delivered on previous units. This leads to short cuts and uncritical copying-and-pasting of older, non-optimal designs.
- Engineers work mainly within the confines of their discipline and do not see opportunities for inter-disciplinary optimization of the total design. For example:
- Mechanical engineers miss out on optimizations from chemical engineering to use waste heat and to optimize plant thermodynamics or create useful by-products.
- Process engineers do not leverage the full potential of automation, selecting instead familiar equipment like valves to perform control tasks better suited to a variable frequency drive.
- Electrical engineers do not fully understand the process needs for power, such as duty cycles, and therefore do not fully optimize their designs.
- None of the engineers mentioned above are typically very quick to leverage advances in materials science, which enable higher operating parameters.

Equipment vendors and design tool providers

Equipment Vendors and Design Tool Providers determine component energy efficiencies. The vendor's tools directly affect the engineer's workflow, models, and documentation. These factors, however, may contribute to energy inefficient plants:

- Vendors provide black-box components with closed/proprietary/rigid interfaces, which are not easily optimized for the whole system; this is the result of a trend toward 'commoditization.'
- Proliferation of design tools and data formats which are non-integrated and their design model is non-navigable between vendor tools; this hinders integrative design.
- Lack of full-scope energy-optimization functionality in the leading design and modeling tools
- As components become commodities, salesmen are replacing sales engineers, and misapplications are increasing (Plant Services.com, 2008)

8.4 Professional and standards organizations

Professional and standards organizations provide basic education standards and best practice certifications. These factors, however, may contribute to energy inefficient designs:

- No widely accepted standards specifically for energy efficient designs of entire plants; some operational energy management standards are in development, however.
- No widely accepted certification for energy design for whole plant systems; an energy manager certification is available in the USA, however.
- Lack of mandatory international labeling system for industrial motors, transformers, and other equipment to enable comparison.
- Protectionism and turf wars limit the global adoption of a single set of standards; the divisions between English and SI units are a cause for some confusion, design errors, and incompatibilities.

8.4.1 Educators and academia

Educators and academia provide basic skills and certification (by diploma) of the next generation of designers and engineers. These factors, however, may contribute to inefficient designs:

- Educators tend to focus on the abstract and theoretical, as opposed to best practice design using state-of-the art commercially available engineering components.
- Systems engineering courses are not mandatory or sometimes not even offered in the average curriculum.
- Electrical engineering curricula increasingly favor more modern topics of electronics and discrete logic at the expense of courses on old-fashioned power engineering; courses on power station design have been dropped.
- Programs or degrees toward industrial or engineering management are too general: the specifics of each discipline cannot be made more abstract.
- Some engineering schools offer no 'capstone' design course that encourages synthesis of all the disciplines toward a single design task.

Standards, Best Practice, Incentives, and Regulations Standards are the designer's and engineer's best design guidelines. Standards also offer customers and authorities an objective measure for applying regulation and incentives. 'Best practices' encompass more than standards, and include case studies, more application details, and some costing information.

8.4.2 Role of standards in energy efficiency

Energy efficiency is an invisible quality and is subject to various interpretations; it is important, therefore, for engineers and managers to be able to have some common definitions and methodologies when assessing efficiency performance. International standards for energy design and management are emerging and some countries, including the U.S., have some standards in these areas. It is likely that these standards will be closely linked to future carbon dioxide compensation schemes, whether at national or international levels (ISO, 2007).

Common benchmarking for performance is good, but at a deeper level, standards can provide the equipment and system inter-operability that can enable a higher performance design. Highly efficient components which are mismatched or poorly integrated make for an inefficient overall system. A joint ISO/IEA technical committee that was recently formed to identify gaps in industrial standards coverage recommended more emphasis on the systemic approach and encouraged a focus on energy efficiency of overall systems and processes as well as retrofitting and refurbishing. This expert committee also recommended that standards should address efficiency improvements through industrial automation.

8.4.3 Standards and best practice

The standardization efforts relevant to plant auxiliaries' energy performance cover a wide variety of disciplines. The list far below refers to existing standards relevant to the systems in this handbook that specify design, application, labeling and minimum energy performance standards. The list focus is on U.S. standards, but some important international standards are also mentioned, in italicized text. The premier, official sources of unbiased standards are the national standards bodies such as American National Standard Institute (ANSI) for the U.S., CEN/CENELEC (for the EU) and the international bodies such as the IEC and the ISO. A convenient way to search for U.S. and global standards is by using the ANSI NSSN search engine at www.nssn.org. Search by title 'power station design' or 'power plant.'

Other sources of objective standards are the professional societies and industry associations, although the latter may show more bias toward their industry in certain situations:

- Institute of Electrical and Electronic Engineers (IEEE)
- Instrumentation, Systems, and Automation Society (ISA)
- The Hydraulic Institute (HI)
- National Fluid Power Association (NFPA)
- Air Movement and Control Association (AMCA)
- American Society of Mechanical Engineers (ASME)
- National Fire Protection Association (NFPA)

Many standards for steam-water cycle design of cycle equipment can be found in the various ASME and NFPA codes, but these are not within the scope of this handbook. The ASME test codes for determining efficiency, however, are of interest. Energy is a political as well as a technical subject; some 'associations' (not those mentioned above) promoting best practice are actually lobby groups with strong, but not obvious, links to commercial or political entities with various agendas. These sources can be useful if their advice is taken together with the objective sources listed above. Some of these unofficial sources of design guidance are listed in the Reference section of this handbook. The following list is not a comprehensive list of all relevant standards; appearing here are only those that have some relevance to plant auxiliaries' energy performance and design.

Power Plant Facilities

- IEEE Std 666-2007 IEEE Design Guide for Electric Power Service Systems for Generating Stations (Revision of IEEE Std 666-1991)
- IEEE Std 762-2006: Standard for Definitions for Use in Reporting Electric Generating Unit Reliability, Availability, and Productivity
- ANSI/ISA S77.43.01-1994 (R2002) : Fossil Fuel Power Plant Unit/Plant Demand Development (formerly ANSI/ISA S77.43-1994)
- ANSI/ASME PTC 46-1996: Overall Plant Performance codes
- ASME PTC 47-2006: Integrated Gasification Combined-Cycle Plants
- IEEE 803.1-1992 : Recommended Practice for Unique Identification in Power Plants and Related Facilities - Principles and Definitions
- ISO 13600 series (1997–2002): Technical energy systems. Methods for analysis of technical energy systems, - enabling the full costing and life cycle analysis

Best Practices

- DoE EERE Best Practice guides for Steam, Pumping Systems, Fans www1.eere.energy.gov/industry/bestpractices
- EPRI studies and reports – there is a large population of useful reports
- ABB Electrical Transmission and Distribution Reference Book (the 'T&D' manual)

Pump and Fan Systems

- ANSI/HI 1.3-2007 : Rotodynamic (Centrifugal) Pumps for Design and Application

- ANSI /HI Pump Standards : Available through the Hydraulic Institute, a standards partner (www.pumps.org/)

Best Practices for Pump and Fan Systems

- ANSI/HI Optimizing Pumping Systems Guidebook
- US DoE Sourcebook (2006). Improving Pump System Performance, from EERE Industrial Technologies Program:
- US DoE Sourcebook (2006). Improving Fan System Performance. from EERE Industrial Technologies Program
- Air Movement and Control Association (AMCA) International

Motors and Drives

- NEMA MG 1 : Motors and Generators
- NEMA ANSI C50.41:2000 : Polyphase induction motors for power generating stations
- IEEE Std 958-2003 : Guide for Application of AC Adjustable-Speed Drives on 2400 to 13,800 Volt Auxiliary Systems in Electric Power Generating Stations
- IEC 60034-3 Ed. 6.0 b:2007 Revises IEC 60034-3 Ed. 5.0 b:2005 Rotating electrical machines - Part 3: Specific requirements for synchronous generators driven by steam turbines or combustion gas turbines
- IEC 60034-2-1: Motor efficiency testing (September 2007); published as EN 60034-2-1 at CENELEC level.

Best Practices for Motors and Drives

- DoE Motor System Best Practices

The Energy Independence and Security Act of 2007 (EISA) calls for increased efficiency of motors manufactured after December 19, 2010.

Electric Power Systems

- IEEE 493 Design of Reliable Industrial and Commercial Power Systems, also has useful equipment reliability data.
- C57.116-1989 IEEE Guide for Transformers Directly Connected to Generators
- IEEE Std C37.010™, IEEE Standard Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.64, 65
- IEEE 519-2006 Harmonic voltage and current distortion limits
- IEEE Std 946-2004 IEEE Recommended Practice for the Design of DC Auxiliary Power Systems for Generating Stations
- IEEE Std C37.21-2005 IEEE Standard for Control Switchboards
- 525-1992 IEEE Guide for the Design and Installation of Cable Systems in Substations
- C62.92-1993 IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems, Part III-Generator Auxiliary Systems
- IEC 60076-1 Power Transformers (VDE 0532 Part 101)
- IEC 62271-1 Ed. 1.0 b:2007 High-voltage switchgear and controlgear
- IEC 61000-2-4 (Worldwide) Harmonic voltage and current distortion limits

Best Practices for Electric Power Systems

- ABB Switchgear Manual, 11th edition, 2006 (available online)

- ABB Transformer Manual, 2007

Energy & Environmental Management

- ISO 14064 and ISO 14065 provide a methodology to help organizations assess carbon footprints and implement emissions trading schemes
- ISO 14001 is an internationally recognized framework for environmental legislation, regulation, management, measurement, evaluation, and auditingassessing.
- ISO 13600 series provides guidelines on technical energy systems

Instrumentation & Control Automation Systems

- ANSI/ISA-77.44.01-2007 - Fossil Fuel Power Plant - Steam Temperature Controls
- ANSI/ISA-RP77.60.05-2001 (R2007) - Fossil Fuel Power Plant Human-Machine

Interface: Task Analysis

- ANSI/ISA-77.42.01-1999 (R2006) - Fossil Fuel Power Plant Feedwater Control System – Drum-Type
- ANSI/ISA-77.20-1993 (R2005) - Fossil Fuel Power Plant Simulators - Functional Requirements
- ANSI/ISA-77.41.01-2005 - Fossil Fuel Power Plant Boiler Combustion Controls
- ANSI/ISA-RP77.60.02-2000 (R2005) - Fossil Fuel Power Plant Human-Machine

Interface: Alarms

- ANSI/ISA-77.70-1994 (R2005) - Fossil Fuel Power Plant Instrument Piping Installation
- ANSI/ISA-77.43.01-1994 (R2002) - Fossil Fuel Power Plant Unit/ Demand

Development-Drum Type

- ANSI/ISA-77.13.01-1999 - Fossil Fuel Power Plant Steam Turbine Bypass System
- 502-1985 IEEE Guide for Protection, Interlocking, and Control of Fossil-Fueled Unit-Connected Steam Stations
- ASME PTC PM-1993 Performance Monitoring Guidelines for Steam Power Plants
- ISO 13380:2002 Condition monitoring and diagnostics of machines - General guidelines on using performance parameters
- ISO/TS 18876-1:2003 Industrial automation systems and integration - Integration of industrial data for exchange, access and sharing

Best I&C Practices

- ISA Instruments and Automation Society, http://isa.org/, both a standards and industry organization with sources on best practice

9. Power generation regulations and incentives

The regulatory environment for coal-fired plants appears likely to change significantly before 2010. Some US states (2008) are considering a moratorium on new coal plant construction, and may slow or stop permitting of plants under construction. A US Supreme Court ruling in 2007 determined that CO2 is an air pollutant; this raises the possibility that CO2 will soon be regulated as such under the Clean Air Act. Some of the most relevant existing regulations are listed below:

- EPACT: Energy Policy Act (1992)
- EPACT: Energy Policy Act (2005)
- CAAA: Clean Air Act (1970, 1990) and National Ambient Air Quality Standards (NAAQS)

EPACT 2005: tax credits for the construction of coal-fired generation projects requisite on meeting efficiency and emissions targets. (International Energy Agency, 2006): According to the IEA, this leads to an increased share of IGCC and 'clean coal' projects, but may also have impact on traditional coal-fired plant designs and operation.

The recent legislation in the Energy Independence and Security Act of 2007 (EISA) will also have an impact on the design and operation of fossil-fuel fired power plants. EISA calls for increased efficiency of motors manufactured after December 19, 2010, for example.

Engineering Basic Standards

- IEEE 280: Standard Letter Symbols for Quantities Used in Electrical Science and Electrical Engineering
- ISO 15926: A meta-structure for information concerning engineering, construction and operation of production facilities.
- ISO 31: Quantities and units, International Organization for Standardization, 1992, now being superseded by the harmonized ISO/IEC 80000 standard.

Efficiency and Lifecycle Cost Calculations

Efficiency Calculations

Efficiency is a measure of how effective a system or component can convert input to output. Efficiency is normally given in units of percentage, or as a value from 0 (0 percent) to 1.0 (100 percent). Energy efficiency can be calculated using either energy (kW/h) or power (kW)

Efficiency percent = (Useful Power Out (kW) / Power In (kW)) x 100

10. Energy and power calculations

Energy must always be defined relative to a given time period or to a given volume, etc. The energy consumed by a system or components during a given time period is determined by multiplying its input power over a time period. The common term 'losses' means wasted energy. Losses can be treated as energy (kWh) in all the calculations in this section. The common term 'loads' means output power. Most energy calculations are based on a year's time, and a year is conventionally assumed to be only 8,000 hours to account for system downtime, when energy consumption is 0. (There are otherwise 8,760 hours in a full year.)

Annual energy consumption (kWhr) = 8,000 (hrs/year) x Power (kW) Load Profile

In practice, power levels (or 'loads') are not constant, as assumed in the formula above. Loads vary over a given period due to changes in the process or ambient conditions. This variation is described by the component's 'load profile,' which describes the percentage of time (in hours per year) at each loading level (as a percentage of full load) as shown in the sample load profile below:

%	Hours	% of Full Load
5%	400	100
10%	800	90
15%	1200	80
20%	1600	70
20%	1600	60
15%	1200	50
10%	800	40
5%	400	30
0%	0	20
100%	8,000 hrs	Weighted Avg 65

Table 1. Load profile.

A more accurate view of annual energy consumption for the above component's profile is the sum of the energies at each load level:

Annual Energy (kWhr) = (#hrs) at load level(i) x (%) full load at load level(i) x full load (kW)

Duty cycle is similar to load profile, but is used to refer to shorter time periods (days or hours) and for cycling (on-off) loads, rather than more continuously variable loads.

11. Energy and power units

Energy has many forms and can be described using many units. These are the three most commonly used units in the global power generation industry.

1 horsepower (hp) = 0.7457 kW = 2546 Btu/hr

11.1 Savings calculations

Savings calculations are used to determine the difference in energy and cost between two components or systems.

By combining the formulas above, one can compare the annual savings of energy for two components or systems of varying efficiency E1(%) and E2(%). The result is an energy saving (Se) in kW per year (assume 8,000 hrs in absence of data):

Annual Energy Savings (kWhr) = 0.746(kW/hp) x P(hp) x 8,000 x 100(%) x (1/E2 – 1/E1)

One can then multiply by the cost of energy (in $/Kwh) to determine the financial (or capitalized) cost of the annual energy savings calculated above, in $:

Annual Dollar Savings ($) = Se (kWh) x Q ($/kWh), where Q is the price per kWh of electricity

In these calculations the price (Q) of energy is assumed to be constant. In fact, energy prices may change as often as every 15 minutes in a de-regulated market, with much higher prices during peak periods. The average annual price of electricity shows a rising trend. See the section on present value for methods to account for this change.

11.2 Lifecycle costing methods

Life-cycle costing (LCC) is a method of calculating the cost of a system over its entire lifespan. LCC is calculated in the same way as 'total cost of ownership' (TCO). A technical accounting of systems costs includes initial costs, installation and commissioning costs, energy, operation, maintenance and repair costs as well as down time, environmental, decommissioning and disposal costs. These technical costs, for an example transformer, are listed below.

$$LCC = C_A + C_E + C_I + \sum_{0}^{n} (CP_M + CC_M + CO_P + CO_0 + CR) + C_D$$

where C_A = cost of apparatus
C_E = cost of erection
C_I = cost of infrastructure
CP_M = cost of planned maintenance
CC_M = cost of corrective maintenance
CO_P = cost of operation (load and no-load losses)
CR = cost of refurbishment or replacement
C_D = cost of disposal
n = years of operational life span

Fig. 6. Life-cycle costing method.

Additional, non-technical costs that should be accounted for in budgetary estimates include insurance premiums, taxes, and depreciation.

All costs in an LCC calculation should be discounted to present value (PV) dollars using the present value formulas in the following section. A very simplified LCC calculation with fewer terms considers only the cost of apparatus and the cost of operation, and does not consider inflation or variation in price of energy per kWh. The operational cost term in an LCC formula is typically the annual energy costs calculated using the formulas above, discounted to PV dollars. See the section Motor System Calculations for a numerical example.

For systems that directly emit carbon dioxide or other pollutants, the cost of operation should include remediation costs, and the taxes which authorities charge (or may charge) per unit of emissions. For electrical loads powered from a fossil-fuel- based source, the carbon dioxide amounts (in tons) are still relevant, but the carbon dioxide tax (in $) should not be added to that component's operational costs if the tax has already been factored into the price of the consumed electricity.

11.3 Carbon dioxide cost calculations

For coal-fired power plants, 1.3 tons of carbon dioxide is emitted per MW hour (C.P. Robie, P.A. Ireland, for EPRI, 1991). A conservative estimate for a future carbon dioxide tax is $25 per metric ton, globally and in the U.S. The tax may take many forms, ether as a direct tax or a traded quota, etc. A metric ton (1,000kg = 2240 lbs) is also written 'tonne.'

The energy and dollar savings calculations can now be applied, using the above data, to give a carbon dioxide (tons) saving and a carbon dioxide dollar savings ($) for reducing power from a fossil-fuel-based source:

$$\text{Annual carbon dioxide savings (tonnes)} = 0.746(\text{kW/hp}) \times P(\text{hp}) \times 8{,}000 \times 100(\%) \times (1/E2 - 1/E1) \times 1{,}300$$

Annual carbon dioxide tax savings ($) = $25/tonne x annual carbon dioxide savings (tonnes)

A rule of thumb for coal-fired plants: a 2 percent steam cycle efficiency improvement can reduce carbon dioxide emissions by up to 5 percent (Ferrer, 'Small-Buck Change Yields Big-Bang Gain,' 2007).

11.4 Limitations of LCC methods

LCC analyses often count only single benefits, such as the electricity directly saved by a new motor's higher nameplate efficiency. In fact, there are numerous other benefits to reduce electricity consumption on the size and wear of upstream, power system components. Other benefits that are hard to quantify in LCC analysis include reduced maintenance via the elimination of the control valve, for example. In a detailed LCC calculation it is important to consider substitution cost.

11.5 Present value formulas

Most of the costs shown in the LCC calculation accrue in the future. These payments must be translated into present values using the time-value of money formulas given here.

Present value (PV) of a future amount (FV) at period 'n' in the future at 'i' interest rate is:

$PV = FVn \times 1/(1 + i)n$

Present value of a uniform series of payments, each of size US (for Uniform Series):

$= US \times ((1 + i)n - 1)/i(1 + i)n$

Where 'i' is the interest rate from 0-1 (for a 6% rate, i = 0.06)

The formula for PV of a uniform series can be used to determine the value of annual energy savings, where the annual cost is calculated as shown at the start of this section.

If the average annual price of electricity rises at p% per year, then the flat rate Q must be multiplied by the following rising price factor 'f':

$$f = (qn - 1) / (q - 1)$$

Where: $q = 1 + p/100$

And p is the price increase in %

Using the formula for a 1 kW loss after 20 years shows an accumulated cost which is 41 times the cost of the first year if the average annual increase in the energy price is 7 percent (ABB Ltd,Transformers, 2007).

11.6 Payback calculations

If the PV of the energy savings over 'n' periods (years) exceeds that of the investment cost (X), then the investment should be made. The number of periods required for PV to equal X is the ‘payback’ period. For a given value of X, therefore, the payback period ‘n’ can be calculated.

The monetary value of energy losses, called the capitalized loss value, is defined as the maximum amount of money the user is willing to invest to invest to reduce losses by 1 kW.

11.7 Levelized cost calculations

For non-uniform payments, use the levelized cost (LC) method to determine the levelized amount. This method simply uses the PV formula on each amount to determine the total PV of the stream, then applies the inverse of the PVus formula to determine a levelized amount for each period. To evaluate projects, one can use either the total PV or the LC method. Both will reach the same conclusion, except that the LC shows a comparison by period. In evaluating energy efficiency project alternatives, it may be useful to calculate the ‘capital equivalent cost’ (CEC).

The CEC is found by adding the capital cost to the PV of all the operating costs over the unit’s lifetime. This calculation provides a sound basis for comparing bids.

11.8. Limitations of PV MethodsPresent value methods make assumptions regarding lifetime (number of periods ‘n’) and discount (interest) rate ‘i’ which have a large impact on the calculated value. In evaluating energy efficiency projects or components, the conventional assumptions tend to undervalue the savings. High-quality, high efficiency motors, for example, may have a longer lifespan (‘n’) than standard motors. Also, the lower risk of energy efficiency projects should be reflected in a lower discount rate, especially in common comparisons with new capacity. This comparison is between ‘negawatts’ (energy efficiency) and Megawatts (new capacity).

11.8 Plant heat rate calculations

In power plants, efficiency is often expressed as ‘heat rate,’ which is the amount of energy generated (kWh) per unit of fuel heating value (Btu = British Thermal Units).

Energy Value: 1kWh= 3414.4 Btu = 3.6 MJ

For a plant with Net Plant Heat Rate of 10,000 Btu/kWh (10.54 MJ/kWh), then the thermal efficiency = 34.14 percent.

Note that heat rate is the inverse of efficiency; a reduction in heat rate is an improvement in efficiency. Sub-critical steam plants use the fuel’s higher heating value (HHV) as basis for heat rate and efficiency calculations, whether the fuel is coal, oil, or gas. Combined-cycle gas turbine plants are usually evaluated on the basis of the lower heating value (LHV) of their fuel. This can lead to the differences in apparent efficiency being somewhat greater than they actually are (Eng-tips.com, Fowler, 2006).

Coals vary considerably in their composition, which determines their heating value and carbon dioxide emissions during combustion. A typical coal has a heating value of about 8,000 Btu/pound, a carbon content of about 48 percent by weight and a moisture content of about 20 percent by weight and is combusted with up to 10 percent excess combustion air.

The ASME performance test codes 6 and 6A for steam turbines describe the method to determine steam turbine efficiency in existing plants. Whole plant international test codes are ASME PTC 46 and ISO 2314.

12. Energy accounting for reliability

12.1 Reliability concepts

The methods and terminology in this section are common to the field of quantitative reliability analysis. Reliability (R) is the probability that a unit is still operational after one year, based on the unit's mean time between failure (MTBF) specification. Reliability is expressed as failure rate on per year basis.

$$R = e(-8760hr/MTBF)$$

Availability (A) of a unit can be calculated as: A = MTBF / (MTBF + MTTR)

Where:

MTTR = mean time to repair

Energy Cost of Plant Trips

The total cost of a plant trip is composed of many parts, including opportunity cost of lost power sales, cost of substitute purchased power, ISO fines, trip-induced repairs, and energy. The energy wasted per year due to trip events is therefore R multiplied by energy wasted during startup/shutdown procedures (R x Ess). The wasted energy due to a complete shutdown and cold restart (Ess) is composed of two parts:

E(shutdown energy) + E(startup energy) =Ess

Where:

E(startup energy) = hours duration of startup x energy input/hr
E(shutdown energy) = rotational energy in all machinery + chemical energy in process lines

E for shutdown is more difficult to measure and calculate. As a rough estimation, therefore, E shutdown is assumed to be ¾ of the E startup. So ultimately, the annual energy costs of plant trips :

R x Ess = R x 1.75 x hours duration of startup x energy input (MMBtu)/hr x Energy price ($/MMBtu)

13. References

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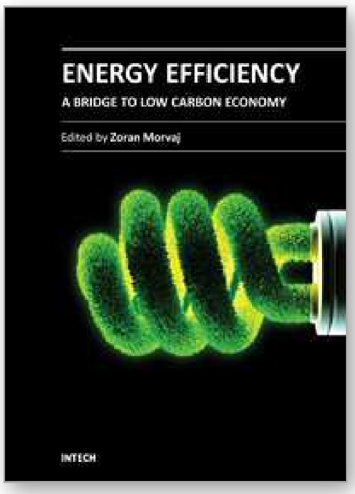
Electric Power Research Institute , http://my.epri.com, Non-profit R&D and consulting organization, utility & industry funded
Leonardo Energy, http://www.leonardo-energy.org, Global community of sustainable energy professionals



Energy Efficiency - A Bridge to Low Carbon Economy
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Energy efficiency is finally a common sense term. Nowadays almost everyone knows that using energy more efficiently saves money, reduces the emissions of greenhouse gasses and lowers dependence on imported fossil fuels. We are living in a fossil age at the peak of its strength. Competition for securing resources for fuelling economic development is increasing, price of fuels will increase while availability of would gradually decline. Small nations will be first to suffer if caught unprepared in the midst of the struggle for resources among the large players. Here it is where energy efficiency has a potential to lead toward the natural next step - transition away from imported fossil fuels! Someone said that the only thing more harmful then fossil fuel is fossilized thinking. It is our sincere hope that some of chapters in this book will influence you to take a fresh look at the transition to low carbon economy and the role that energy efficiency can play in that process.

How to reference

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